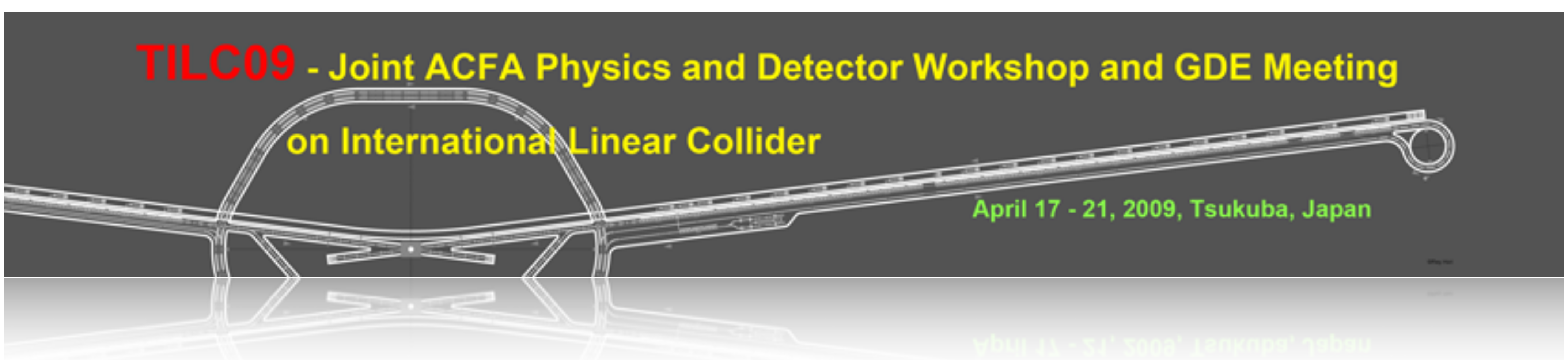
Higgs hadronic branching ratios in the ZH → llqq channel

Roberval Walsh
University of Edinburgh
*[on behalf of J. Goldstein, M. Grimes and C. Lynch (U. Bristol);
V. Martin and H. Tabassam (U. Edinburgh)*



Outline

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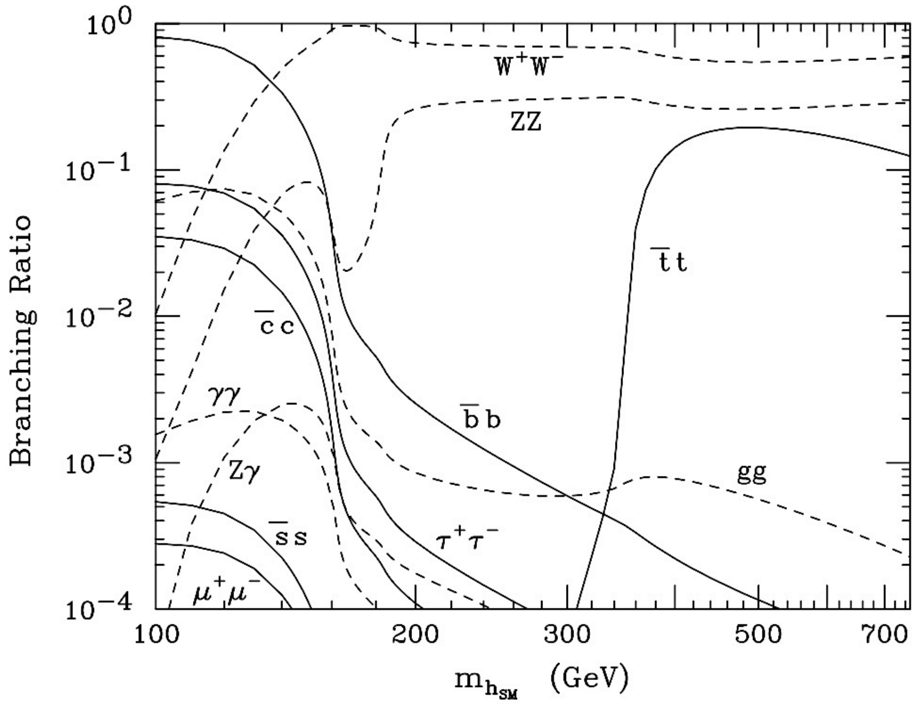
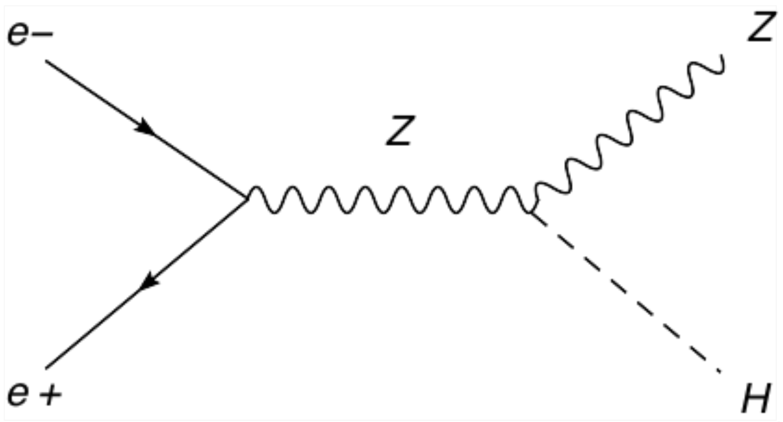
- Samples
- Event reconstruction
- Event selection
- Branching ratios
- Summary

Introduction

- Determination of the Higgs branching ratios is very important as a test of the Higgs mechanism.
- We studied the performance of the ILD detector to measure
  - BR(H → bb)
  - BR(H → cc)
  - BR(H → gg)
- The process used in this study was $e^+e^- \to ZH \to llH$, $l=e,\mu$
  - Main backgrounds: $e^+e^- \to ZZ$, $e^+e^- \to W^+W^-$



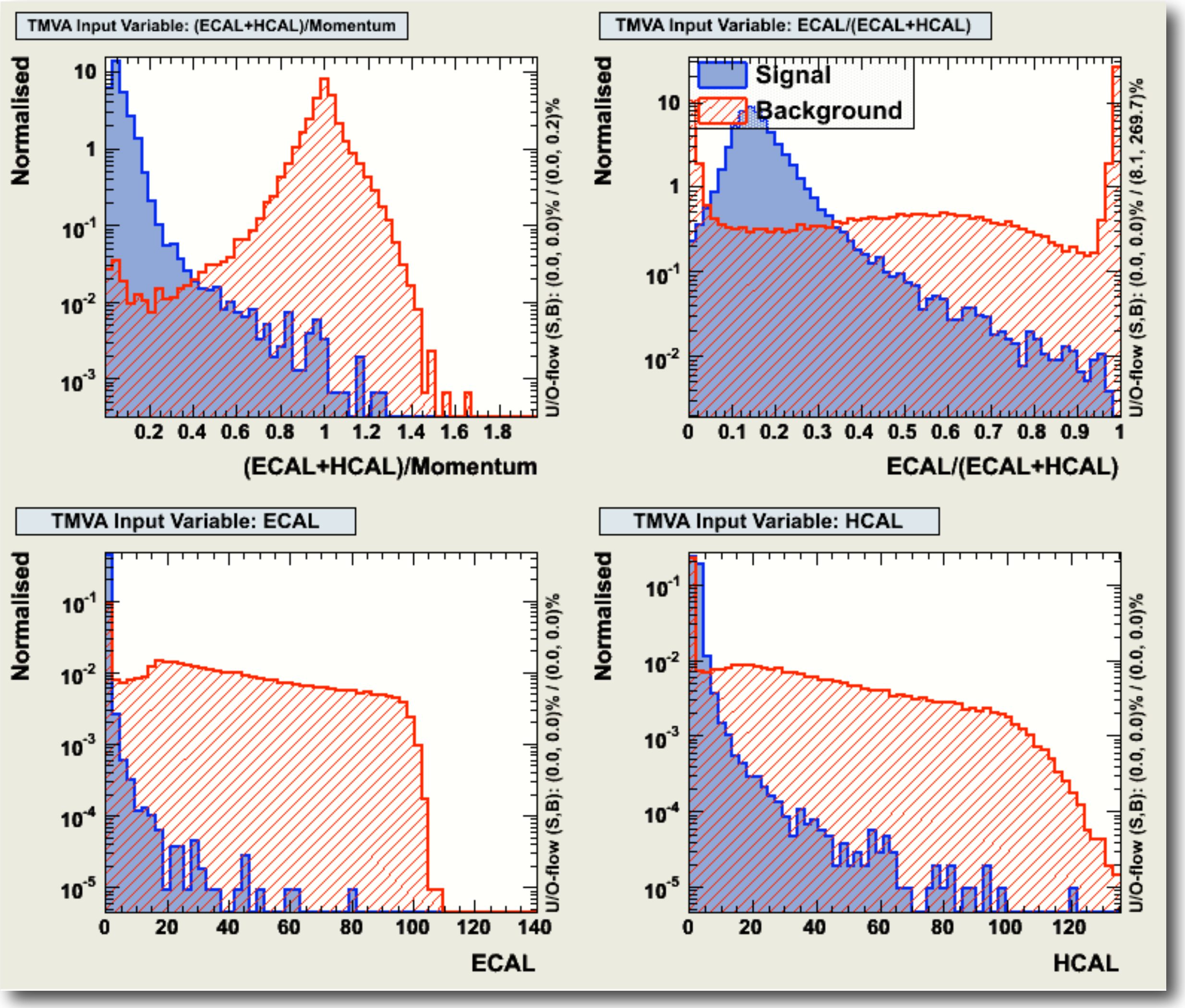


Samples

- $e^+e^- \to llH$, $l=e,\mu$ (signal)
- $e^+e^- \to llqq$, $l\nu qq$ (background)
- Samples generated with Whizard at SLAC, and simulated with Mokka for the detector model ILD_00 and fully reconstructed with the ILCSOFT at DESY (Mass production samples):
  - M_H = 120 GeV;
  - Centre of mass energy $\sqrt{s}$ = 250 GeV;
  - Beam polarisation: $P(e^-) = -80\%$, $P(e^+) = +30\%$;
  - Beamstrahlung effects included (but no hits added);
  - Luminosity $L = 250\ fb^{-1}$.
- Standard reconstruction forced final states into fixed number of jets. Needed procedure to identify the final state leptons.

Event reconstruction - lepton identification

- **Muon candidates**
  - Particle objects with a track and associated calorimeter cluster.
    - Neural network in TMVA*:
      - E_{Total}/p, E_{ECAL}/E_{Total}, E_{ECAL}, E_{HCAL}
      - NN cut provided efficiency of 99.7% for μ ID, and 0.6% for e/π.
    - Momentum p > 20 GeV;
    - No track within 5° of muon candidate direction.



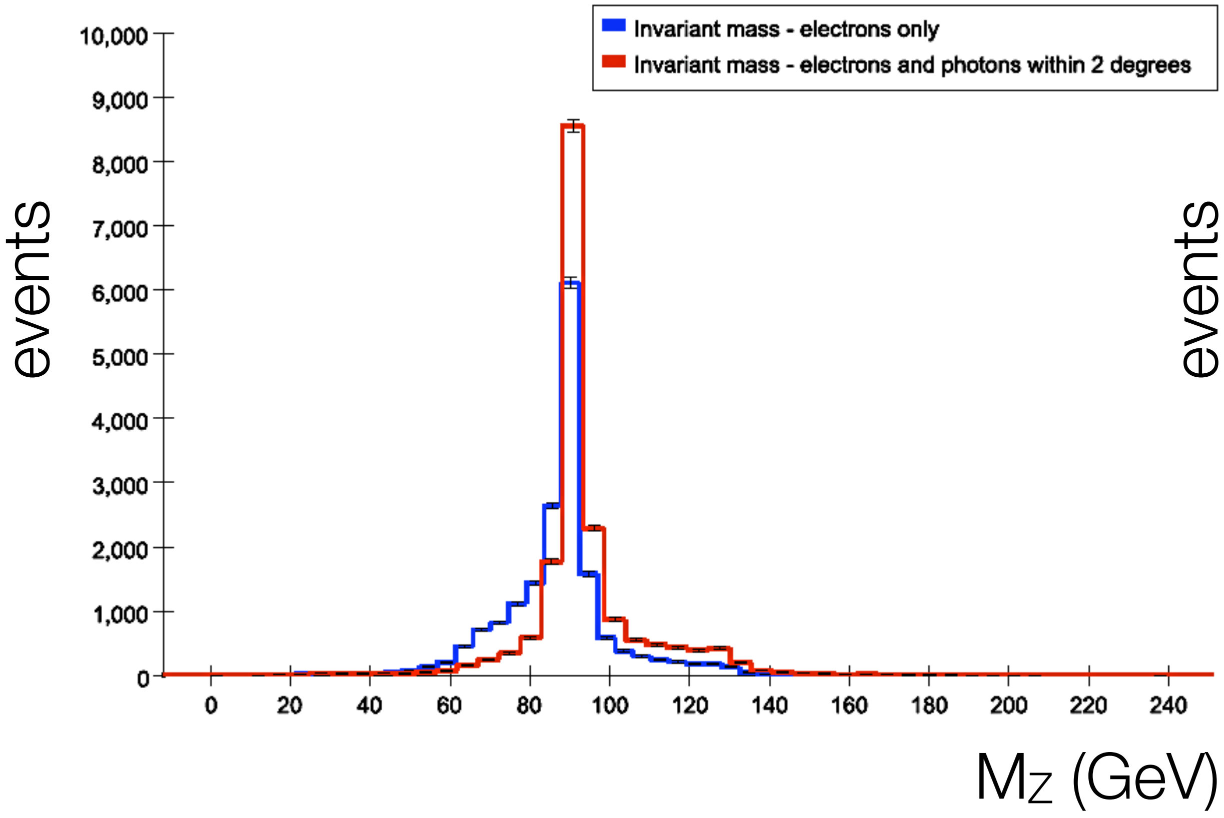
* http://tmva.sourceforge.net

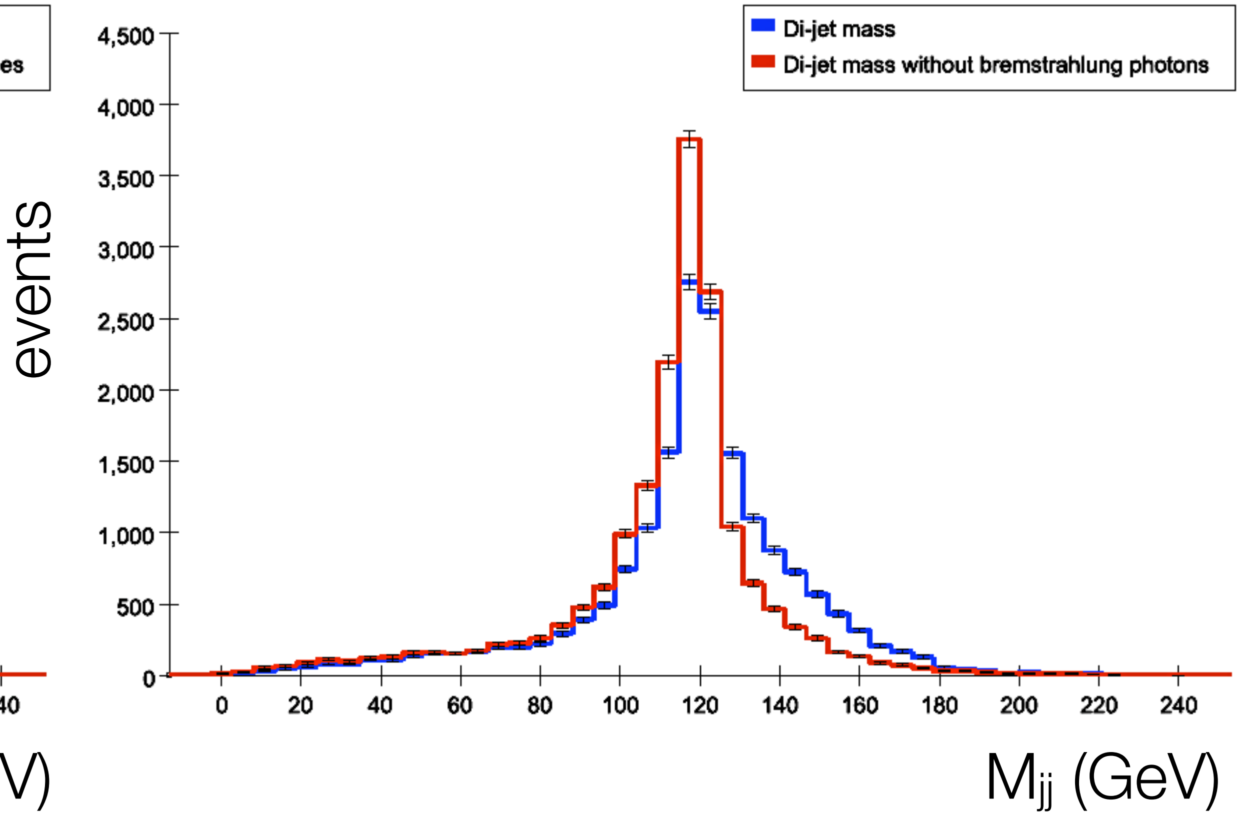
Event reconstruction - lepton identification

- **Electron candidates**
  - Particle objects with a track and associated calorimeter cluster:
    - $E_{ECAL}/E_{Total} > 0.9$;
    - $0.8 < E_{Total}/p < 1.2$;
    - $p > 4$ GeV.
  - Bremstrahlung photons within 2° of the primary electron direction used to form the electron candidate.
  - No isolation cut.

Event reconstruction - Z and Higgs

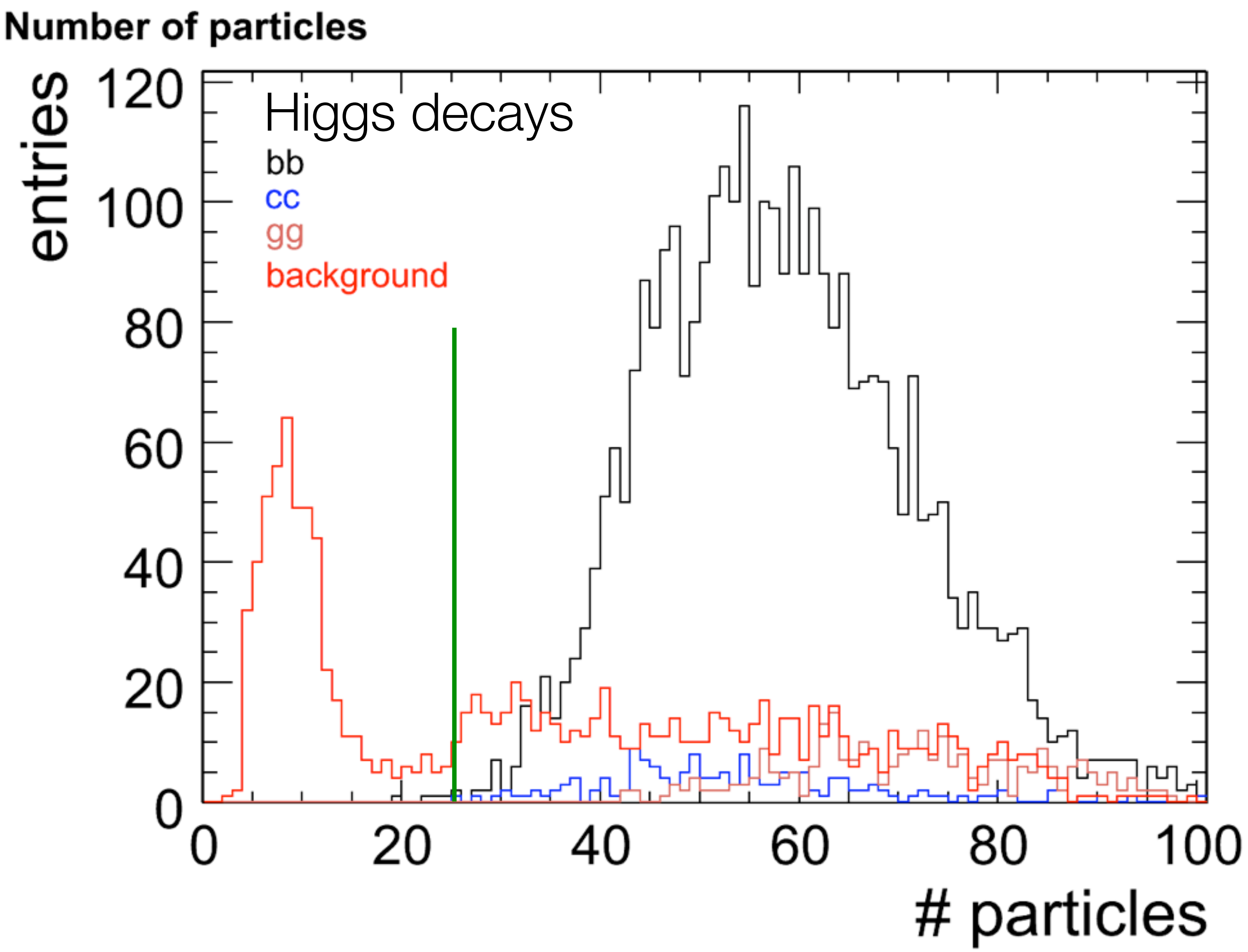
- Z candidates
  - Composed of pair of leptons with opposite charges;
  - The candidate with mass closer to M_Z=91.2 GeV was taken if more than one candidate found.
- Higgs candidates
  - After Z (lepton pair) candidates are reconstructed, the remaining particles are forced into 2 jets;
  - The di-jet system formed the Higgs candidate.





Event selection

- Pre-selection
  - $N_{particles} \geq 25$ (removes 100% $\tau^+\tau^-$, ~10% W^+W^-)
  - 1 Z candidate;
  - 1 Higgs candidate.



Event selection

- Cut-based selection
  - $70 < M_Z < 110$ GeV
  - $100 < M_{jj} < 140$ GeV
  - $117 < M_{recoil} < 150$ GeV
  - $|\cos(\theta_Z)| < 0.9$

- Likelihood ratio cut (electrons only):
  - M_{jj}, M_{5C_fit}, M_{recoil}, Thrust, $\cos(\theta_{Thrust})$, $\cos(\theta_Z)$

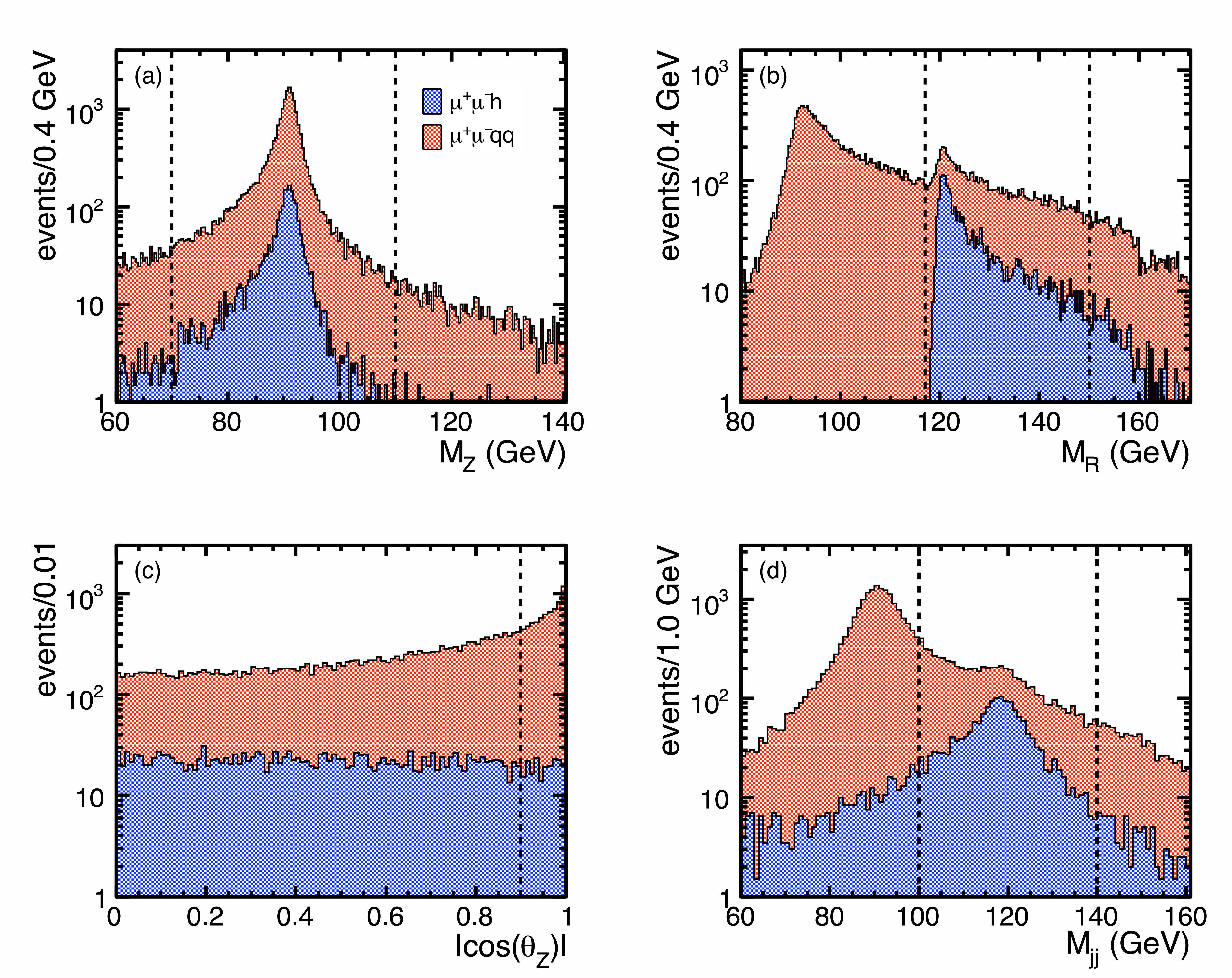
Number of reconstructed events (250fb^{-1})

e channel	e^+e^-H	e^+e^-qq	$e\nu qq$
initial	2493	87580	218378
cut selection	1445	2050	270
likelihood	1240	941	62

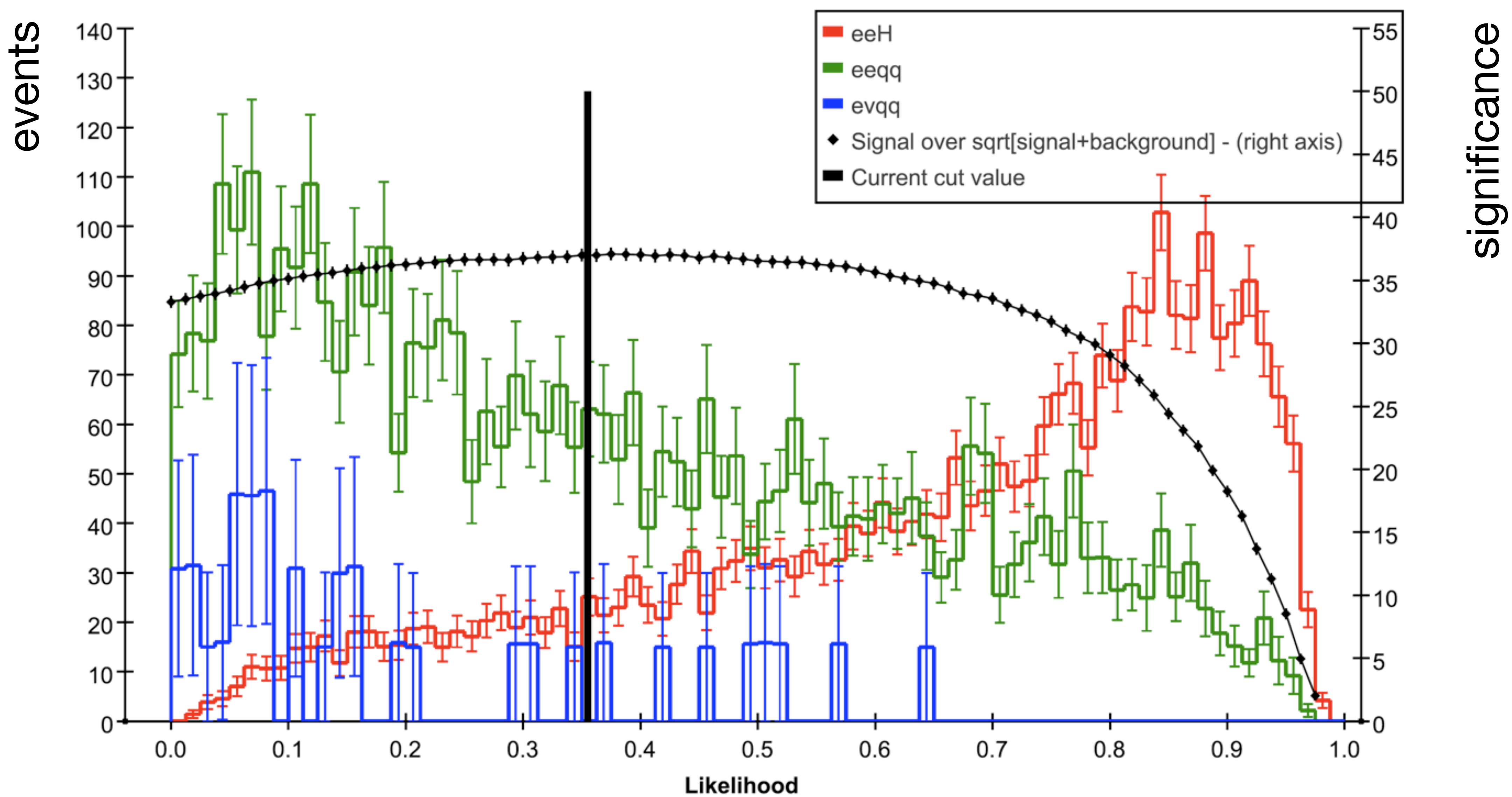
μ channel*	$\mu^+\mu^-H$	$\mu^+\mu^-qq$
initial	2202	24003
cut selection	1371	1665

* In the muon channel no μνqq event survived after the cut selection. A likelihood ratio cut did not improve the results.

Event selection



Event selection



Flavour tagging

- Used the LCFIVertex package:
  - Vertex reconstruction with ZVTOP;
  - Flavour tagging based on neural networks:
    b-tag and c-tag assigned to the jets.
- Defined an event-wise tag variable* based on b/c-tag of the two jets

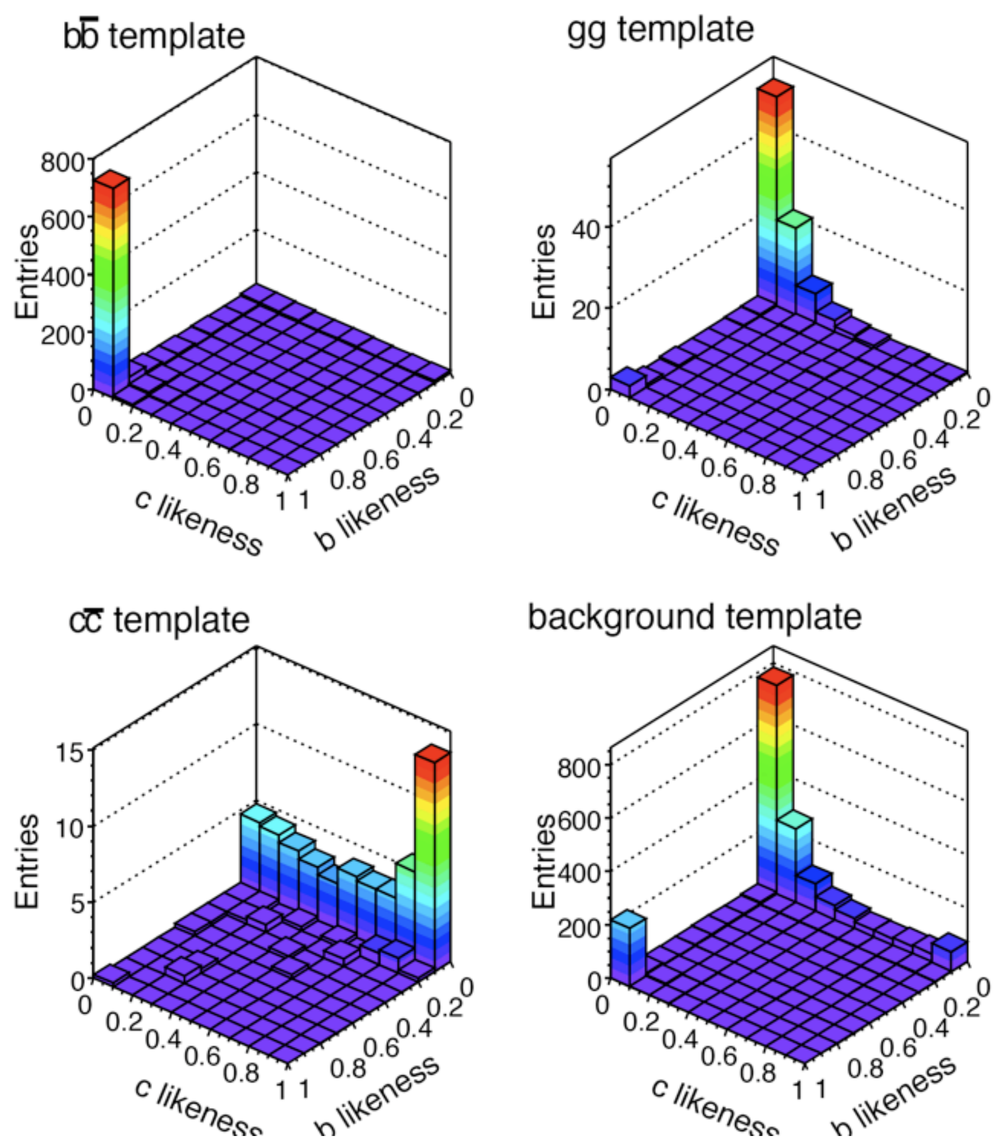
$$\text{X-likeness} = \frac{X1 \cdot X2}{X1 \cdot X2 + (1 - X1) \cdot (1 - X2)}$$

where X=b-tag or c-tag of jets 1 and 2.

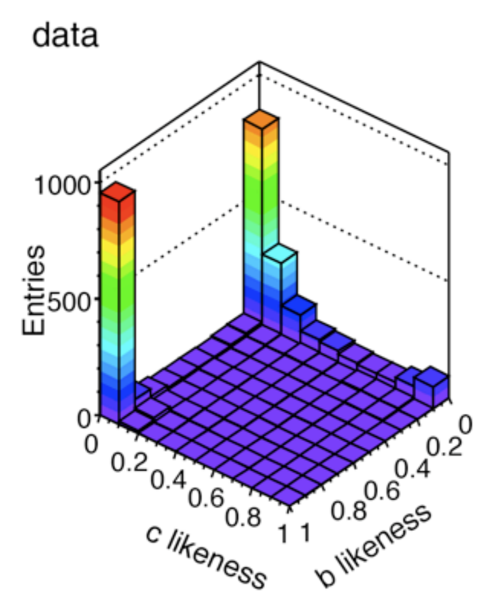
* Kuhl & Desch, LC-PHSM-2007-001

Branching ratios

- Template fitting method: Independent Monte Carlo samples with same reconstruction and selection as the ‘data’.



Flavour likeness distributions



Branching ratios

- The branching ratios were extracted minimising the χ^2 function:

$$\chi^2 = \frac{\sum_{i,j} (N_{data}^{ij} - f \sum_s r_s N_s^{ij})^2}{\sigma_{ij}^2}$$

where

$$\sigma_{ij}^2 = N_{data}^{ij} + f^2 \sum_s N_s^{ij}$$

$$f = L_{data}/L_{MC}$$

- The fit parameters r_s, where *s = bb, cc, gg, bkg,* represent the ratio of bb, cc, gg and background events to the SM predicted number of events.
- N^{ij} is the number of events in the bin (i,j) of the flavour likeness distributions.
- $N^{ij}_{data} > 6$.
- Binning of the distributions: 10 x 10.
- Fixed $r_{bkg} = 1$.

Branching ratios

- Results from the fit

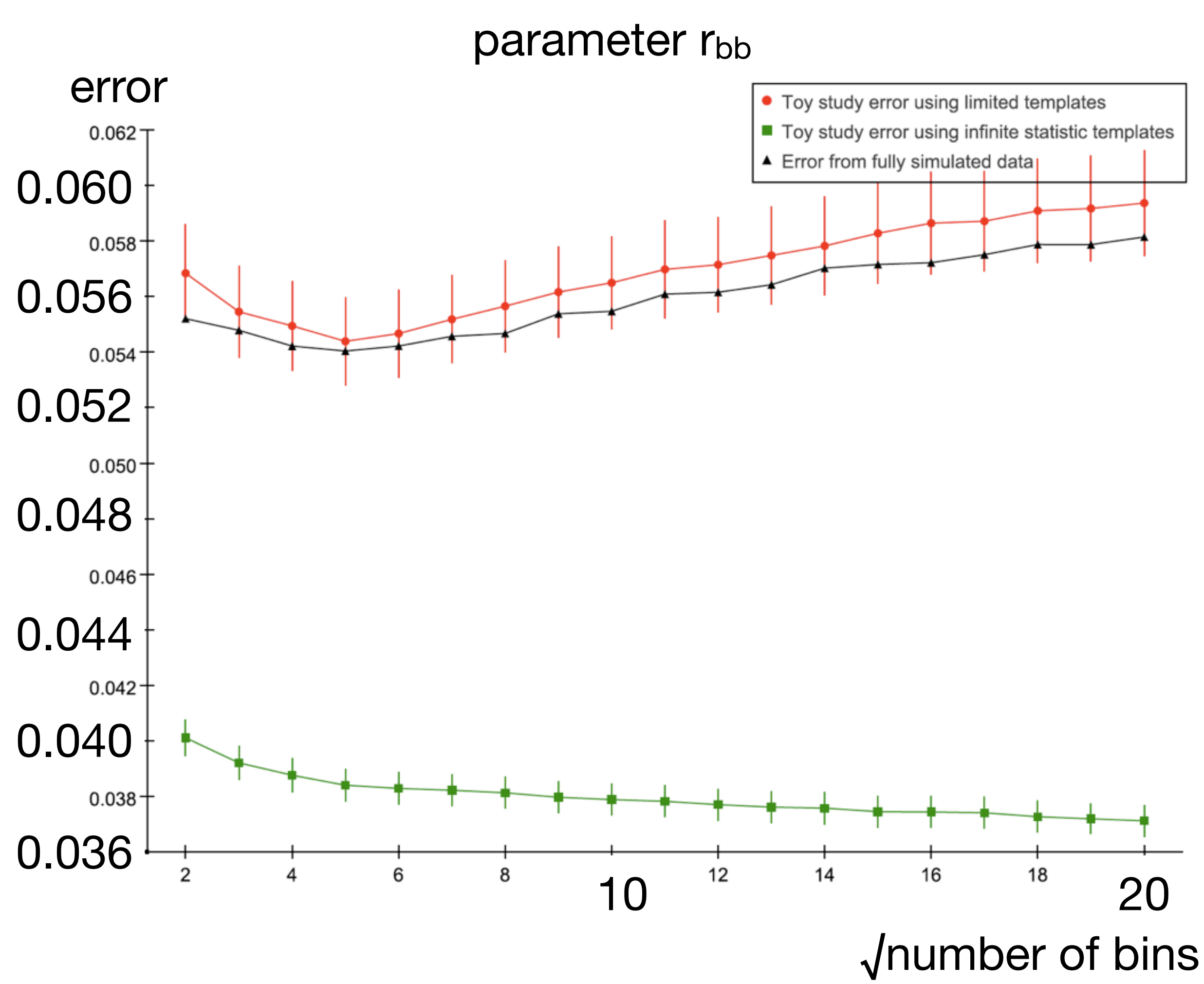
	r_{bb}	r_{cc}	r_{gg}
electron channel	0.95 ± 0.06	1.3 ± 0.6	1.2 ± 0.5
muon channel	1.01 ± 0.04	0.87 ± 0.54	0.93 ± 0.51

- Branching ratios can be obtained from

$$\sigma(e^+e^- \rightarrow Zh) \times BR(h \rightarrow s) = \mathrm{r}_s \times BR(h \rightarrow s)_{SM} \times \sigma(e^+e^- \rightarrow Zh)_{SM}$$

Branching ratios

- Accuracy of the measurements
  - Errors from the fit includes uncertainties from limited Monte Carlo samples.
  - Used ‘toy’ Monte Carlo to test the stability of the fits and to extract the experimental statistical uncertainties of the branching ratios.



Branching ratios

- Accuracy in the Higgs hadronic branching ratios at ILD

Relative errors	$H \to bb$	$H \to cc$	$H \to gg$
electron channel	4%	36%	38%
muon channel	4%	46%	45%
combined	2.7%	28%	29%

- The estimated uncertainty in $\sigma(e^+e^- \to llH)$ is 5% (ref. ILD LoI) and is not included.

Summary

- The statistical uncertainties of the Higgs hadronic branching ratios were estimated for the ILD detector using the process

$$e^+e^- \rightarrow ZH \rightarrow llH,\ l=e,\mu$$

at $\sqrt{s}$ = 250 GeV for an integrated luminosity of 250 fb-1 and beams with polarisation $P(e^-) = -80\%$, $P(e^+) = +30\%$.

- The relative errors, combining the electron and the muon channels and adding the estimated relative error of the Higgs cross section, are:

$$\frac{\Delta BR}{BR}(H \rightarrow b\bar{b}) = 2.7\% \oplus 5\%$$

$$\frac{\Delta BR}{BR}(H \rightarrow c\bar{c}) = 28\% \oplus 5\%$$

$$\frac{\Delta BR}{BR}(H \rightarrow g\bar{g}) = 29\% \oplus 5\%$$