Higgs Branching Ratios
$e^+ e^- \rightarrow ZH \rightarrow \ell\ell qq$

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Outline

- Data Sample
- Particle Identification
- Event Selection
- Branching ratio
- Summary
- LOI outline

SAMPLE USED

▸ ILD_00 centrally reconstructed sample with $\sqrt{s} = 250$ GeV.

▸ Signal process is $e^+ e^- -> \ell\ell\, H$

▸ Background is $e^+ e^- -> \ell\ell qq$

▸ Our beams are polarized 80%-30% to e^- e^+

▸ Luminosity = 293 fb^{-1} (μ) and 500 fb^{-1} (e).

Lepton Identification

▸ **Muon Identification:**

○ Discriminating variables are used to train the Multivariate Analysis package. Cuts on NN output are optimized to get the **99.7% (0.6%)** for **μ (e, π)**, using a test on independent sample of single particle.
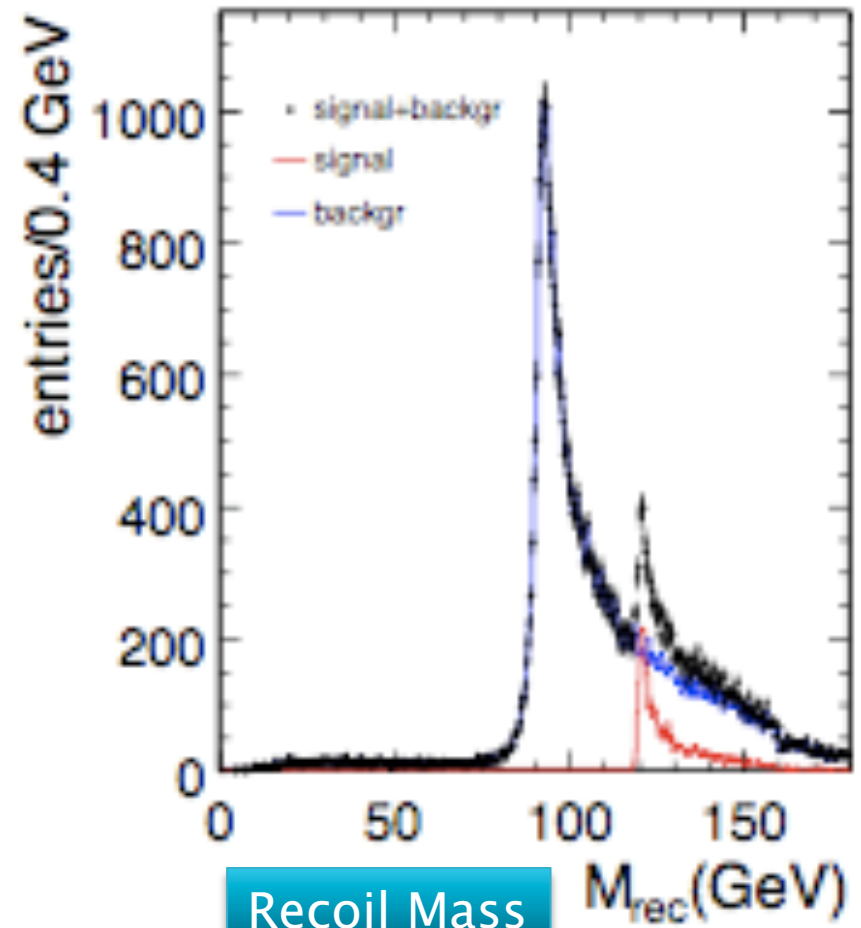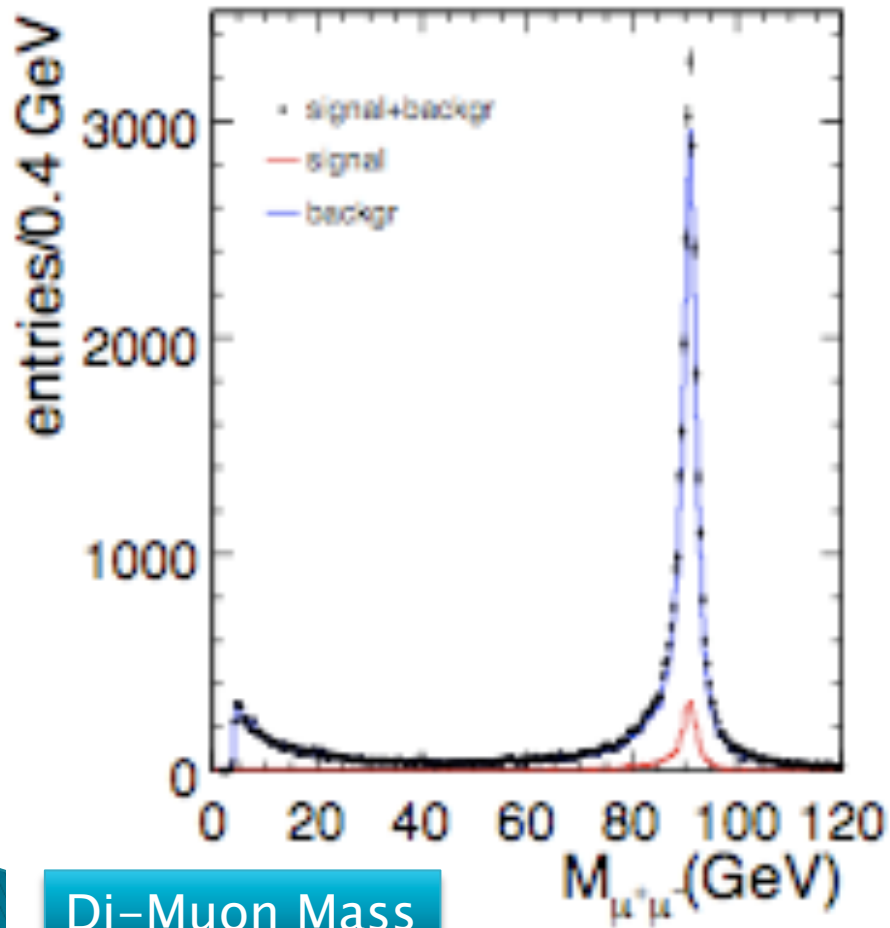
▸ **Electron Identification:**

○ Cut-based selection has showed that 98.57% electron are identified by using the selection cuts:

1) $E_{ecal} / E_{tot} > 0.6$

2) $E_{tot} / p > 0.9$

Z Reconstruction (μ case)

- ISR photons are identified with selection cuts:
  1) $E_\gamma > 5$ GeV,
  2) $E_{t\gamma} < 3$ GeV,
  3) And no particle within 10°.
- Two tracks with opposite charges, each with
  1. momentum $p > 20$GeV
  2. No other track within 5°

     are identified as Muon with NN, combined in a Z candidate.
- If more than one Z candidate are found, the one with mass closest to the Z nominal mass is taken.
- The two tracks are then removed from the PandoraPFO's collection.

Z Reconstruction (μ)


Di-Muon Mass

Recoil Mass

Z Reconstruction (electron)

- If more than two electrons are identified, then only those with di-electron mass closest to the Z mass are kept.
- Bremsstrahlung Identification:
- Any photon within 2 degrees of the electron are added to the di-electron mass.

Di-jet Mass

Invariant mass - electrons only
Invariant mass - electrons and photons within 2 degrees
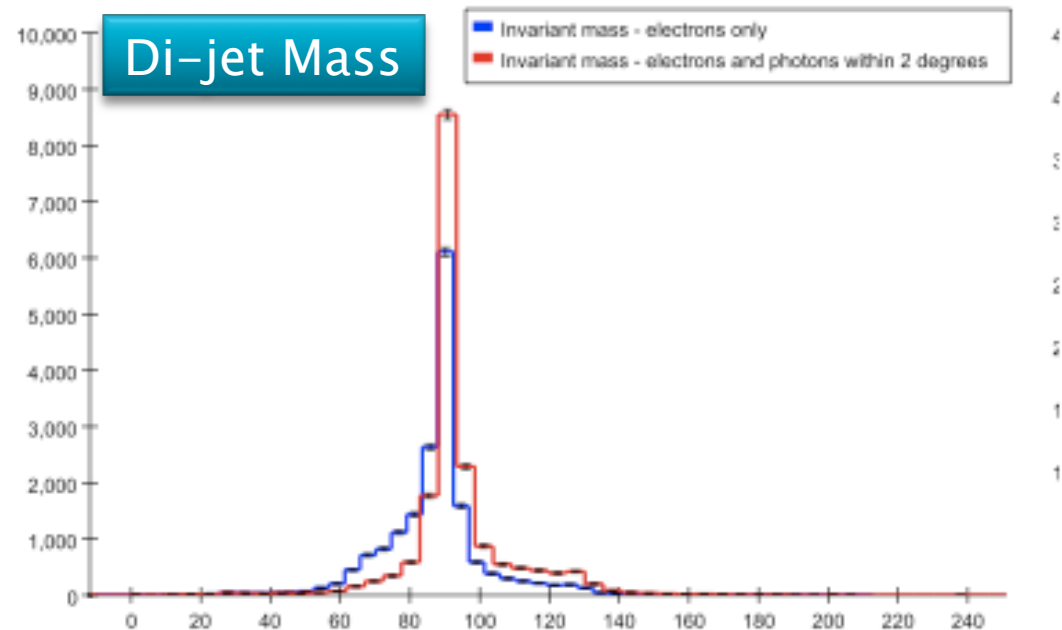
Pre-Selection

As our pre-selection, we considered only events which have

▸ Muon Case: particles ≥ 25. All H -> ττ and ~10% H -> WW are removed.

▸ Electron Case: electrons ≥ 2.
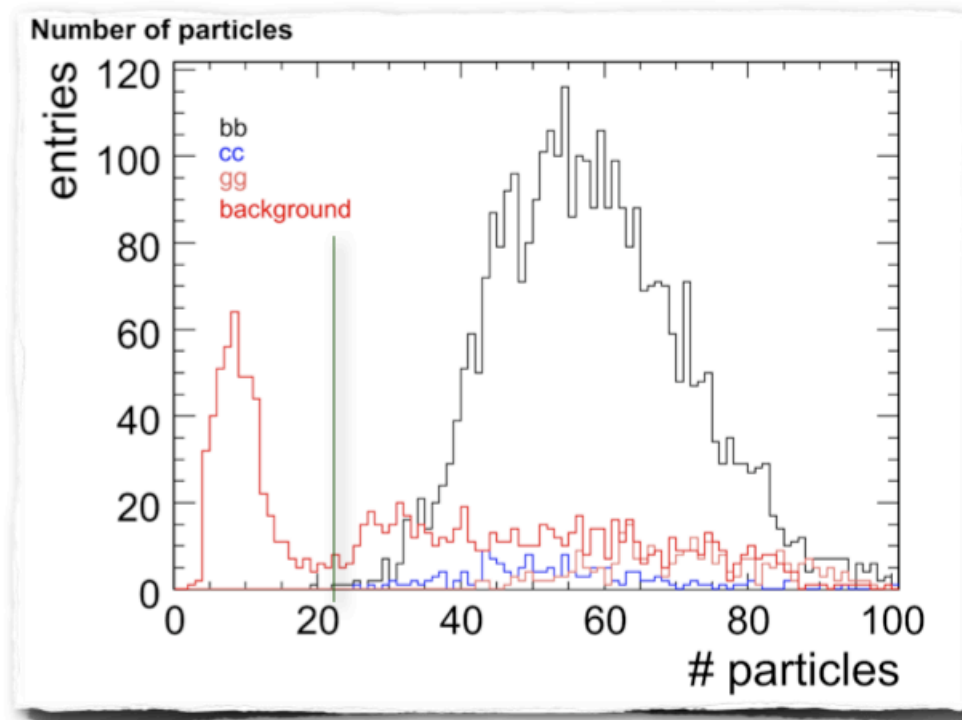
Event Selection (μ)

As pre-selection only
- one Z boson with $80 < M_Z < 100$ GeV
- one reconstructed Higgs boson
- Likelihood Selection:
  Variables used to train Multivariate analysis package are:
1) Recoil Mass
2) $|\cos\theta_{\mu\mu}|$; $\theta_{\mu\mu}$ is the polar angle of Z boson
3) M_{jj},
4) $|E_{j1} - E_{j2}|$,
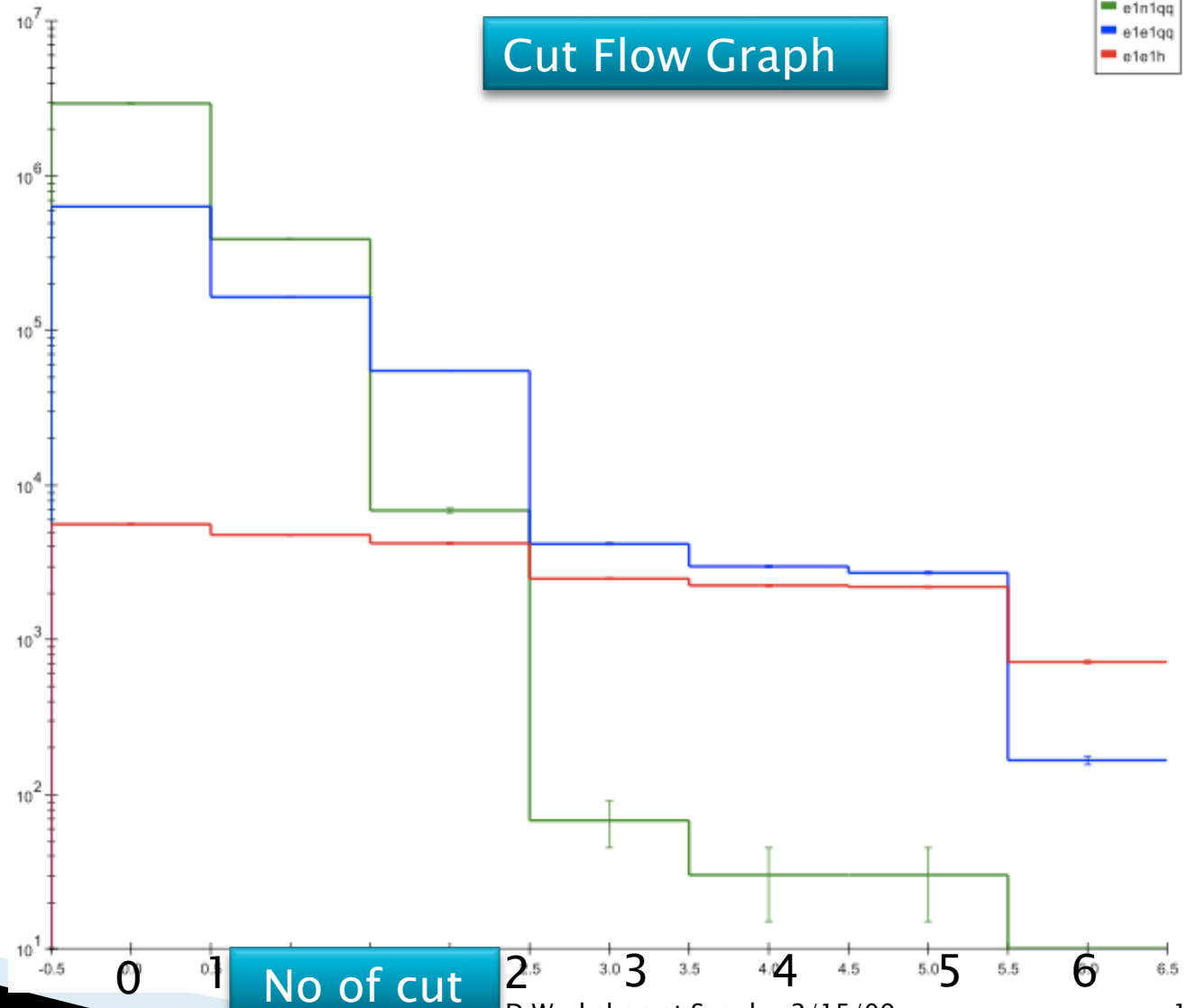5) $|\cos\theta_{Th}|$

to get 81.9% (7.7%) efficiency.

	$\mu^+\mu^- h$	$\mu^+\mu^- q\bar{q}$
di-muons	4284	50994
pre-selection	3327	31132
likelihood	2725	2386

No of particles after cuts

Event Selection (e^-)
Cut based Selection

| No of cut	Name of cut
0	Initial no. of events
1	no. of e^-
2	$M_{di-electron}$
3	M_{di-jet}
4	$Cos\theta_{Thrust}$
5	M_{recoil}
6	Likelihood

Cut Flow Graph

No of cut

e1n1qq
e1e1qq
e1e1h

Event Selection (e^-)
Likelihood Selection

Higgs Reconstruction (μ)

- Once muons and ISR photons are identified, they are removed and the remaining particles are forced into two jets that are combined in Higgs candidates.
- The jets are tagged using LCIFIVertex package.
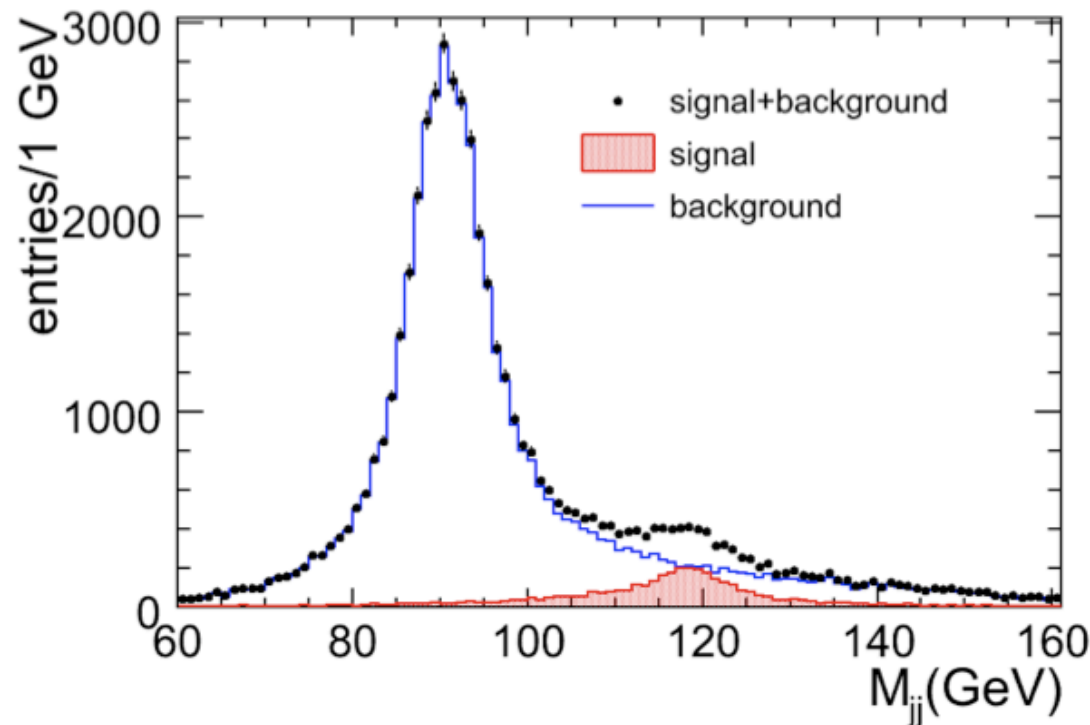
Higgs Reconstruction (e^-)

Electrons and bremsstrahlung photons are identified and removed. The remaining particles are forced into two jets that are combined in Higgs candidates.
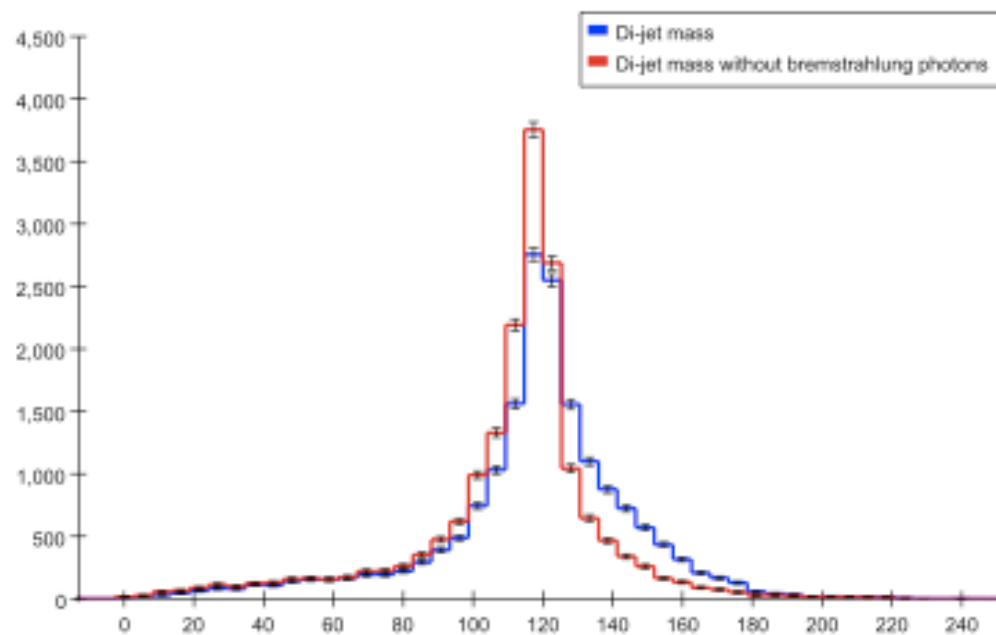
Higgs Branching Ratio

▸ Signal sample is split into "data" and "monte carlo", with same number of events. Monte carlo sample is split into the decay modes bb, cc, gg and others.

▸
$$\text{X-likeness} = \frac{X1 \cdot X2}{X1 \cdot X2 + (1 - X1) \cdot (1 - X2)}$$

where $X = b$ or c and X_1, $X_2 = $ b-tag or c-tag of the 2 jets.

Higgs Branching Ratio

▸ Branching ratio is given by

$$\sigma(e^+e^- \to Zh) \times BR(h \to s) =$$
$$r_s \times BR(h \to s)_{SM} \times \sigma(e^+e^- \to Zh)_{SM}$$

where $r_s = r_{bb}$, r_{cc}, r_{bkg} are parameters obtained by minimizing

$$\chi2 = \Sigma_{i,j}(N_{data}{}^{ij} - f\Sigma_s\ r_s\ N_s{}^{ij})^2/\ \sigma_{ij}{}^2$$

here $N_{data}{}^{ij}$ and $N_s{}^{ij}$ are number of events in the b- and c-likeness bins of the data and bb, cc, gg and background templates.

▸ $\sigma_{ij}{}^2 = N_{data}{}^{ij} + f^2\ \Sigma_s\ N_s{}^{ij}$ takes into account the limited statistics of samples with $f = 0.217$, the ratio of luminosity of simulated data and the luminosity of MC samples .
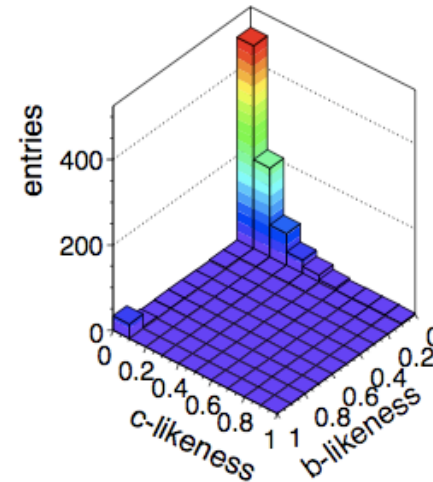
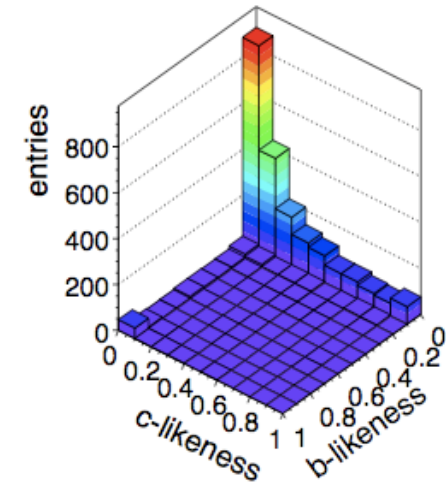# Higgs Branching Ratio (μ)

Data
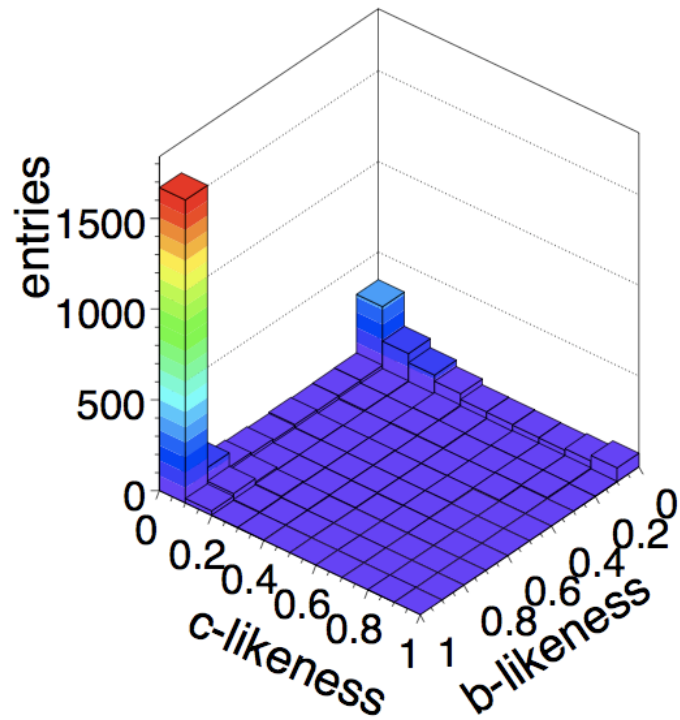
Monte Carlo bb template
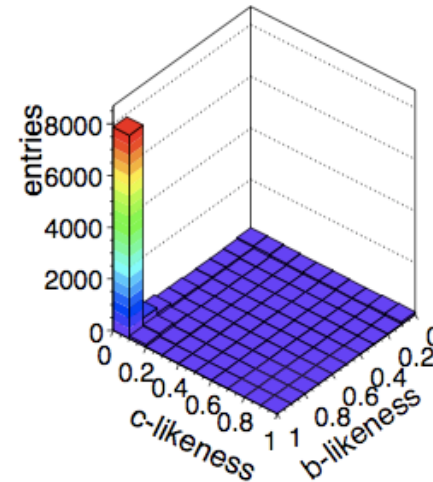
Monte Carlo cc template
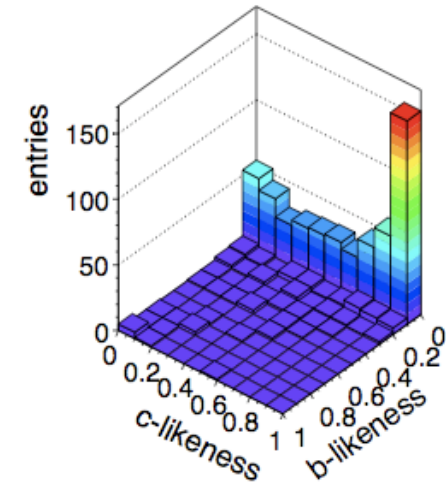
Monte Carlo gg template

Ionte Carlo background template

Higgs Branching Ratio (e^-)

The plot is c-likeness and b likeness for bb, cc, gg and the other decay modes

(treated as background).

▸ Plot top left:

c-likeness vs b-likeness for bb template

▸ Plot top right:

c-likeness vs b-likeness for cc template

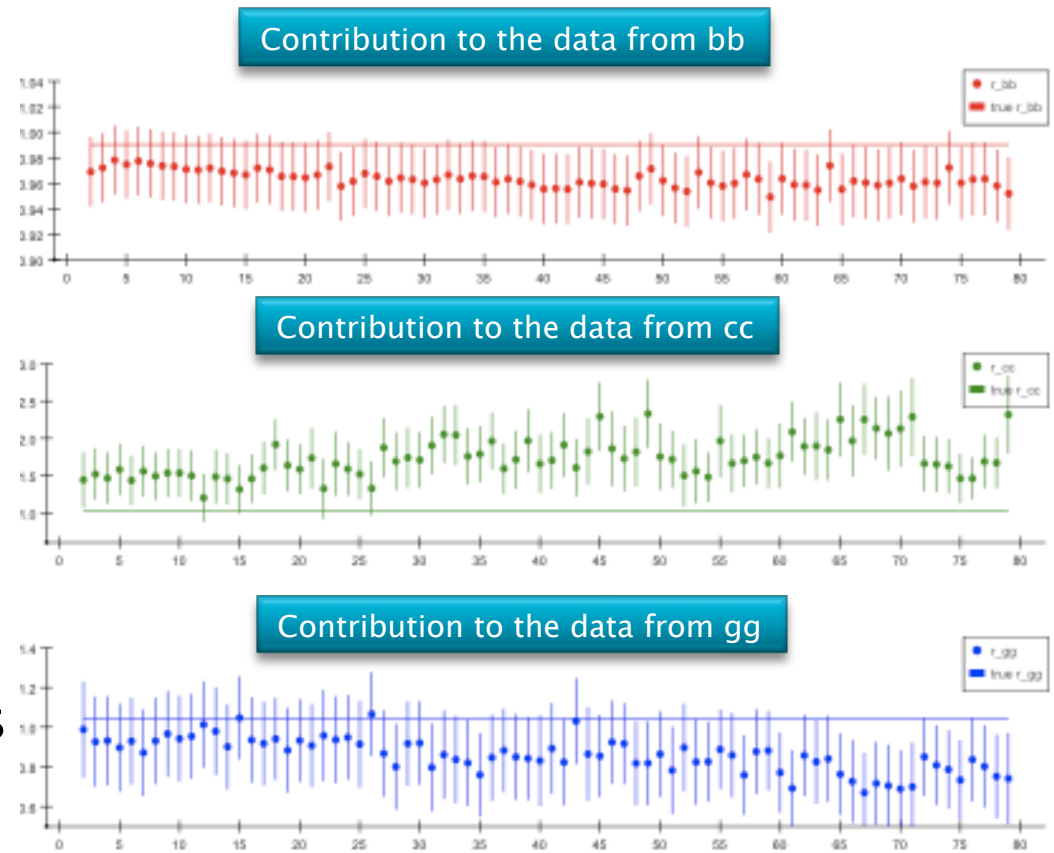▸ Plot bottom left:

c-likeness vs b-likeness for gg template

▸ Plot bottom right:

c-likeness vs b-likeness for bkg template
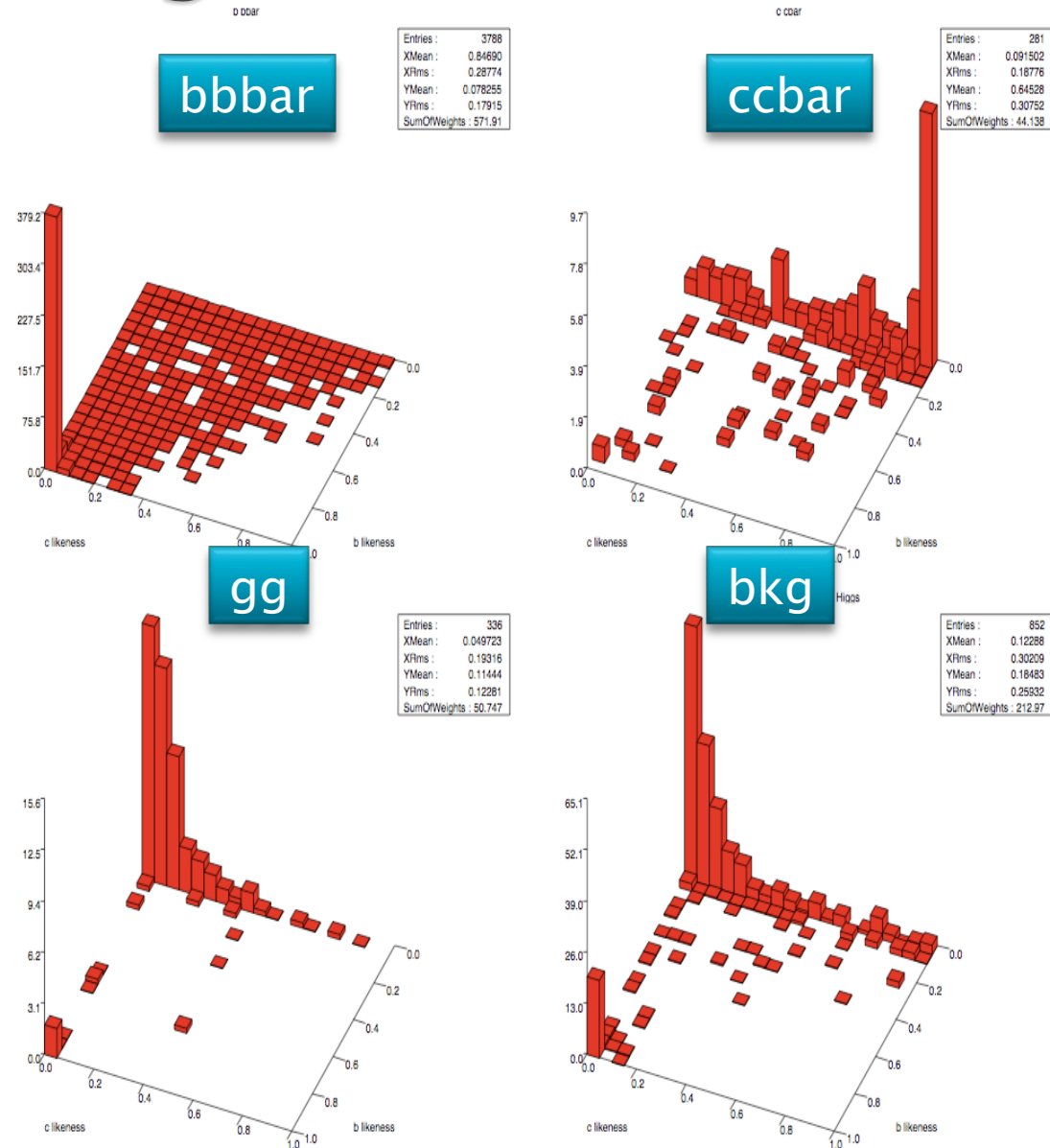
Higgs Branching Ratios

▸ Muon:
Results from fit (10×10 bins):
1. bkg = 1 (fixed)
2. r_{bb} = 0.933 ± 0.023
3. r_{cc} = 0.84 ± 0.20
4. r_{gg} = 1.04 ± 0.16

▸ Electron:
Plot shows the fit values
Note that electron finding was cheated in this particular plot.
X-axis: no of bins used in the fit.

Contribution to the data from bb

Contribution to the data from cc

Contribution to the data from gg

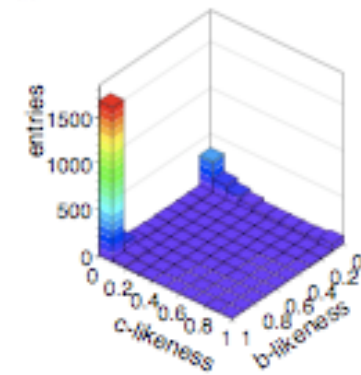# Summary

- An analysis of Higgs branching ratio for Z-boson decaying into leptons is presented
- Improvements are still going on
- Results are being finalized
- Need to coordinate with other groups
- We are going to open discussion with groups Z -> qq and Z -> vv

LOI Summary
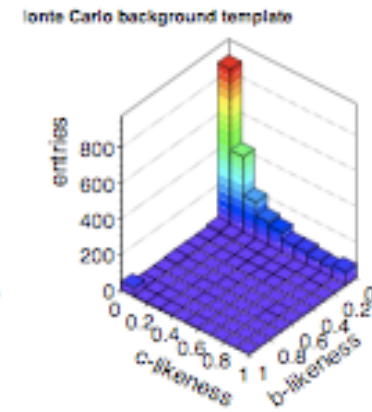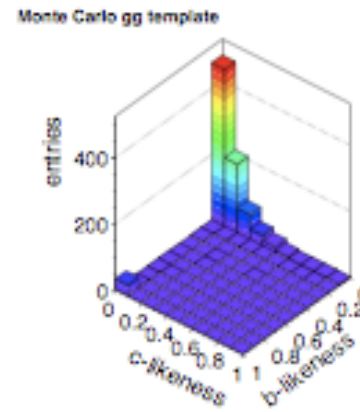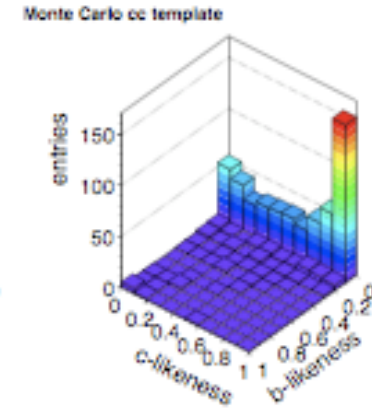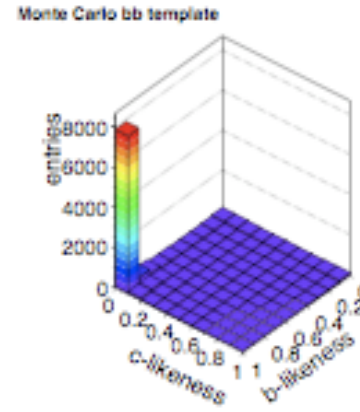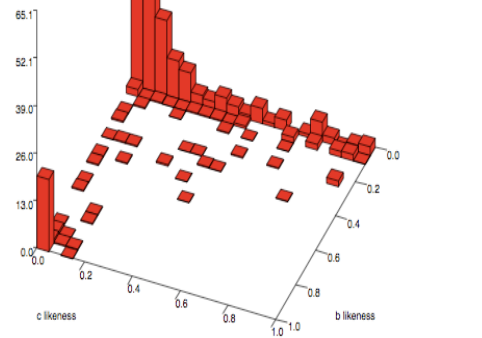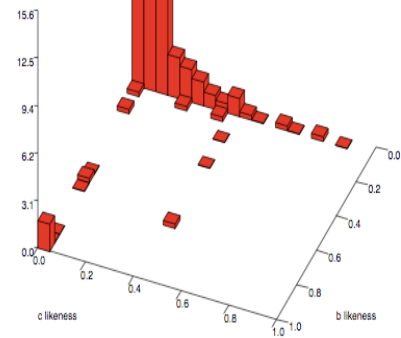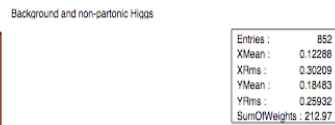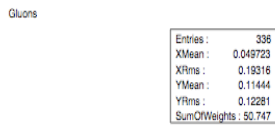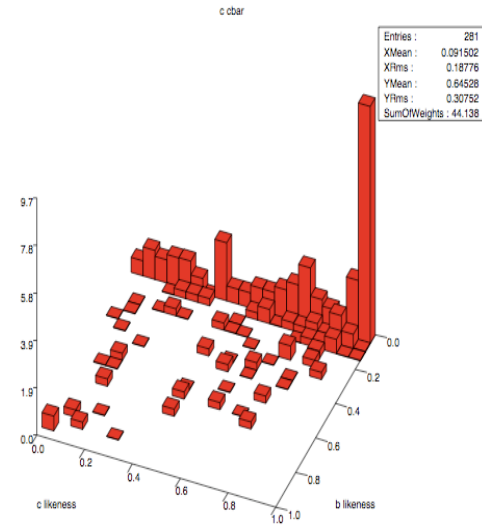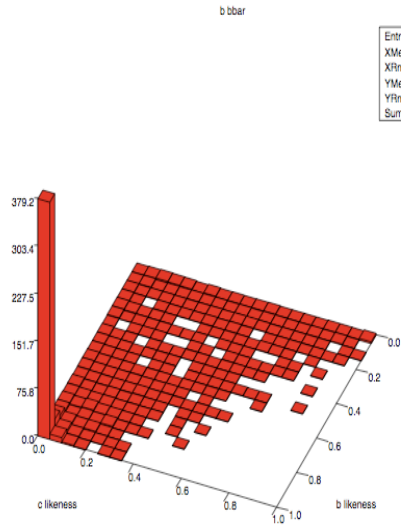
Extra Slides
SAMPLE USED (μ)

- ILD_00 central reconstructed sample with $\sqrt{s} = 250$ GeV.

process	σ(fb)	N_{events}*
e2e2h	17.1	5000
e2e2bb	56.5	16800
e2e2dd	57.5	17200
e2e2ss	57.6	17000
uue2e2	53.0	15400
cce2e2	53.1	15600

*Number of events used in the analysis so far correspond to Luminosity = 292 fb^{-1}.

ISR Photons
(ZH -> $\mu^+\mu^-$H)

- Initial state radiation photons are isolated having very low transverse momentum even if they are high energy, compared to other photons. Once identified, ISR Photons are removed from PandoraPFOs collection with Selection:
  - $E_\gamma > 5$ GeV
  - no particle within 10°
  - $P_{T\gamma} < 3$ GeV
- 95 photons are identified as ISR and only 45 match the generated one, so efficiency is poor.
- Further studies needed.

Muon cut-Selection

o Studies showed that for LDC detector 98.8%(0.8%) μ (e, π) are identified for $P >$ 15 GeV with selection cuts:

(1) $(E_{ECal} + E_{HCal})/p < 0.3$ (2) $E_{ECal} < 2.5$ GeV

(3) $E_{ECal}/(E_{ECal} + E_{HCal}) < 0.5$ (4) $E_{HCal} < 15$ GeV