Branching ratio H-->mu+mu-

Short Description.

Physics Motivation: measure Higgs Yukawa coupling to muons, which provides useful test for ratio of Yukawa coupling between 2nd/3rd generation leptons (with $H\tau\tau$); between 2nd generation lepton/quark (with Hcc).

Search Channel: $e^+e^- \to \nu\bar{\nu}H$ with $H \to \mu^+\mu^-$ at $\sqrt{s}$ of 500 GeV.

Detector Benchmark: very sensitive to high momentum resolution/tracking efficiency, algorithm for isolated lepton tagging.

Two different works are ongoing or finish in soon.

1. Work using DBD-world samples: explored at $\sqrt{s}$ of 250/500 GeV, left-/right-handed beam polarization, two processes of $e^+e^- \to q\bar{q}H$ and $e^+e^- \to \nu\bar{\nu}H$
2. Work using IDR-world samples: written in above

Main Observables.

final observable: precision on the cross section times branching ratio $\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$, branching ratio of $H \to \mu^+\mu^-$.

intermediate observables: track momentum resolutions, muon pair invariant mass $M_{\mu^+\mu^-}$, event-by-event mass resolution $\sigma(M_{\mu^+\mu^-})$ which is calculable using the covariance matrix of momenta space.

Brief Description of Analysis.

Two muons are selected using IsolatedLeptonTagging (without E_{yoke} and impact parameters) as the $H \to \mu^+\mu^-$ candidate. Various pre-cuts are applied to select signal and reject background. Further background rejection is done using TMVA(BDTG). Estimating the precision on $\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$ is done using toy MC technique. In the signal process, two processes are mixed up: $e^+e^- \to ZH \to \nu\bar{\nu}\mu^+\mu^-$ and $e^+e^- \to \nu\bar{\nu}H \to \nu\bar{\nu}\mu^+\mu^-$ via WW-fusion. These two should be separated in the end, but such separation is not considered in the analysis; it is beyond the scope of this analysis.

Candidate Plots for IDR.

Some comparison between IDR-L and IDR-S in reconstructed particle level has done. More details can be found in my talk on 2019Apr03. All plots are left-handed beam polarization. All histograms are normalized to 1.

Overall distribution after BDTG score cut: $M_{\mu^+\mu^-}$ and $\sigma(M_{\mu^+\mu^-})$. IDR-L gives better performance in both variables.

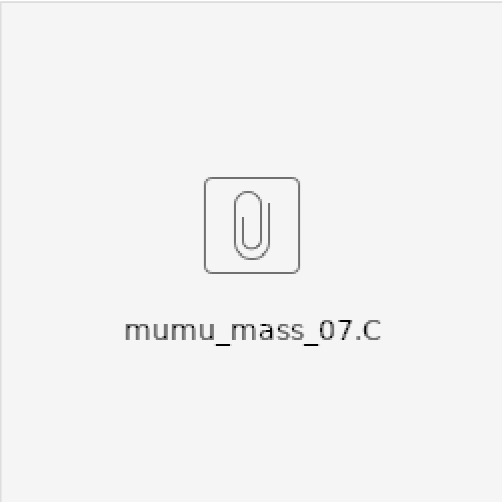
mumu_mass.pdf

sigma_mumu_mass.pdf

mumu_mass.C

sigma_mumu_mass.C

Similar plot for "barrel category"; require both muons are in barrel region $|\cos\theta_{\mu^\pm}| < 0.7$. $M_{\mu^+\mu^-}$ is significantly better in IDR-L, $\sigma(M_{\mu^+\mu^-})$ as well.



Similar plot for "mixed category"; require one muon is in barrel region $|\cos\theta_{\mu 1}| < 0.7$, and another is in endcap/forward region $|\cos\theta_{\mu 2}| > 0.7$. $M_{\mu^+\mu^-}$ is pretty much same in both detector model, but slightly better $\sigma(M_{\mu^+\mu^-})$ performance in IDR-L.

mumu_mass_mix.pdf

sigma_mumu_mass_mix.pdf

mumu_mass_mix.C

sigma_mumu_mass_mix.C

Only ~5% events are the case with both muons flying in endcap/forward region. We will not discuss here.

Remaining Events After All Cuts.

A toy MC technique is applied by using overall $M_{\mu^+\mu^-}$ distribution after BDTG score cut to estimate the precision on $\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$. Two detector models and two beam polarization cases are considered. Next table shows the total remaining events in the full range (120 - 130 GeV) after BDTG score cut for each detector model and each beam polarization.

	IDR-L-left	IDR-S-left	IDR-L-right	IDR-S-right
N_{sig}	33.17	33.01	5.43	5.26
N_{bkg}	1101.55	1069.25	245.34	202.37

- In the right-handed case, N_{sig} is pretty small, hard to perform precise measurement. We only have ~8 signal events with 1600 fb-1 statistics from the beginning. We will not consider right-handed case for further discussion.
- We see some differences in N_{bkg} between IDR-L and IDR-S, but this is due to statistical fluctuation caused by the lack MC statistics for SM background.

Discussion and Final Results.

From the table above, N_{sig} and N_{bkg} in the full range are pretty much same between IDR-L and IDR-S. The level of total background fluctuates due to limited number of MC statistics, thus, we can conclude that the background distribution and total number of backgrounds in full range are the same. For further analysis, we treat the background condition is common in IDR-L and IDR-S. We take the average number of N_{bkg} and average slope in background modeling of IDR-L and IDR-S, for generating pesudo-background data. We perform toy MC using common parametrization for background, and evaluate the precision. Next table shows the final result of the precision on $\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$ after 50000 times pseudo-experiments. The theoretical number is provided in addition which assumes 100% signal efficiency, no backgrounds, and no detector effects.

	IDR-L	IDR-S	Theory
precision	$40.16 \pm 0.15\%$	$41.28 \pm 0.15\%$	13.18%

- My real analysis is about a factor of 3 worse than the theoretical number. There are several reasons mixed up: imperfection of cuts, existence of irreducible backgrounds mainly come from $e^+e^- \to W^+W^- \to 2\mu 2\nu$, detector effect, and so on.
- IDR-L gives relatively 2.8% better precision than IDR-S.
  - Because overall $M_{\mu^+\mu^-}$ distribution is better in IDR-L. In detail, IDR-L gives significantly better performance in "barrel category", and similar performance in "mixed category". Almost all events are categorized in these two groups, resulting better result with IDR-L.
  - The number of signal events in $M_{\mu^+\mu^-}$ peak region is basically same between IDR-L and IDR-S, but ~10% more backgrounds lyng in the peak region with IDR-S due to ~10% wider width caused by worse momentum resolution. This ~10% more backgrounds can translate into ~3.3% difference in the statistical significance. This 2.8% difference is consistent to the estimation from statistics.

Conclusion.

- IDR-L gives better result than IDR-S, because of better momentum resolution in barrel region.
- Worse momentum resolution makes wider width of $M_{\mu^+\mu^-}$ distribution of signal, resulting more backgrounds lying in peak region, and resulting worse precision on $\sigma \times \mathrm{BR}(H \to \mu^+\mu^-)$.
- Specifically for this analysis, IDR-L is better option.

IDR note.

You can see my private overleaf project from **here**. The contents are only IDR-world.

People.

Shin-ichi Kawada (DESY)

Reviewed by Ivanka Bozovic and Filip Zarnecki

References.

GitHub repository: LINK

(1) DBD-world references

Branching ratio measurement of $h \to \mu^+\mu^-$ at the ILC [Talk at LCWS2017]

Impact of Momentum Resolution on $\mathrm{BR}(h \to \mu^+\mu^-)$ Measurement [Talk at ILD Meeting 2018]

Branching ratio measurement of $h \to \mu^+\mu^-$ at the ILC [Talk at ALCW2018]

Prospects of measuring Higgs boson decays into muon pairs at the ILC [Talk at LCWS2018]

Shin-ichi Kawada, Jenny List, Mikael Berggren, "Branching ratio measurement of $h \to \mu^+\mu^-$ at the ILC" (LCWS2017 proceedings) [LINK]

Shin-ichi Kawada, Jenny List, Mikael Berggren, "Prospects of measuring Higgs boson decays into muon pairs at the ILC" (LCWS2018 proceedings) [LINK]

(2) IDR-world references

Talk at Wednesday ILD Analysis/Software Meeting [2018Oct10, 2018Nov21, 2019Jan30, 2019Apr03]

Status Report: $h \to \mu^+\mu^-$ Benchmark [Talk at ILD Benchmarking Days]

Status Report: $h \to \mu^+\mu^-$ Benchmark [Talk at ILD Benchmarking Days II]