



# A COMBINED FIT TO THE HIGGS BRANCHING RATIOS AT ILD

Higgs 2021

# RECAP (1/2) : SETUP

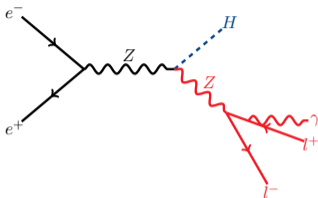
ILD full simulation study @ILC250.

RECAP



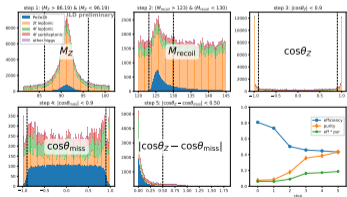
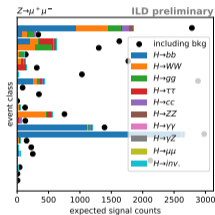
## Event selection

$Z \rightarrow \mu^+ \mu^-, e^+ e^-$ . Cut-based.  
All Higgs decays, only uses the Z.



## Higgs classes

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

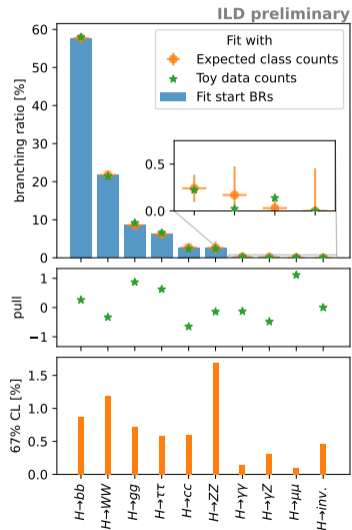
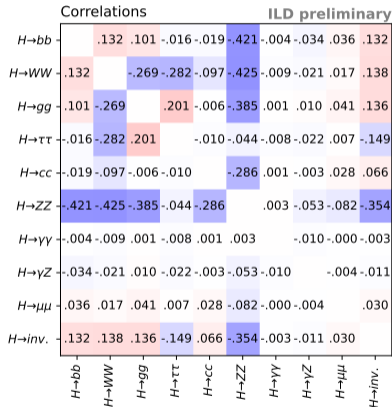


## Higgs BRs

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

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

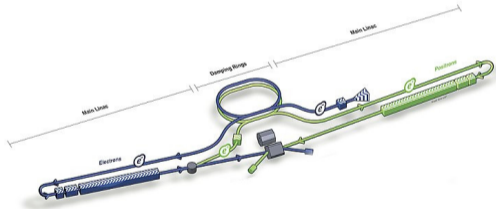
# RECAP (2/2) : RESULTS



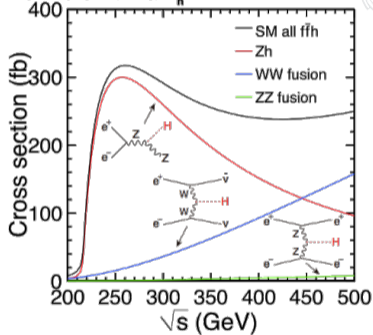
# THE INTERNATIONAL LINEAR COLLIDER (ILC)



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



$P(e^+, e^-) = (-0.8, 0.3)$ ,  $M_h = 125$  GeV



ILC Technical Design Report (2013)

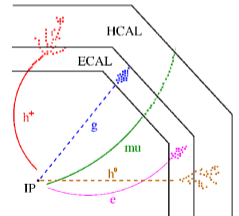
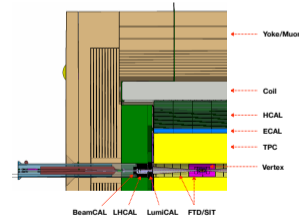
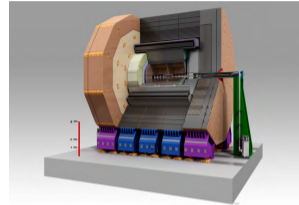
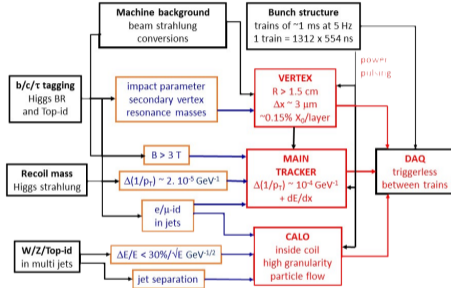
The International Linear Collider : A Global Project : [arXiv:1903.01629](https://arxiv.org/abs/1903.01629)

Jonas Kunath – Combined Higgs fit

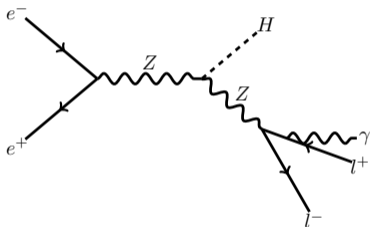
# THE INTERNATIONAL LARGE DETECTOR (ILD)



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  $\cos\theta_{l\gamma} > 0.99$ .

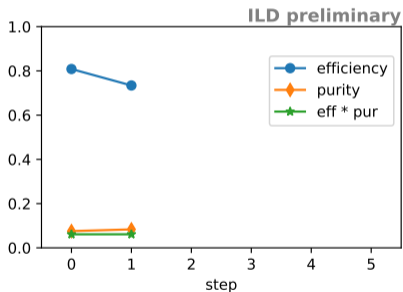
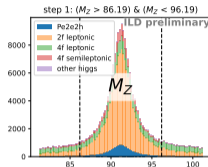
Golden channels due to recoil mass method,  
 $M_{\text{recoil}}^2 = s + M_Z^2 - 2\sqrt{s} \cdot E_Z$ .

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

# EVENT SELECTION



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

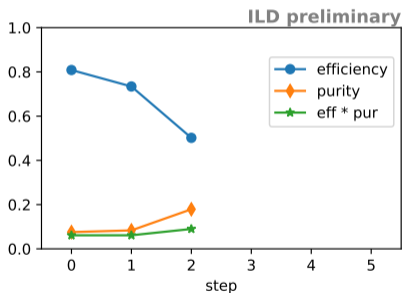
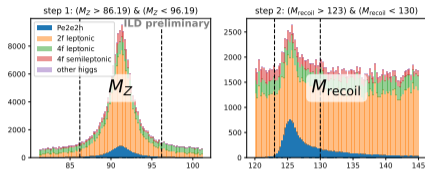


Step 0 : Find a lepton pair.

# EVENT SELECTION



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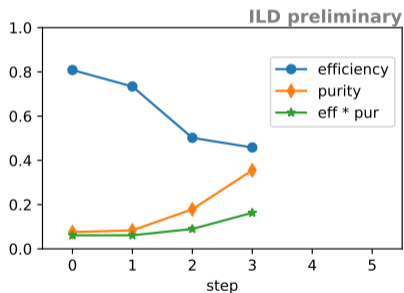
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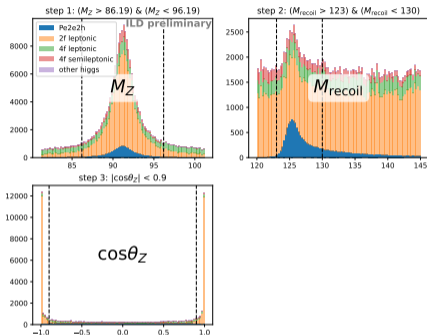
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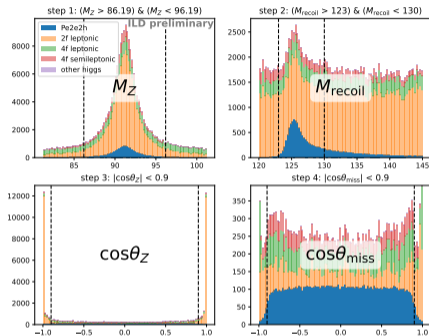
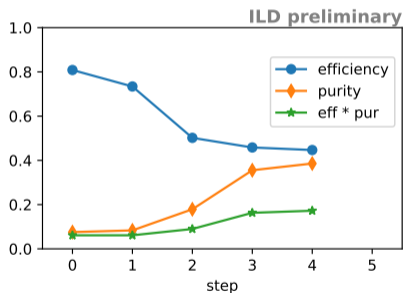
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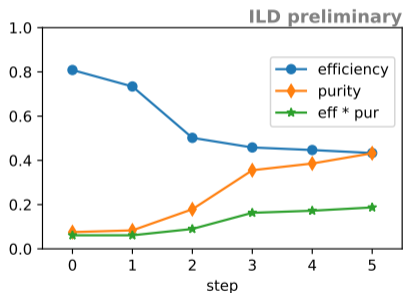


Step 0 : Find a lepton pair.

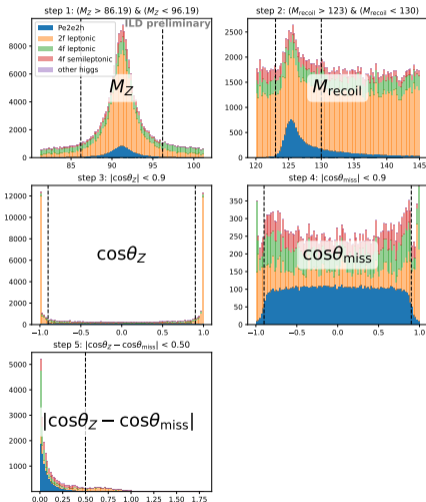
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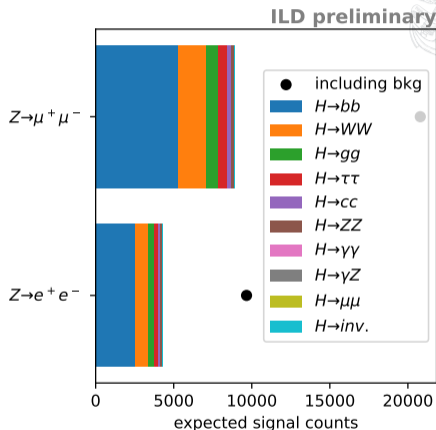
Step 0 : Find a lepton pair.



# HIGGS-BRS ALL-IN-ONE



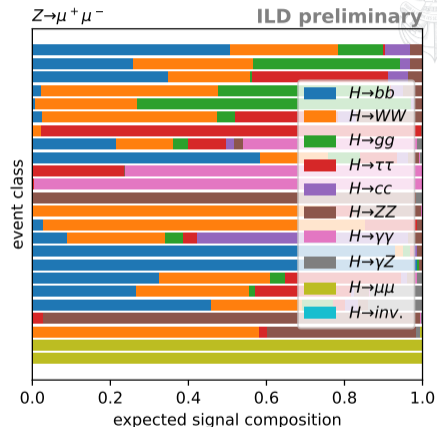
1. Build samples with all Higgs decay modes (Higgsstrahlung,  $Z \rightarrow (e^+e^-, \mu^+\mu^-)$ ).
2. Construct categories to separate the decay modes (& background) as well as possible.
3. Fit the Higgs branching ratios to the observed category counts.



# HIGGS-BRS ALL-IN-ONE



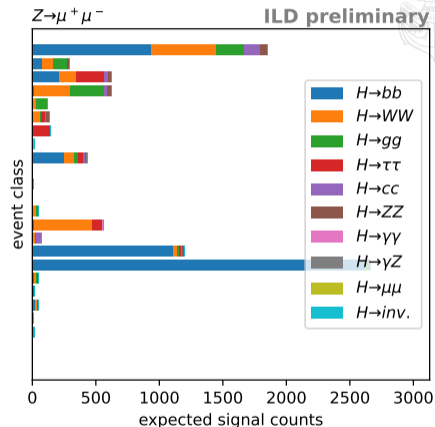
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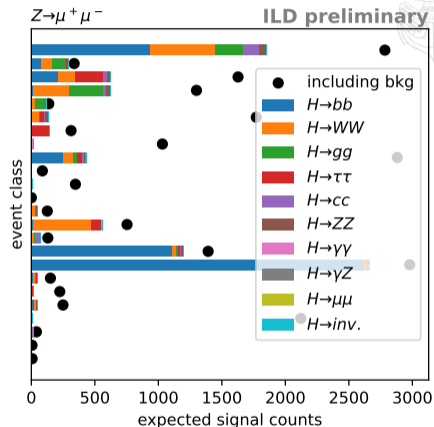
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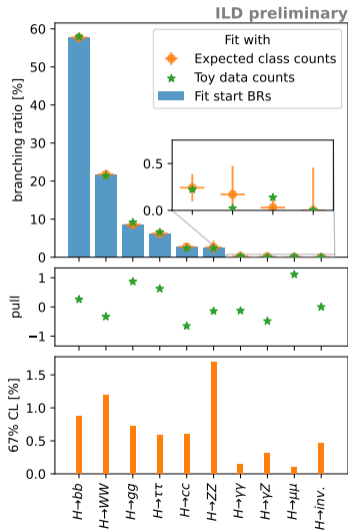


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# IMPLEMENTATION WITHIN ILC



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

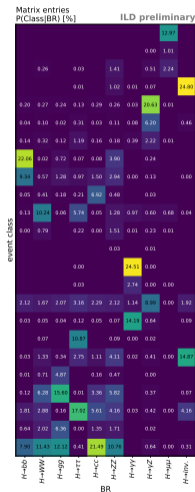
- $\sqrt{s} = 250$  GeV ideal for the Higgsstrahlung process.
  - $Z \rightarrow e^+e^-$  and  $Z \rightarrow \mu^+\mu^-$  as signal channels.
  - $\geq 400k$  simulated events/Standard Model decay mode.
- Considered backgrounds : Standard model processes with 2 or 4 fermions in the final state.
- Polarized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

# OPTIMIZATION - SETUP



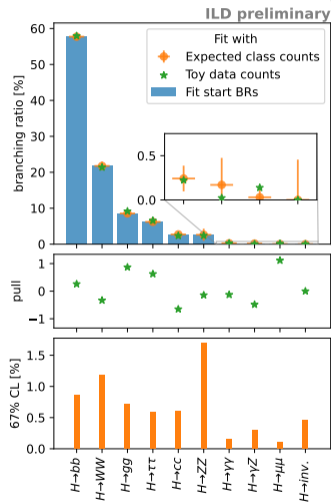
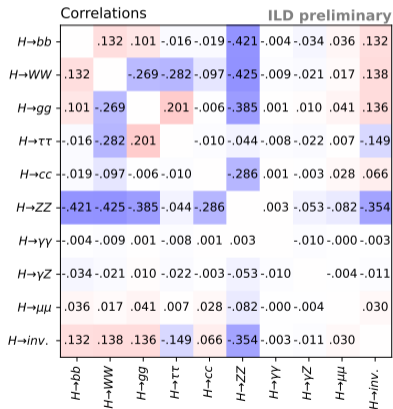
BRs from minimization through MINUIT/*iminuit*.

- 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  $BR^{\text{true}}$  within its uncertainties.  $\sigma_{B_{H \rightarrow ZZ^*}}$  through uncertainty propagation.

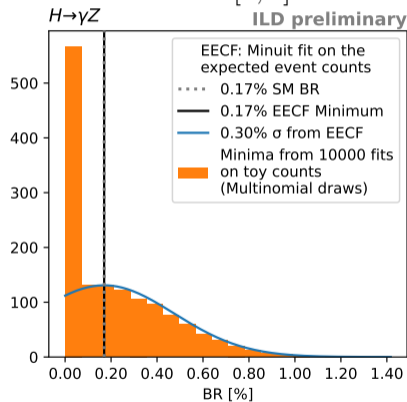
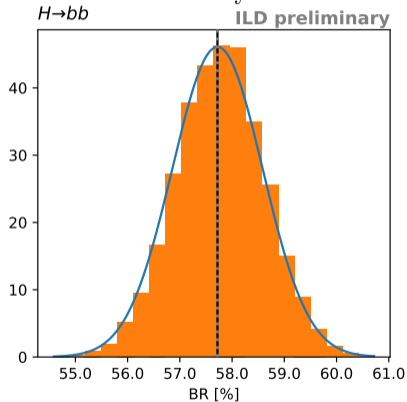


# OPTIMIZATION - VALIDITY CHECK

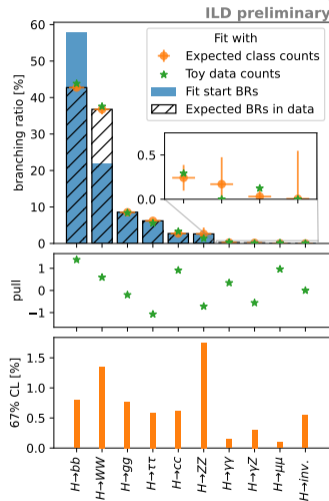
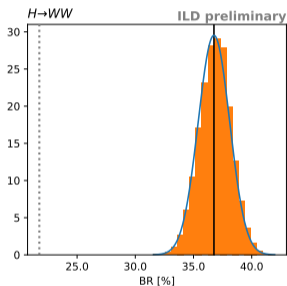
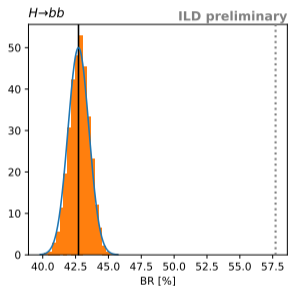


Toy study : Draw from multinomial ( $N_{\text{data}}$  fixed).

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

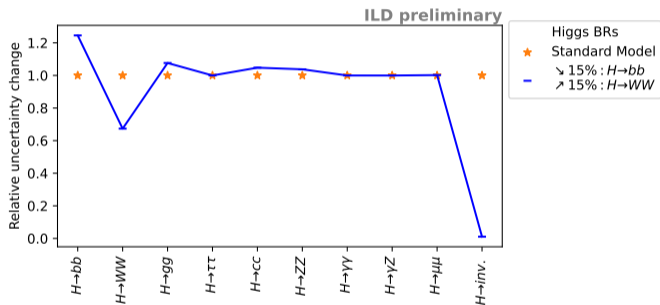


# FIT IN A NON-SM SCENARIO



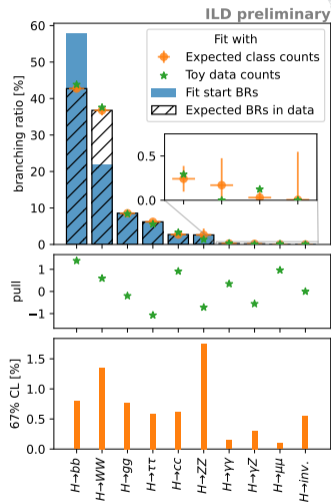
Assume 57.7% → 42.7%  $BR(H \rightarrow b\bar{b})$ ,  
 21.8% → 36.8%  $BR(H \rightarrow W^+W^-)$ .

# FIT IN A NON-SM SCENARIO

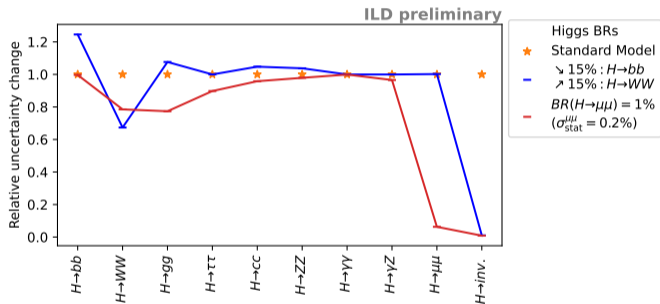


Assume 57.7%  $\rightarrow$  42.7%  $BR(H \rightarrow b\bar{b})$ ,  
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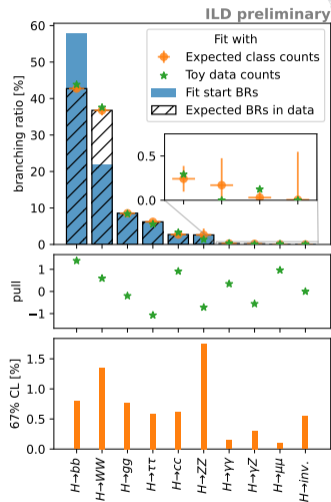
Jonas Kunath – Combined Higgs fit



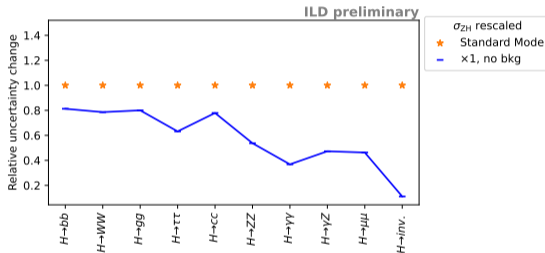
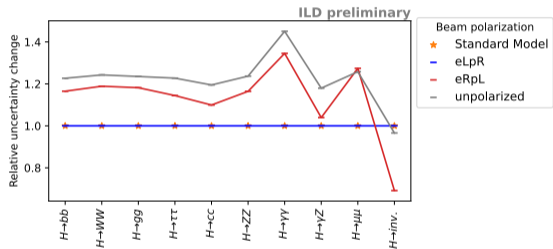
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# POLARIZATION AND BACKGROUND LEVEL





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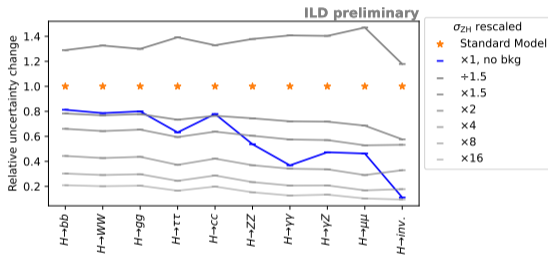
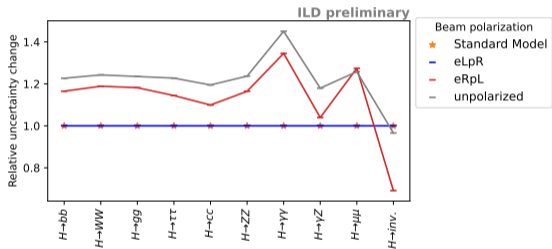


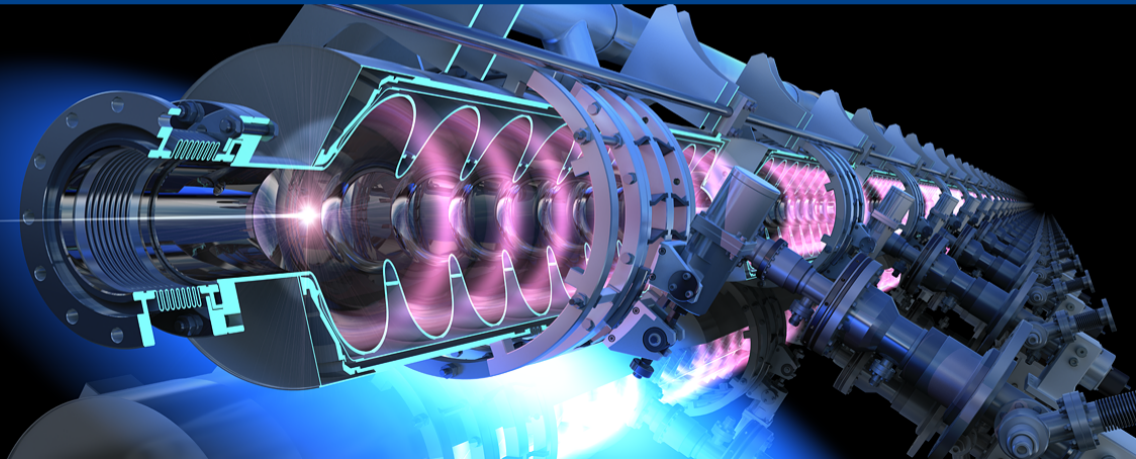


TABLE – Results of a fit on the expected event counts. In percent. ILD preliminary.

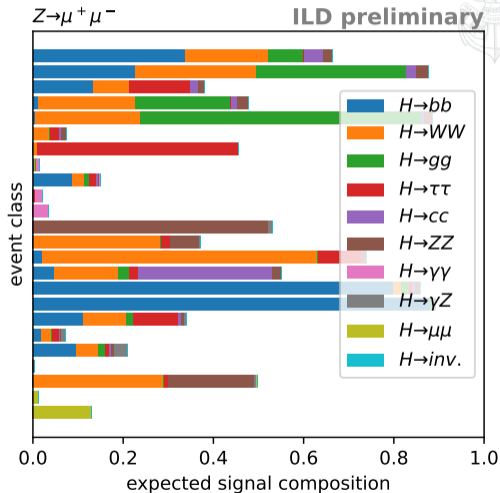
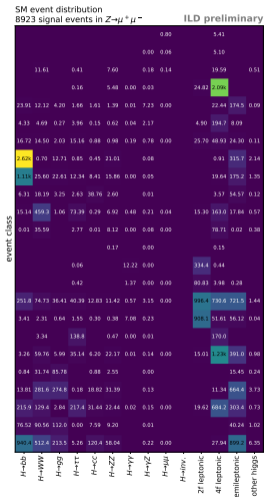
	SM BR	$\sigma_{\text{stat}}$
$H \rightarrow bb$	57.72	0.87
$H \rightarrow WW$	21.76	1.19
$H \rightarrow gg$	8.55	0.71
$H \rightarrow \tau\tau$	6.20	0.59
$H \rightarrow cc$	2.72	0.60
$H \rightarrow ZZ$	2.62	1.69
$H \rightarrow \gamma\gamma$	0.24	0.15
$H \rightarrow \gamma Z$	0.17	0.30
$H \rightarrow \mu\mu$	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  $\sigma_{ZH}$  and  $\sigma_{VV\text{-fusion}}$ .
- + Can automatically adapt to BR scenarios drastically different from SM.

# 8 BACK-UP



# EXPECTED COUNTS PER (CATEGORY, BR) PAIR

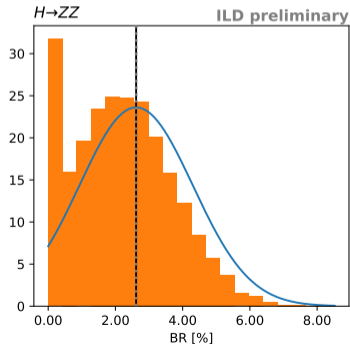
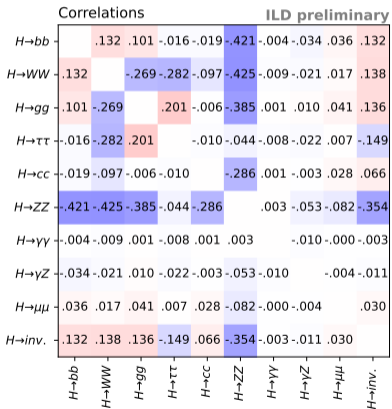


# BR CORRELATIONS WITH THE CURRENT CATEGORIES

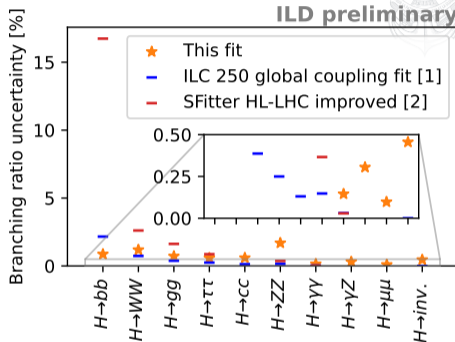


Higher correlations motivate improvements in the category definition. Needed to include the results in a global fit. Also needed for the last BR :

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



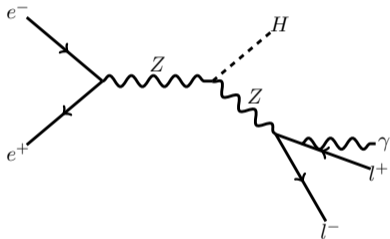
# COMPARISON WITH GLOBAL COUPLING FITS



- [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  $\tau$  is complicated.

- Large  $\tau$  decay opening angle (low  $E_\tau$ ).
- Diverse environment from the Higgs decay.

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

- Significant WW-fusion contribution in  $\nu \bar{\nu} H$ .
- Cannot tag event on  $\nu$ .
- + 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.