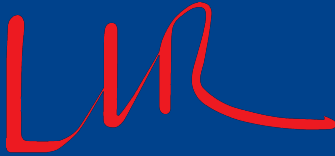




INSTITUT
POLYTECHNIQUE
DE PARIS



A COMBINED FIT TO THE HIGGS BRANCHING RATIOS AT ILD

Higgs 2021

RECAP (1/2) : SETUP

ILD full simulation study @ILC250.

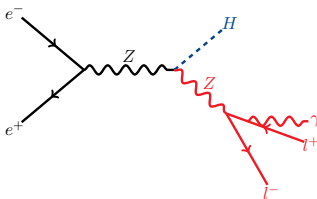
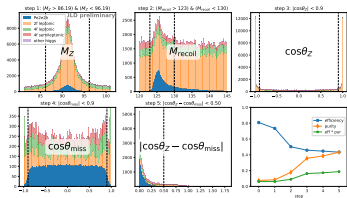
RECAP



Event selection

$Z \rightarrow \mu^+ \mu^-, e^+ e^-$. Cut-based.

All Higgs decays, only uses the Z.

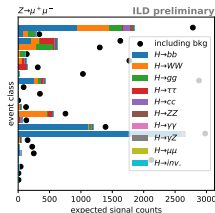


Higgs classes

Handcrafted. E.g. ($btag1 > 0.9$) & ($btag2 > 0.9$) & (no IsoLepton).

Higgs BRs

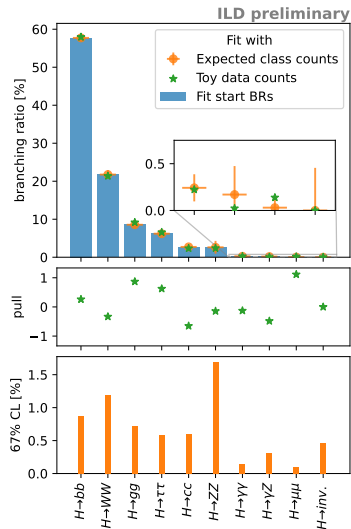
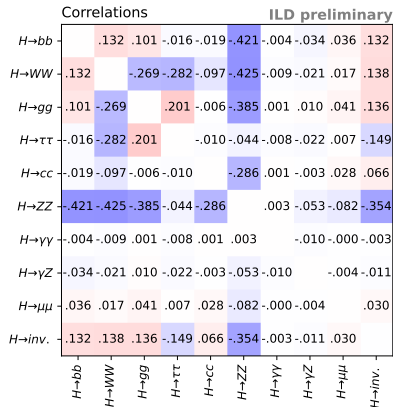
Obtain \mathcal{B} and correlations from fit.
 Matrix from large MC samples per Higgs decay and background.



$$\text{Matrix} = \text{Matrix} \times \mathcal{B}$$

RECAP (2/2) : RESULTS

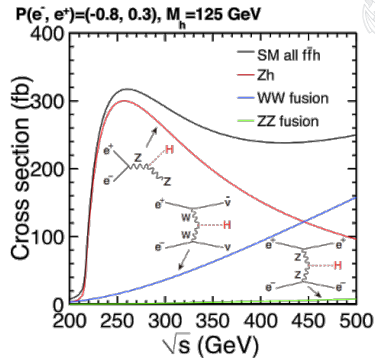
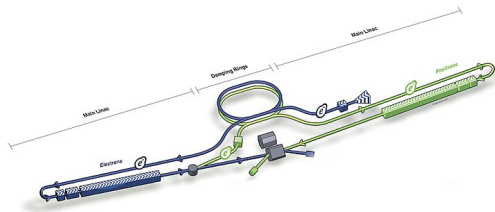
RECAP



THE INTERNATIONAL LINEAR COLLIDER (ILC)



- Linear e^+e^- collider.
- Polarized beams.
- Initial stage $\sqrt{s} = 250$ GeV (considered here).
- Upgradable (350 GeV, 500 GeV, 1 TeV).



ILC Technical Design Report (2013)

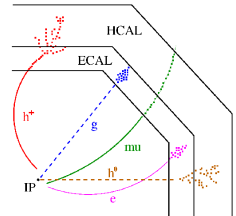
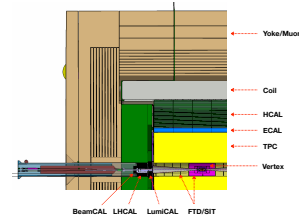
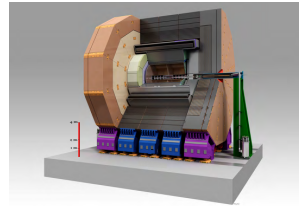
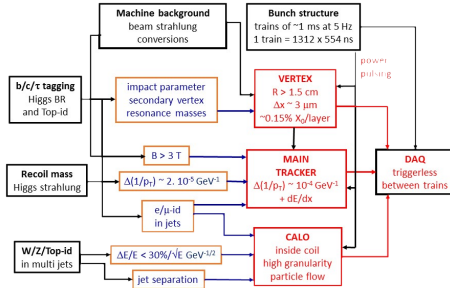
The International Linear Collider : A Global Project : [arXiv:1903.01629](https://arxiv.org/abs/1903.01629)

Jonas Kunath – Combined Higgs fit

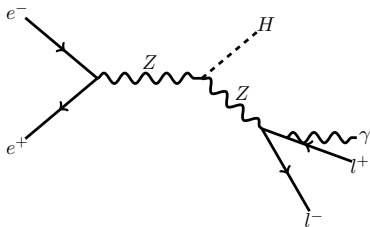
THE INTERNATIONAL LARGE DETECTOR (ILD)



Based on the Particle Flow approach.



Interim Design Report : [arXiv:2003.01116](https://arxiv.org/abs/2003.01116)



- $Z \rightarrow \mu^+ \mu^-, Z \rightarrow e^+ e^-$:
 - IsolatedLeptonTagger :
Lepton pair with same type and opposite charge.
 - Final state radiation :
Add photons with $\cos\theta_{l\gamma} > 0.99$.

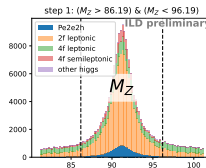
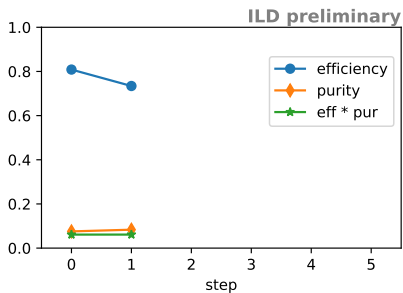
Golden channels due to recoil mass method,
 $M_{\text{recoil}}^2 = s + M_Z^2 - 2\sqrt{s} \cdot E_Z$.

- Higgs :
Event selection that keeps events with all Higgs decays.

EVENT SELECTION



Selection only on information from decay of the primary Z boson.

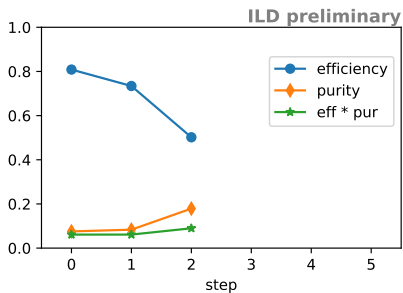


Step 0 : Find a lepton pair.

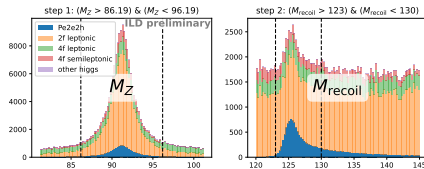
EVENT SELECTION



Selection only on information from decay of the primary Z boson.



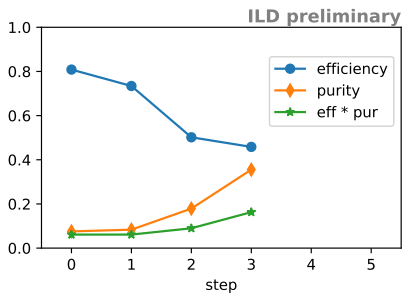
Step 0 : Find a lepton pair.



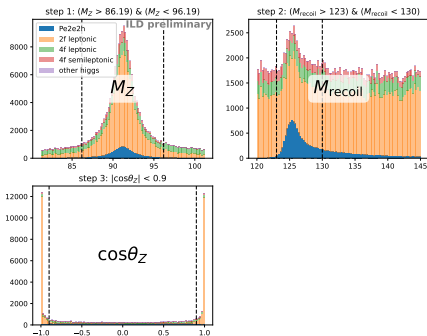
EVENT SELECTION



Selection only on information from decay of the primary Z boson.



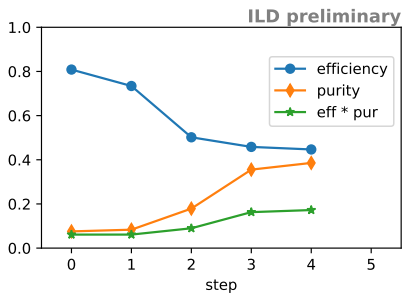
Step 0 : Find a lepton pair.



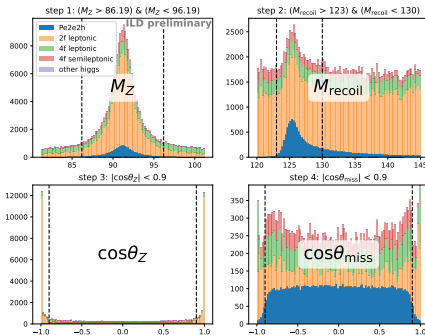
EVENT SELECTION



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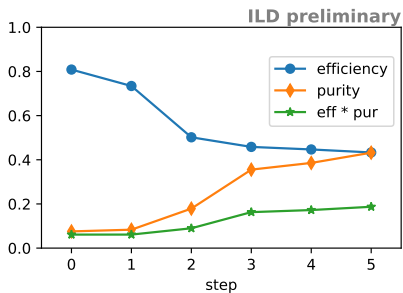
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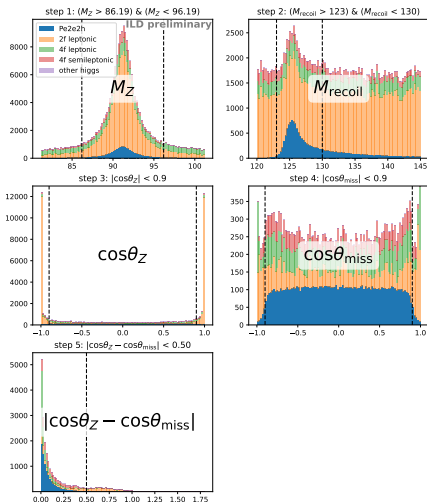
EVENT SELECTION



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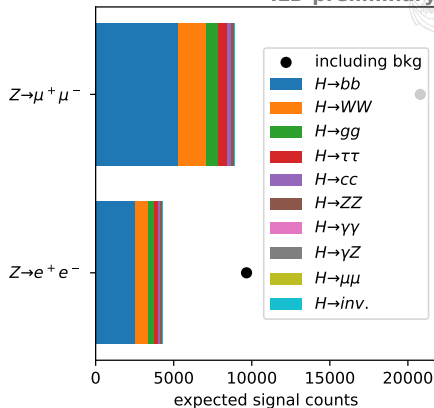
HIGGS-BRS ALL-IN-ONE

IDEA



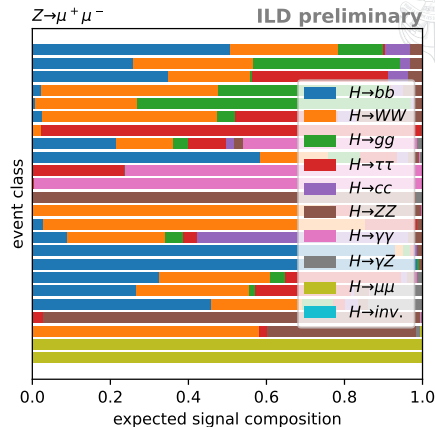
ILD preliminary

1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \rightarrow (e^+e^-, \mu^+\mu^-)$).
2. Construct categories to separate the decay modes (& background) as well as possible.
3. Fit the Higgs branching ratios to the observed category counts.



HIGGS-BRS ALL-IN-ONE

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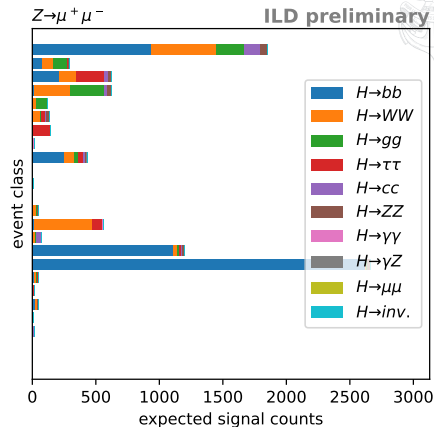


HIGGS-BRS ALL-IN-ONE

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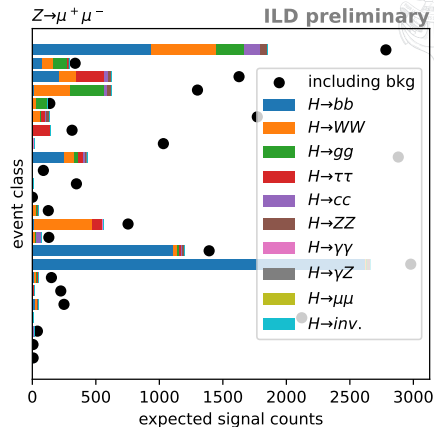


HIGGS-BRS ALL-IN-ONE

IDEA



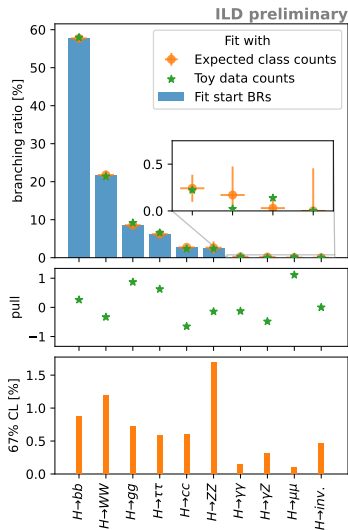
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HIGGS-BRS ALL-IN-ONE



1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \rightarrow (e^+e^-, \mu^+\mu^-)$).
2. Construct categories to separate the decay modes (& background) as well as possible.
3. Fit the Higgs branching ratios to the observed category counts.



IMPLEMENTATION WITHIN ILC



Reconstructed events from $\sqrt{s} = 250$ GeV MC2020 ILD mass production.

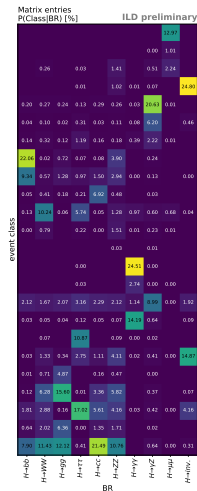
- $\sqrt{s} = 250$ GeV ideal for the Higgsstrahlung process.
 - $Z \rightarrow e^+e^-$ and $Z \rightarrow \mu^+\mu^-$ as signal channels.
 - $\geq 400k$ simulated events/Standard Model decay mode.
- Considered backgrounds : Standard model processes with 2 or 4 fermions in the final state.
- Polarized initial beams :
 - 80% left polarized electron beam.
 - 30% right polarized positron beam.
- 2000 fb^{-1} integrated luminosity.

OPTIMIZATION - SETUP



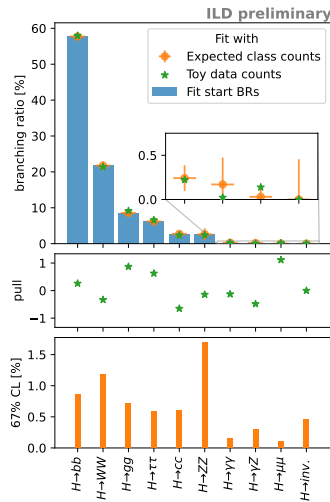
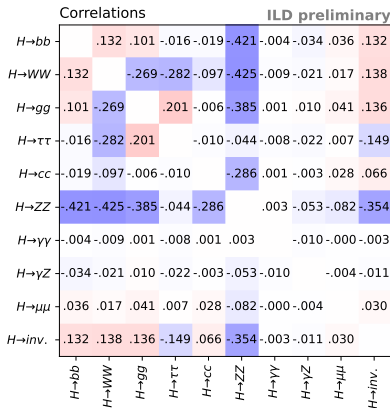
BRs from minimization through MINUIT/*iminuit*.

- MC2 : Will be replaced by the detector data.
- $\vec{S} = M \cdot \vec{B} = \vec{f}(\vec{B})$, with
 - \vec{S} : The signal counts per category ($S = data - bkg$). MC2.
 - M : The matrix built from simulated events, as outlined above. MC1.
 - \vec{B} : The target. Use e.g. the Standard Model BRs as fit starting values.
- The cost function : Multinomial log-likelihood.
 - $-\ln\mathcal{L} = -N_{\text{data}} \sum_i S_i \ln \left(\sum_j M_{ij} B_j \right)$.
 - $B_{H \rightarrow ZZ^*} = 1 - \sum_{i \neq H \rightarrow ZZ^*} B_i$.



OPTIMIZATION - RESULTS

The fitted BR^{\min} reproduces BR^{true} within its uncertainties. $\sigma_{B_{H \rightarrow ZZ^*}}$ through uncertainty propagation.

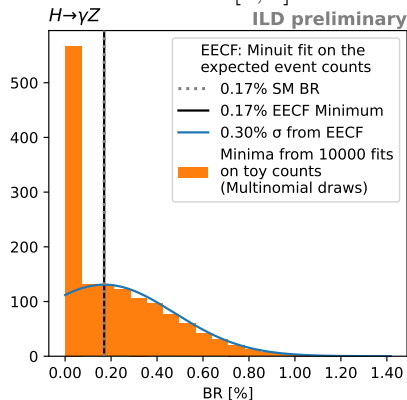
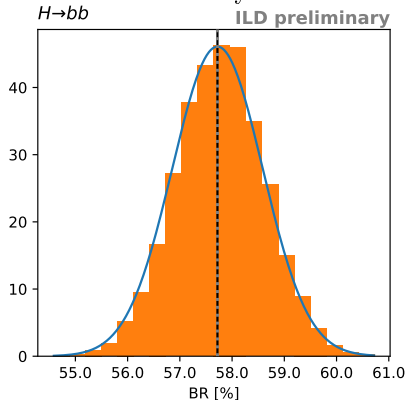


OPTIMIZATION - VALIDITY CHECK



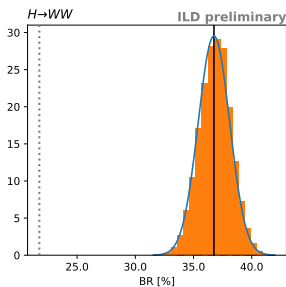
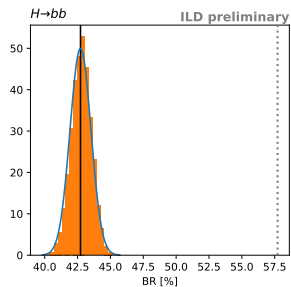
Toy study : Draw from multinomial (N_{data} fixed).

Shown : 2 of the toy fit distributions for multinomial $\ln\mathcal{L}$ with $[0, 1]$ boundaries.



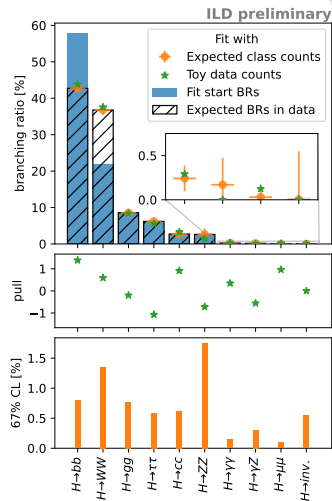
FIT IN A NON-SM SCENARIO

FIT



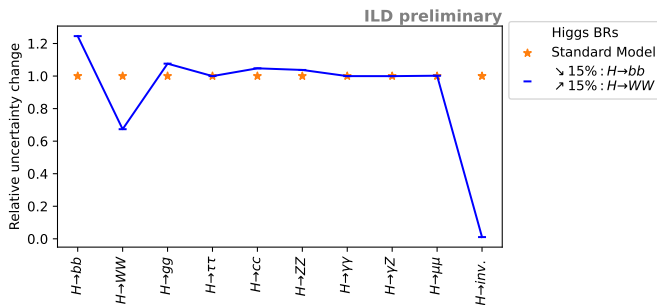
Assume $57.7\% \rightarrow 42.7\%$ $BR(H \rightarrow b\bar{b})$,
 $21.8\% \rightarrow 36.8\%$ $BR(H \rightarrow W^+W^-)$.

Jonas Kunath – Combined Higgs fit



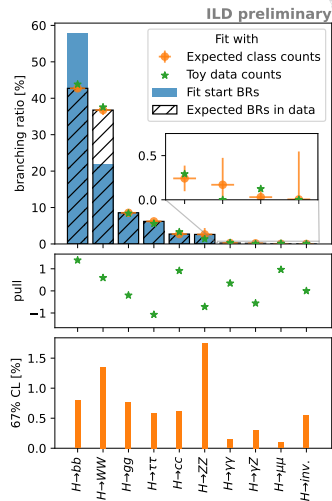
FIT IN A NON-SM SCENARIO

FIT



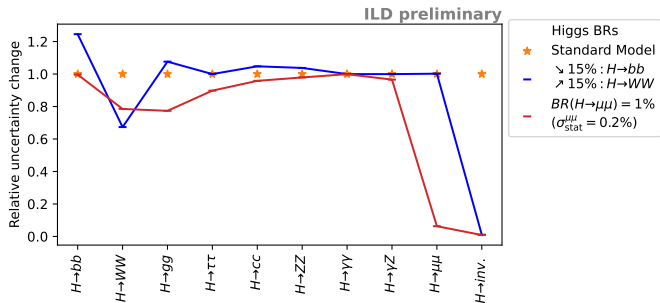
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Jonas Kunath – Combined Higgs fit



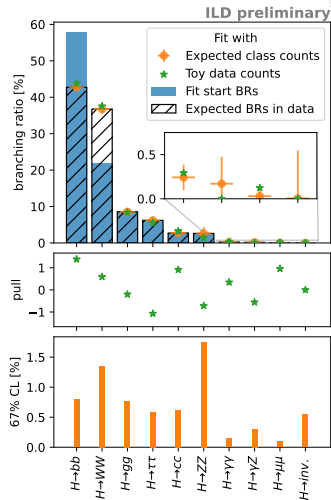
FIT IN A NON-SM SCENARIO

FIT



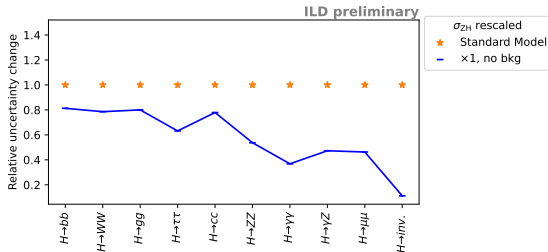
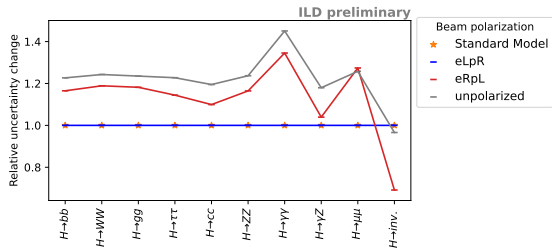
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Jonas Kunath – Combined Higgs fit



POLARIZATION AND BACKGROUND LEVEL

FIT



POLARIZATION AND BACKGROUND LEVEL

FIT

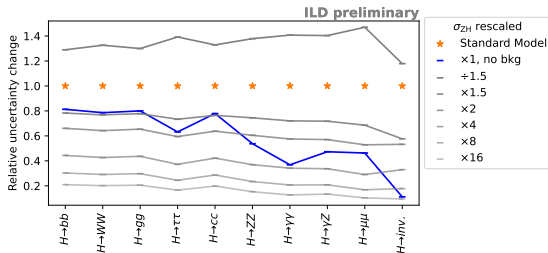
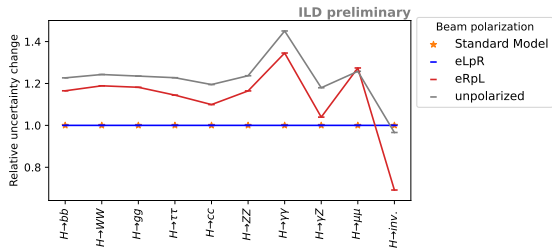


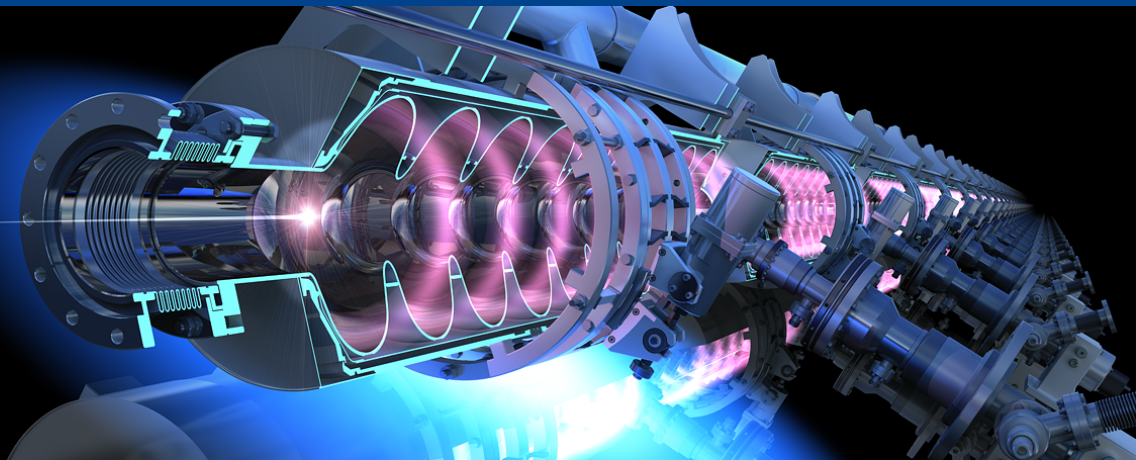


TABLE – Results of a fit on the expected event counts. In percent. ILD preliminary.

	SM BR	σ_{stat}
$H \rightarrow bb$	57.72	0.87
$H \rightarrow WW$	21.76	1.19
$H \rightarrow gg$	8.55	0.71
$H \rightarrow \tau\tau$	6.20	0.59
$H \rightarrow cc$	2.72	0.60
$H \rightarrow ZZ$	2.62	1.69
$H \rightarrow \gamma\gamma$	0.24	0.15
$H \rightarrow \gamma Z$	0.17	0.30
$H \rightarrow \mu\mu$	0.03	0.10
$H \rightarrow inv.$	0.00	0.46

- More work needed :
 - Better categories.
 - Exotic Higgs decays.
- + Extraction of major branching ratios from single analysis.
 - Correlation matrix.
- + Independent of σ_{ZH} and $\sigma_{VV\text{-fusion}}$.
- + Can automatically adapt to BR scenarios drastically different from SM.

8 BACK-UP



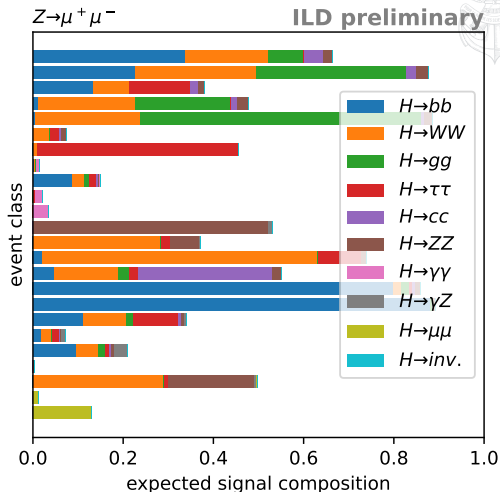
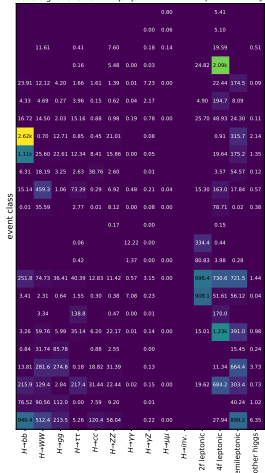
EXPECTED COUNTS PER (CATEGORY, BR) PAIR

BACK-UP



SM event distribution
8923 signal events in $Z \rightarrow \mu^+ \mu^-$

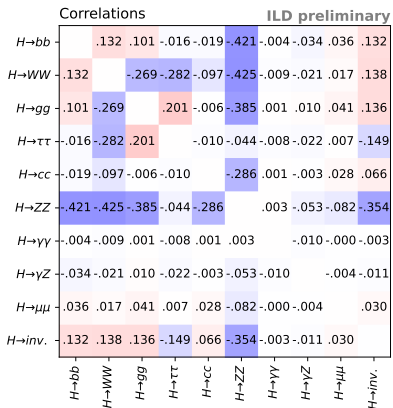
ILD preliminary



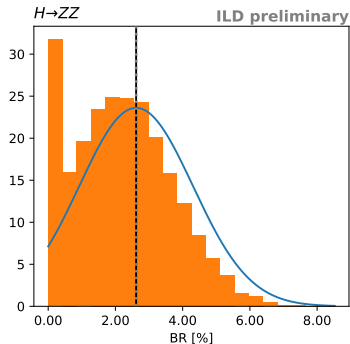
BR CORRELATIONS WITH THE CURRENT CATEGORIES

BACK-UP

Higher correlations motivate improvements in the category definition. Needed to include the results in a global fit. Also needed for the last BR :



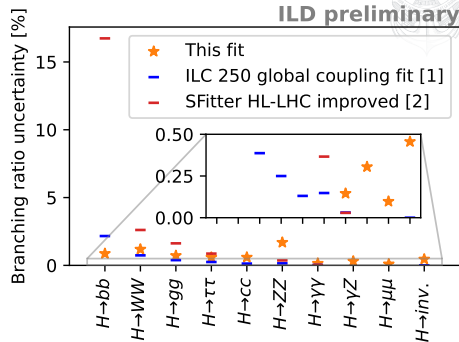
$$B_{ZZ^*} = 1 - \sum_{i \neq ZZ^*} B_i \Rightarrow \sigma_{ZZ^*}^2 = \sum_{i \neq ZZ^*} \sum_{j \neq ZZ^*} \rho_{ij} \sigma_i \sigma_j$$



COMPARISON WITH GLOBAL COUPLING FITS

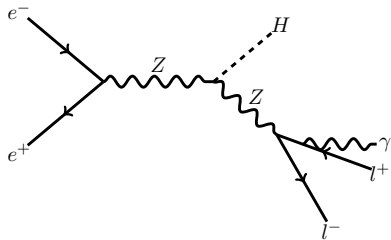


- [1], [2] use existing analyses and combine them to extract a combined sensitivity for the Higgs boson couplings.
- [1] scaled to the H-20 ILC250 scenario.
- *This fit* is our approach.
 - A single analysis directly fitting the branching ratios to data.
 - So far only $Z \rightarrow e^+e^-$, $Z \rightarrow \mu^+\mu^-$.
 - Only statistical uncertainty.



[1] J. Tian, K. Fujii *Measurement of Higgs boson couplings at the International Linear Collider*.

[2] SFitter *Measuring Higgs Couplings at a Linear Collider*.



- $Z \rightarrow \mu^+ \mu^-, Z \rightarrow e^+ e^-$:

Golden channels due to recoil mass method,

$$M_{\text{recoil}}^2 = s + M_Z^2 - 2\sqrt{s} \cdot E_Z.$$

- $Z \rightarrow \tau^+ \tau^-$:

Event tagging on the τ is complicated.

- Large τ decay opening angle (low E_τ).
- Diverse environment from the Higgs decay.

- $Z \rightarrow \nu \bar{\nu}$:

- Significant WW-fusion contribution in $\nu \bar{\nu} H$.
- Cannot tag event on ν .
- + Only Higgs boson (and beam overlay) in event.
- + $6\times$ higher cross section.

- $Z \rightarrow q \bar{q}$:

- + Highest cross section.
- Hard to identify the traces from the Z decay without making assumptions on the Higgs decay.