H $\rightarrow \mu\mu$ @ 1 TeV

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Tokusui Workshop 2012

December 21th, 2012

Overview

I joined ILC group one year ago (time spend very fast).

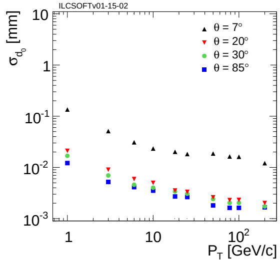
- Activities inside Asian Physics Group:
  1. $\mathrm{H} \to \gamma\gamma$ Analysis (250 GeV, LOI samples)
     - Not cover in this review (not mature enough).
     - It will be summarize after DBD dead line.
  2. Benchmark Analysis $\mathrm{H} \to \mu\mu$ (1 TeV) for the DBD.
     - Now concentrate on this analysis.

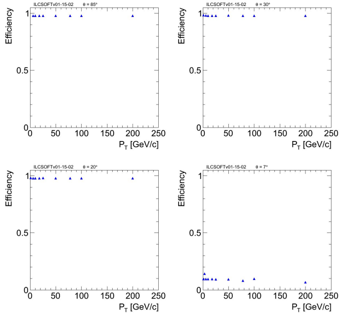
- ILD Analysis Software Group.
  1. Testing new realeses of ILD software.
  2. Testing produced samples for the DBD studies.

- Recently joined to the FPCCD VTX group.
  1. I will do beam test next year.

ILD Analysis Software Group

- Testing Tracking performance for new ILDsoft releases.



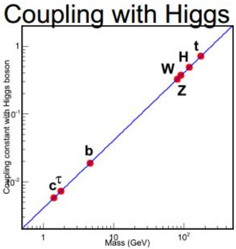


- Checked old LOI data samples and new DBD samples.
  - Important thing, sometimes you find problems.

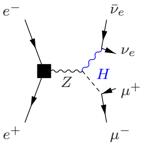
⟶ Found duplicated events on LOI samples (reported and fixed).

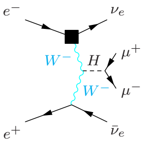
⟶ Found DBD samples with stable Higgs bosons (reported and fixed).

$H \rightarrow \mu\mu$



- One of the ILC goals is measure the Higgs couplings.
- The SM Higgs follows a linear relation in the couplings VS mass particle plot.

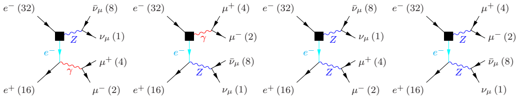




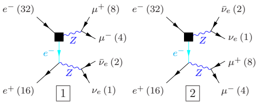
H $\rightarrow \mu\mu$

- E=1 TeV
- cross section (100 % polarized beam): 748.4 fb (lr), 5.905 fb (rl)
- branching ratio: 0.000221
- Only left-handed beam provides significant contribution.
  - $\approx$ 45 events with L=500 $\mathrm{fb}^{-1}$and (e^{-1},e^{+1})=($-$0.8,+0.2)
  - $\approx$ 4 events with L=500 $\mathrm{fb}^{-1}$and (e^{-1},e^{+1})=(+0.8,$-$0.2) $\longleftarrow$ tiny
- ILCSOFTv16
- Included overlay $\gamma\gamma \rightarrow \mathrm{hadrons}$

Main Background Sources



$ZZ(WW) \rightarrow \nu\nu\mu\mu$



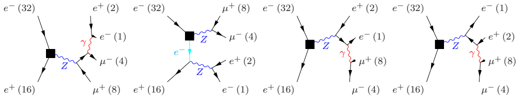
$Z \rightarrow \nu\nu\mu\mu$

- same final state as the signal.
- Only showed a few of the total Feynman diagrams.

Other Background Sources

Other sources considered:

- $\mu\mu e^+ e^-$ (leptons being forward)



- $Z \rightarrow \mu\mu$
- 4f_sw_l
- 4f_ww_l
- 4f_zz_l

$\longrightarrow$ All signal and background samples full simulated/reconstructed.
$\longrightarrow$ Background $\gamma\gamma \rightarrow \text{hadrons}$ overlay on every event (it was not included in my slides at Arlingtown LCWS12).

Preselection

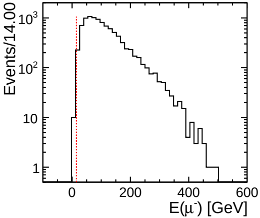
2 Muons

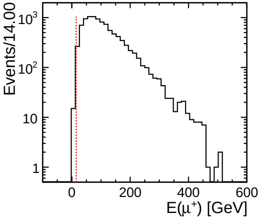
- 2 opposite charged PFO's
- $E > 15$ GeV
- $E_{calE}/(E_{calE} + E_{calH}) < 0.5$
- $(E_{calE} + E_{calH})/|\vec{P}| < 0.3$

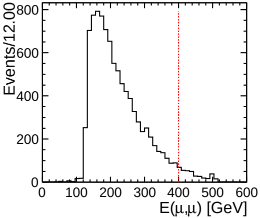
H candidate

- $E_{muon1} + E_{muon2} < 400$ GeV
- $|M(\mu^+, \mu^-) - 125| < 30\ \mathrm{GeV/c^2}$

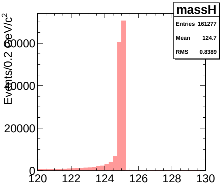
- No isolation requirement.
- 87 % of signal pass this requirements.

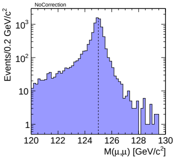


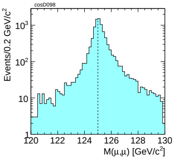




Final State Radiation (FSAR)







generator level   reco (not recovered)   reco (FSAR recovered)

- Low mass tail due to FSAR.
- The probability P($\mu^+ \rightarrow \mu^+ \gamma$ OR $\mu^- \rightarrow \mu^- \gamma$) = 0.62
- Recovered adding E/P from photons around muons.

Optimization

Optimization Scans

- Signal optimized over all backgrounds with Score Func. $\frac{S}{\sqrt{S+B}}$,
  - S: signal inside $123.92 < \mathrm{m_H} < 126.08$ (3 σ's, $\sigma = 0.36\ \mathrm{GeV/c^2}$)
  - B: total back in sidebands $(118,122) \cup (128,132)$ (normalized to signal region: $\mathrm{F} = 0.135 = \frac{3\sigma}{4+4}$)
- Variables are scanned until we rise a stable point.
  - $\mathrm{var}_1 \longrightarrow \mathrm{var}_2 \longrightarrow \mathrm{var}_{N-1} \longrightarrow \mathrm{var}_1$
  - If var_i best value changed we scan var_1 again.
  - Any var changed in a full cycle ($\mathrm{var}_1 \longrightarrow \mathrm{var}_1$): we found a stable point.
- A new variable is added var_N and we scan it.
- New cycle of scans to find a new stable point: $\mathrm{var}_1 \longrightarrow \mathrm{var}_2 \longrightarrow \mathrm{var}_N \longrightarrow \mathrm{var}_1$

Order on variables

- $\not{E}_T$, $\not{E}$, $\mathrm{P_T(H)}$, $\mathrm{P_T}(\mu^+)$+$\mathrm{P_T}(\mu^-)$, $E_{PFO's} - E_{\mu^+} - E_{\mu^-}$, $\cos^*$, cos(H),$\cos(\mu^+,\mu^-)$, $|d_0|$, $|z_0|$

Optimization (*)

Cut Based

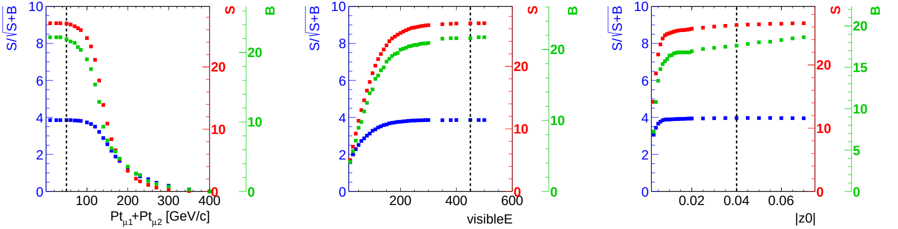
Variable	best Value
min $\not{E}_T$	40
min $\not{E}$	400
min $P_T(H)$	40
min $P_T(\mu^+)+P_T(\mu^-)$	60
min cos(μ^+, μ^-)	no cut
max $\lvert d_0 \rvert$	no cut
max $\lvert z_0 \rvert$	no cut

BDT + Cuts

Variable	best Value
min BDTOut	-0.028
min $\not{E}_T$	10
min $\not{E}$	350
max E_{vis}	450
min $P_T(H)$	25
min $P_T(\mu^+)+P_T(\mu^-)$	60
min cos(μ^+, μ^-)	no cut
max $\lvert d_0 \rvert$	0.02
max $\lvert z_0 \rvert$	0.055

MLP + Cuts

Variable	best Value
min MLPOut	0.40
min $\not{E}_T$	15
min $\not{E}$	350
max E_{vis}	450
min $P_T(H)$	40
min $P_T(\mu^+)+P_T(\mu^-)$	60
min cos(μ^+, μ^-)	no cut
max $\lvert d_0 \rvert$	0.018
max $\lvert z_0 \rvert$	0.04



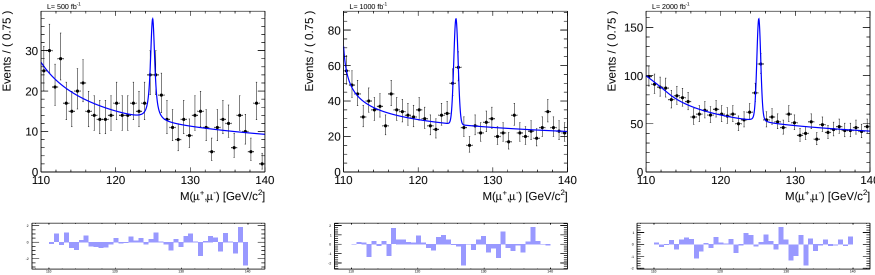
(*) Numbers are preliminary.

- The statistical precision of $\frac{\Delta(\sigma \cdot \mathrm{Br})}{\sigma \cdot \mathrm{Br}}$ is evaluated generating/fitting many pseudoexperiments(*) withing `RooFit`.
- Samples are generated from templates extracted from fits to data.
- The expected statistical precision is the average over all pseudoexperiments of the ratio: $\frac{\Delta N_S}{N_S}$
  - N_S (ΔN_S) the yield (yield undertaiinty) returned by the fit,
- Cut Based analysis and TMVA analysis explored for toy samples at 500 fb^{-1}, 1 $\mathrm{ab}^{-1}$and 2 ab^{-1}.

(*) Same approach as used on CLIC *Conceptual Design report*

Statistical Precision (*)

- Estimated the Precision on the $\frac{\Delta(\sigma \cdot \mathrm{Br})}{\sigma \cdot \mathrm{Br}}$



$\frac{\Delta(\sigma \cdot \mathrm{Br})}{\sigma \cdot \mathrm{Br}}$ (%)

Method	L=500 fb^{-1}	L=1 ab^{-1}	L=2 ab^{-1}
cut Based	33.3	25.8	19.5
BDT	32.8	23.4	18.0
MLP	30.8	24.6	17.9

(*) Numbers are preliminary.

Summary

- First year (from many, i hope) working for ILC.
  - New country, new food, new software tools...
- Involved in analysis group
  - $\mathrm{H} \rightarrow \mu\mu$ (DBD benchmark), $\mathrm{H} \rightarrow \gamma\gamma$
- and ILD software group.
- Starting next year working for the FPCCD VTX group.
- Looking forward ILC project be realized soon.

Thank You

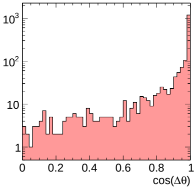
Merry Christmass and Happy New Year!!!

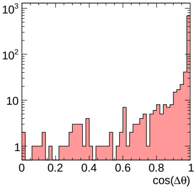
Back Up

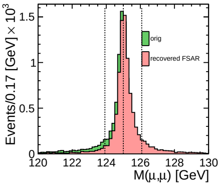
Final State Radiation (FSAR)

FSAR in $\mathrm{H} \to \mu\mu$ (probability 63 %)

- μ^+,μ^-(or both) emit γ's (includes interaction with material).
- That causes low tails in Higgs mass distribution
- Tipicaly angle between emited γ and μ very small cos($\Delta\theta$) $\approx$ 1
  - left plot: cos(μ, γ) distribution
  - center plot: cos(μ, γ) distribution E(γ)$>$ 500 MeV
  - right: $\mathrm{m}(\mu, \mu)$ w/ and w/o $\mu \to \mu\gamma$ correction.
- Added to muon P/E from γ's inside cone (semiangle 11.48^o)



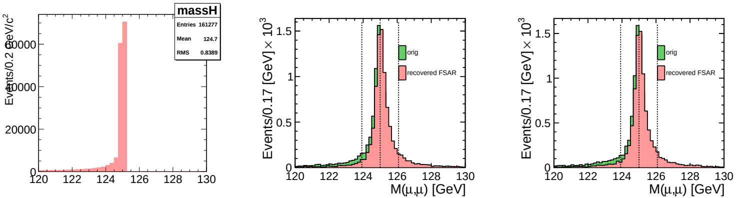




Final State Radiation (FSAR)

FSAR in $\mathrm{H} \to \mu\mu$ (probability 62.70 %)

- $\mathrm{m}_\mu = 0$ in `whizard.in` (*)
- Print out of the m_μ running over the `sdthep` files shows the right mass (0.10566 $\mathrm{MeV/c^2}$)
- Generated/Sim/Reco new 10^4 signal events with same intial configuration but $\mathrm{m}_\mu = 0.10566$.
  - Similar probability for $\mu \to \mu\gamma$: 63.26 %
- Generator level: $\mathrm{P}(\mu_1 \to \mu_1\gamma \text{ OR } \mu_2 \to \mu_2\gamma) \approx 0.62$



generator level $\qquad$ $\mathrm{m}_\mu = 0$ $\qquad$ $\mathrm{m}_\mu = 0.10566$

(*) (http://www.slac.stanford.edu/ timb/higgs_production/ffh_m120/E1000-B1b_ws.Pvvh_mumu.Gwhizard-1.95.eL.pR.I36003/whizard.in)

FSAR

- Muon (PDG=13) stable.
- Anti-muon (PDG=-13) emit γ.

PDG	gen Status	energy	P_T	cosθ
22	2	0	0	1
22	2	1.33953	1.33811	-0.0461053
25	2	262.186	143.788	0.78151
22	1	0	0	1
22	1	1.33953	1.33811	-0.0461053
25	2	262.186	143.788	0.78151
13	2	214.899	145.462	0.736086
-13	2	47.2871	41.8939	0.46378
13	1	214.876	145.447	0.736086
-13	2	47.3096	41.8911	0.464079
-13	1	47.1372	41.7619	0.463747
22	1	0.17236	0.14843	0.508333

FSAR

- Muon (PDG=13) emit γ.
- Anti-muon (PDG=-13) stable.

PDG	gen Status	energy	P_T	cosθ
22	2	5.47783e-14	3.58122e-16	0.999979
22	2	4.76897e-06	2.51788e-08	-0.999986
25	2	209.414	63.331	0.926239
22	1	5.47783e-14	3.58122e-16	0.999979
22	1	4.76897e-06	2.51788e-08	-0.999986
25	2	209.414	63.331	0.926239
13	2	144.678	14.1117	0.995232
-13	2	64.736	63.6818	0.179721
13	2	144.678	14.1117	0.995232
-13	1	64.736	63.6818	0.179721
13	1	144.314	14.0767	0.995231
22	1	0.363252	0.0351287	0.995313

- Both, muon a-muon stable (status = 1)

PDG	gen Status	energy	P_T	$\cos\theta$
22	2	74.5424	21.9292	0.955749
22	2	0.0134528	0.000106008	-0.999969
25	2	231.598	142.949	-0.680024
22	1	74.5424	21.9292	0.955749
22	1	0.0134528	0.000106008	-0.999969
25	2	231.598	142.949	-0.680024
13	1	200.504	160.48	-0.599486
-13	1	31.094	28.5214	-0.398268

FSAR

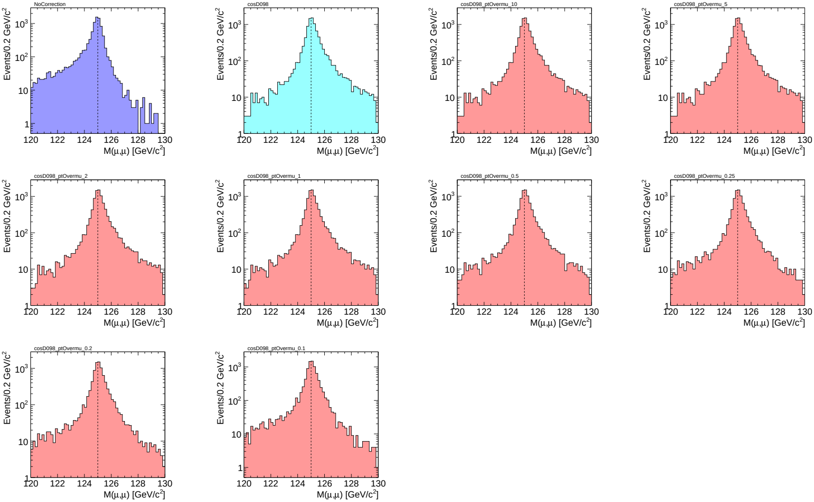
- Both, muon a-muon unstable (status = 2)

PDG	gen Status	energy	P_T	cosθ
22	2	0.0021251	0.000231734	0.994037
22	2	4.99517e-07	3.4965e-09	-0.999976
25	2	231.093	159.696	-0.57004
22	1	0.0021251	0.000231734	0.994037
22	1	4.99517e-07	3.4965e-09	-0.999976
25	2	231.093	159.696	-0.57004
13	2	20.1112	20.1108	0.0034987
-13	2	210.982	179.504	-0.525486
13	2	20.091	20.0899	0.00348981
-13	2	211.002	179.483	-0.525528
13	2	20.0225	20.0221	0.00343475
22	1	0.068509	0.0684959	0.0195483
-13	1	210.136	178.649	-0.526524
22	1	0.866272	0.836249	-0.260987
13	1	20.0224	20.022	0.0034356
22	1	3.47889e-05	3.04306e-05	-0.48463

RecoverFSAR

- Next slide shows plots before and after recovering for FSAR.
  - Blue plot: no correction.
  - Cyan plot: Added photons inside cone with semiangle α, $cos\alpha = 0.98$
  - Red plots: Added photons inside cone if they have $\mathrm{P_T}$(respect μ direction) lower than a mav value.
- Not big differences: decided just keep using same method as before.

RecoverFSAR



Signal Efficiency/Purity Check

- The efficiency/purity on the muon selection was checked using MCTruth (`RecoMCTruthLink`, `MCParticlesSkimmed`).

Test Efficiency/Purity

- Efficiency: $\frac{\#\ \text{PFO match pass cuts}}{\#\ \text{muons MC}}$
- Purity: $\frac{\#\ \text{PFO match pass cuts}}{\#\ \text{PFO pass cuts}}$
- PFO match means PandoraPFO's identified as muons from $\mathrm{H} \rightarrow \mu\mu$ using MCTruth information.

Signal Efficiency

Signal Efficiency (%), $\sigma = 0.36\ \mathrm{GeV/c^2}$

Selection	Efficiency	# Events
0) Nature	1.00	45
1) reco	99.53 (99.53)	44.79
2) μ selec.	99.88 (99.41)	44.73
3) $\lvert mH - 125\rvert < 30, eH < 400$	86.06 (86.57)	38.73
x) $\lvert mH - 125\rvert < 3 * \sigma$	82.86 (71.73)	32.28

- Only muons from $\mathrm{H} \rightarrow \mu\mu$ with $E > 15$ GeV(99.55 % of the produced muons satisfy this requirement).

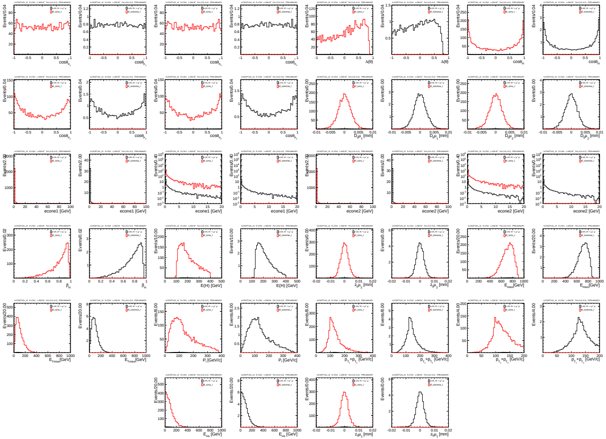
Muon Selection Efficiency/Purity

process	effi (%)	purity(%)
signal	98.1747	99.8674
2f_z_bhabhag	NA	0
2f_Z_hadronic	95	37.2549
2f_Z_leptonic	95.4683	95.4683
4f_WW_leptonic	98.1707	95.2663
4f_ZZWWMix_hadronic	92.3077	21.0526
4f_ZZWWMix_leptonic	97.4763	96.5625
4f_ZZ_hadronic	94.7368	45.5696
4f_ZZ_leptonic	96.1123	97.8022
4f_ZZ_semileptonic	98.1595	85.5615
4f_singleW_leptonic	99.0741	99.0741
4f_singleZnunu_leptonic	98.0831	99.3528
4f_singleZnunu_semileptonic	100	52.381
4f_singleZsingleWMix_leptonic	NA	0
4f_singleZee_semileptonic	100	27.2727
4f_singleZee_leptonic	97.7778	95.6522
4f_WW_semileptonic	96.4103	87.4419
4f_singleW_semileptonic	100	31.25

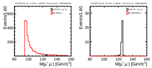
- High efficiency/purity for the relevant modes (leptonic final states).

Signal VS sznu_l Distributions

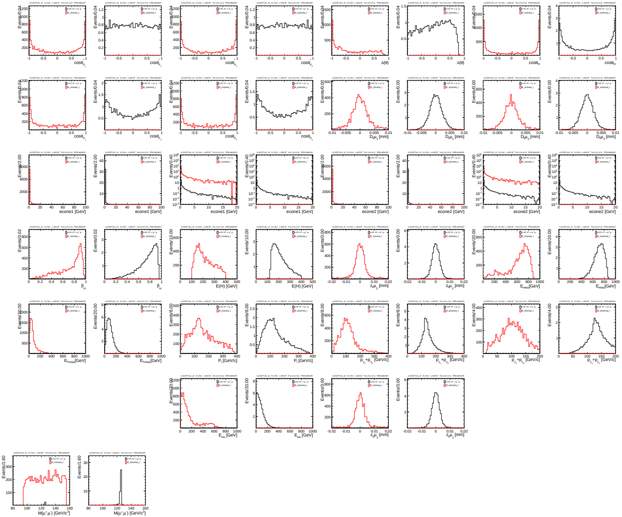
- Event Variables looks very similar.



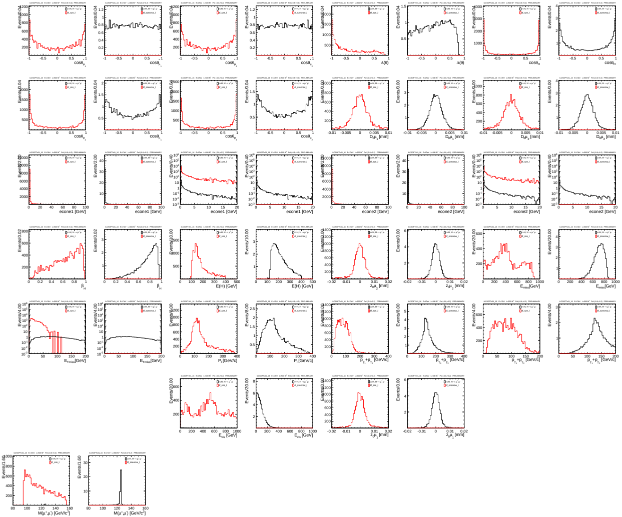
- Only the mass looks different.



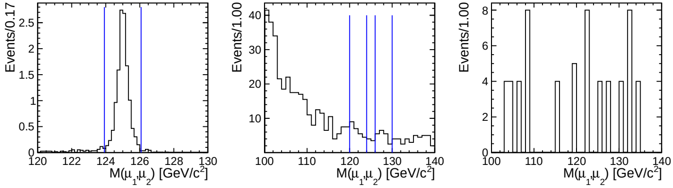
Signal VS zzorww_l Distributions



Signal VS sze_l Distributions



Naive Estimation of $\Delta(\sigma \cdot Br)/\sigma \cdot Br$



- Signal: 3 σ ($\sigma \approx 0.36\ \mathrm{GeV/c^2}$) around peak
- sznu: sidebands (120,124) & (126,130)
- zzorww: assumed flat, averaged over (100,140)

$\longrightarrow$ Normalized number of background events to signal window size

Yields

- Signal: 12.4
- sznu: 6.21
- zzorww: 1.62

- $\frac{\Delta(\sigma \cdot Br)}{\sigma \cdot Br} = \frac{\sqrt{S+B}}{S} = 36.3\ \%$

(This is for $L = 500\ \mathrm{fb}^{-1}$)

Estimation of $\Delta(\sigma \cdot Br)/\sigma \cdot Br$

- Alternative calculation provides 34 %
  - Fitting sznu and extrapolatin integral in region $(124.53, 125.47)$
  - Previous slide used bigger signal region definition $(123.92, 126.08)$
- Method using toy MC stil under development
- No good fit to the data, so no realistic templates to generate toy samples. :-(