Measurement Accuracies of Higgs Hadronic Branching Fractions in vvh at a 350GeV ILC

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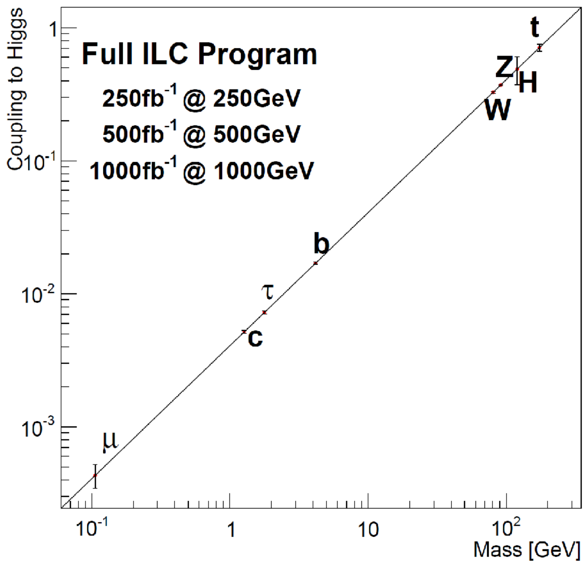
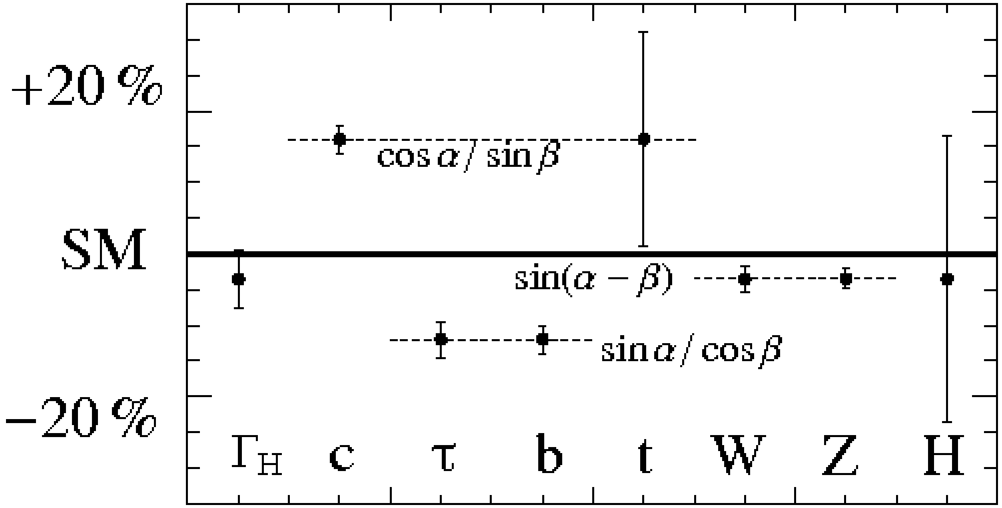
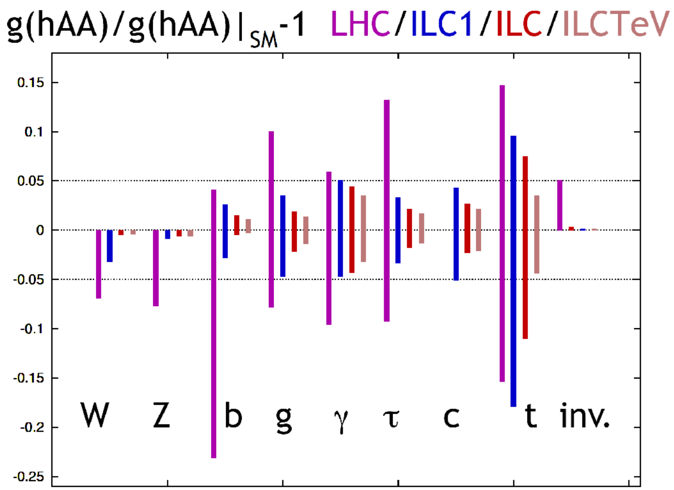
Introduction and Motivation

- Measuring the Higgs BR is one of the key issues of the ILC after the discovery of the 125 GeV Higgs
- Any deviations in the Higgs coupling to mass relation is an indication of new physics
- Need precision measurements as predicted deviation are small

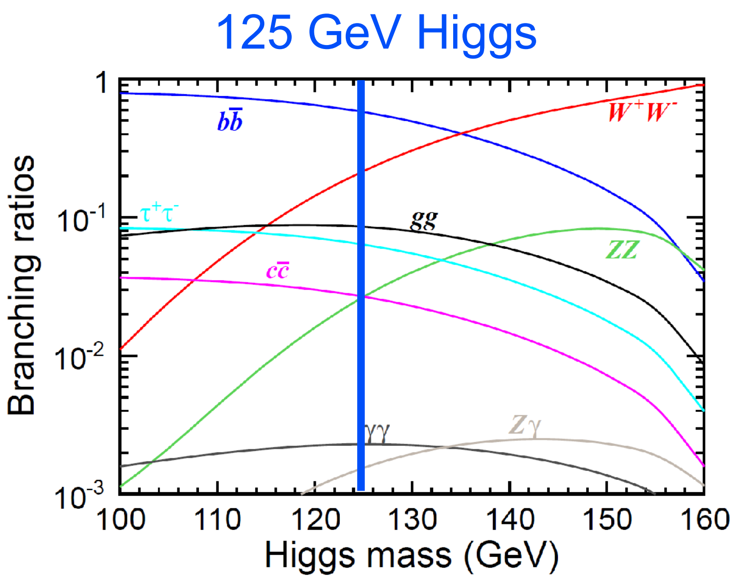






Introduction and Motivation

- All decay channels accessible for the ILC (even charm)
- High precision measurements of Higgs hadronic decay channels possible for a 125 GeV Higgs

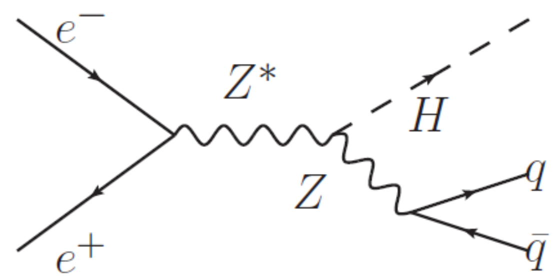


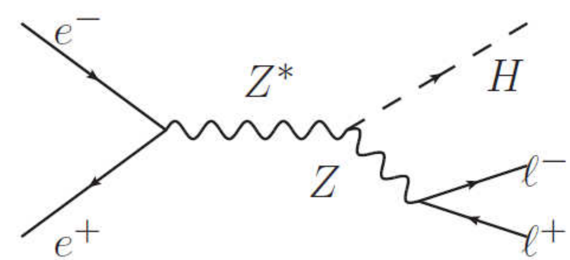
BR	bb	cc	gg	ττ	WW*	ZZ*	μμ
LHCHXSWG	57.8%	2.7%	8.6%	6.4%	21.6%	2.7%	0.2%

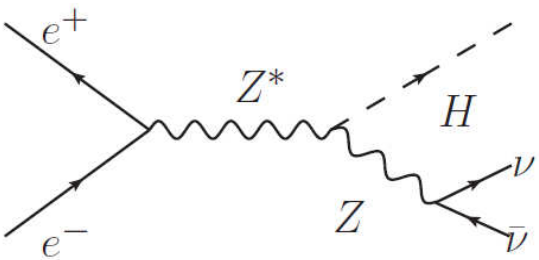
Possible Final States for the ILC

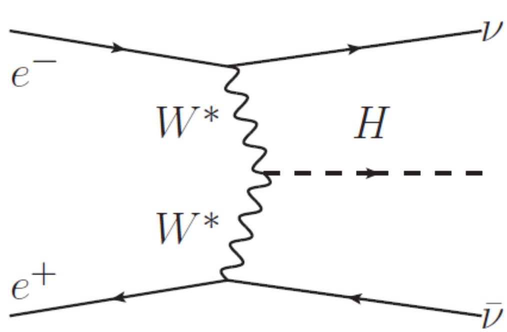
- Nearly all final states from Higgs Strahlung and Vector Boson Fusion (VBF) accessible
- Z→qq possible due to tagging performance (b and c) and low QCD background
- Z→ee has very low VBF contribution and good reconstruction of the Z
- Z→νν possible due to the known initial state

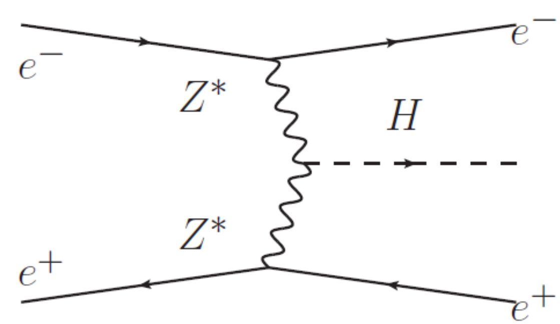
  →BUT more difficult to distinguish between VBF and Higgs Strahlung





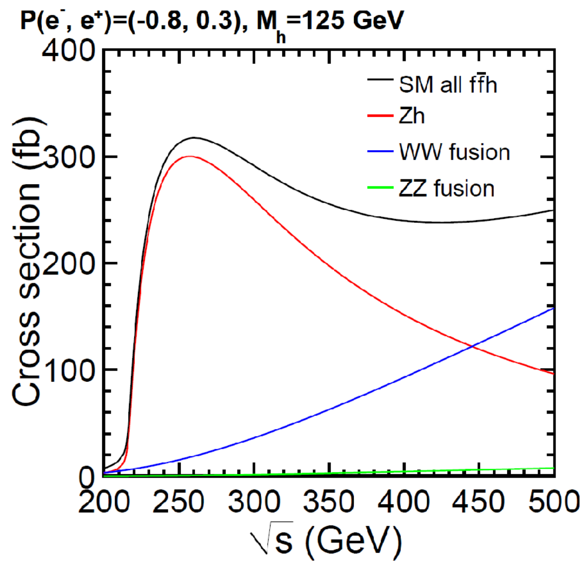


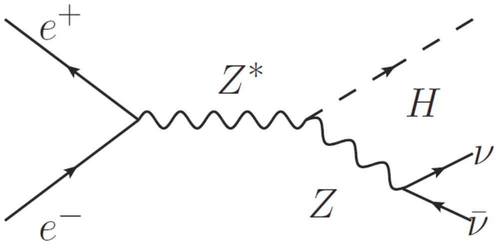


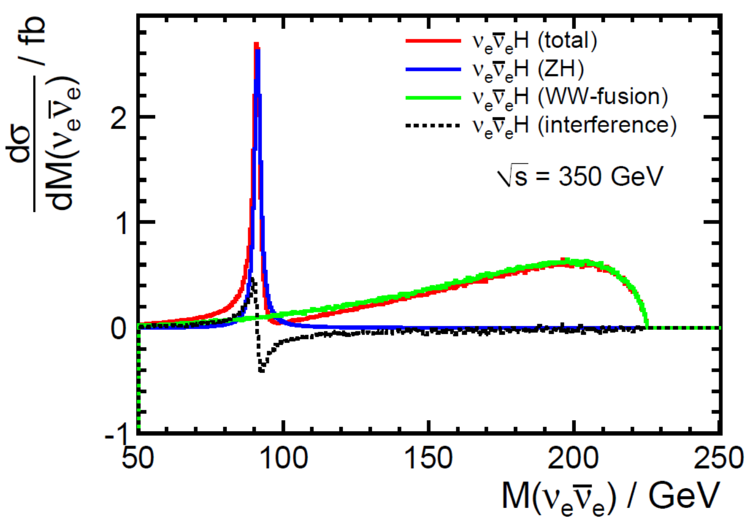


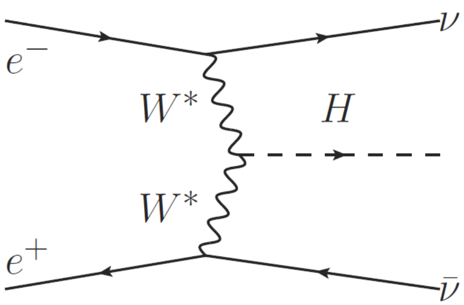
Introduction and Motivation

- 250 GeV: Higgs Strahlung dominant
  - σ_{ZH} x BR
  - σ_{ZH} from recoil measurement
- 350 GeV: Higgs Strahlung + WW-fusion
  - $(\sigma_{ZH} + \sigma_{WW})$ x BR
  - Need σ_{WW}









Goal of the Analysis

- Update the Letter Of Intent (LOI) analysis (arXiv:1207.0300) with a full simulation study using Technical Design Report (TDR) data samples
  - Update Higgs Mass (from 120 GeV to 125 GeV)

    → Branching fractions depend on the mass of the Higgs
- Check the influence of γγ-overlay
- Add missing mass in the fit to get cross section ratio of Higgs Strahlung and WW-fusion

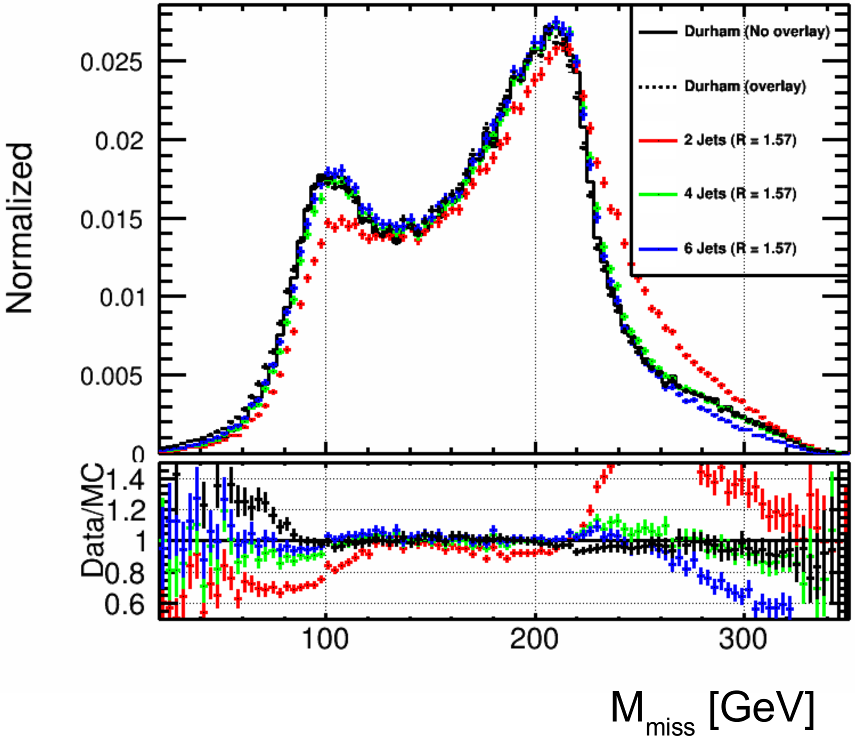
BR	bb	cc	gg	ττ	WW	ZZ	γγ	Zγ
previous study	65.7%	3.6%	5.5%	8.0%	15.0%	1.7%	0.3%	0.1%
new study	57.8%	2.7%	8.6%	6.4%	21.6%	2.7%	0.2%	0.2%

Reconstruction Strategy

- $\nu\nu h \rightarrow$ 2 Jets + Missing Mass
- $\gamma\gamma$-overlay removal
  - Low p_T $\gamma\gamma \rightarrow$ hadron background
  - Virtual photons get radiated off the primary beam e^-/e^+
  - Real photons from bremsstrahlung and syncrotron radiation
- Jet clustering and flavor tagging (LCFIPlus)
- Event selection with cut analysis and BDT
- Log Likelihood Template fit to the flavor likeness of the Higgs di-jets

γγ-Overlay Removal

- Overlaid background per event depends on beam energy :
  350 GeV → < $N_{\gamma\gamma}$ > = 0.33
- Exclusive k_t algorithm to remove overlay
- By tuning the number of jets and r parameter the overlay can be removed
- Kinematic variables are correctly reconstructed in the relevant energy regime
- Getting more important for higher beam energies (500 GeV → < $N_{\gamma\gamma}$ > = 1.7)



Binned Log Likelihood Template Fit

- Create 3D-Templates with b,c and bc likeness of the events
- LOI study used the fit function:

$$N_{ijk}^{Data} = \sum_{s=b,c,g,other} \frac{\sigma \cdot BR(h \rightarrow s)}{(\sigma \cdot BR(h \rightarrow s))^{SM}} \cdot N_{ijk}^{h \rightarrow s} + N_{ijk}^{bkg}$$

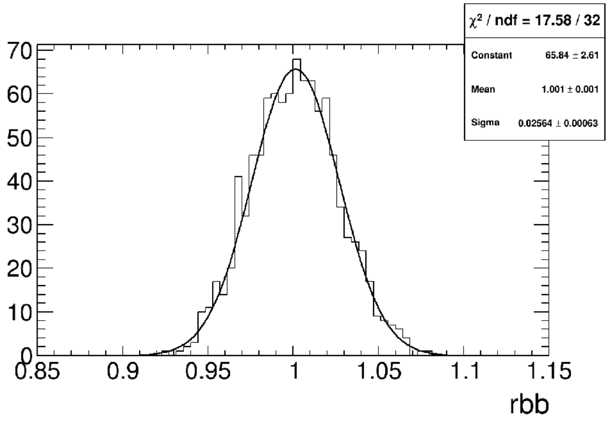
  with N_{ijk} the number of events in the bin ijk
- h → other was fixed
- σ includes Higgs Strahlung and WW-fusion
  - Disentangling both processes done by hand
- Binned log likelihood fit ignoring zero entry bins
  - Zero entry bins do contain information
  - Bias of the fit results

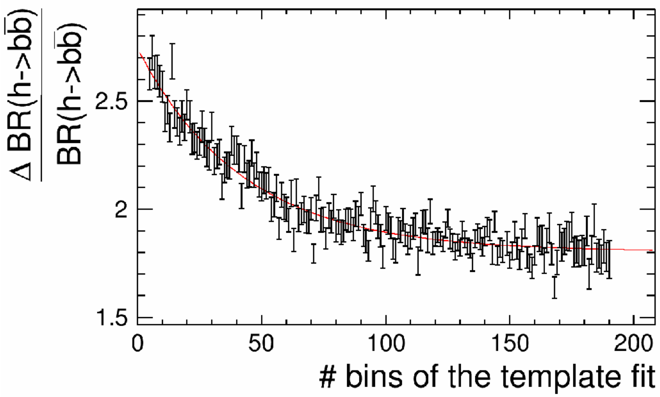
Improved Fit Function

- Assuming the knowledge of σ(Zh) from recoil measurements

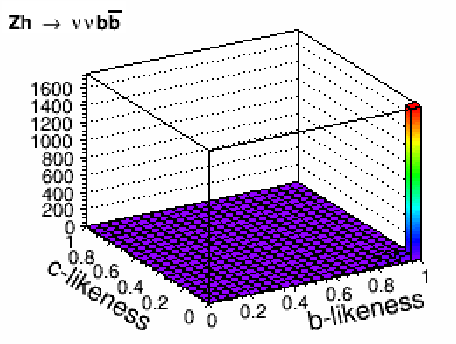
$$\frac{\sigma^{SM}(Zh)}{\sigma(Zh)} N_{ijk}^{Data} = \sum_{t=ZH,WWH} \sum_{s=b,c,g,other} \frac{\sigma^{SM}(Zh)}{\sigma(Zh)} \frac{\sigma(t)}{\sigma^{SM}(t)} \cdot \frac{BR(h\to s)}{BR^{SM}(h\to s)} \cdot N_{ijk}^{t\to s} + \frac{\sigma^{SM}(Zh)}{\sigma(Zh)} N_{ijk}^{bkg}$$

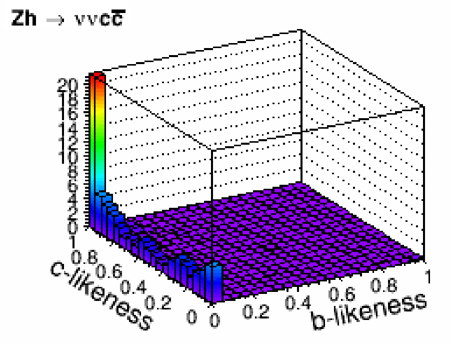
- One can fit the cross section ratio and the branching ratios directly
- Log likelihood fit which also takes zero bins into account
- Determination the error on the fit:
  - Fit 1000 toy MC samples from data
  - Study dependency on the binning (expect convergence)

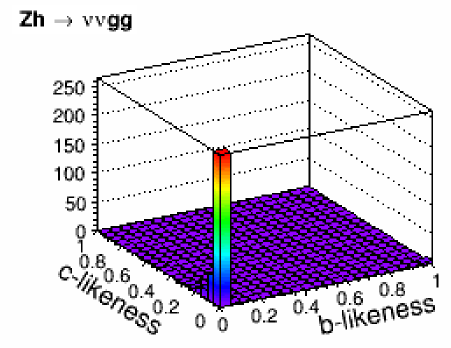


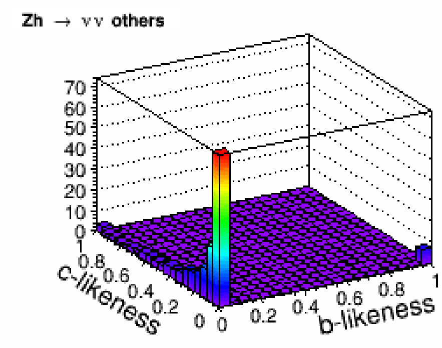


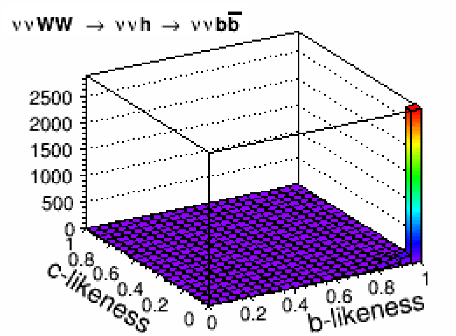
3D-Templates (Branching Ratio)

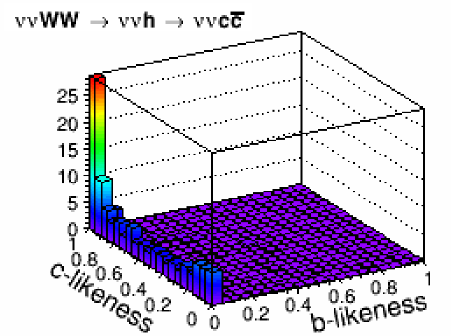


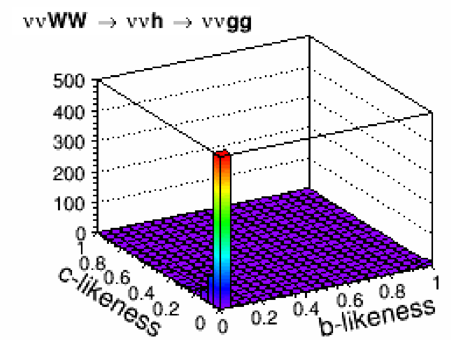


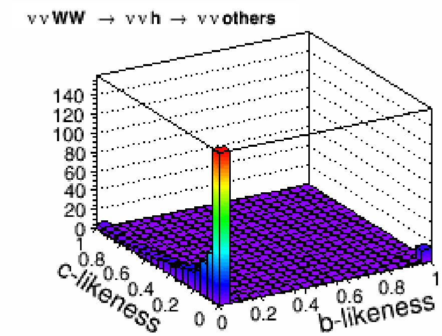


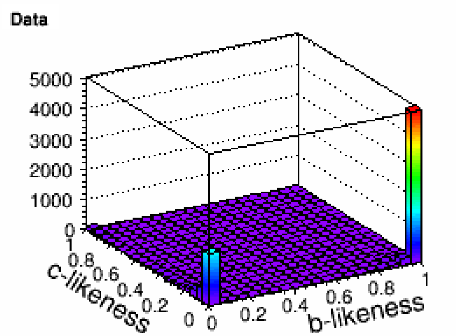


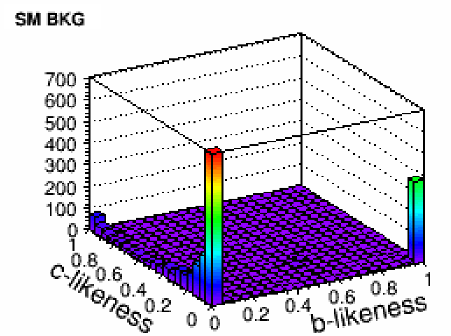




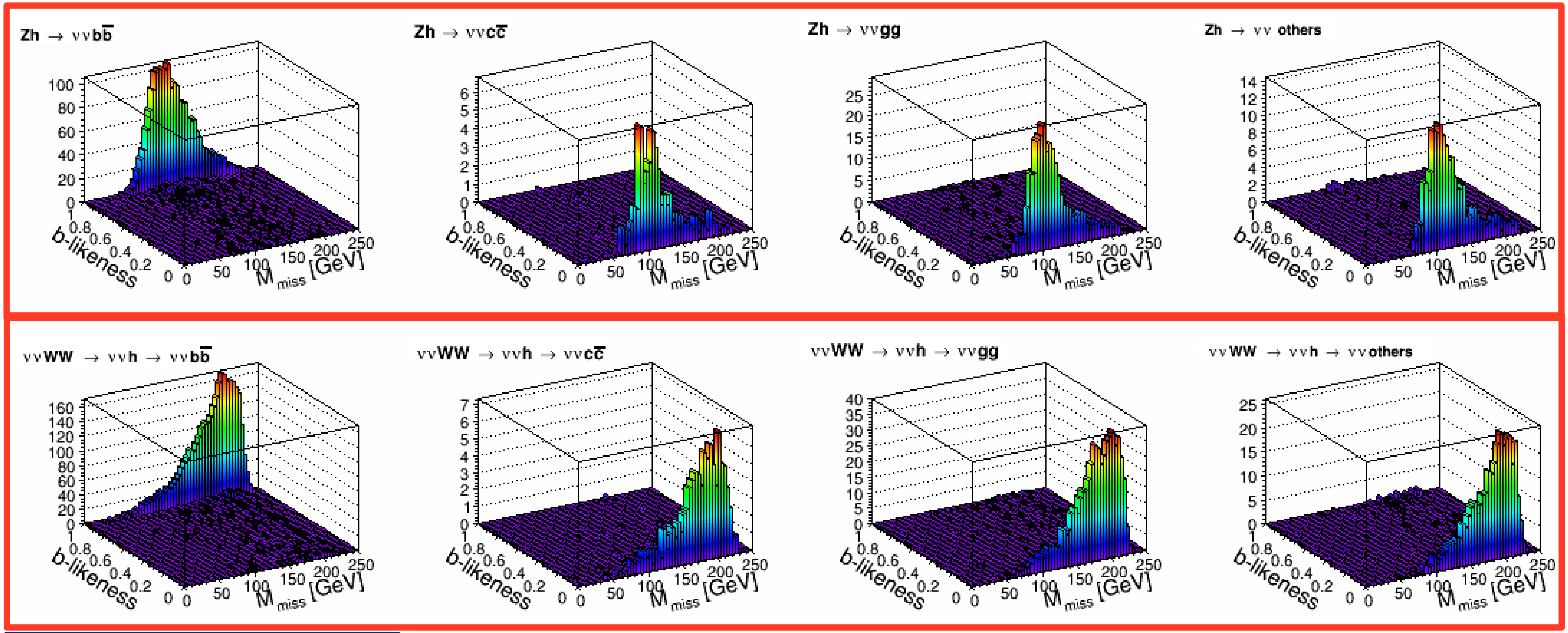


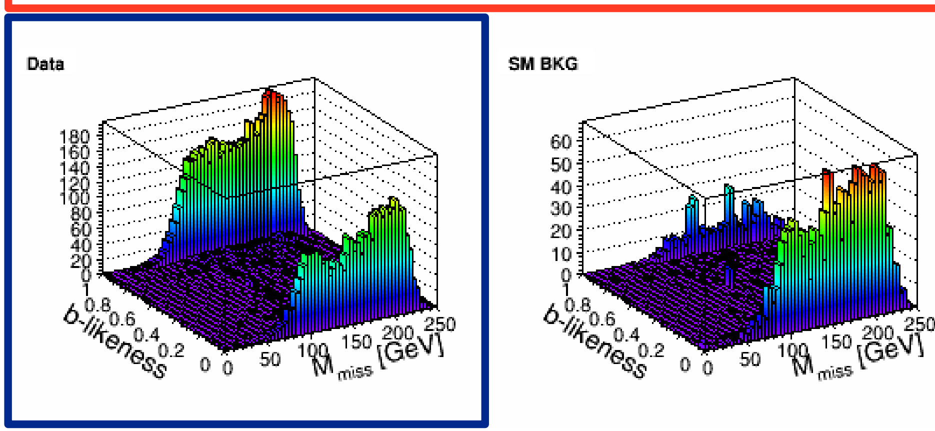






3D-Templates (Cross Section)



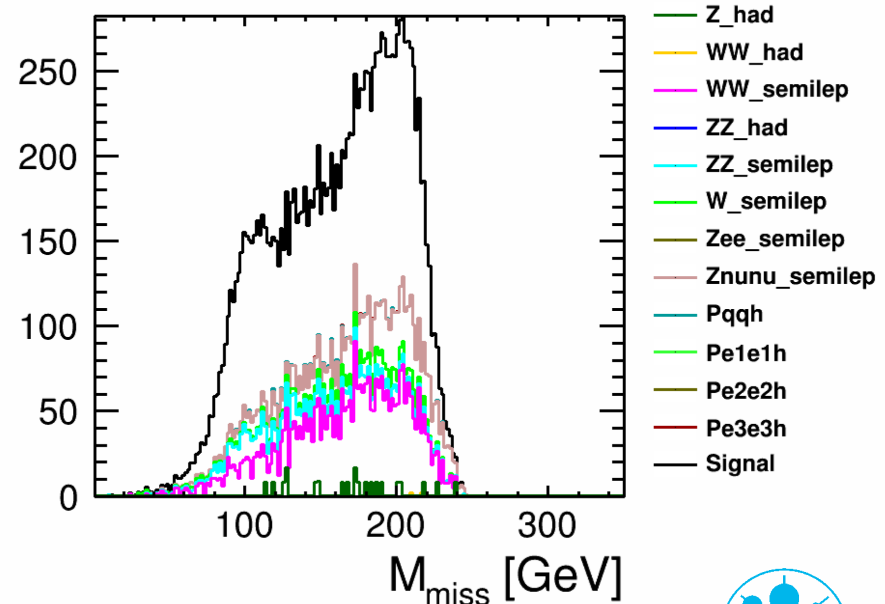


Results

- Using the LOI fit function the obtained results worsen with the additional free parameter of h → other
- No cut on the missing mass as this seems difficult in the final missing mass spectrum

→ assume knowledge of: $\sigma = e_{Zh} \cdot \sigma(Zh) + e_{WWh} \cdot \sigma(WWh)$

Realtive Error on	3 par. Fit [%]	4 par. Fit [%]
σ·BR(h->bb)	1.0	1.0
σ·BR(h->cc)	5.9	5.9
σ·BR(h->gg)	2.5	3.0
σ·BR(h->other)	-	3.9



Results

- With the new fit function, one directly receives the branching ratios
- Slightly worse performance expected due to a new free parameter, but we don't need to get the BR out of $\sigma \cdot BR$
- The error on $\sigma(Zh)$ is not yet included

Realtive Error on	%
BR (h->bb)	1.8
BR (h->cc)	6.0
BR (h->gg)	3.2
BR (h->other)	4.0
$\sigma(WWh)/\sigma(Zh)$	2.3

Combining Results

- Combining ννh with other final state analysis
- Extrapolated results from scaling signal and background with the effective cross sections with the current beam parameter and by using LHC recommended Higgs BR
- The fitting procedure was changed which improved the results compared to the extrapolated results

Updated results	250 GeV			350 GeV		
L(fb^{-1})	250 fb^{-1} P(-0.8,+0.3)			330 fb^{-1} P(-0.8,+0.3)		
ΔσBR/σBR	bb	cc	gg	bb	cc	gg
ννh (WW and ZH)	1.6%	14.8%	9.7%	1.1%	5.9%	2.5%
qqh (ZH)	1.6%	24.0%	18.4%	1.5%	15.0%	13.2%
eeh (ZH)	4.4%	57.4%	36.3%	6.5%	>100%	>100%
μμh (ZH)	3.4%	34.0%	22.3%	4.6%	65.7%	30.9%
Combined	1.0%	11.6%	7.8%	0.8%	5.5%	2.5%
Extrapolated	1.1%	8.0%	6.8%	0.9%	6.5%	5.2%

All ZH only studies performed by Hiroaki Ono

Summary and Outlook

- Higgs hadronic branching ratios were studied in the ννh final state for a 350 GeV ILC
- γγ-overlay not an issue for a center of mass energy of 350 GeV
- New method to extract the branching fractions and cross section ratio was introduced
  - More model independent

→ Qualitative and quantitative improvement of the existing analysis

- Incorporate in global Higgs coupling fit
- Exploit opposite polarization → different polarization dependence of the two signal processes

Backup

- Study was performed for the LOI with a 120 GeV Higgs

E_{cm} (GeV)	250	350	500
Lumi (fb^{-1})	250	250	500
M_H (GeV)	120	120	120
$\Delta\sigma_{BR}/\sigma_{BR}$ ($h\to bb$)	1.0%	1.0%	0.57%
$\Delta\sigma_{BR}/\sigma_{BR}$ ($h\to cc$)	6.9%	6.2%	5.2%
$\Delta\sigma_{BR}/\sigma_{BR}$ ($h\to gg$)	8.5%	7.3%	5.0%

- Extrapolate results by scaling signal and background with the effective cross sections with the current beam parameter and by using LHC recommended Higgs BR

E_{cm} (GeV)	250	350	500
Lumi (fb^{-1})	250	330	500
M_H (GeV)	125	125	125
$\Delta\sigma_{BR}/\sigma_{BR}$ ($h\to bb$)	1.1%	0.9%	0.66%
$\Delta\sigma_{BR}/\sigma_{BR}$ ($h\to cc$)	8.0%	6.5%	6.2%
$\Delta\sigma_{BR}/\sigma_{BR}$ ($h\to gg$)	6.8%	5.2%	4.1%

Jet Clustering and Flavor Tagging

- Decluster the 4 Jets from the γγ-overlay and cluster the particles into 2 jets using Durham algorithm
- Determine the flavor tag from LCFIPlus
- Evaluate flavor likeness X_i of the event (i=b,c,bc)

$$X_i = \frac{x_{i1} x_{i2}}{x_{i1} x_{i2} + (1 - x_{i1})(1 - x_{i2})}$$

with x_i the flavor tag of the single jets

- LOI study: LCFIVertex → bc-tag = c-tag trained with b-jets as background only
- TDR study: LCFIPlus → $x_{bc} = \frac{x_c}{x_c + x_b}$

Cut Optimization

- Cuts optimized for significance and for equal sensitivity to Higgs strahlung and WW fusion (~39% signal left for both processes)
- BDT variables:
  - All cut parameters, Longitudinal momentum, global cos(Θ), thrust, thrust axis, jet masses, jet momenta, jet angles

	condition	BG	Signal	Signf
Expected		19856532.5	32555.3	7.3
isolated leptons	#iso lep = 0	16605973.9	28922.8	7.0
Transverse P	$240 > P_{t,vis} > 30$	1171943.3	24423.1	22.3
Visible Mass	$135 > m_{vis}$	366041.9	23242.9	37.2
Angle between jets	0.27 > cos a	194536.1	21636.8	46.5
# tracks > 1GeV	$N_{chd} > 26$	58945.0	14903.7	54.8
max. jet mass	$135 > M_{j,max} > 40$	34911.1	13375.9	60.9
Durham minus	$Y_{12} > 0.05$	32837.3	13318.7	62.0
BDT	BDT > -0.02	3103.2	10478.6	89.9

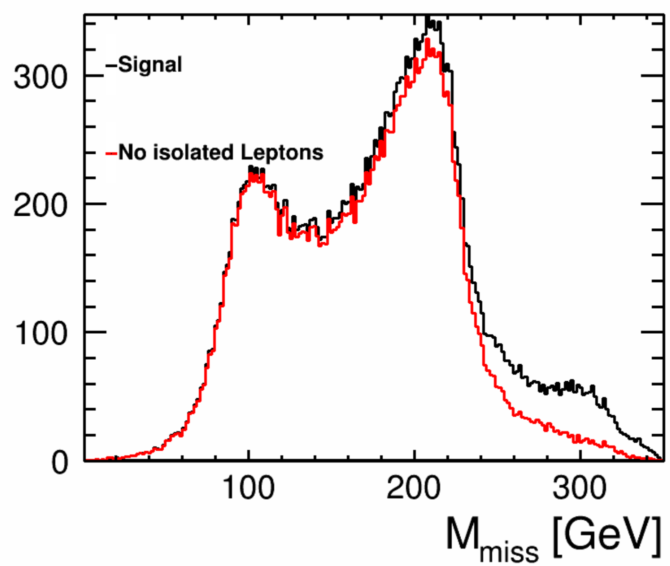
LOI Study		11092.0	9543.0	66.4

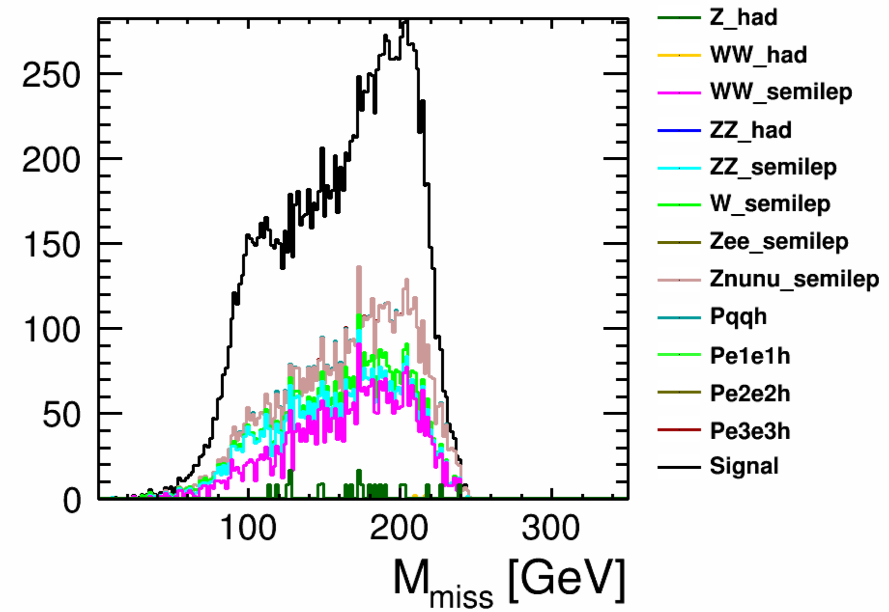
Fit Function

$$
\begin{aligned}
\frac{\sigma^{SM}(ZH)}{\sigma(ZH)} N^{Data}_{ijk} = & \frac{BR(h\rightarrow bb)}{BR^{SM}(h\rightarrow bb)} \cdot N^{Zh\rightarrow bb}_{ijk} \\
& + \frac{BR(h\rightarrow cc)}{BR^{SM}(h\rightarrow cc)} \cdot N^{Zh\rightarrow cc}_{ijk} \text{¿} \\
& + \frac{BR(h\rightarrow gg)}{BR^{SM}(h\rightarrow gg)} \cdot N^{Zh\rightarrow gg}_{ijk} \\
& + \frac{BR(h\rightarrow oth)}{BR^{SM}(h\rightarrow oth)} \cdot N^{Zh\rightarrow oth}_{ijk} \\
& + \frac{\sigma^{SM}(ZH)}{\sigma(ZH)} \frac{\sigma(WWH)}{\sigma^{SM}(WWH)} \cdot \frac{BR(h\rightarrow bb)}{BR^{SM}(h\rightarrow bb)} \cdot N^{WWh\rightarrow bb}_{ijk} \\
& + \frac{\sigma^{SM}(ZH)}{\sigma(ZH)} \frac{\sigma(WWH)}{\sigma^{SM}(WWH)} \cdot \frac{BR(h\rightarrow cc)}{BR^{SM}(h\rightarrow cc)} \cdot N^{WWh\rightarrow cc}_{ijk} \\
& + \frac{\sigma^{SM}(ZH)}{\sigma(ZH)} \frac{\sigma(WWH)}{\sigma^{SM}(WWH)} \cdot \frac{BR(h\rightarrow gg)}{BR^{SM}(h\rightarrow gg)} \cdot N^{WWh\rightarrow gg}_{ijk} \\
& + \frac{\sigma^{SM}(ZH)}{\sigma(ZH)} \frac{\sigma(WWH)}{\sigma^{SM}(WWH)} \cdot \frac{BR(h\rightarrow oth)}{BR^{SM}(h\rightarrow oth)} \cdot N^{WWh\rightarrow oth}_{ijk} \\
& + \frac{\sigma^{SM}(ZH)}{\sigma(ZH)} N^{bkg}_{ijk}
\end{aligned}
$$

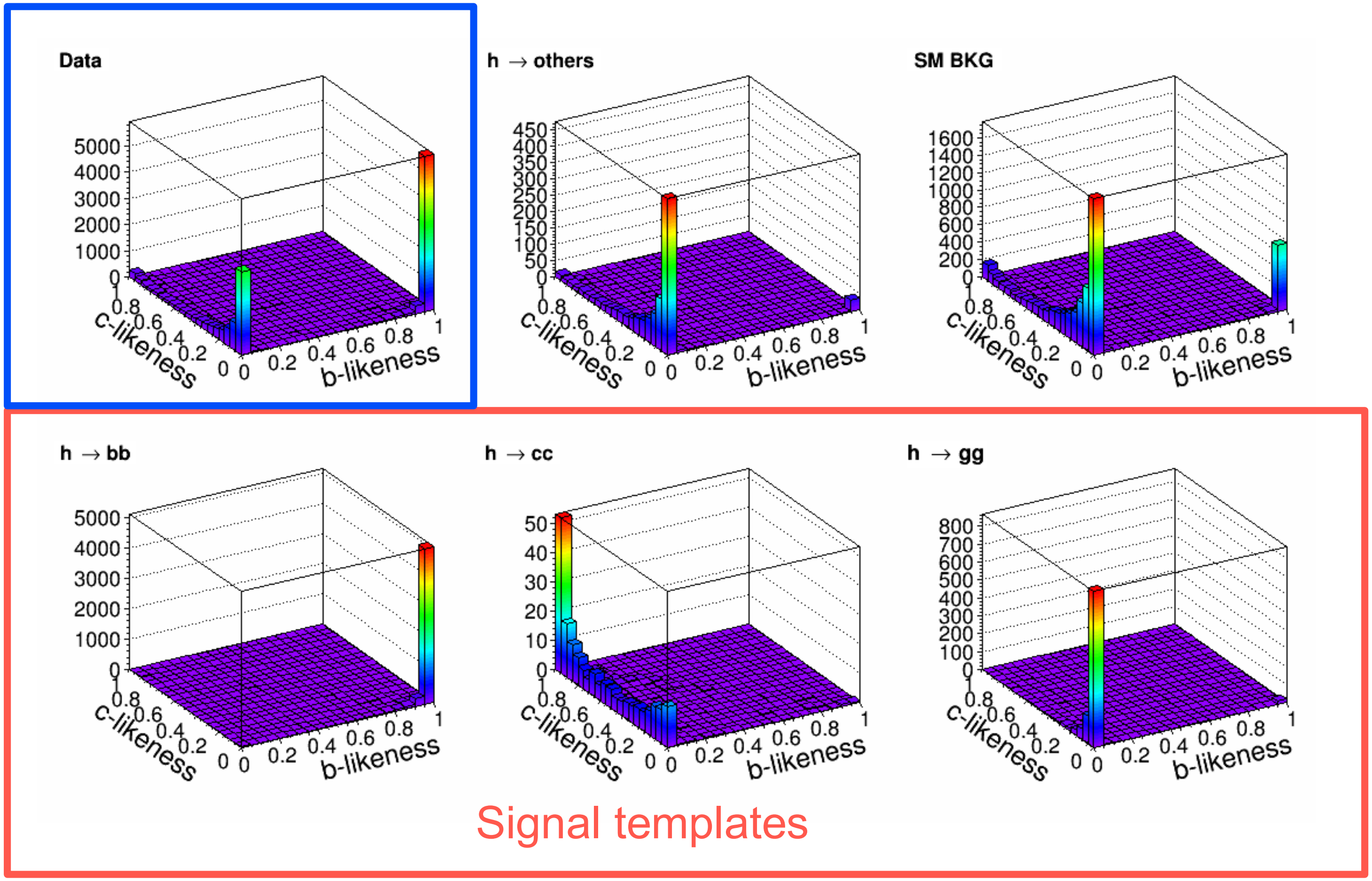
Event Preselection

- The expected behavior is visible in the missing mass distribution
  - A peak at the Z mass from the Higgs strahlung events
  - A sharp cutoff at 350 GeV- M_H from the WW fusion events
- Access in the missing mass distribution above 250 GeV
- The access in the missing mass distribution comes from $H \rightarrow WW, \tau\tau$
  - Leptonic decays cause the problem
  - Use Isolated lepton finder to remove these events



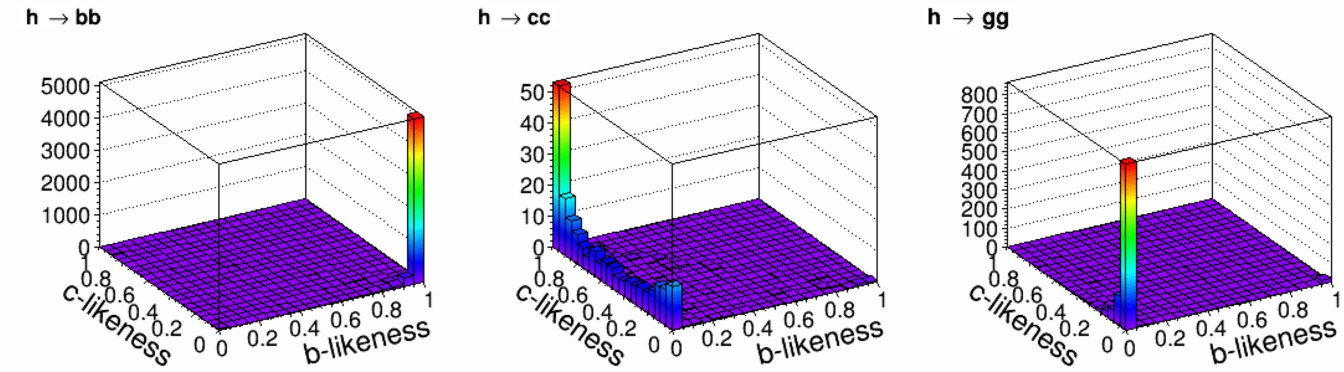


Old 3-D Template Fit

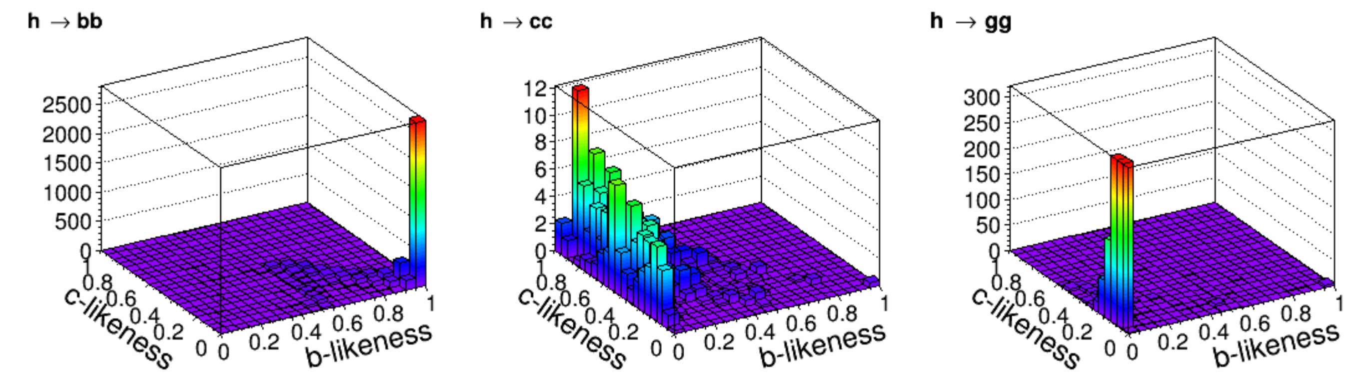


Different Flavor Likeness Definitions

$$\frac{x_{i1}x_{i2}}{x_{i1}x_{i2}+(1-x_{i1})(1-x_{i2})}$$



$$\frac{x_{i1}+x_{i2}}{2}$$



Simple mean tag value gives better results than the standard likeness definition

h->	Standard likeness	$(x_1+x_2)/2$
bb	1.148+-0.013	1.135+-0.013
cc	15.35+-0.16	14.56+-0.16
gg	4.758+-0.052	4.694+-0.049