A COMBINED FIT TO THE HIGGS BRANCHING RATIOS AT ILD

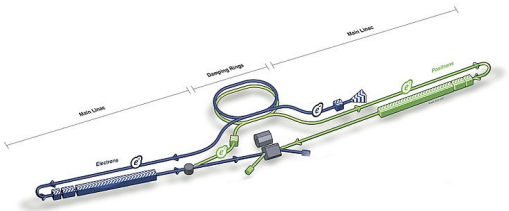
EPS-HEP2021

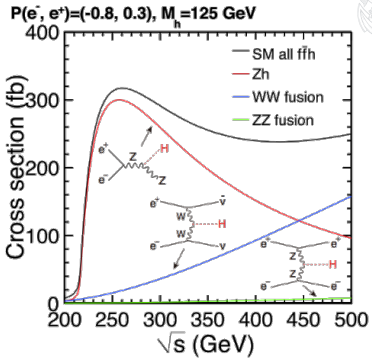
Jonas Kunath (LLR), on behalf of the ILD concept group

29.07.2021

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).



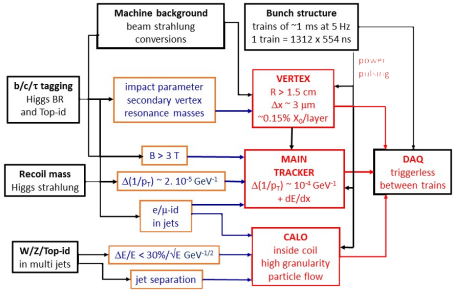


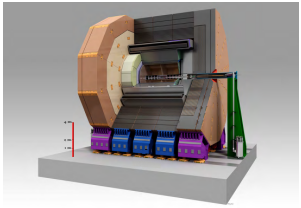
ILC Technical Design Report (2013)

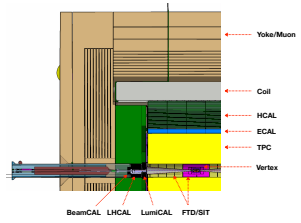
The International Linear Collider : A Global Project : arXiv:1903.01629

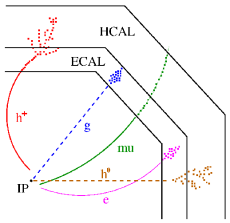
THE INTERNATIONAL LARGE DETECTOR (ILD)

Based on the Particle Flow approach.



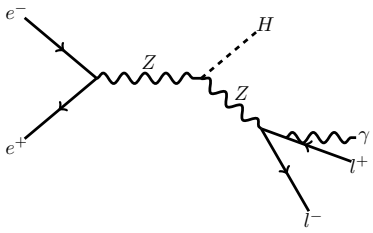






Interim Design Report : arXiv:2003.01116

HIGGSSTRAHLUNG

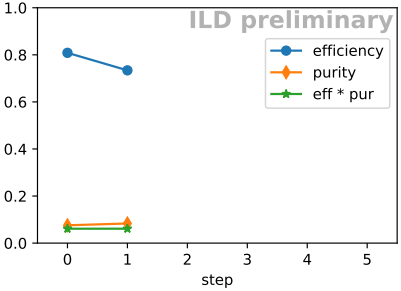


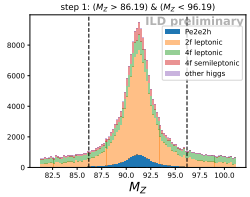
- $Z \to \mu^+\mu^-, Z \to e^+e^-$:
  - IsolatedLeptonTagger :
    Lepton pair with same type and opposite charge.
  - Final state radiation :
    Add photons with $\cos\theta_{l\gamma} > 0.99$.

  Golden channels due to recoil mass method,
  $M^2_{\text{recoil}} = s + M_Z^2 - 2\sqrt{s} \cdot E_Z$.
- Higgs :
  Event selection that keeps events with all Higgs decays.

EVENT SELECTION

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

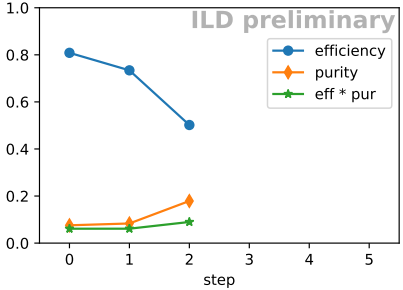


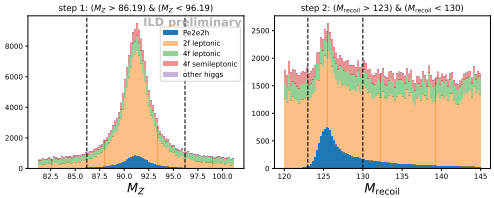


Step 0 : Find a lepton pair.

EVENT SELECTION

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

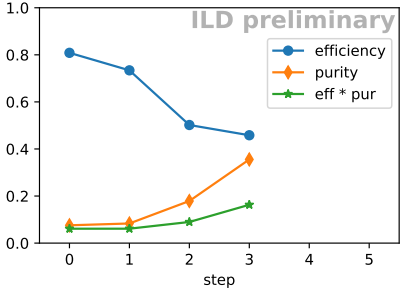


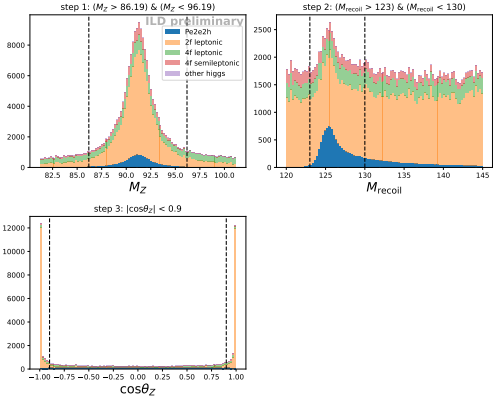


Step 0 : Find a lepton pair.

EVENT SELECTION

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

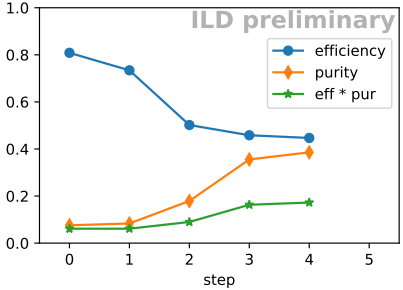


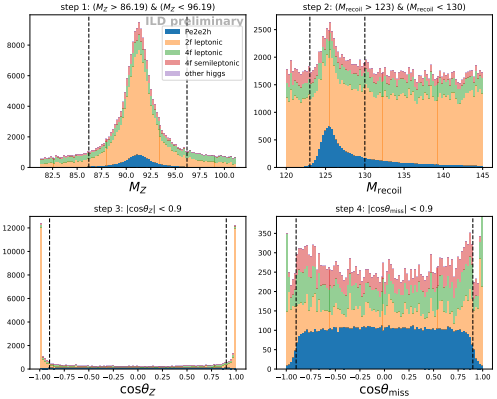


Step 0 : Find a lepton pair.

EVENT SELECTION

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

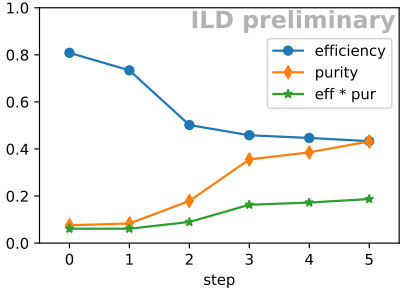




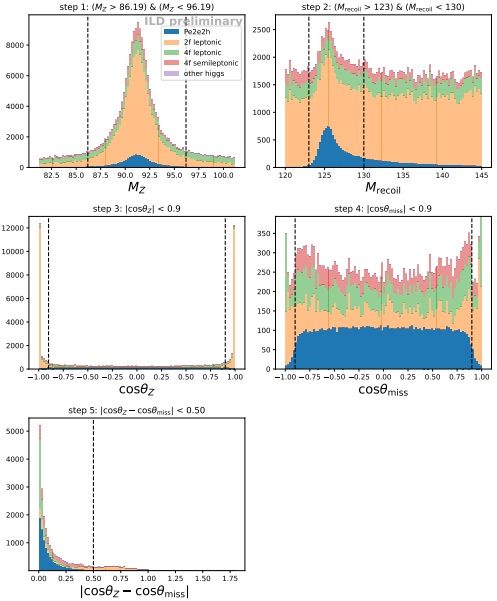
Step 0 : Find a lepton pair.

EVENT SELECTION

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



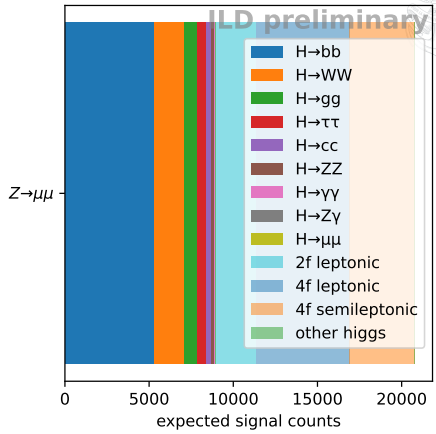
Step 0 : Find a lepton pair.



HIGGS-BRS ALL-IN-ONE

IDEA

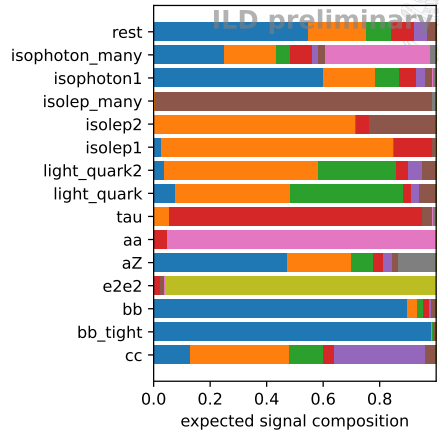
1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \to (e^+e^-, \mu^+\mu^-)$).
2. Construct categories to separate the decay modes (& background) as well as possible.
3. Fit the Higgs branching ratios to the observed category counts.



HIGGS-BRS ALL-IN-ONE

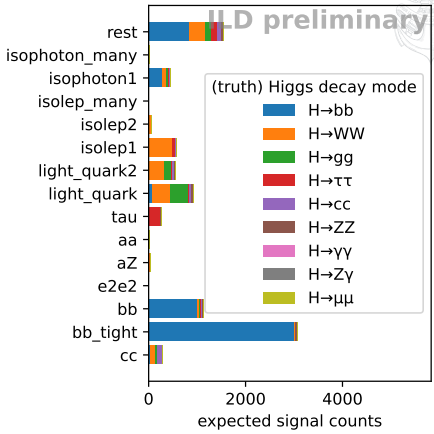
IDEA

1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \to (e^+e^-, \mu^+\mu^-)$).
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

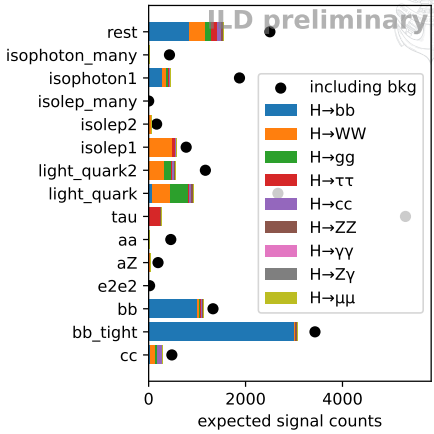
1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \to (e^+e^-, \mu^+\mu^-)$).
2. Construct categories to separate the decay modes (& background) as well as possible.
3. Fit the Higgs branching ratios to the observed category counts.



HIGGS-BRS ALL-IN-ONE

IDEA

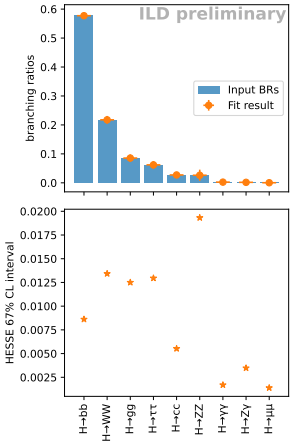
1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \to (e^+e^-, \mu^+\mu^-)$).
2. Construct categories to separate the decay modes (& background) as well as possible.
3. Fit the Higgs branching ratios to the observed category counts.



HIGGS-BRS ALL-IN-ONE

IDEA

1. Build samples with all Higgs decay modes (Higgsstrahlung, $Z \to (e^+e^-, \mu^+\mu^-)$).
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.
  - $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ 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.

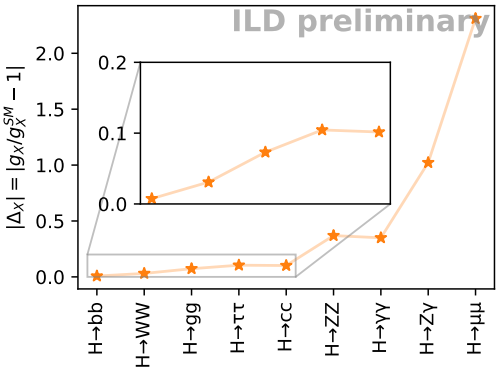
OPTIMIZATION - SETUP

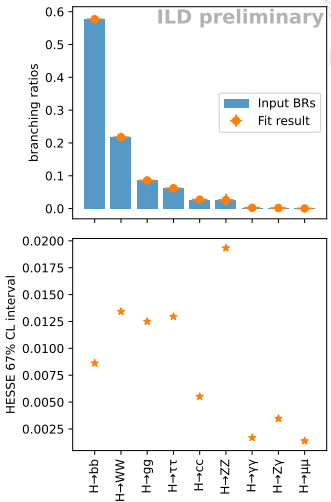
BRs from minimization through `MINUIT`/iminuit.

- `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.
  - $-\ln\mathcal{L} = -N_{\text{data}} \sum_i S_i \ln\left(\sum_j M_{ij} B_j\right)$.
  - $B_{H\to ZZ^*} = 1 - \sum_{i\neq H\to ZZ^*} B_i$.

OPTIMIZATION - RESULTS

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

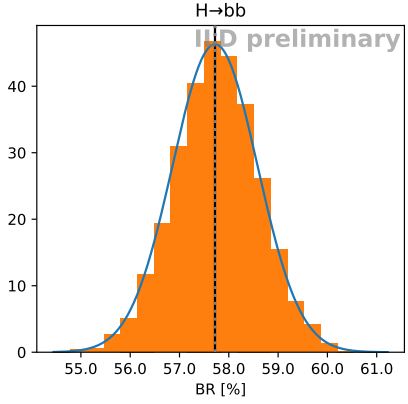


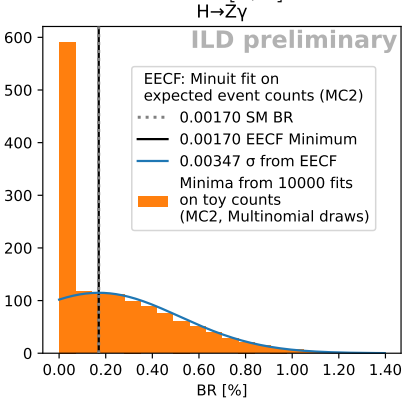


OPTIMIZATION - VALIDITY CHECK

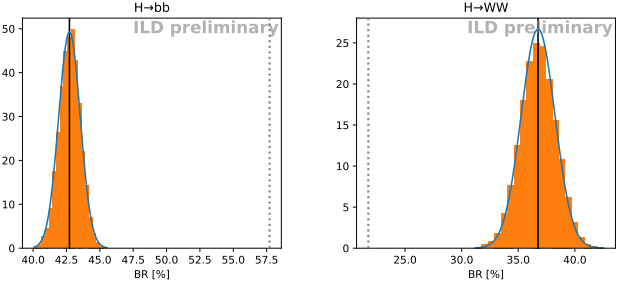
Toy study : Draw from multinomial (N_{data} fixed).

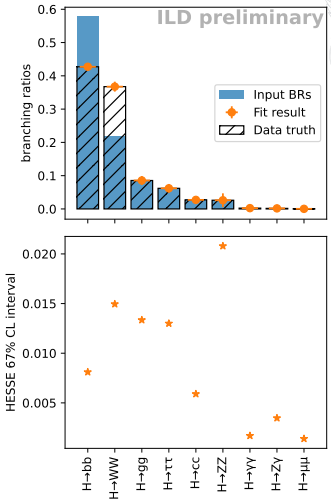
Shown : 2 of the toy fit distributions for multinomial $\ln\mathcal{L}$ with $[0, 1]$ boundaries.





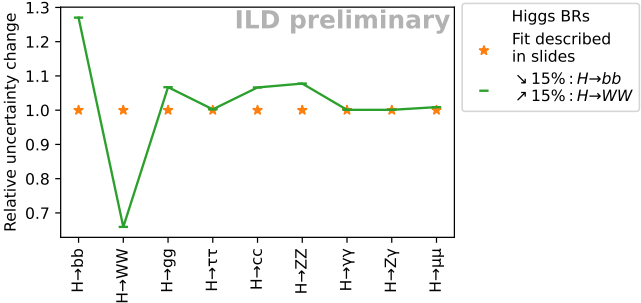
FIT IN A NON-SM SCENARIO

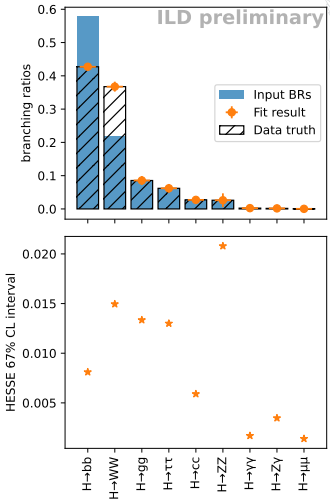




Assume $57.7\% \to 42.7\%$ $BR(H \to b\bar{b})$,
$21.8\% \to 36.8\%$ $BR(H \to W^+W^-)$.

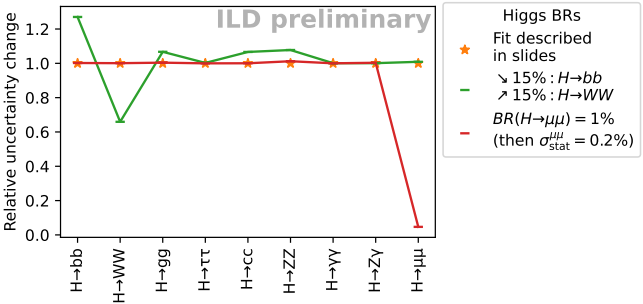
FIT IN A NON-SM SCENARIO

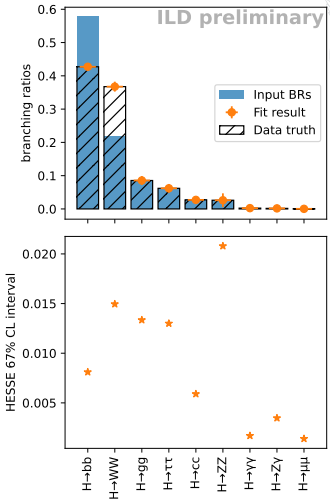




Assume $57.7\% \to 42.7\%$ $BR(H \to b\bar{b})$,
$21.8\% \to 36.8\%$ $BR(H \to W^+W^-)$.

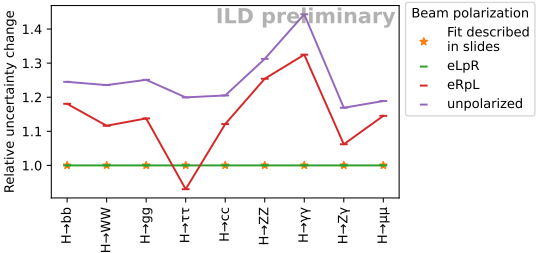
FIT IN A NON-SM SCENARIO

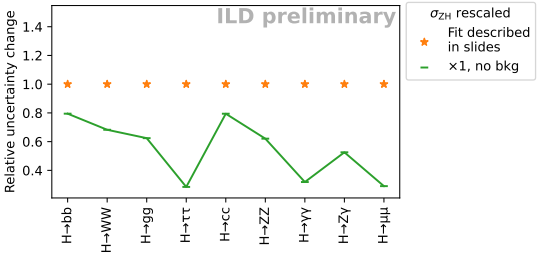




Assume $57.7\% \to 42.7\%$ $BR(H \to b\bar{b})$,
$21.8\% \to 36.8\%$ $BR(H \to W^+W^-)$.

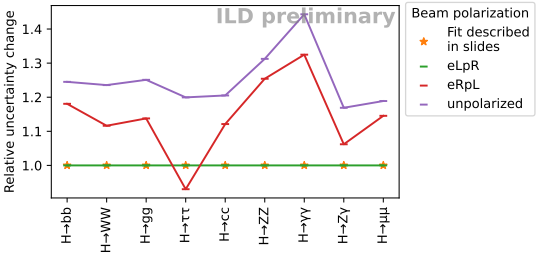
DEPENDENCY ON POLARIZATION AND BACKGROUND LEVEL

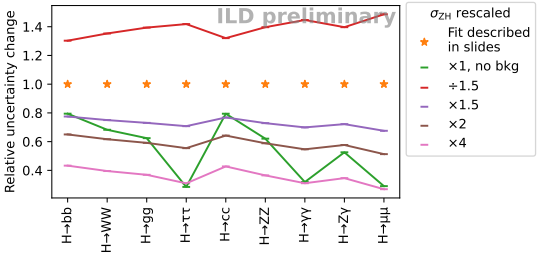




DEPENDENCY ON POLARIZATION AND BACKGROUND LEVEL

FIT





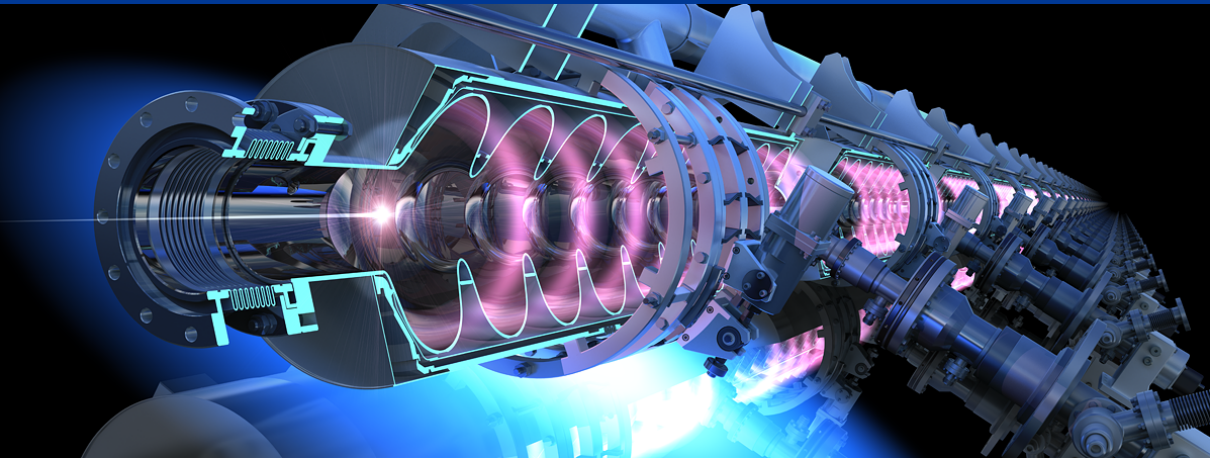
CONCLUSIONS

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

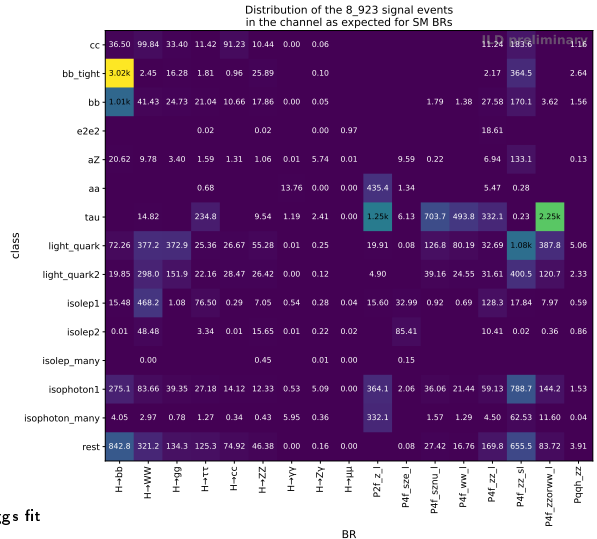
TABLE – Results of a fit on the expected event counts. In percent. ILD preliminary.

	SM BR	σ_{stat}
$H \to bb$	57.72	0.86
$H \to WW$	21.76	1.34
$H \to gg$	8.55	1.25
$H \to \tau\tau$	6.20	1.30
$H \to cc$	2.72	0.55
$H \to ZZ$	2.62	1.93
$H \to \gamma\gamma$	0.24	0.17
$H \to Z\gamma$	0.17	0.35
$H \to \mu\mu$	0.03	0.14

7
BACK-UP

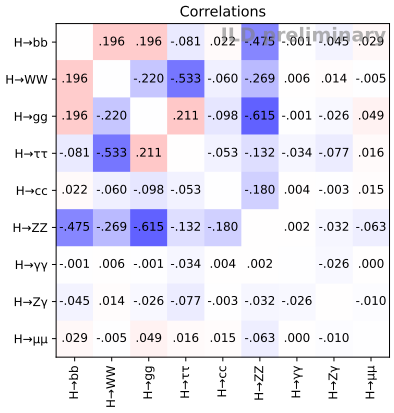


EXPECTED COUNTS PER (CATEGORY, BR) PAIR

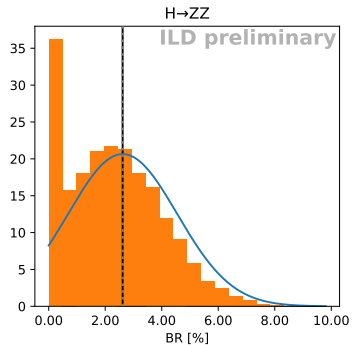


BR CORRELATIONS WITH THE CURRENT CATEGORIES

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

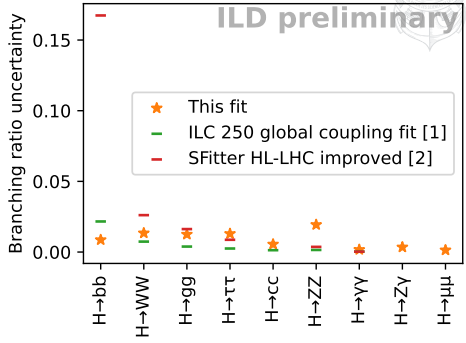


$$B_{ZZ^*} = 1 - \sum_{i \neq ZZ^*} B_i \Rightarrow \sigma^2_{ZZ^*} = \sum_{i \neq ZZ^*} \sum_{j \neq ZZ^*} \rho_{ij} \sigma_i \sigma_j$$



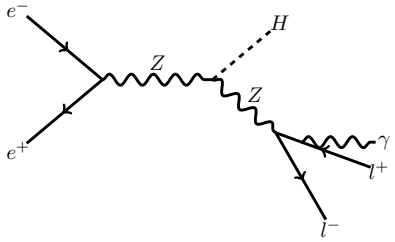
COMPARISON WITH GLOBAL COUPLING FITS

- [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 $Z \to e^+e^-$, $Z \to \mu^+\mu^-$.
  - 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*.

HIGGSSTRAHLUNG



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

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

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

  Event tagging on the τ is complicated.

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

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

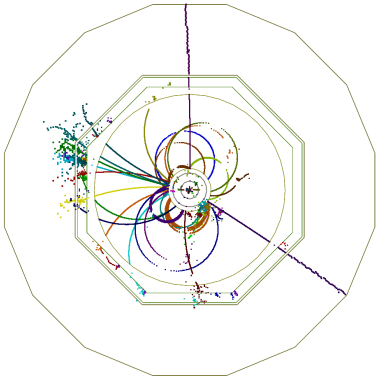
  – Significant WW-fusion contribution in $\nu\bar{\nu}H$.
  – Cannot tag event on ν.
  \+ Only Higgs boson (and beam overlay) in event.
  \+ 6× higher cross section.

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

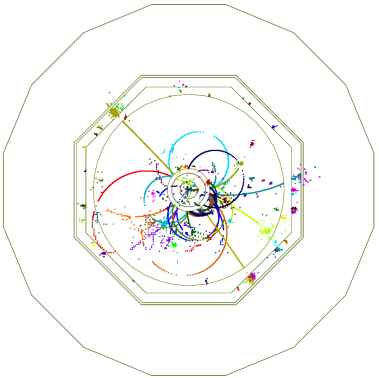
  \+ Hightest cross section.
  – Hard to identify the traces from the Z decay without making assumptions on the Higgs decay.

EXAMPLE EVENTS

After removing the primary Z boson, the *signal* events per channel are interchangeable.



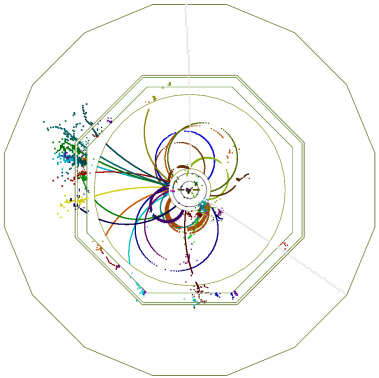
$e^+e^- \to H\ Z,\ Z \to \mu^+\mu^-$



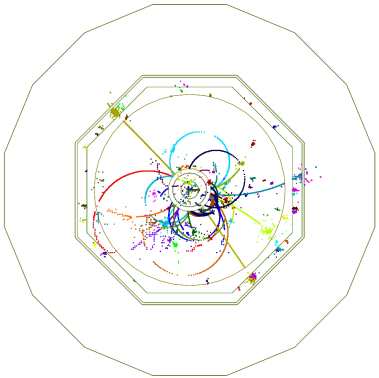
$e^+e^- \to H\ Z,\ Z \to e^+e^-$

EXAMPLE EVENTS

After removing the primary Z boson, the *signal* events per channel are interchangeable.



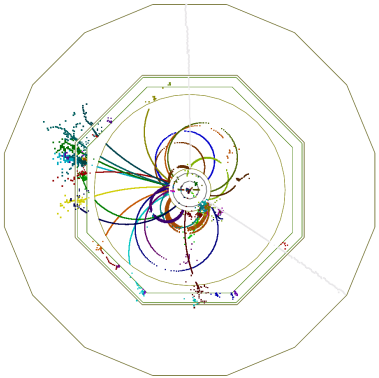
$e^+e^- \to H$



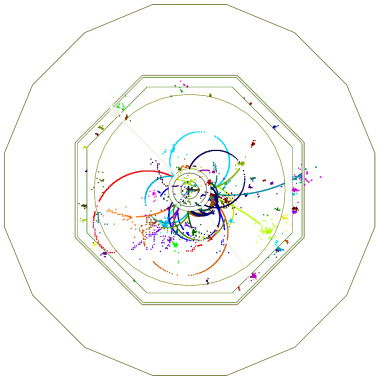
$e^+e^- \to H\ Z,\ Z \to e^+e^-$

EXAMPLE EVENTS

After removing the primary Z boson, the *signal* events per channel are interchangeable.



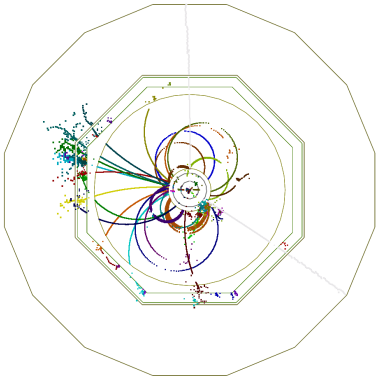
$e^+e^- \to H$



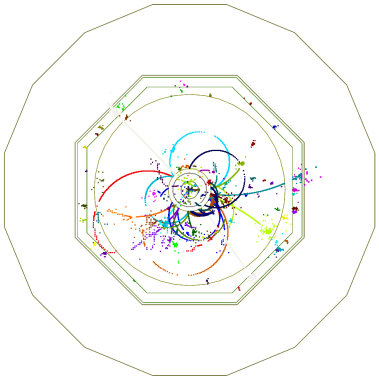
$e^+e^- \to H$

EXAMPLE EVENTS

After removing the primary Z boson, the *signal* events per channel are interchangeable.



$e^+e^- \to H$



$e^+e^- \to H$