# Higgs recoil mass analysis: status and prospects
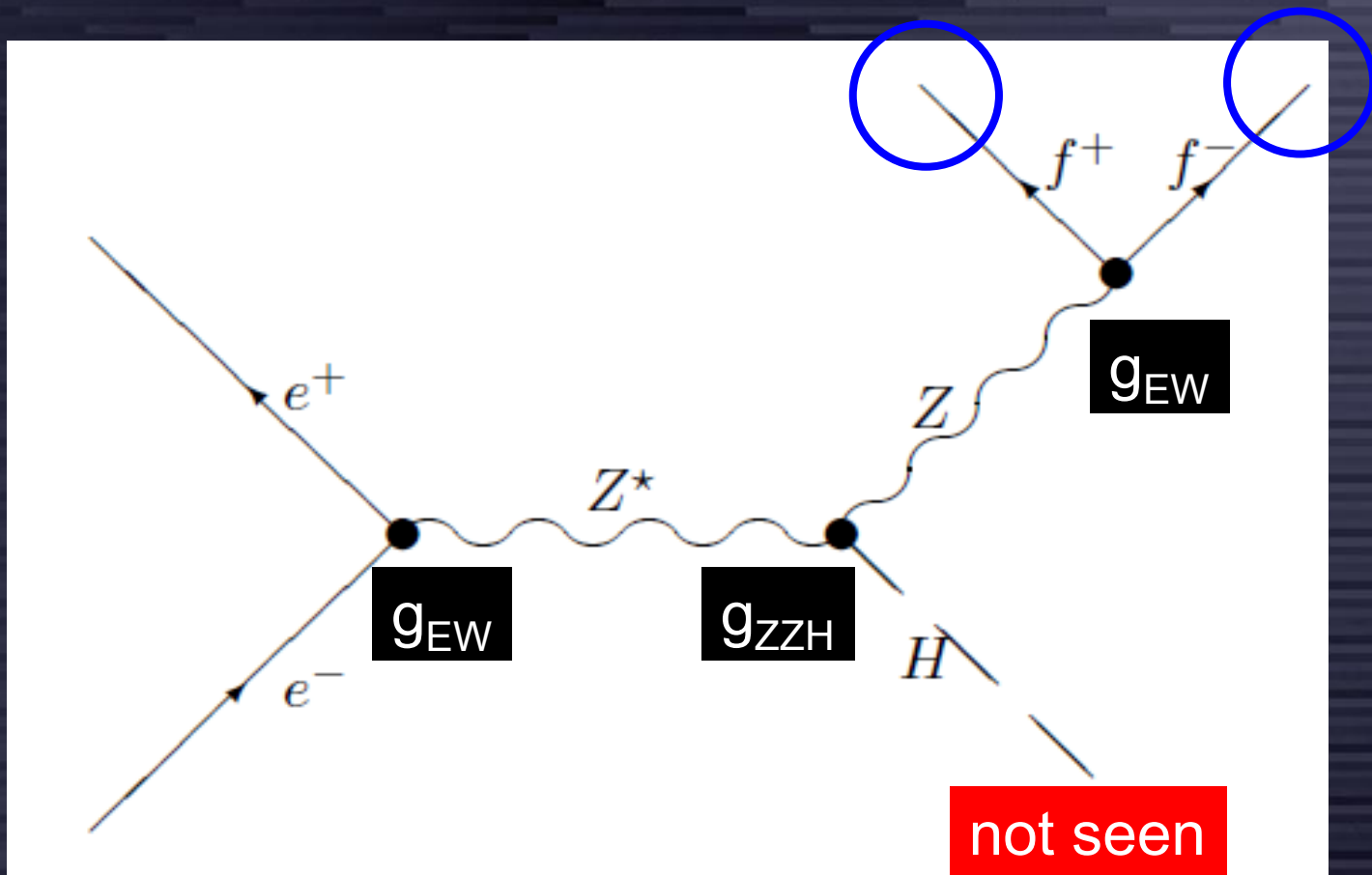
Taikan Suehara (Kyushu)
A. Miyamoto (KEK), T. Tomita (Kyushu)

# Recoil in ILC

Direct measurement of $g_{ZZH}$ with high precision
NOT the "ratio" of Higgs couplings
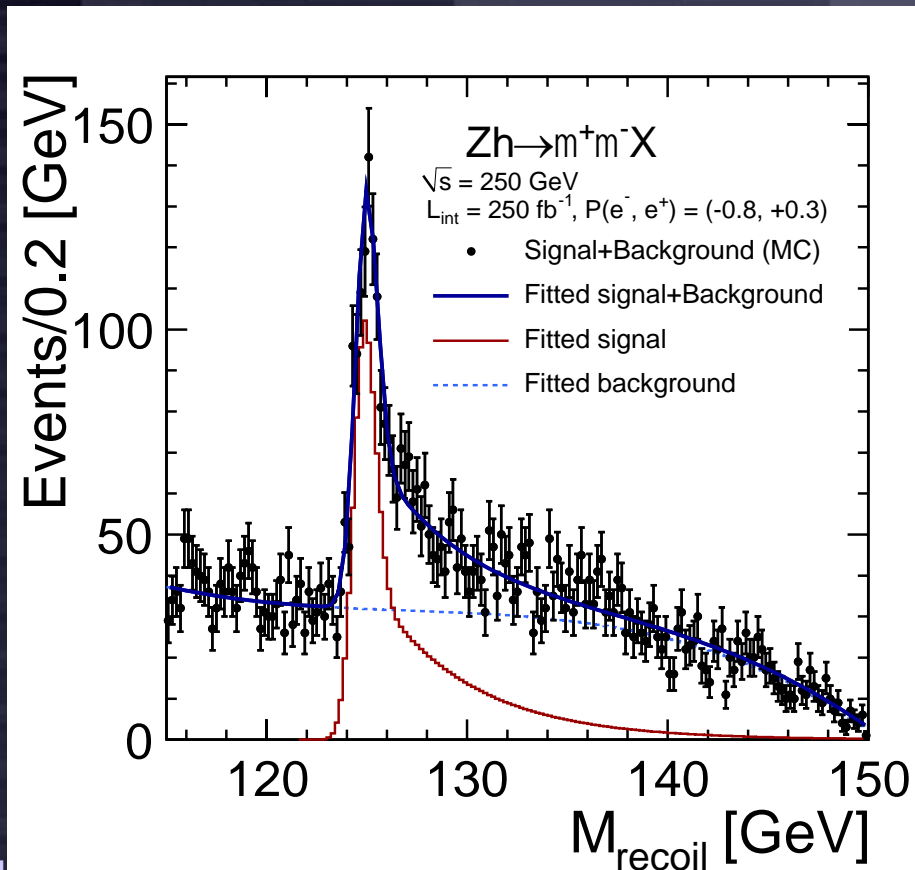NOT suffered from QCD uncertainty

# Recoil mass

$$m_{\text{recoil}}^2 = (\sqrt{s} - E_{\ell\ell})^2 - |\vec{p}_{\ell\ell}|^2$$

- Using 4-momentum conservation (not possible in LHC)

- Excellent mass resolution (lepton only: no jet ambiguity) ~ 30 MeV in ILC (1ˢᵗ phase only)

- Usable as a cut to separate the main background ZZ (recoil mass peaked at 91.2 GeV)

only looking 2f from Z



Zh→m⁺m⁻X
√s = 250 GeV
$L_{int}$ = 250 fb⁻¹, P(e⁻, e⁺) = (-0.8, +0.3)
• Signal+Background (MC)
— Fitted signal+Background
— Fitted signal
--- Fitted background

# global fit of higgs couplings

Model independent

| Facility | ILC | | | ILC(LumiUp) |
|---|---|---|---|---|
| $\sqrt{s}$ (GeV) | 250 | 500 | 1000 | 250/500/1000 |
| $\int \mathcal{L}dt$ (fb$^{-1}$) | 250 | +500 | +1000 | 1150+1600+2500 |
| $P(e^-, e^+)$ | $(-0.8, +0.3)$ | $(-0.8, +0.3)$ | $(-0.8, +0.2)$ | (same) |
| $\Gamma_H$ | 11% | 5.9% | 5.6% | 2.7% |
| $BR_{\mathrm{inv}}$ | < 0.69% | < 0.69% | < 0.69% | < 0.32% |
| | | | | |
| $\kappa_\gamma$ | 18% | 8.4% | 4.1% | 2.4% |
| $\kappa_g$ | 6.4% | 2.4% | 1.8% | 0.93% |
| $\kappa_W$ | 4.8% | 1.4% | 1.4% | 0.65% |
| $\kappa_Z$ | 1.3% | 1.3% | 1.3% | 0.61% |
| | | | | |
| $\kappa_\mu$ | — | — | 16% | 10% |
| $\kappa_\tau$ | 5.7% | 2.4% | 1.9% | 0.99% |
| $\kappa_c$ | 6.8% | 2.9% | 2.0% | 1.1% |
| $\kappa_b$ | 5.3% | 1.8% | 1.5% | 0.74% |
| $\kappa_t$ | — | 14% | 3.2% | 2.0% |

limited by $\sigma_{\mathrm{ZH}}$ @ 250 GeV

# Further improvements

- llh 250 → 3.0% (model independent)
  / 2.6% (model dependent)

- Combining other modes
  - Higher energies: ILC500
  - Jet recoil qqh
    - 350/500 GeV
    - 250 GeV

# llh at 500 GeV

- Cross section ($\mu\mu$h) eL(0.8) pR(0.3)
  - 250 GeV: 10 fb
  - 500 GeV: 3.3 fb
  - Combining two may improve the resolution
- Recoil mass
  - Smeared in 500 GeV
- Background
  - Large t-channel diagram in 500 GeV
- Analysis
  - Almost the same as 250 GeV

# Cuts

Almost same as LoI

- Lepton ID

- Z mass (81.2 to 101.2 GeV)

- di-lepton pT > 20 GeV

- recoil mass (115-250 $\mu\mu$, 100-250 ee)

- acoplanarity ($\pi$ +- 0.1 rad vetoed)

- pT balance
  |di-lepton pT – pT of the most energetic neutral particle| > 10 GeV

# Likelihood

Same as LoI

- di-lepton pT
- cosθ of di-lepton
- acolinearity
- Z mass

TMVA used

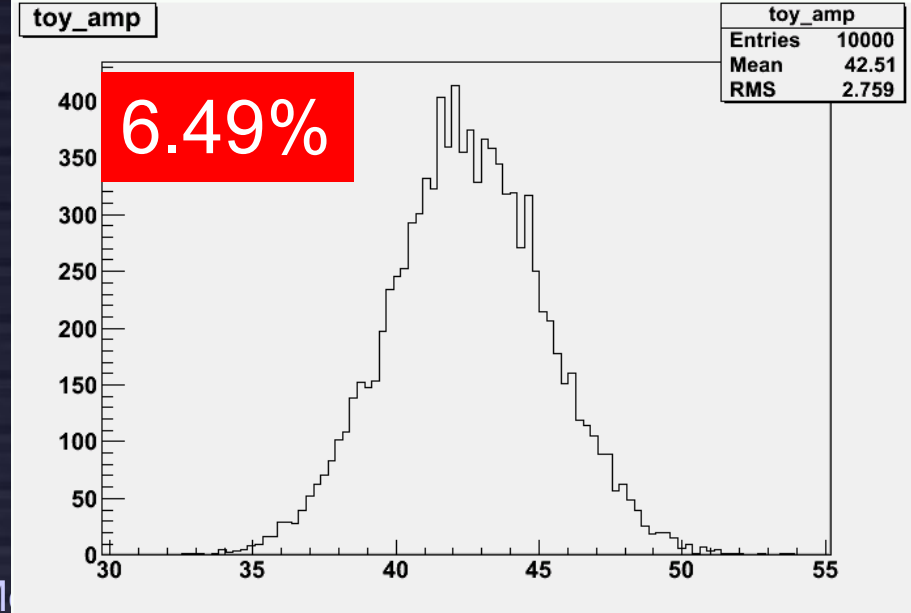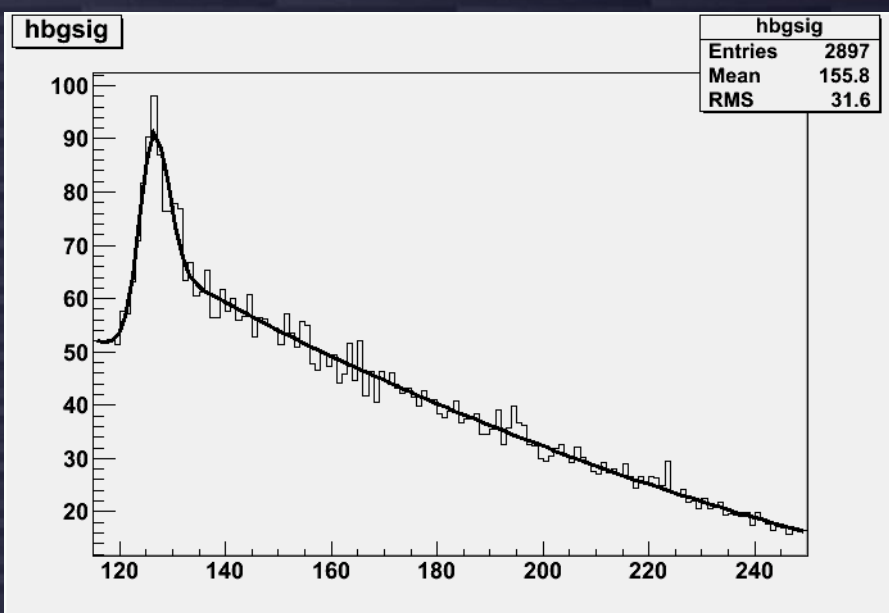- BDT & likelihood gives similar results
- Likelihood adopted

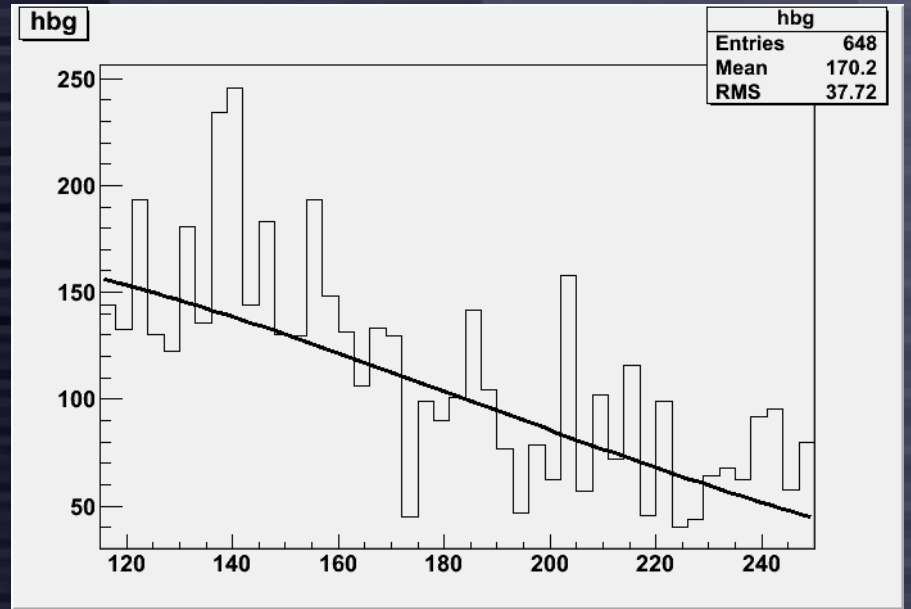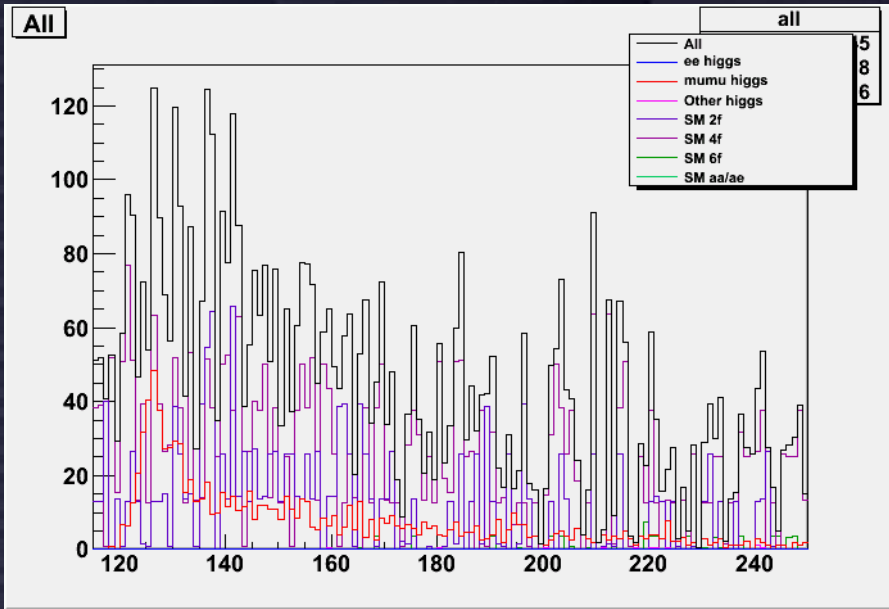# mumu channel: cut table

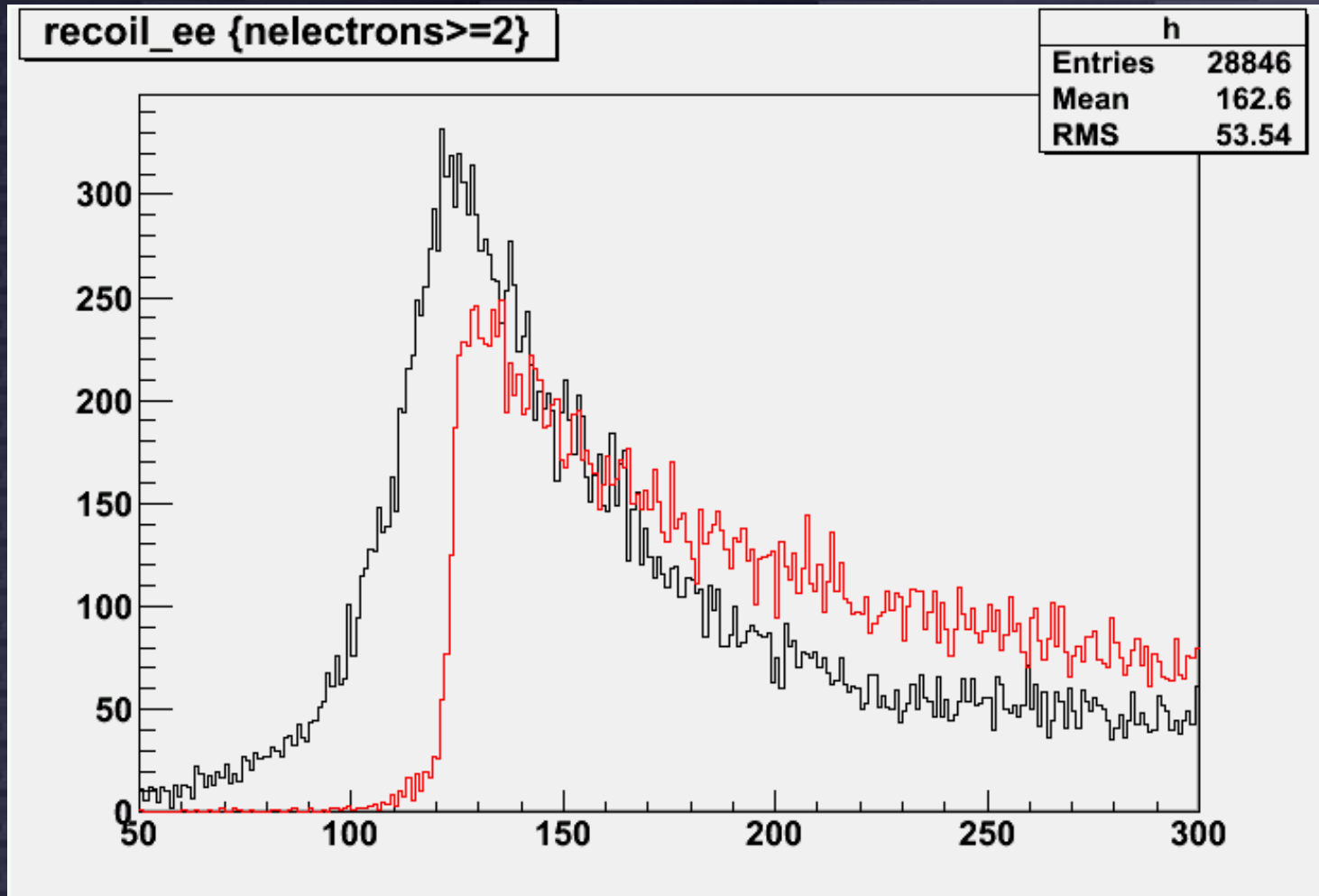| cut | eeh | mmh | ooh | 2f | 4f | 6f | o |
|---|---|---|---|---|---|---|---|
| m>=2 | 128 | 1691 | 3490 | 1.03e+6 | 966334 | 56719 | 361231 |
| z mass | 7.2 | 1499 | 141 | 225706 | 111908 | 4203 | 2765 |
| ptdl>20 | 6.2 | 1492 | 124 | 64342 | 95766 | 3861 | 1573 |
| recoil | 1.6 | 1211 | 11 | 15198 | 30594 | 232 | 68 |
| acop | 1.3 | 1208 | 11 | 14598 | 28447 | 227 | 56 |
| ptbal | 1.2 | 1206 | 10 | 4544 | 27618 | 217 | 35 |
| like>0.8 | 0 | 997 | 6.5 | 1632 | 3345 | 63 | 1.3 |

# Recoil fit

- BG fit (Gaus * 2$^{nd}$ pol for mm, linear for ee)
- Fit will all paremeters free
  - GPET with 5 parameters
    Gaus (left side)
    Gaus + expo (right side)
  - background distribution from fit function
    - to avoid large fluctuation due to the small stat
- Toy-MC – 10000 times
  - Poisson from data (sig), func (bg)
  - Fit with fixing shape parameters
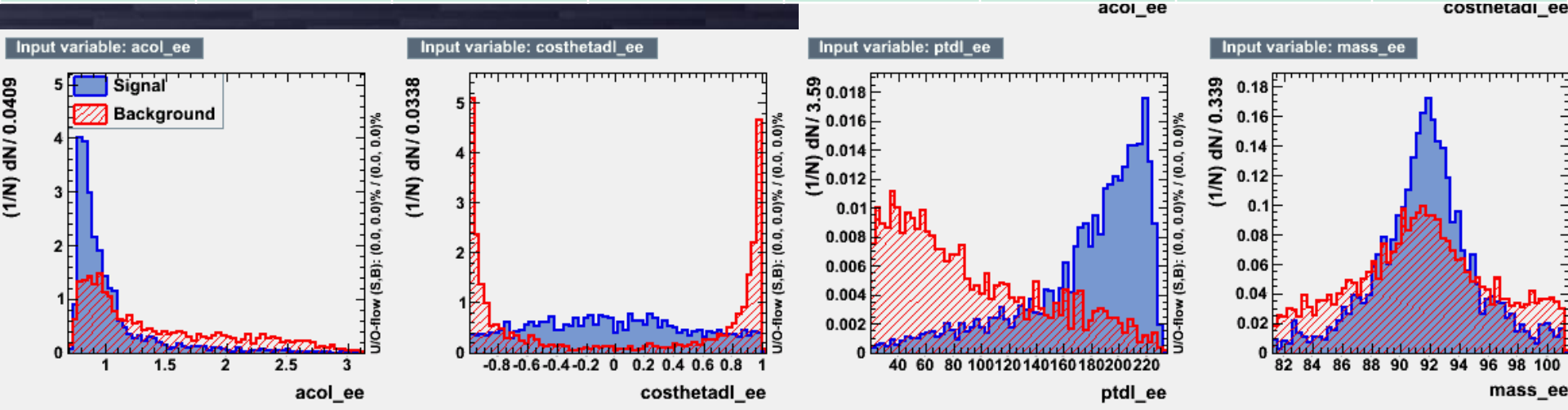    (mean and amplitude free)

# mumu: recoil fit

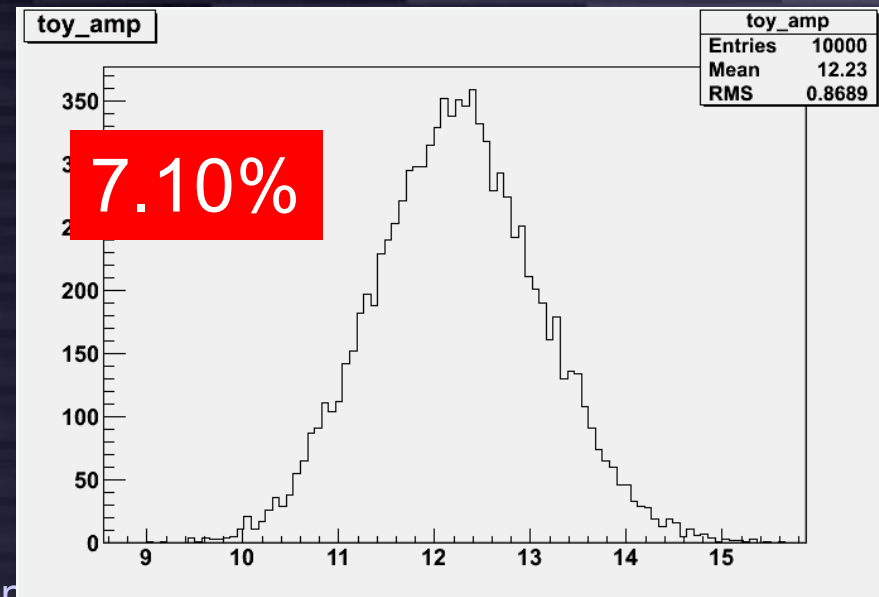# ee: brems recovery

all neutral particle at cosθ > 0.99 are added
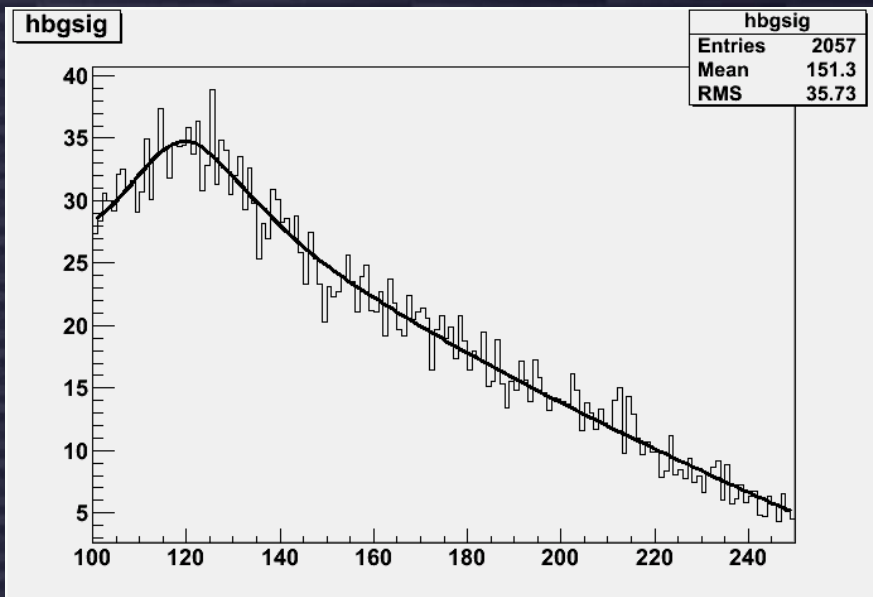
# ee: cut table
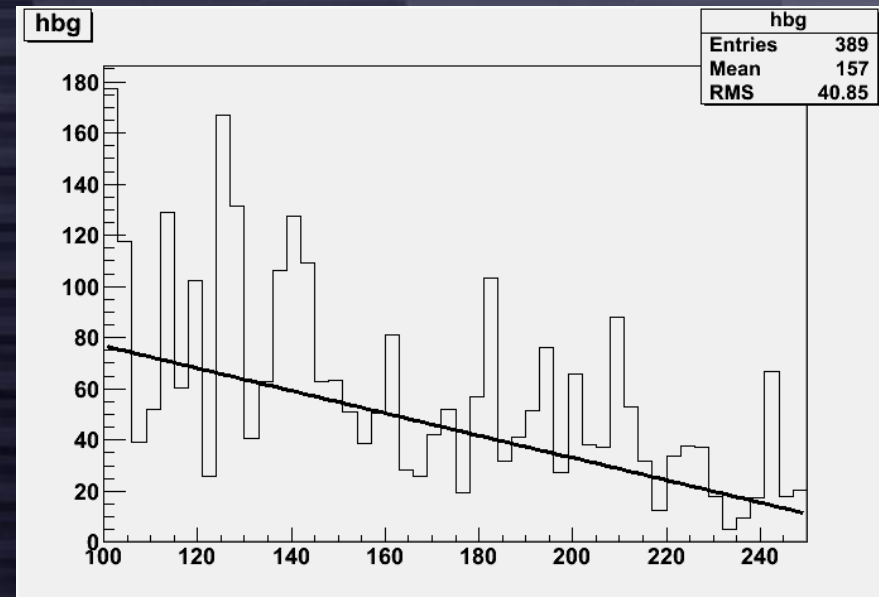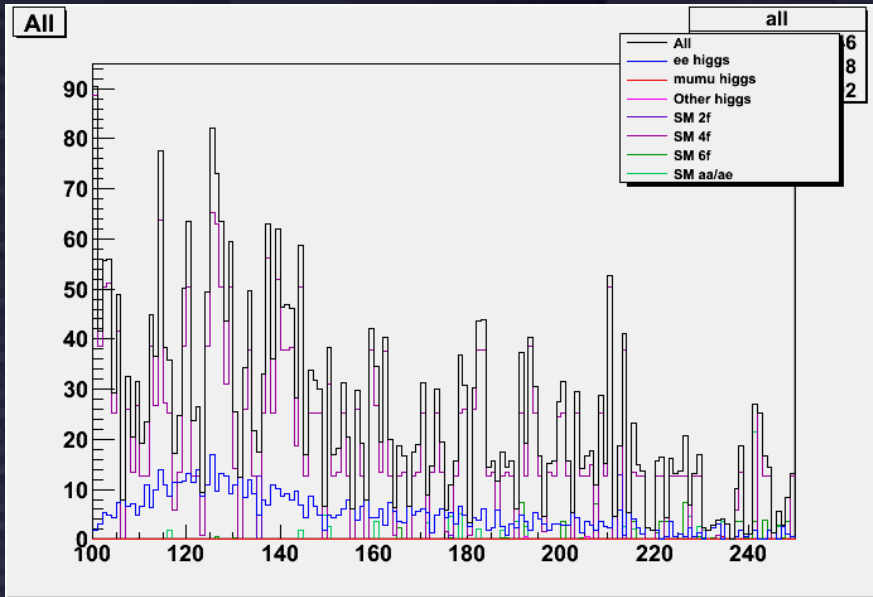
| cut | eeh | mmh | ooh | 2f | 4f | 6f | o |
|---|---|---|---|---|---|---|---|
| e>=2 | 4582 | 76 | 6241 | 500994 | 1.6e+4 | 94156 | 413309 |
| z mass | 1654 | 2.3 | 559 | 18976 | 151032 | 14827 | 15562 |
| ptdl>20 | 1627 | 2.0 | 459 | 12987 | 115384 | 12983 | 11496 |
| recoil | 1126 | 0.6 | 14 | 478 | 31324 | 443 | 1278 |
| acop | 1118 | 0.6 | 14 | 426 | 30123 | 429 | 1193 |
| ptbal | 1113 | 0.6 | 14 | 388 | 28417 | 417 | 1154 |
| l>0.9 | 757 | 0.6 | 1.4 | 26 | 2763 | 66 | 84 |

# ee: recoil fit



7.10%

# Summary of llh 500

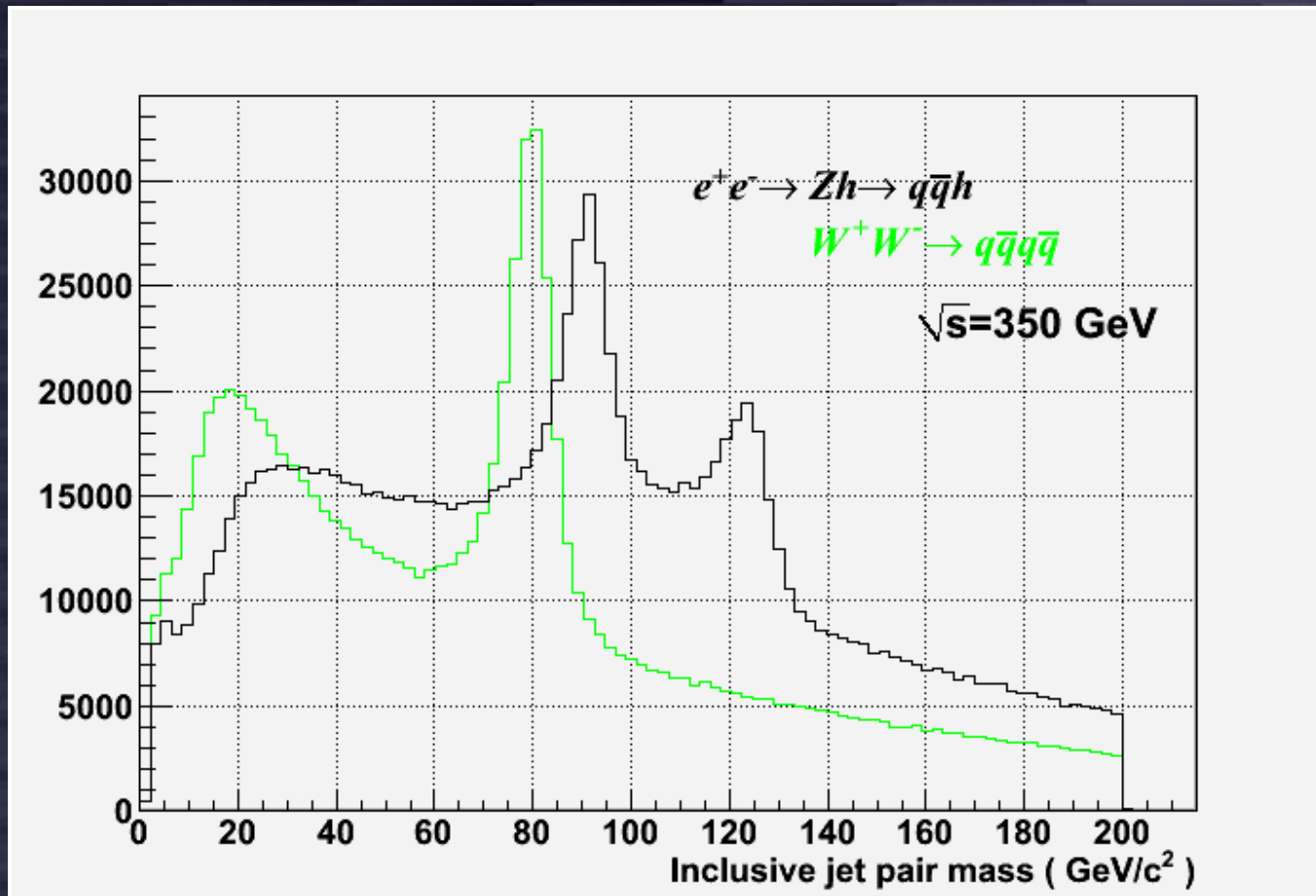- mmh: 6.49%
- eeh: 7.10%

- combined: 4.8%

# qqh recoil

- llh: only 6% of Z (e+$\mu$)
- qqh: 70% $\rightarrow$ hopeful!
- $\nu\nu$h, $\tau\tau$h: impossible to get recoil


- Jet clustering
  - efficiency can be different
    among higgs decay modes (6-jet, 4-jet, 2-jet)
- Jet energy resolution
  - Worse than leptons
  - Wider peak of recoil mass

# qqh 350: W/Z separation
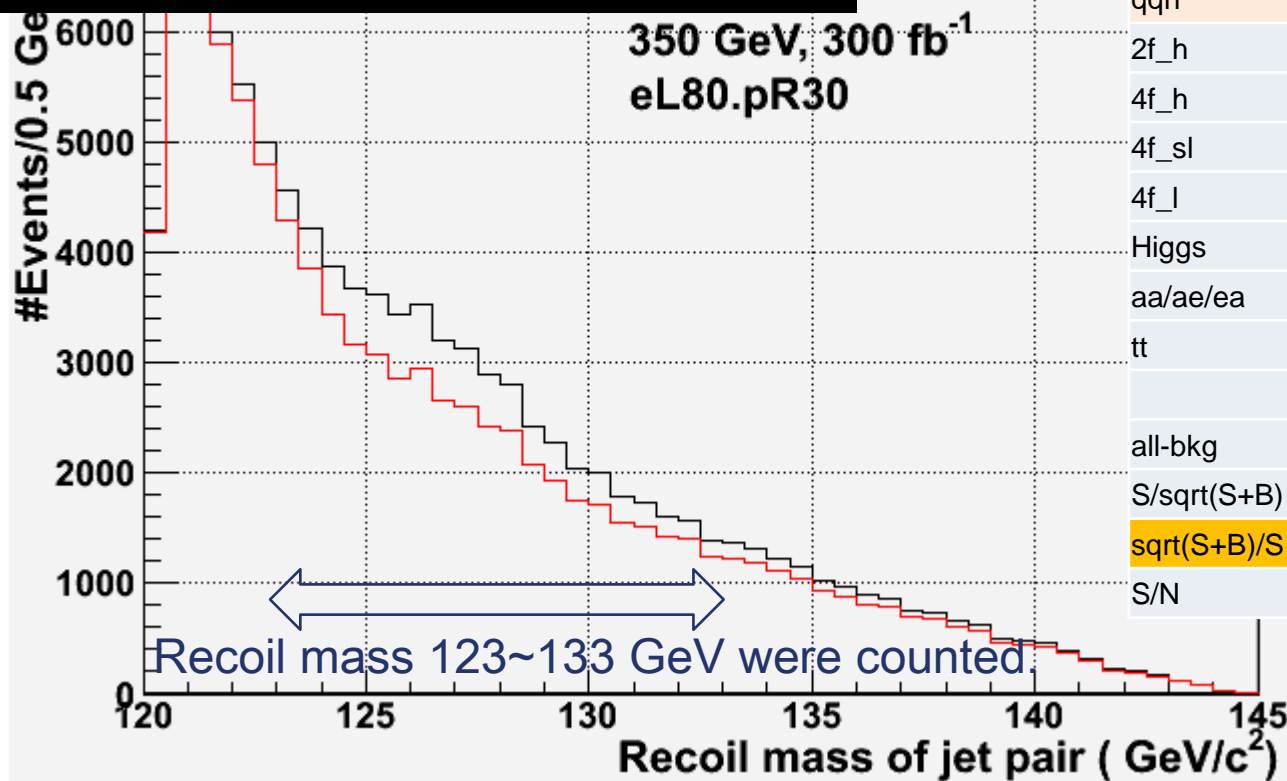
A. Miyamoto

sales point of
PFA calorimeter



$e^+e^- \rightarrow Zh \rightarrow q\bar{q}h$

$W^+W^- \rightarrow q\bar{q}q\bar{q}$

$\sqrt{s} = 350$ GeV

Inclusive jet pair mass ( GeV/c$^2$ )

# 350 GeV result

A. Miyamoto

- $k_t$ clustering w/ R=1.2 (may not be optimal)
- Basic cuts of Z mass etc.

Selection statistics

350 GeV, 300 fb$^{-1}$
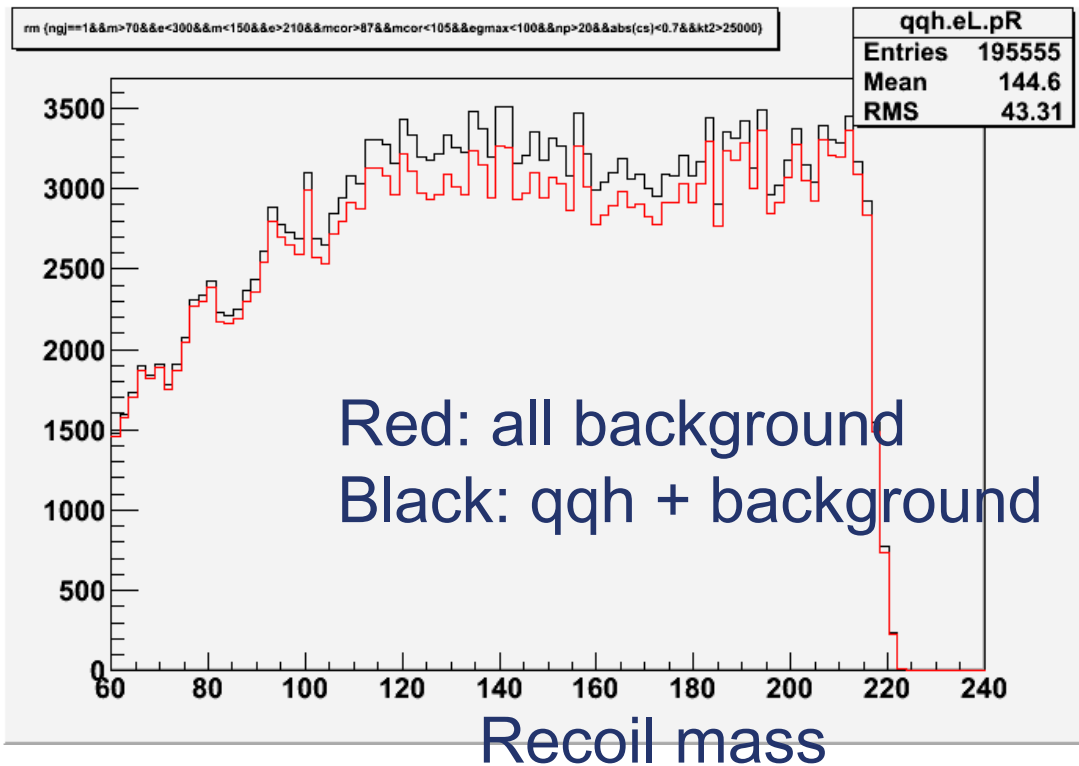eL80.pR30



Recoil mass 123~133 GeV were counted.

**#Events/0.5 GeV** vs **Recoil mass of jet pair ( GeV/c$^2$ )**

| | eR80.pR30 (300fb-1) | eL80.pR30 (300fb-1) |
|---|---|---|
| qqh | 7581 | 11263 |
| 2f_h | 13049 | 33326 |
| 4f_h | 15726 | 109011 |
| 4f_sl | 10767 | 65971 |
| 4f_l | 597 | 1755 |
| Higgs | 1313 | 1975 |
| aa/ae/ea | 3971 | 7320 |
| tt | 4124 | 8441 |
| | | |
| all-bkg | 49546 | 227800 |
| S/sqrt(S+B) | 31.72 | 23.04 |
| sqrt(S+B)/S | 0.03153 | 0.04341 |
| S/N | 0.153 | 0.049 |

150 fb-1 each to
-80/+30 & +80/-30%

$\Delta\sigma/\sigma \sim 3.6\%$

# 500 GeV



| | qqh.eL.pR | |
|---|---|---|
| Entries | 195555 | |
| Mean | 144.6 | |
| RMS | 43.31 | |

Red: all background
Black: qqh + background

Recoil mass

Event statistics for 500 fb-1, eL80.pR30 at 500 GeV

| | Process | Nevents | Fraction(%) |
|---|---|---|---|
| S | qqh | 11113 | |
| | ffh | 338 | 0.19 |
| | 2f | 47377 | 27.01 |
| B | 4f | 121086 | 69.02 |
| | 6f | 6357 | 3.62 |
| | aa_2f | 91 | 0.05 |
| | ae/ea | 186 | 0.11 |

S/N=0.0633

sqrt(S+N)/S=0.0389

$\Delta\sigma/\sigma \sim 3.9\%$

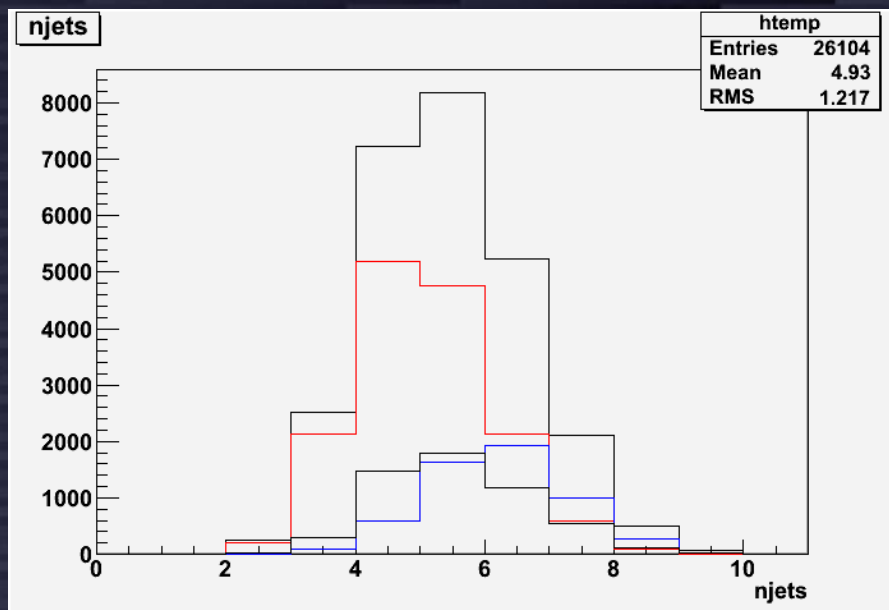Hard to see recoil mass peak,
but excess due to qqh could be seen

# Summary

- A possibility to measure $\sigma_{ZH}$ using using Z→qq mode was investigated.

- At 350 GeV, Higgs peak in jet recoil mass can be seen. Combining eL80/eR30 150fb$^{-1}$ and eR80/eL30 150fb$^{-1}$, $\Delta\sigma/\sigma \sim 3.6\%$ is expected.

- At 500 GeV, hard to see Higgs peak in jet recoil mass distribution. But from event excess in qqh like events, $\Delta\sigma/\sigma \sim 3.9\%$ is expected for 500 fb$^{-1}$, eL80.pR30 beam polarization.

- Further improvement may be possible by more sophisticated analysis.
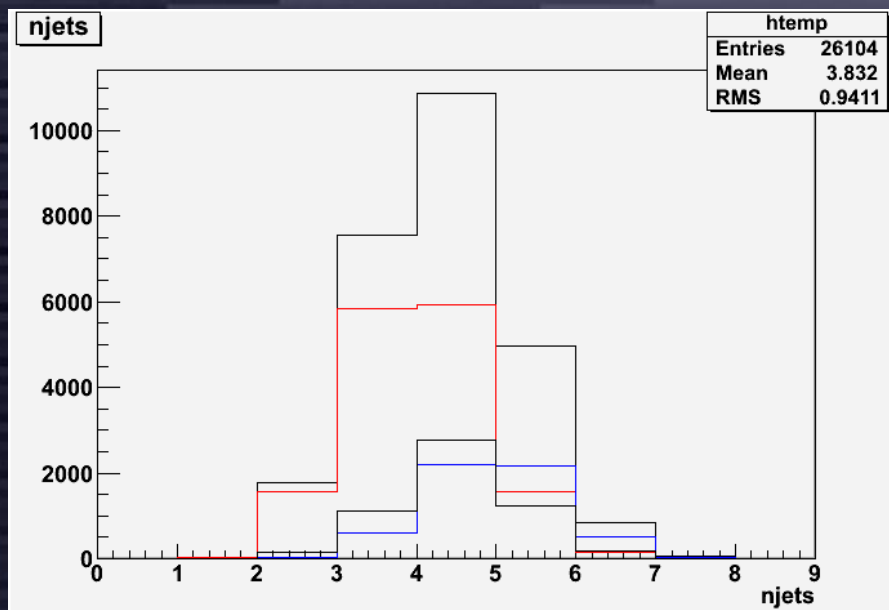- A possibility to use Z→qq at 250 GeV should be investigated.

# qqh 250

- 250 GeV analysis ($\sigma_{ZH}$ ~ maximum)
  - Durham y-fix clustering (should be optimized)
  - or dedicated Z$\rightarrow$qq finder from PFOs
- Difference of efficiency in Higgs decay modes should be investigated (as systematic error study)
- Also used for detector optimization
  - performance with various jet energy resolution will be investigated
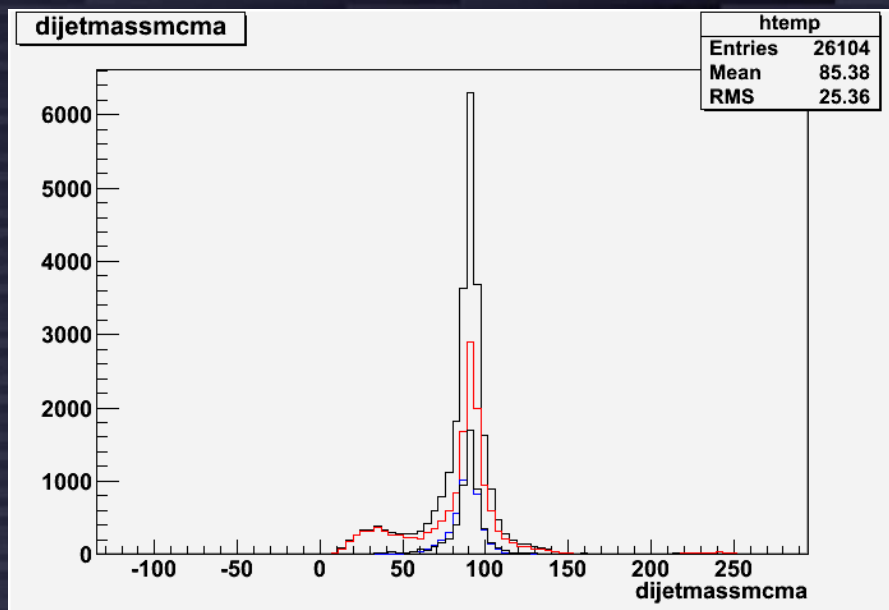
# qqh 250: some plots



ycut = 0.001

ycut = 0.005

black: all
red: H→bb
blue: H→WW*
black: H→others

# qqh 250: some plots



ycut = 0.001

ycut = 0.005

The combination with
mass nearest to Z is selected

black: all
red: H→bb
blue: H→WW*
black: H→others

# qqh 250: some plots

**recoil mass**

ycut = 0.001

ycut = 0.005

The combination with
mass nearest to Z is selected

cut on $81.2 < m_Z < 101.2$

black: all
red: H→bb
blue: H→WW*
black: H→others

# qqh 250 summary

- Recoil mass peak observed
- will see WW/ZZ events (before LCWS)
- Optimization with ycut
- Kinematic fit
- Preliminary number? (not sure)

- Dedicated Z→qq finder (after LCWS)