Higgs recoil mass analysis: status and prospects in various channels

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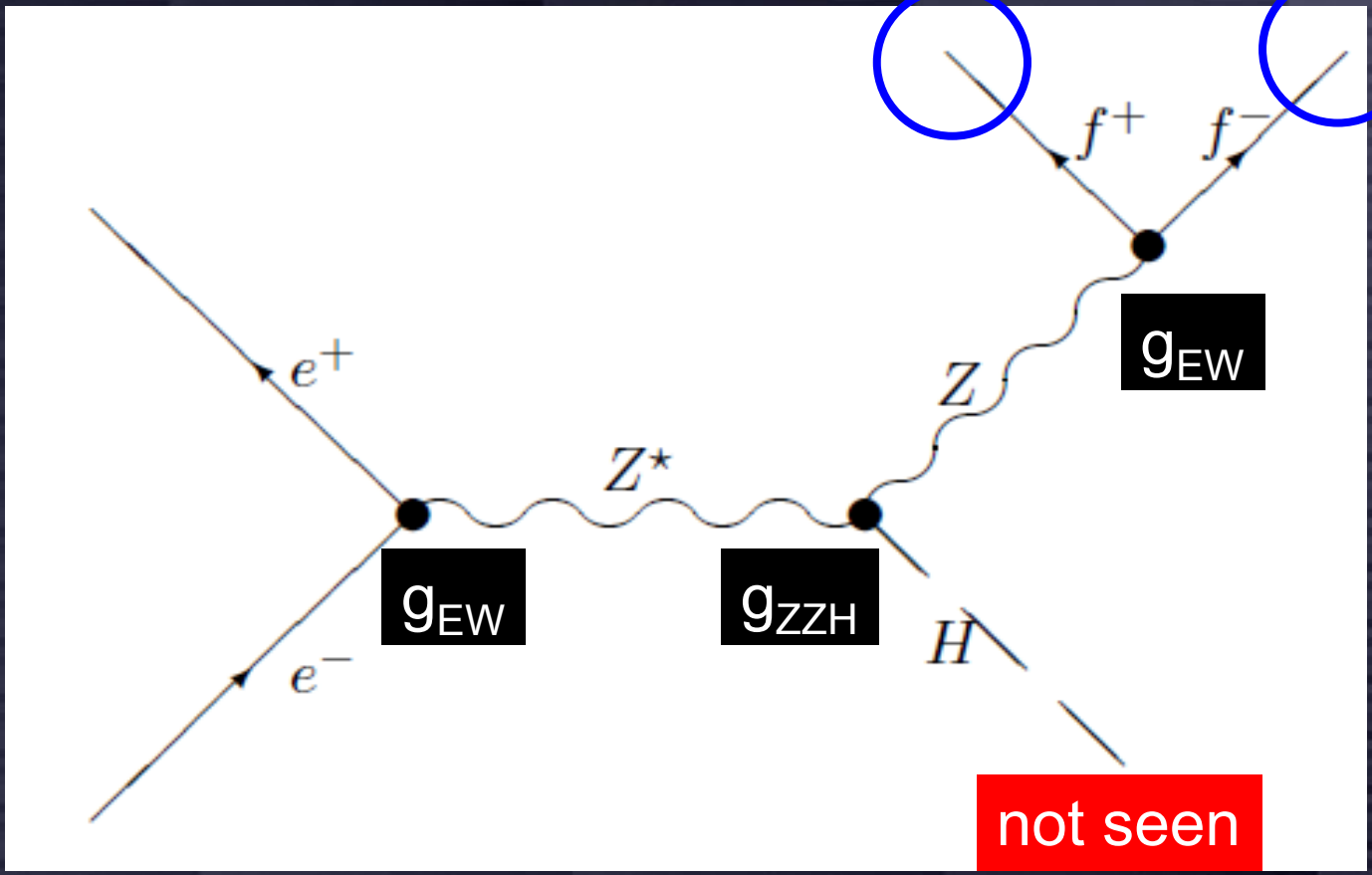
Recoil in ILC

Direct measurement of g_{ZZH} with high precision
cf. to LHC: NOT the "ratio" of Higgs couplings
NOT suffered from QCD uncertainty



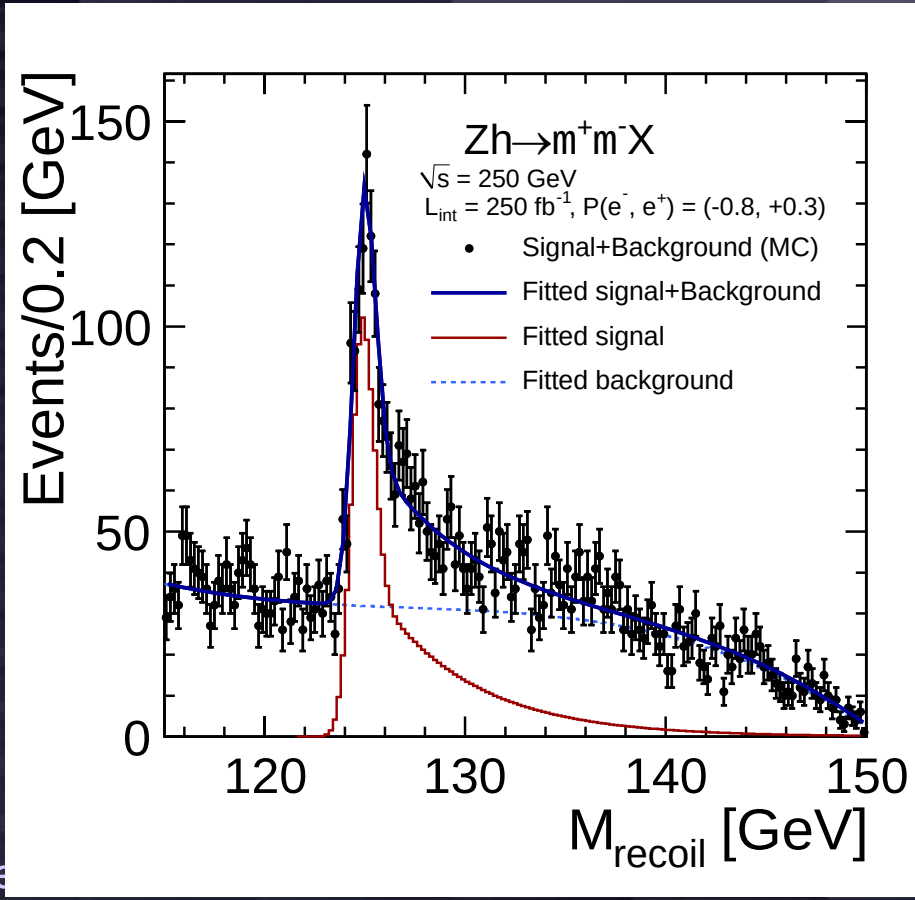
Recoil mass

$$m^2_{\mathrm{recoil}} = \left(\sqrt{s} - E_{ff}\right)^2 - \left|\vec{p}_{ff}\right|^2$$

- 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



global fit of higgs couplings

Snowmass energy frontier report

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)
Γ_H	11%	5.9%	5.6%	2.7%
BR_{inv}	$< 0.69\%$	$< 0.69\%$	$< 0.69\%$	$< 0.32\%$
κ_γ	18%	8.4%	4.1%	2.4%
κ_g	6.4%	2.4%	1.8%	0.93%
κ_W	4.8%	1.4%	1.4%	0.65%
κ_Z	1.3%	1.3%	1.3%	0.61%
κ_μ	–	–	16%	10%
κ_τ	5.7%	2.4%	1.9%	0.99%
κ_c	6.8%	2.9%	2.0%	1.1%
κ_b	5.3%	1.8%	1.5%	0.74%
κ_t	–	14%	3.2%	2.0%

limited by σ_{ZH} @ 250 GeV

Further improvements

- llh 250 → 3.0% (model independent) / 2.5% (semi model independent)
- 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

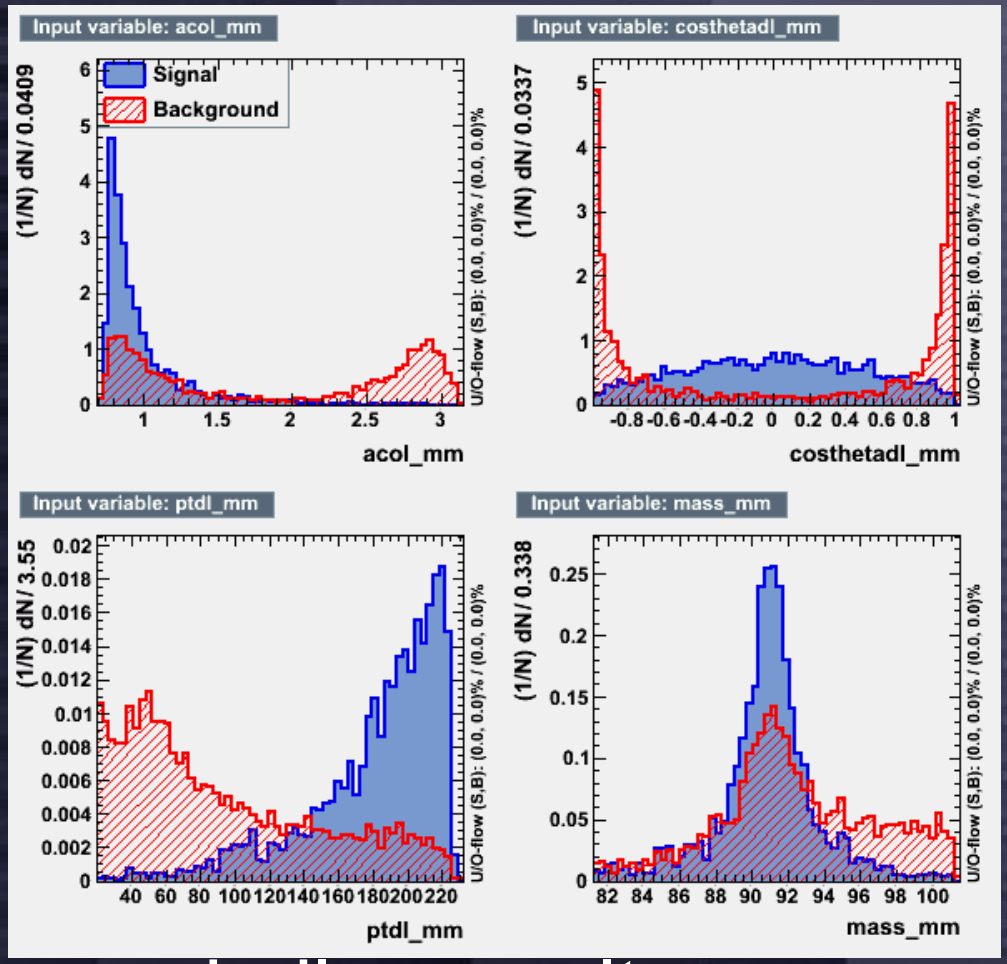
Almost same as LoI

- 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 (π +- 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

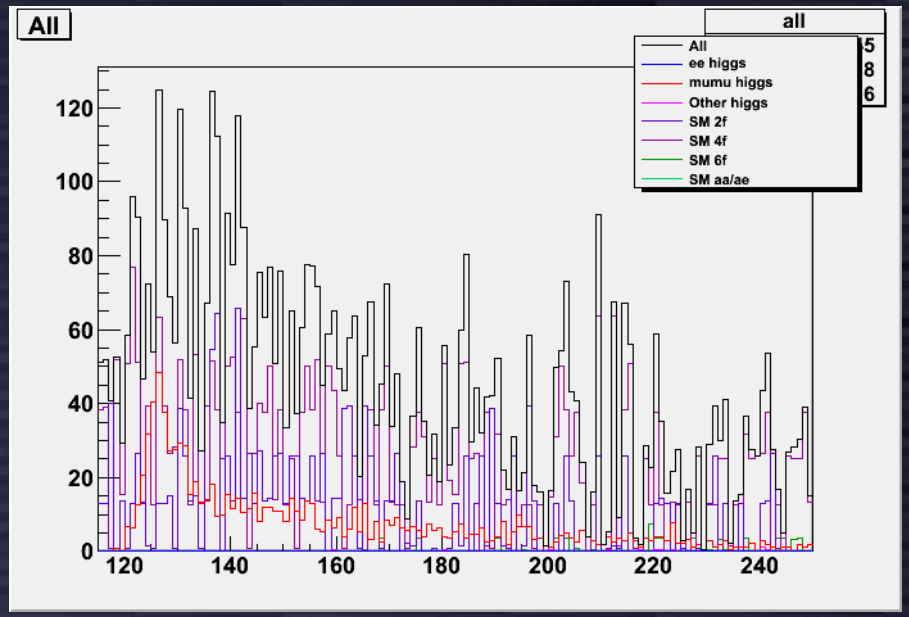
mumu channel: cut table

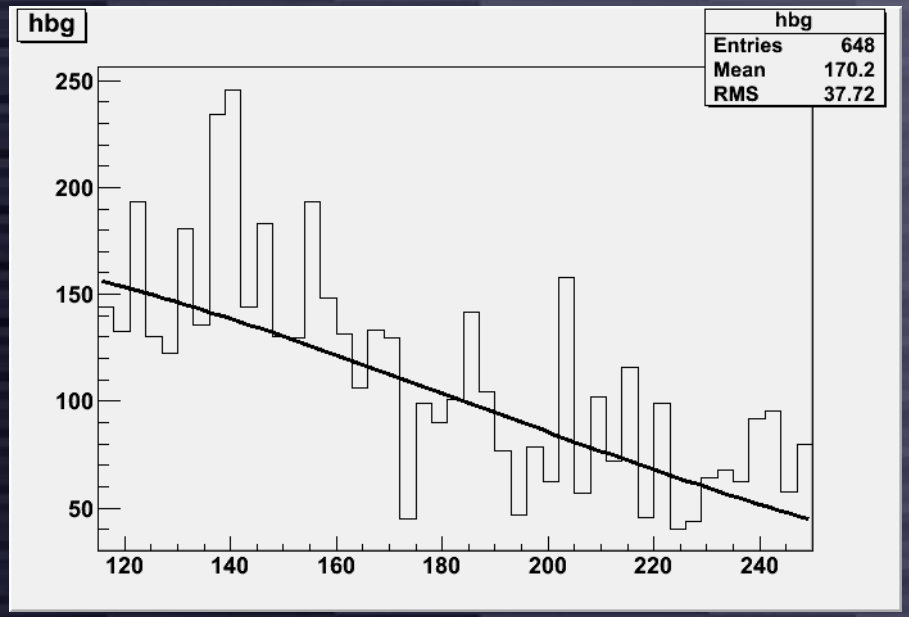
cut	eeh	mmh	ooh	2f	4f	6f	o
m>=2	128	1691	3490	1.03e+6	966334	56719	361231
z mass	7.2	1499	141	225706	111908	4203	2765
ptdl>20	6.2	1492	124	64342	95766	3861	1573
recoil	1.6	1211	11	15198	30594	232	68
acop	1.3	1208	11	14598	28447	227	56
ptbal	1.2	1206	10	4544	27618	217	35
like>0.8	0	997	6.5	1632	3345	63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

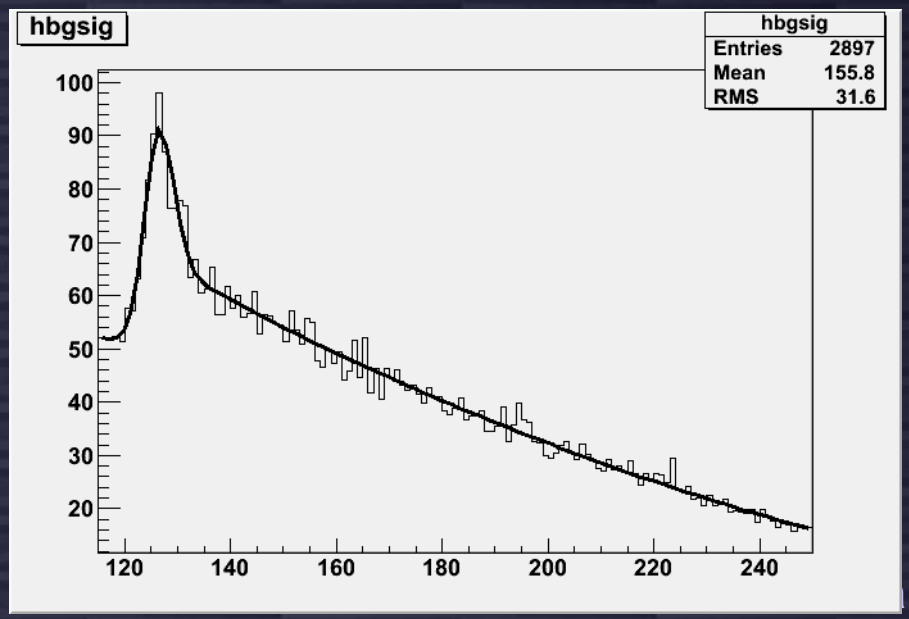
Recoil fit

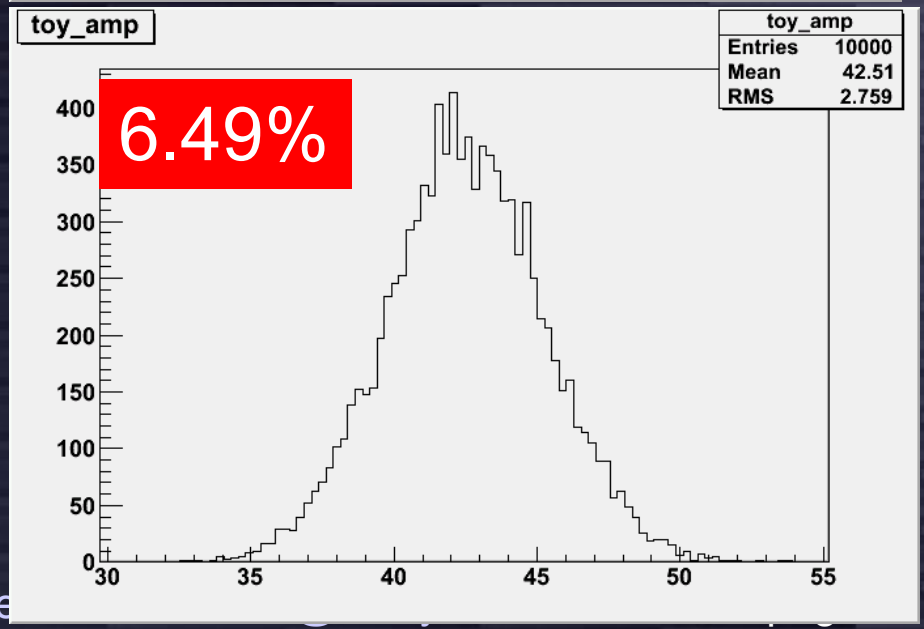
- BG fit (Gaus * 2nd pol for mm, linear for ee)
- Fit will all paremeters free
  - GPET with 5 parameters
    Gaus (left side)
    Gaus + expo (right side)
  - background distribution from fit function
    - to avoid large fluctuation due to the small stat
- Toy-MC – 10000 times
  - Poisson from data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

mumu: recoil fit



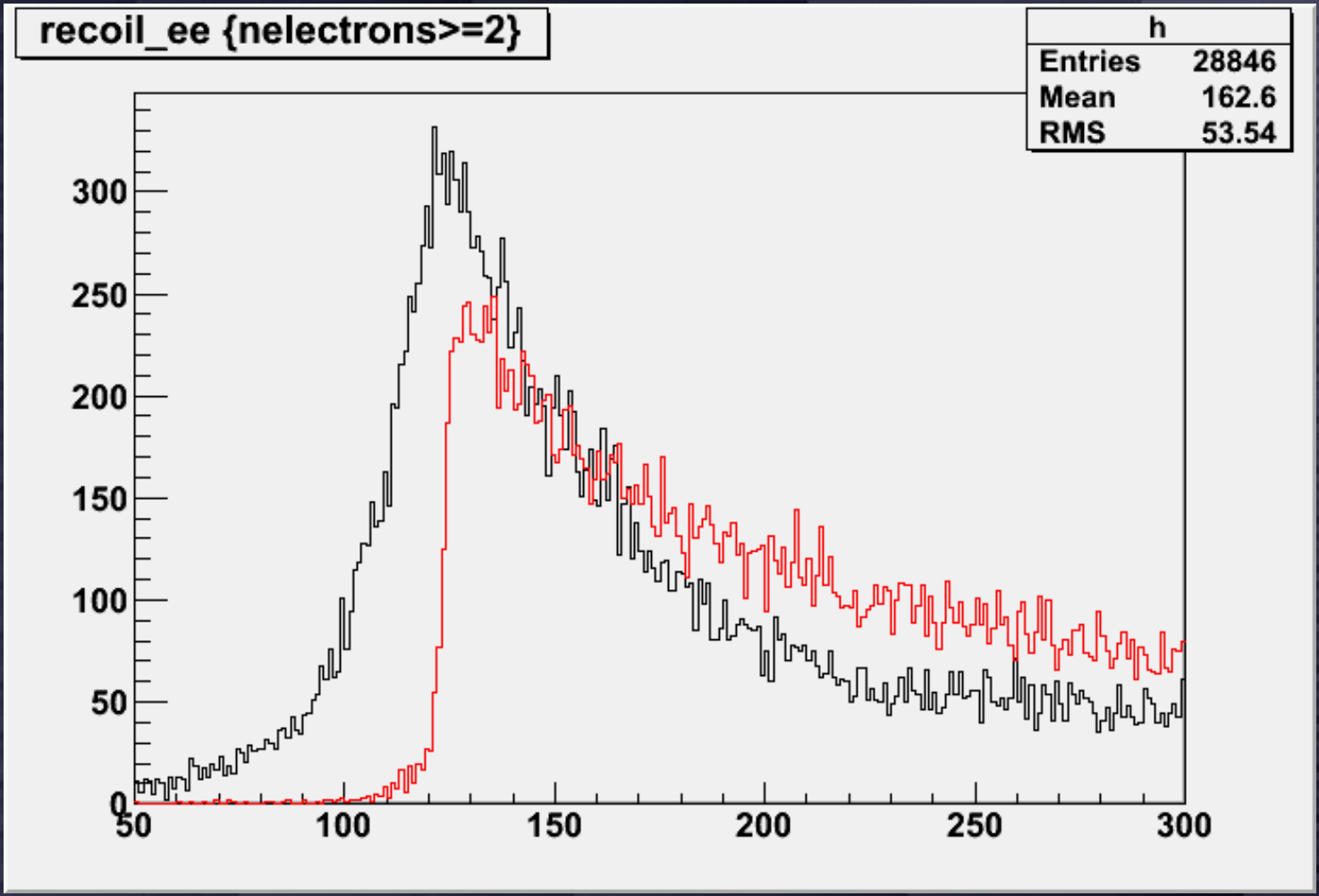






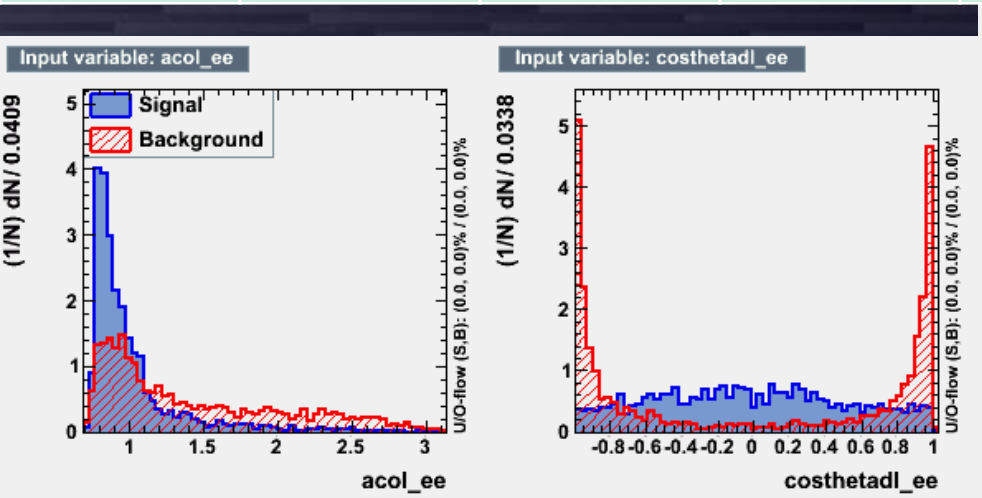
ee: brems recovery

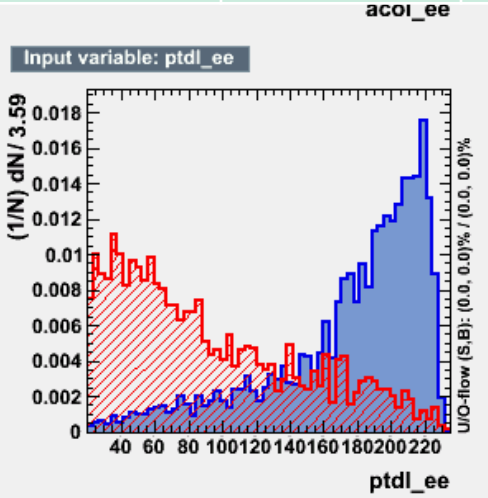
all neutral particle at cosθ > 0.99 are added

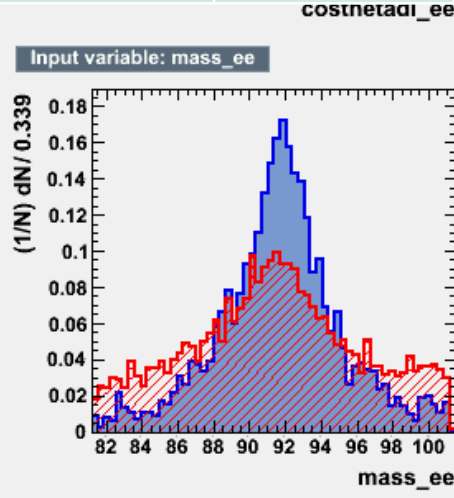


ee: cut table

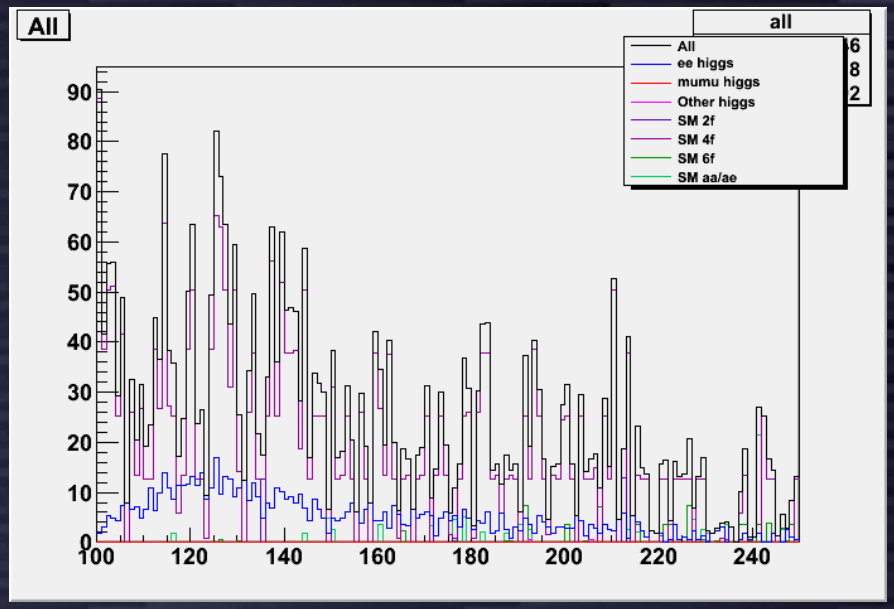
cut	eeh	mmh	ooh	2f	4f	6f	o
e>=2	4582	76	6241	500994	1.6e+4	94156	413309
z mass	1654	2.3	559	18976	151032	14827	15562
ptdl>20	1627	2.0	459	12987	115384	12983	11496
recoil	1126	0.6	14	478	31324	443	1278
acop	1118	0.6	14	426	30123	429	1193
ptbal	1113	0.6	14	388	28417	417	1154
l>0.9	757	0.6	1.4	26	2763	66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

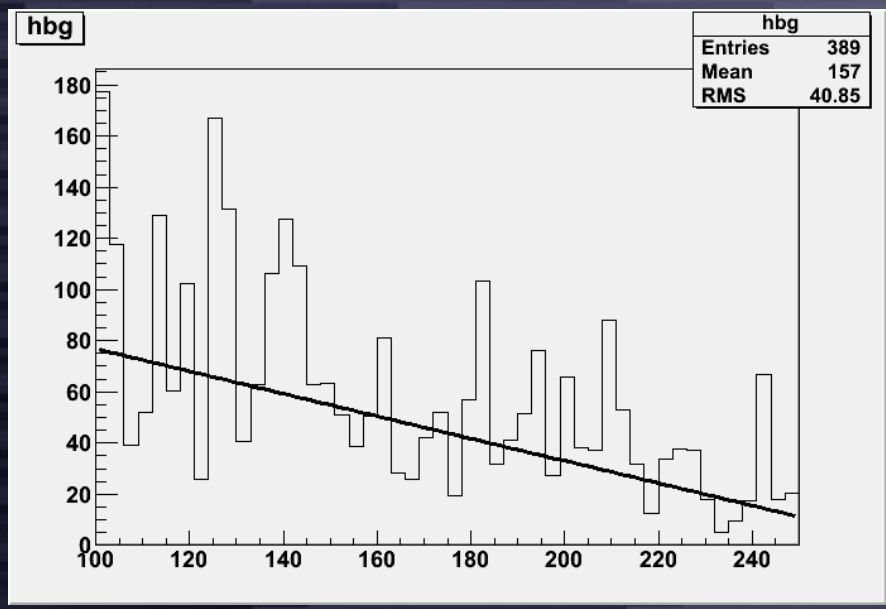


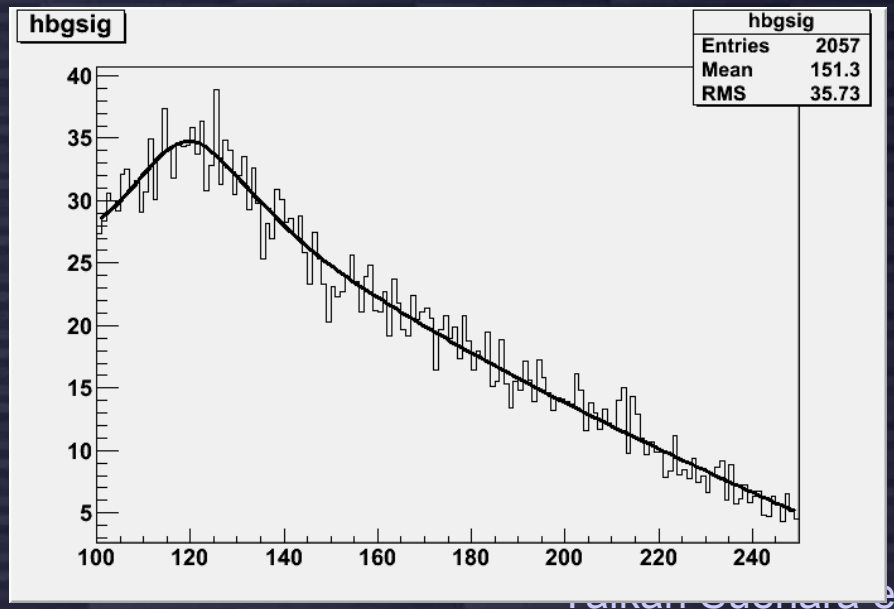


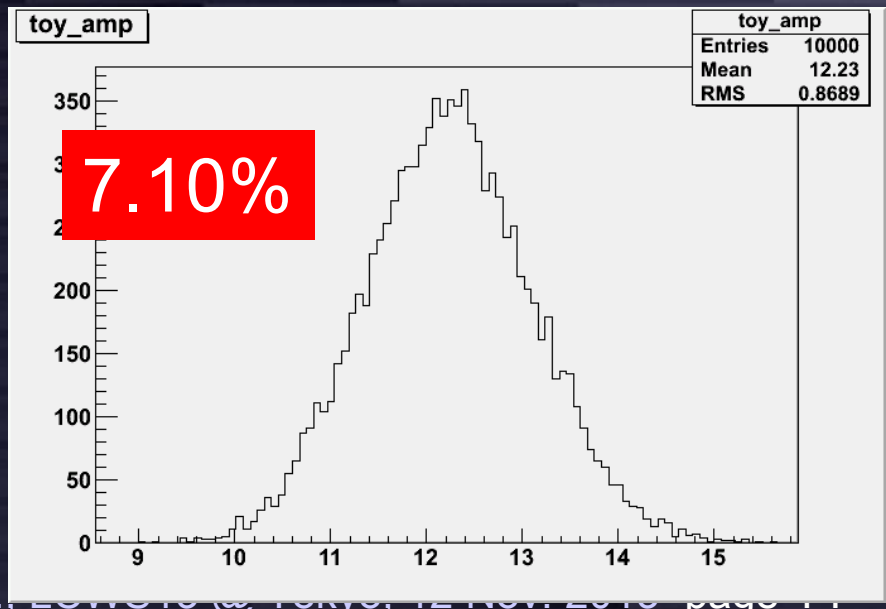


ee: recoil fit









Summary of llh 500

- mmh: 6.49%
- eeh: 7.10%

- combined: 4.8%

qqh recoil

- llh: only 6% of Z (e+μ)
- qqh: 70% → hopeful!
- νν̄h, ττh: 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

A MEASUREMENT OF σ_{Zh} AT A FUTURE e^+e^- COLLIDER USING THE HADRONIC DECAY OF Z

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Abstract

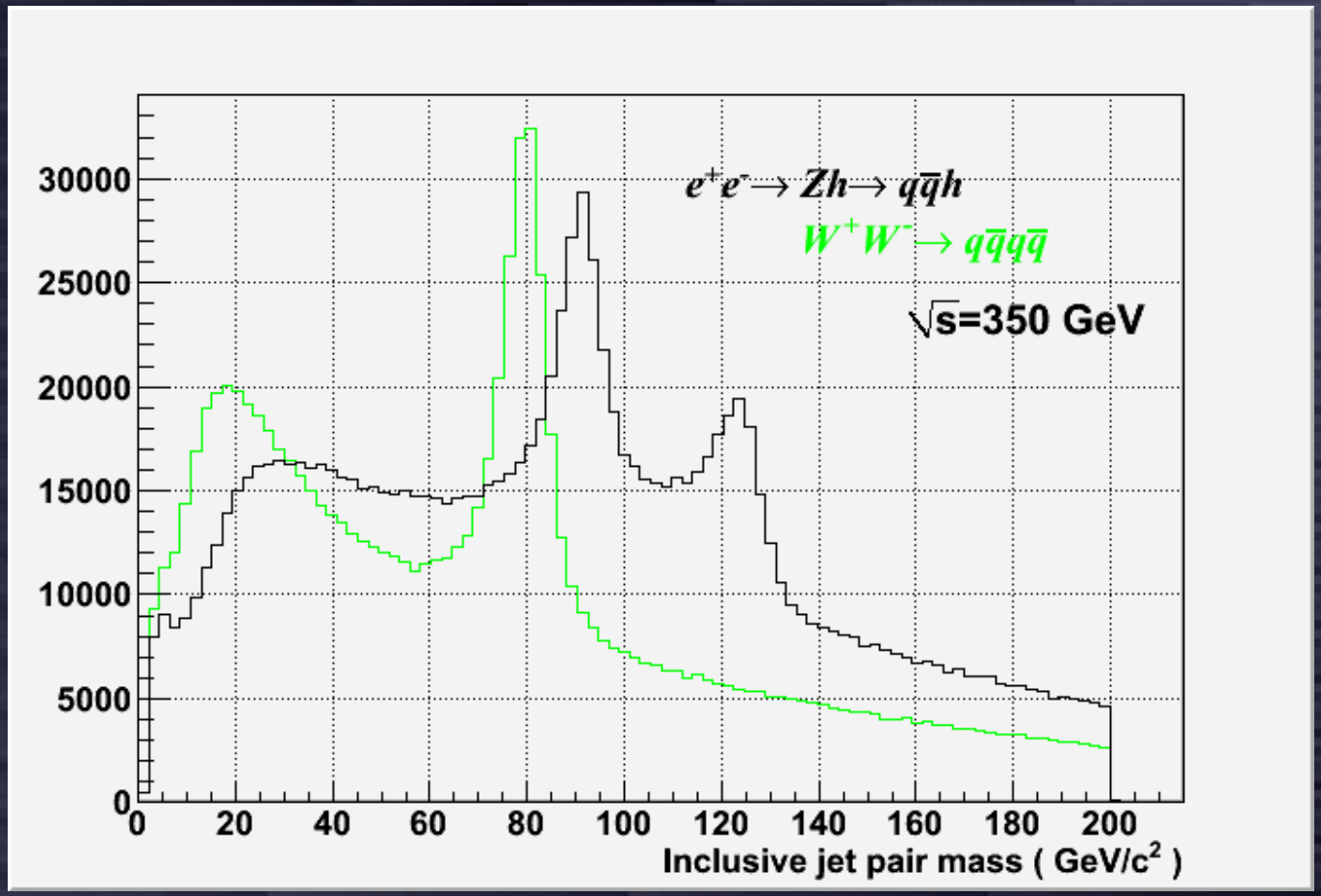
A feasibility to use the hadronic decay mode of Z for the model independant measurement of the total cross section of Higgs-strahlung process (σ_{Zh}) at a future e^+e^- collider was studied. For the recoil mass measurement from hadronic decay of Z, a simple cut based analysis was applied on samples produced by the ILD full detector simulation at $\sqrt{s} = 350$ GeV and 500 GeV using the ILC beam parameters. At 350 GeV, a bump in the recoil mass distribution was reconstructed, and $\Delta\sigma_{Zh}/\sigma_{Zh} = 3.4\%$ was obtained assuming 165 fb^{-1} data with $e^-(e^+)$ beam polarization of -80%(+30%) and +80%(-30%), respectively. At 500 GeV, clear Higgs boson peak in the recoil mass distribution was not seen, however, from the excess of the events, $\Delta\sigma_{Zh}/\sigma_{Zh} = 3.9\%$ was obtained assuming 500 fb^{-1} data with $e^-(e^+)$ beam polarization of -80%(+30%).

arXiv: 1311.2248

qqh 350: W/Z separation

A. Miyamoto

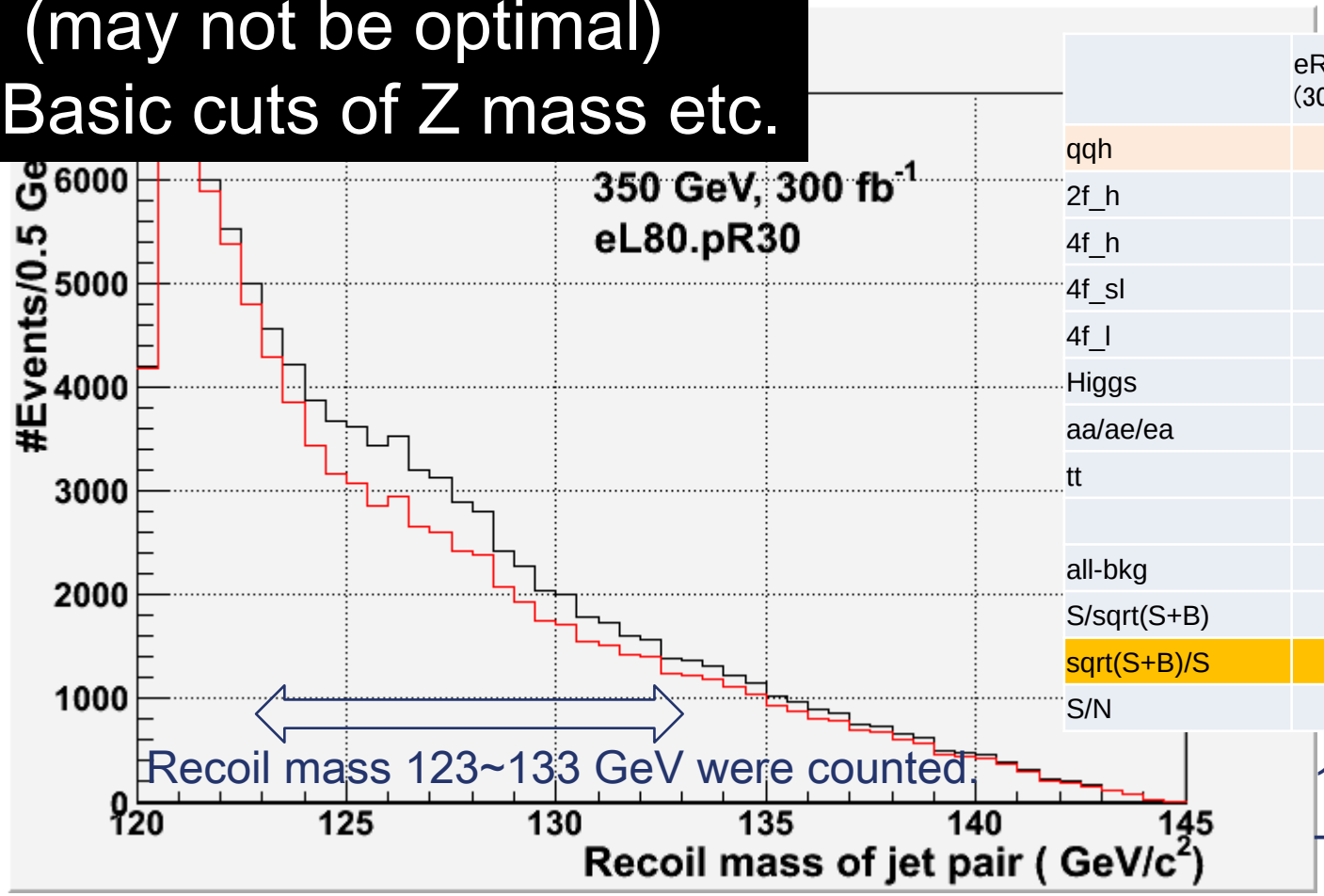
sales point of
PFA calorimeter



350 GeV result

A. Miyamoto

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



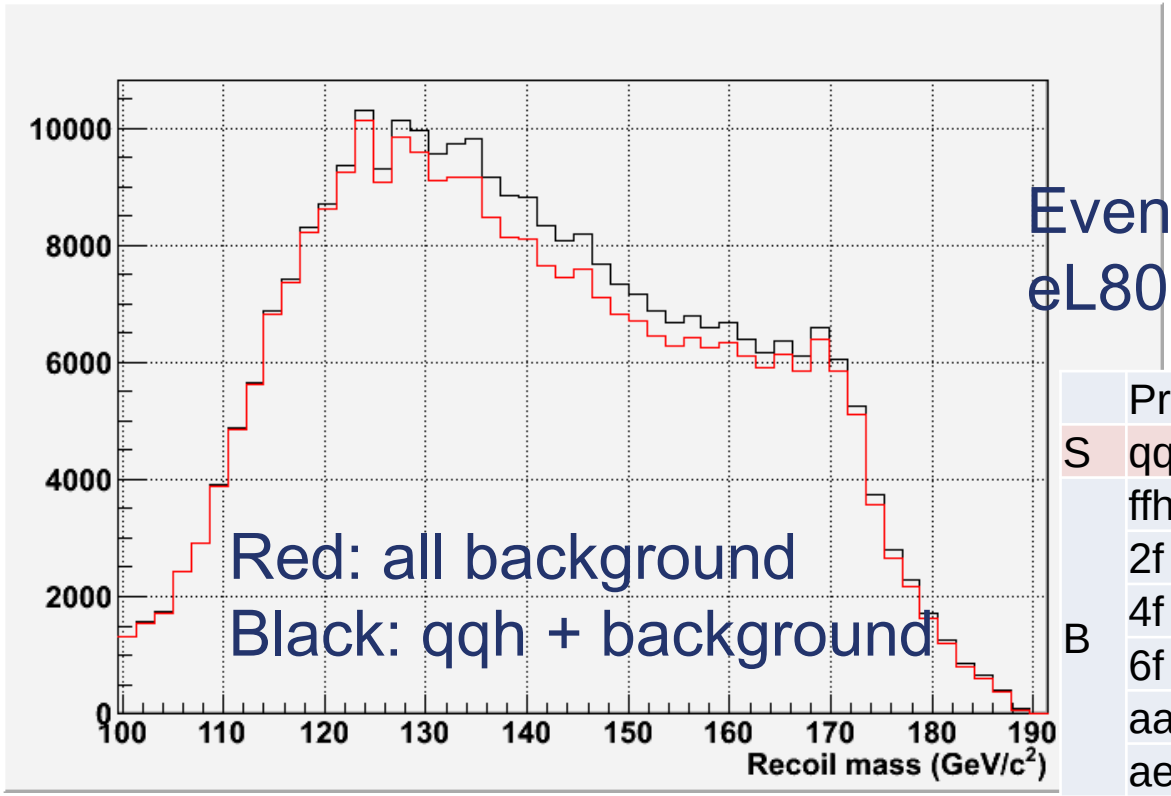
Selection statistics

	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



Recoil mass

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

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

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

S/N=0.0633

sqrt(S+N)/S=0.0389

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

Summary

- A possibility to measure σ_{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

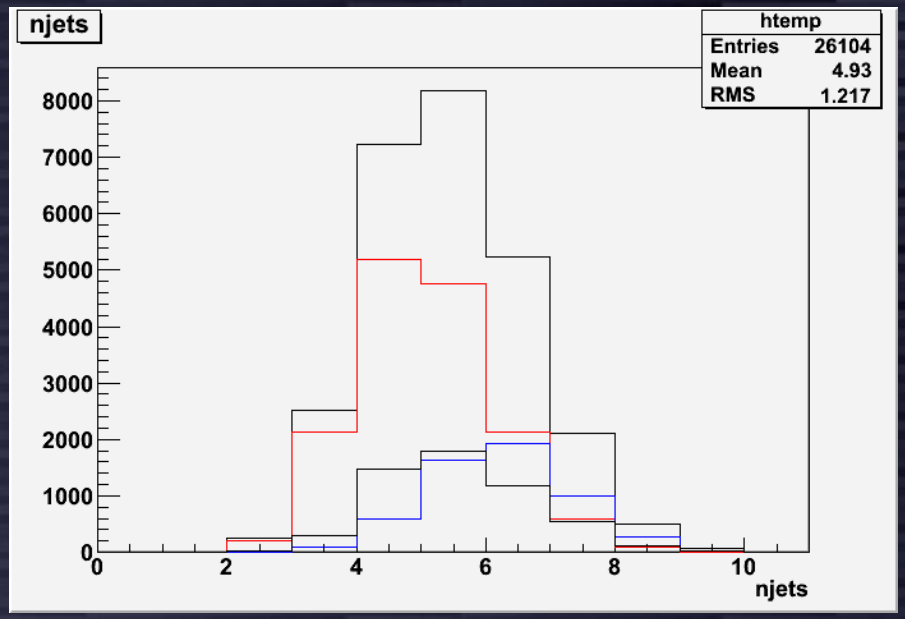
- 250 GeV analysis (σ_{ZH} ~ maximum)
  - Durham y-fix clustering (should be optimized)

$$y = \frac{2\min(E_1, E_2)^2(1-\cos\theta_{ij})}{Q^2}$$

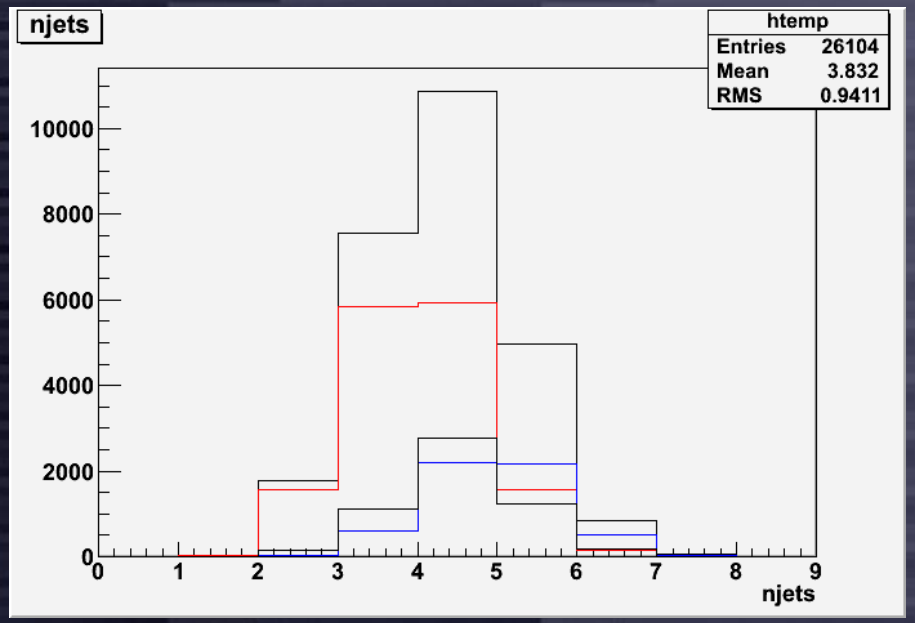
  - or dedicated Z→qq finder from PFOs
- Difference of efficiency in Higgs decay modes should be investigated (as systematic error study)
- Also used for detector optimization
  - performance with various jet energy resolution will be investigated

njets

qqh 250: some plots



ycut = 0.001

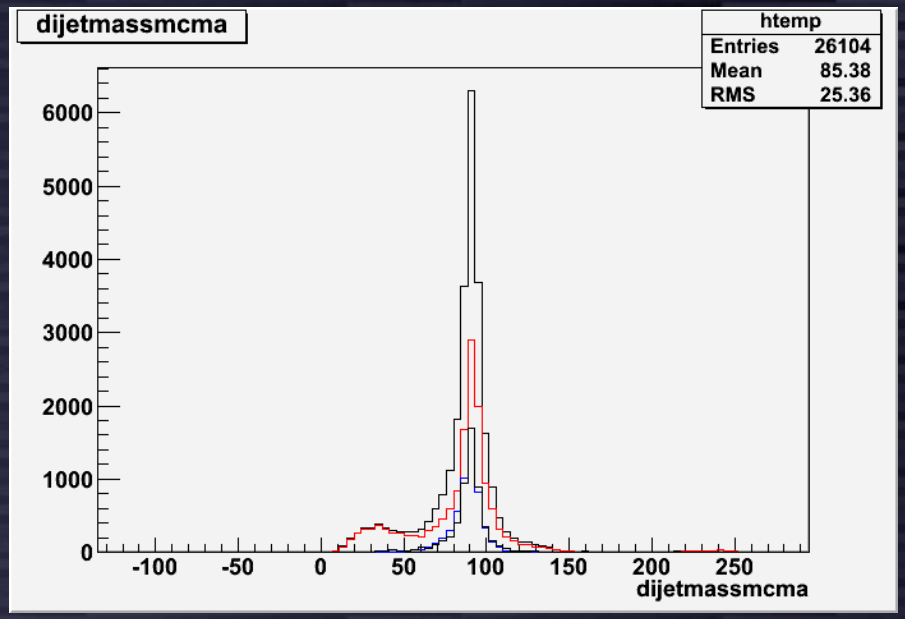


ycut = 0.005

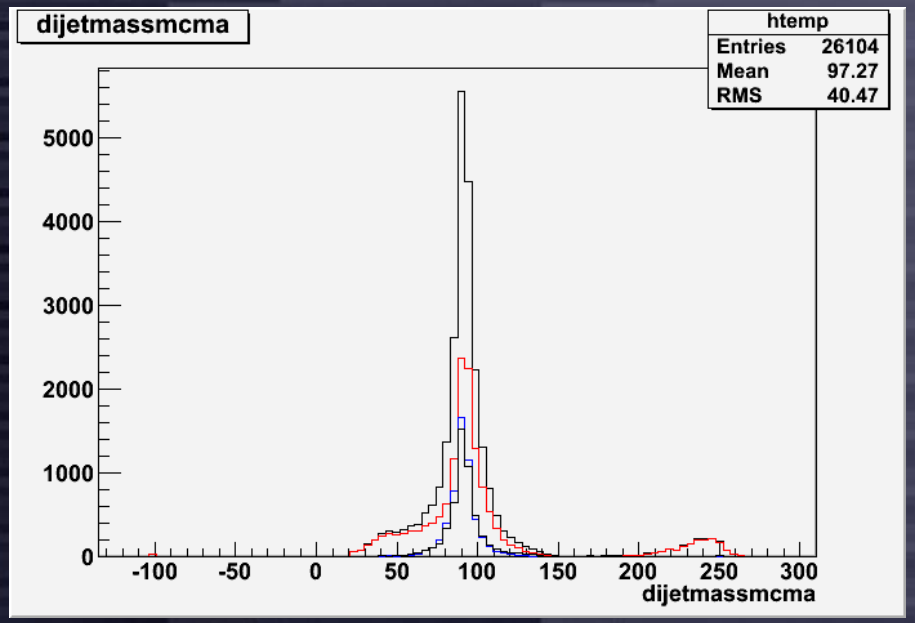
black: all
red: H→bb
blue: H→WW*
black: H→others

Z mass

qqh 250: some plots



ycut = 0.001



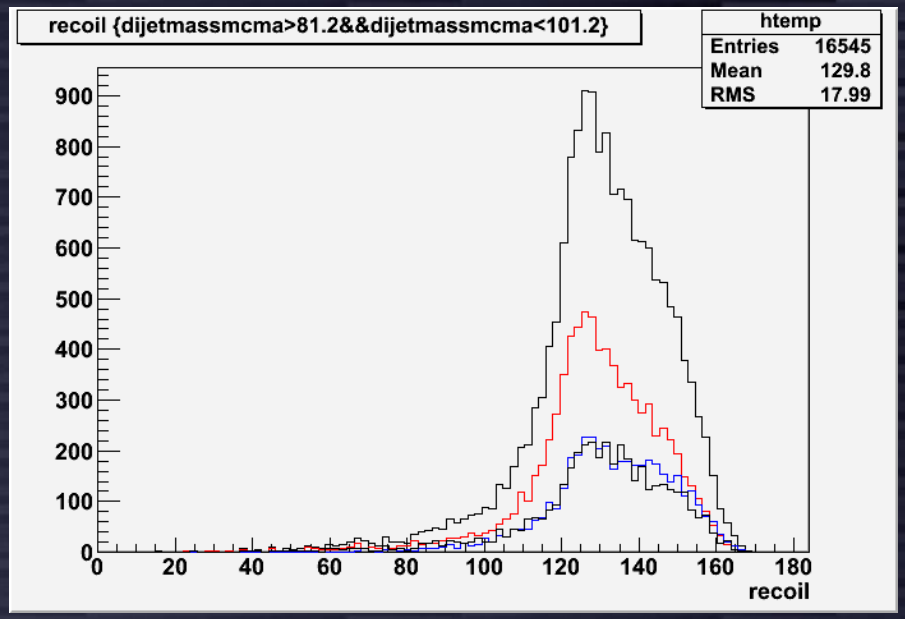
ycut = 0.005

The combination with mass nearest to Z is selected

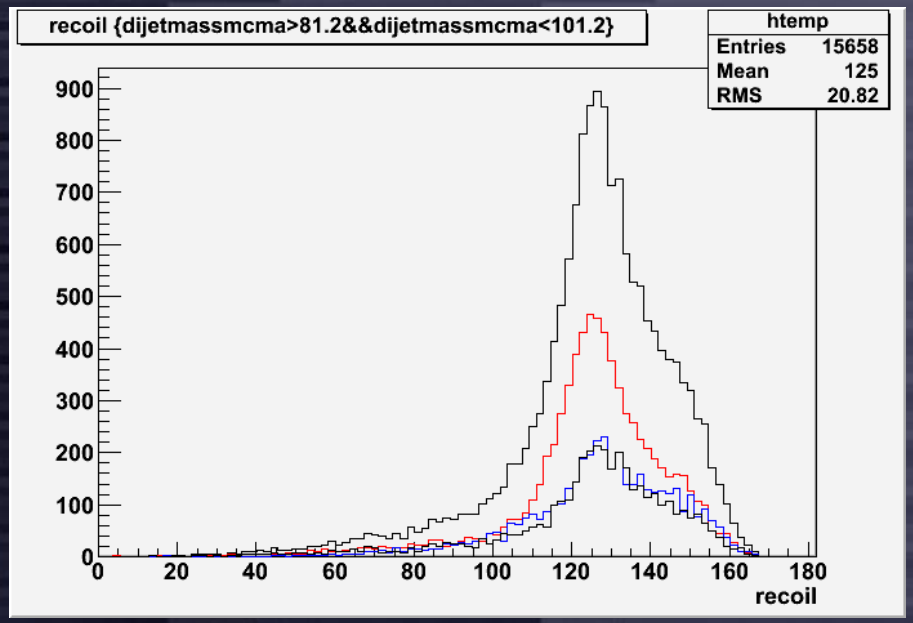
black: all
red: H→bb
blue: H→WW*
black: H→others

bb → lower efficiency

recoil mass qqh 250: some plots



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

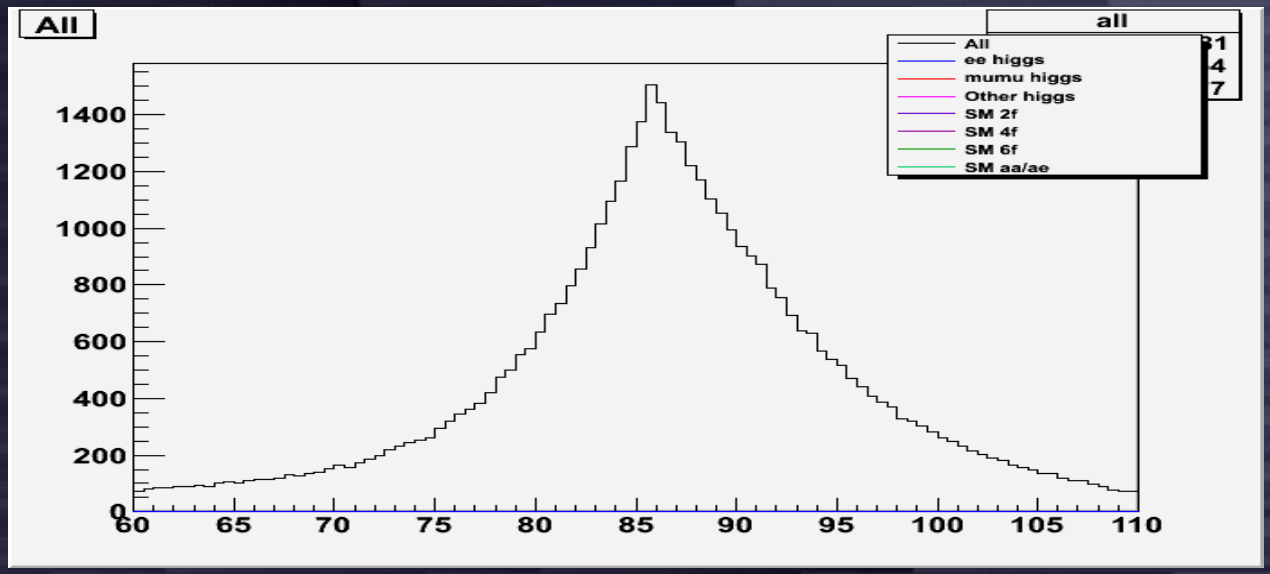
WW → many mis-jet pairings

a bit more realistic

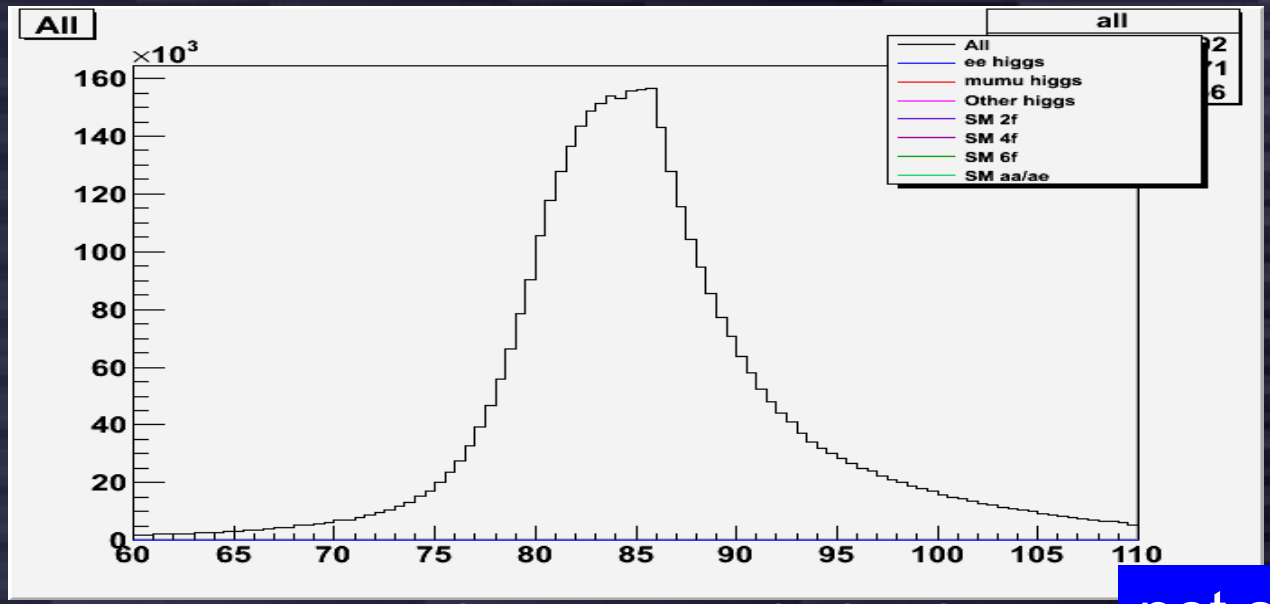
- ycut fixed to 0.005
- Jet pairing done for 86 GeV (not 91.2 GeV)
  - To check the performance on W/Z separation
- Considering background of WW/ZZ → 4q
  - suffered from mis-jet pairing/clustering
- Considering both $e^-_L e^+_R$ and $e^-_R e^+_L$ cases
  - $P(e^-,e^+) = (0.8,0.3)$
  - Signal cross section larger in $e^-_L e^+_R$
  - WW suppressed in $e^-_R e^+_L$

di-jet mass

ZH



WW/ZZ



$e^-_L e^+_R$

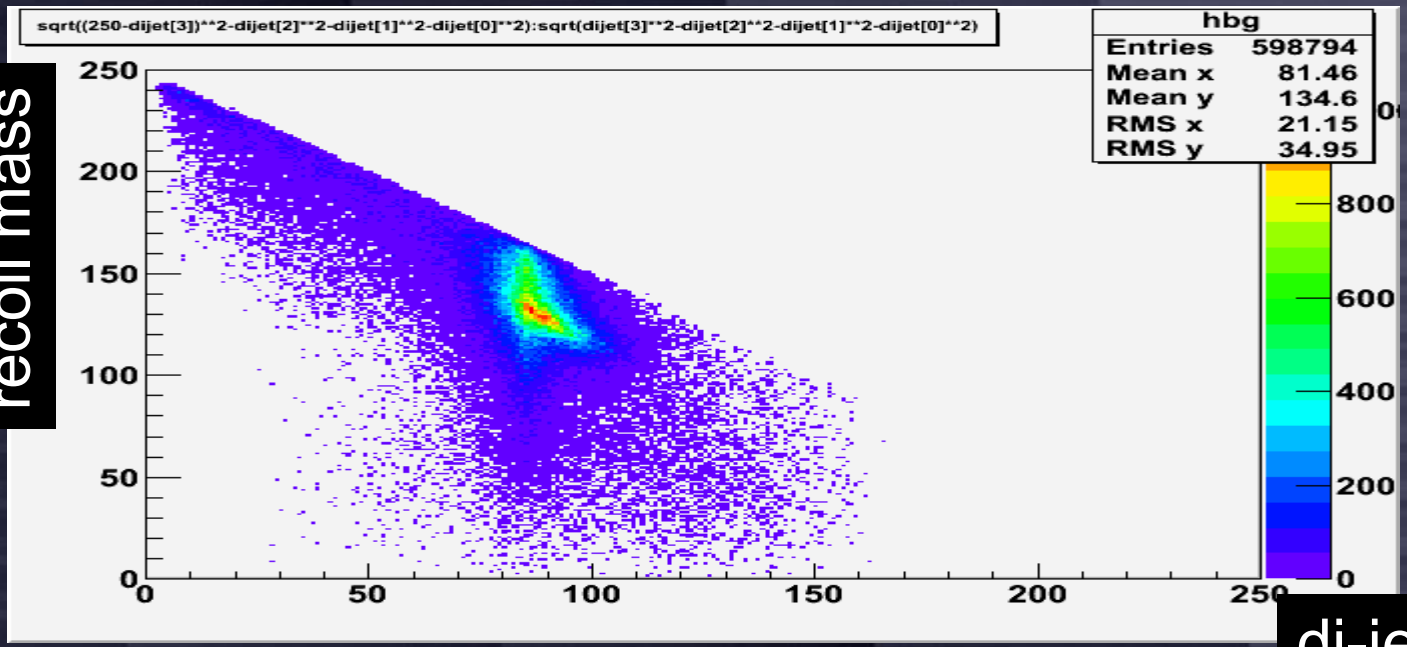
Taikan Suehara et al., LCWS13 @ Tokyo,

not so powerful

Recoil vs dijet mass

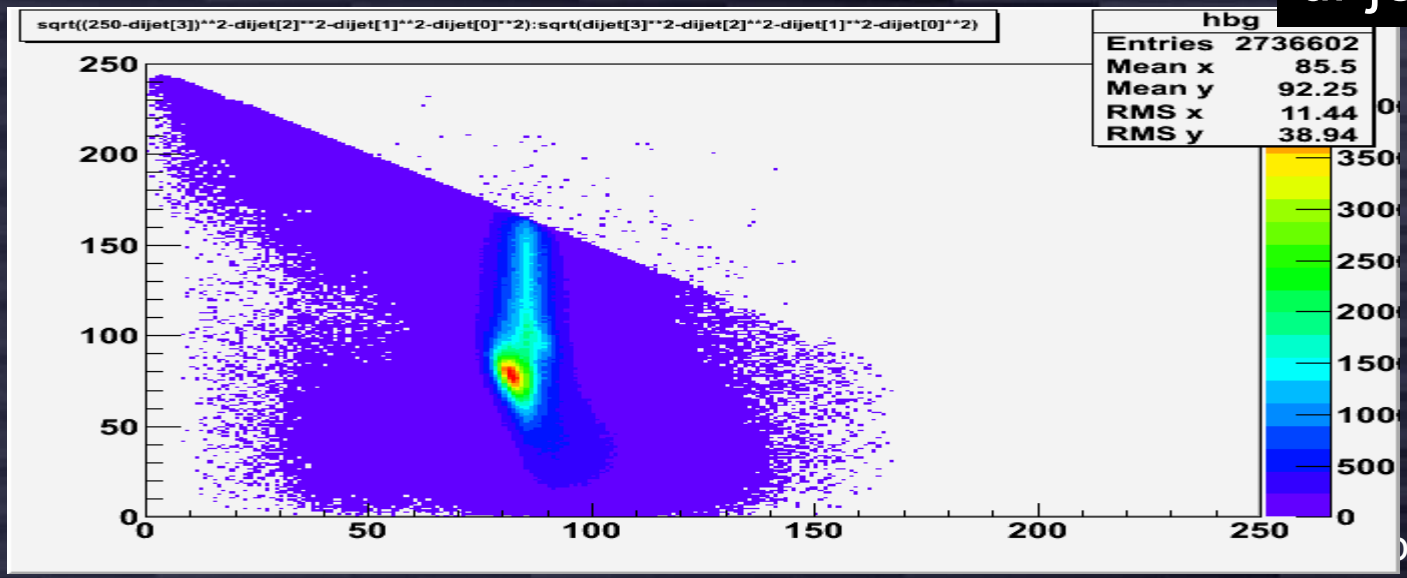
recoil mass

ZH

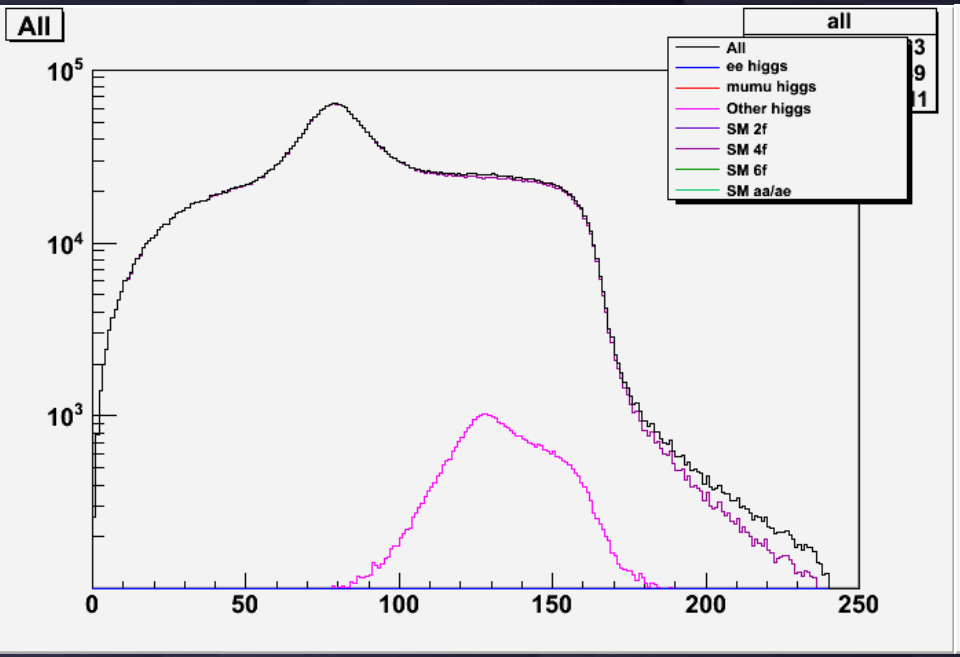


di-jet mass

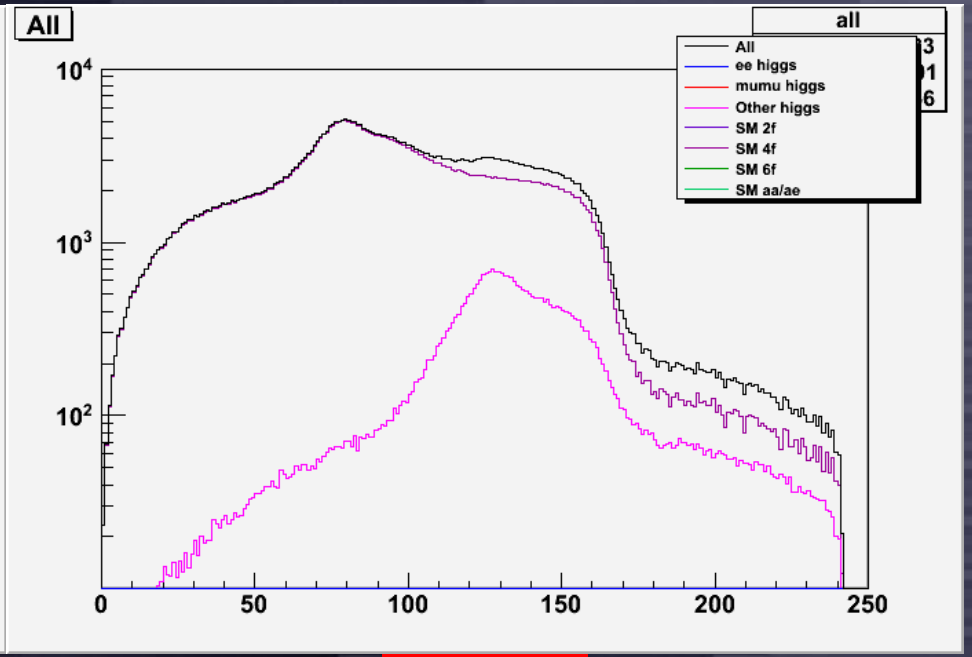
WW/ZZ



Recoil mass



$e^-_L e^+_R$



$e^-_R e^+_L$

Events with L = 250 fb^{-1}, cut of m_{recoil} > 120 GeV only

	qqH	WW/ZZ	significance
$e^-_L e^+_R$	38,593	991,504	38 σ
$e^-_R e^+_L$	26,032	101,227	73 σ

Taikan Suehara et al., LCWS13

VERY PRELIMINARY

qqh 250 To do

Remained issues improving results

- Optimization on jet clustering
- More cuts / MVAs
- Kinematic fit

Remained issues degrading results

- Other backgrounds
  - WW/ZZ → qq + lepton/neutrinos
  - 2f + ISR and others
- Efficiency depends on Higgs decay
  - Need study on systematic errors

Summary

- llh 250 GeV – 3.0/2.5% with 250 fb^{-1} $e^-_L e^+_R$
- Various channels for σ_{ZH}
  - llH 500 GeV – 4.8% with 500 fb^{-1} $e^-_L e^+_R$
  - qqH 350 GeV – 3.6% with 150 + 150 fb^{-1}
  - qqH 500 GeV – 3.9% with 500 fb^{-1} $e^-_L e^+_R$
  - qqH 250 GeV (VERY PRELIMINARY)
    - 2.6% with 250 fb^{-1} $e^-_L e^+_R$
    - 1.4% with 250 fb^{-1} $e^-_R e^+_L$
    - Study ongoing
- Systematic effects should be investigated