An analysis of $h \to \mu^+\mu^-$ mode at the center-of-mass energy of 500 GeV ILC — part 2

Shin-ichi Kawada

Abstract

[1] This note is a second log of $h \to \mu^+\mu^-$ analysis at the 500 GeV ILC. Here we will discuss the case when increasing the MC samples statistics.

[1] release note

- 2016/August/10: release
- 2016/August/14: everything re-wrote due to mistake in the analysis
- 2016/August/31: some typos are fixed

1 Incresing sample

I used many MC samples in previous analysis [1], but still the event weight was high especially 4f processes. Also some processes were not included. This time, I included these kinds of backgrounds. Below is the list of newly added samples.

- $e^{\pm}\gamma \to$ 3f (new process, SGV [2])
- $\gamma\gamma \to$ 2f (new process, SGV)
- $e^{+}e^{-} \to$ 4f
  - WW hadronic (new process)
  - ZZ hadronic (new process)
  - singleZnunu leptonic (increased)
  - ZZWWMix leptonic (increased)
  - singleZsingleWMix leptonic (increased)
  - singleZee leptonic (increased)

I used the samples placed at:

- $e^{\pm}\gamma \to$ 3f and $\gamma\gamma \to$ 2f:

  `/pnfs/desy.de/ilc/users/berggren/mc-dbd/sgv-dst_6/500-TDR_ws/1f_3f(aa_2f)`

- $e^{+}e^{-} \to$ 4f:

  `/pnfs/desy.de/ilc/prod/ilc/mc-dbd/ild/dst-merged/500-TDR_ws/XXX`

, as of August 2. The assumptions for cross sections and integrated luminosities are same as used in Ref. [1]. I used the cross section numbers which directly included in slcio files for $e^{\pm}\gamma \to$ 3f and $\gamma\gamma \to$ 2f processes. Unfortunately, the process parameters in slcio files of increased 4f samples are written as 4f, so I temporary coded to solve this problem in my own processor.

2 Analysis using SGV samples

We will discuss the analysis with using SGV samples.

2.1 Event reconstruction

The reconstruction procedure of muons are completely same as written in Ref. [1].

2.2 Analysis

Before optimization, I required following conditions:

- exactly one μ^{+} and one μ^{-},
- number of tracks in an event should equal or less than 4,
- $124 < M_{\mu\mu} < 126$ GeV,

where $M_{\mu\mu}$ is reconstructed muon pair mass with FSR correction. The following 3 figures show the distribution of number of tracks, $M_{\mu\mu}$ and zoom up of $M_{\mu\mu}$, respectively.

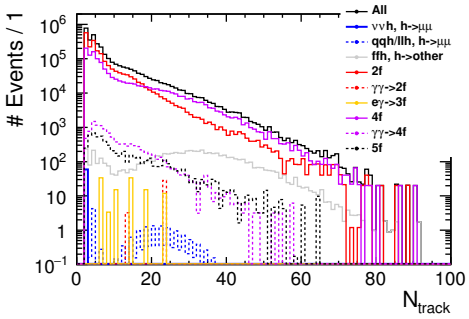

Figure 1: Distribution of number of tracks in an event.

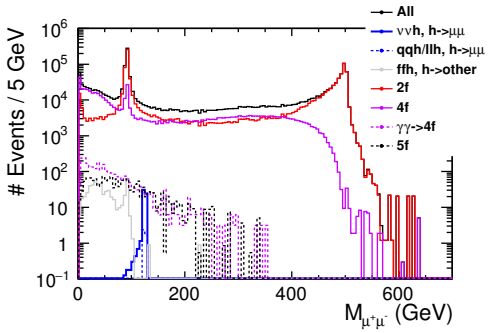

Figure 2: Distribution of $M_{\mu\mu}$.

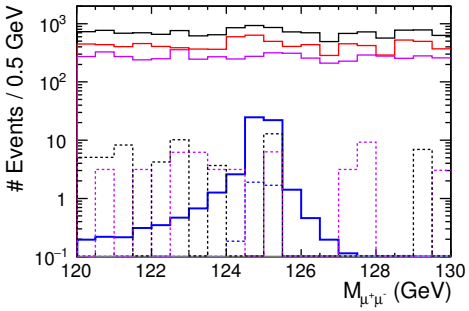

Figure 3: Zoom up of $M_{\mu\mu}$.

At this point, the newly included process $e^{\pm}\gamma \to 3\text{f}$ and $\gamma\gamma \to 2\text{f}$ are completely disappeared. After these, I applied following cuts as optimum.

- visible energy $E_{\text{vis}} < 285$ GeV
- $P_t > 50$ GeV
- thrust < 0.88
- $|\cos\theta_{\text{thrust}}| < 0.96$

where P_t is computed transverse momentum from the four-momentum of summing up of all visible particle's four-momentum. The following 4 figures show each variable distribution.

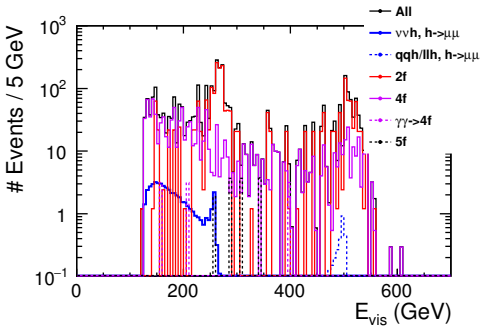

Figure 4: Distribution of E_{vis}.

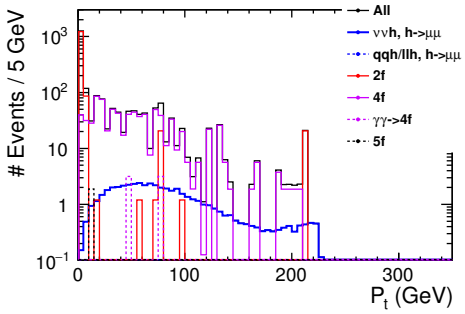

Figure 5: Distribution of P_t.

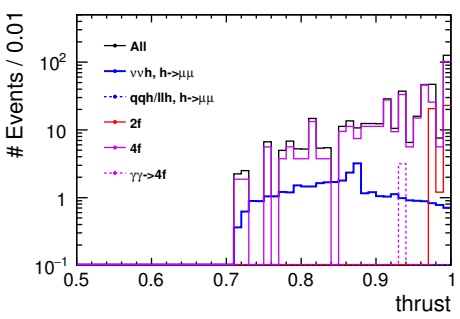

Figure 6: Distribution of thrust.

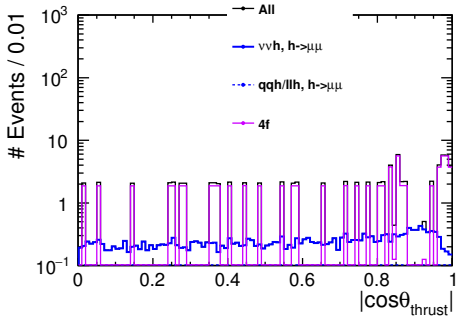

Figure 7: Distribution of $|\cos\theta_{\rm thrust}|$.

Table 1 shows the cut table using SGV sample.

Table 1: Cut statistics with using SGV samples.

	$\nu\nu h$ $h \to \mu\mu$	$qqh+\ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	$\gamma\gamma \to$ 2f	3f	4f	$\gamma\gamma \to$ 4f	5f
No cut	60.07	20.19	4.116×10^5	4.224×10^7	4.283×10^9	4.269×10^8	4.592×10^7	3.356×10^5	2.209×10^5
# $\mu^{\pm}$	58.95	18.24	6669.72	1.999×10^6	31.33	112.83	1.136×10^6	1.095×10^4	5891.07
# tracks	58.95	4.47	528.13	1.135×10^6	0	0	4.917×10^5	2725.73	1523.30
$M_{\mu\mu}$	50.74	3.86	0	2135.56	0	0	1150.16	9.45	12.92
$E_{\rm vis}$	50.21	0.07	0	1354.20	0	0	810.57	6.30	1.88
P_t	35.75	0.05	0	44.81	0	0	379.31	3.15	0
thrust	24.20	0.04	0	0	0	0	75.20	0	0
$\lvert\theta_{\rm thrust}\rvert$	23.41	0.04	0	0	0	0	56.48	0	0

From these, I obtained $N_{\rm sig} = 23.41$ and $N_{\rm bkg} = 56.52$. The significance is $\dfrac{23.41}{\sqrt{23.41+56.52}} = 2.62$, the precision is $\dfrac{\Delta(\sigma \times {\rm BR})}{(\sigma \times {\rm BR})} = 38\%$.

3 Analysis using fully-simulated samples

We will discuss the analysis using full-simulated samples in this section.

3.1 Event reconstruction

The reconstruction procedure is almost same as written in Ref. [1]. However, the information of yoke is not correctly stored in SGV samples ($e^{\pm}\gamma \to$ 3f and $\gamma\gamma \to$ 2f). Therefore, I removed the condition for yoke. Even I removed the condition for yoke, the reconstruction efficiency which correctly reconstruct exactly one μ^+ and one μ^- was 94.6%. The correction of FSR is same as written in Ref. [1].

3.2 Analysis

Before optimization, I required following conditions:

- exactly one μ^+ and one μ^-
- number of tracks in an event which have the transverse momentum greater than 5 GeV ($N^{\rm track}_{P_t>5{\rm GeV}}$) should be less or equal to 4
- $124 < M_{\mu\mu} < 126$ GeV

where $M_{\mu\mu}$ is the reconstructed muon pair mass with FSR correction. The reason why I required the cut for $N^{\rm track}_{P_t>5{\rm GeV}}$ is to avoid the effect of $\gamma\gamma \to$ hadron(s) overlay. The overlay background produces additional charged particles. Due to this, the simple variable of number of tracks no longer works anymore. But the overlay particles tend to have low transverse momentum. By using this kind of variable, the effect of overlay backgrounds would be small. This is a point which I try to improve from Ref. [1]. The following 3 figures show the distribution of $N^{\rm track}_{P_t>5{\rm GeV}}$, $M_{\mu\mu}$ and its zoom up.

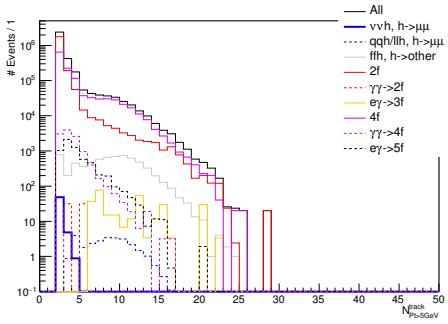

Figure 8: Distribution of $N^{\text{track}}_{P_t>5\text{GeV}}$.

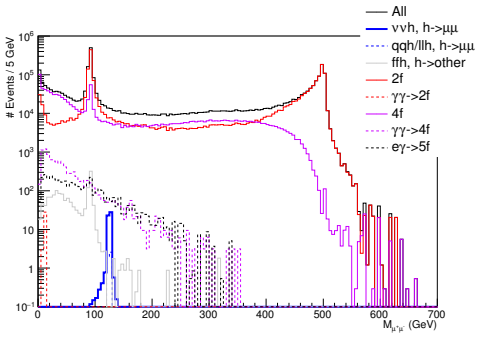

Figure 9: Distribution of $M_{\mu\mu}$.

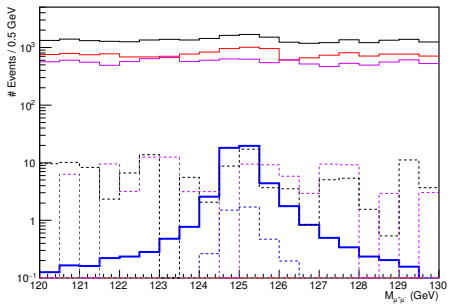

Figure 10: Zoom up of $M_{\mu\mu}$.

At this point, newly introduced 3f processes are completely disappeared. After these, I required the following conditions as the optimum cuts:

- visible energy $E_{\text{vis}} < 315$ GeV
- $P_t > 65$ GeV
- thrust < 0.88
- $|\cos\theta_{\text{thrust}}| < 0.96$

where P_t is computed transverse momentum from the four-momentum of summing up of all visible particle's four-momentum, θ_{thrust} is the angle of thrust axis with respect to beam axis. The following 4 figures are the distributions of each variable.

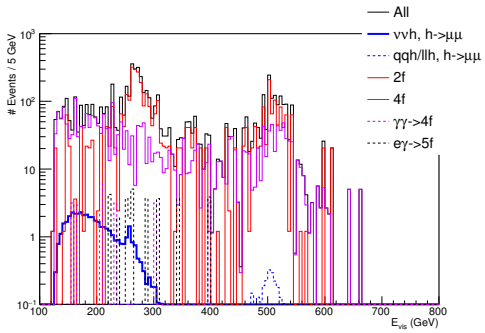

Figure 11: Distribution of E_{vis}.

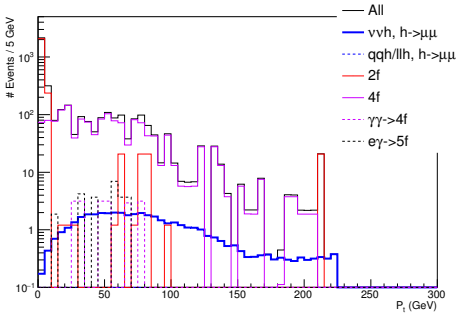

Figure 12: Distribution of P_t.

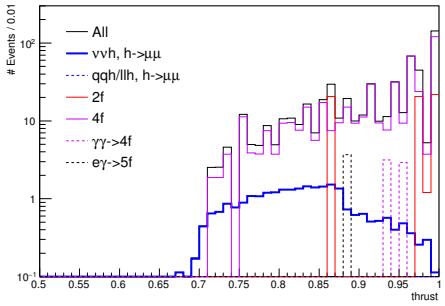

Figure 13: Distribution of thrust.

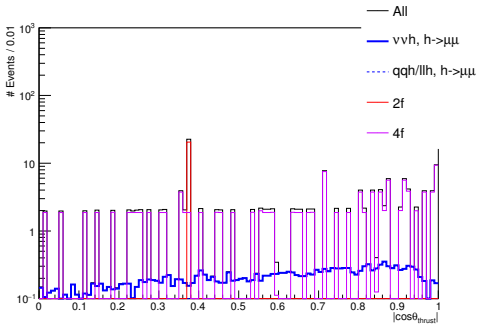

Figure 14: Distribution of $\cos\theta_{\rm thrust}$.

Table 2 shows the cut table of the case of using fully-simulated samples.

Table 2: The cut statistics using fully-simulated samples.

	$\nu\nu h$ $h \to \mu\mu$	$qqh+\ell\ell h$ $h \to \mu\mu$	ffh $h \to$ other	2f	$\gamma\gamma \to$ 2f	3f	4f	$\gamma\gamma \to$ 4f	5f
No cut	57.53	31.13	4.116×10^5	4.224×10^7	4.283×10^9	4.269×10^8	4.592×10^7	3.356×10^5	2.209×10^5
# $\mu^{\pm}$	54.39	27.39	6895.00	2.071×10^6	62.62	299.75	1.209×10^6	1.131×10^4	6125.00
# $N^{\rm track}_{P_t>5{\rm GeV}}$	54.27	4.89	1425.76	2.014×10^6	31.28	0	9.826×10^5	9544.48	4411.00
$M_{\mu\mu}$	44.61	3.94	0	3741.41	0	0	2407.24	21.81	31.63
$E_{\rm vis}$	43.88	0.17	0	2390.68	0	0	1529.57	18.66	24.10
P_t	25.97	0.07	0	64.20	0	0	457.80	6.07	3.68
thrust	20.48	0.05	0	20.60	0	0	118.92	0	0
$\theta_{\rm thrust}$	19.84	0.05	0	20.60	0	0	102.07	0	0

I obtained $N_{\rm sig} = 19.84$ and $N_{\rm bkg} = 122.72$. The significance is $\dfrac{19.84}{\sqrt{19.84+122.72}} = 1.66$, and the precision is $\dfrac{\Delta(\sigma \times {\rm BR})}{(\sigma \times {\rm BR})} = 60\%$.

4 Summary and future plans

We discussed the case of increased MC statistics to reduce statistical error in the analysis. Also I included some other processes which previously did not considered. I obtained 38%(60%) precision with using SGV(fully-simulated) samples. These numbers are relatively about 10% worse than the numbers in Ref. [1]. But, newly added processes ($e^{\pm}\gamma \to$ 3f and $\gamma\gamma \to$ 2f) are completely suppressed by the analysis.

The future plan is as follows:

- application of $\sigma(M_{\mu^+\mu^-})$: re-weighting
- separation of $e^+e^- \to Zh$ (Higgs-strahlung) and $e^+e^- \to \nu\nu h$ (WW-fusion)

References

[1] Shin-ichi Kawada
"An analysis of $h \to \mu^+\mu^-$ mode at the center-of-mass energy of 500 GeV ILC"

[2] Mikael Berggren
"SGV 3.0 — a fast detector simulation"
arXiv:1203.0217 [physics.ins-det] (2012)