Higgs coupling measurements at the ILC of a light Higgs in the HxSM

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Final Degree Project

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Real scalar singlet extension of the SM

SM: $V(\Phi) = \mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2, \quad \lambda > 0$

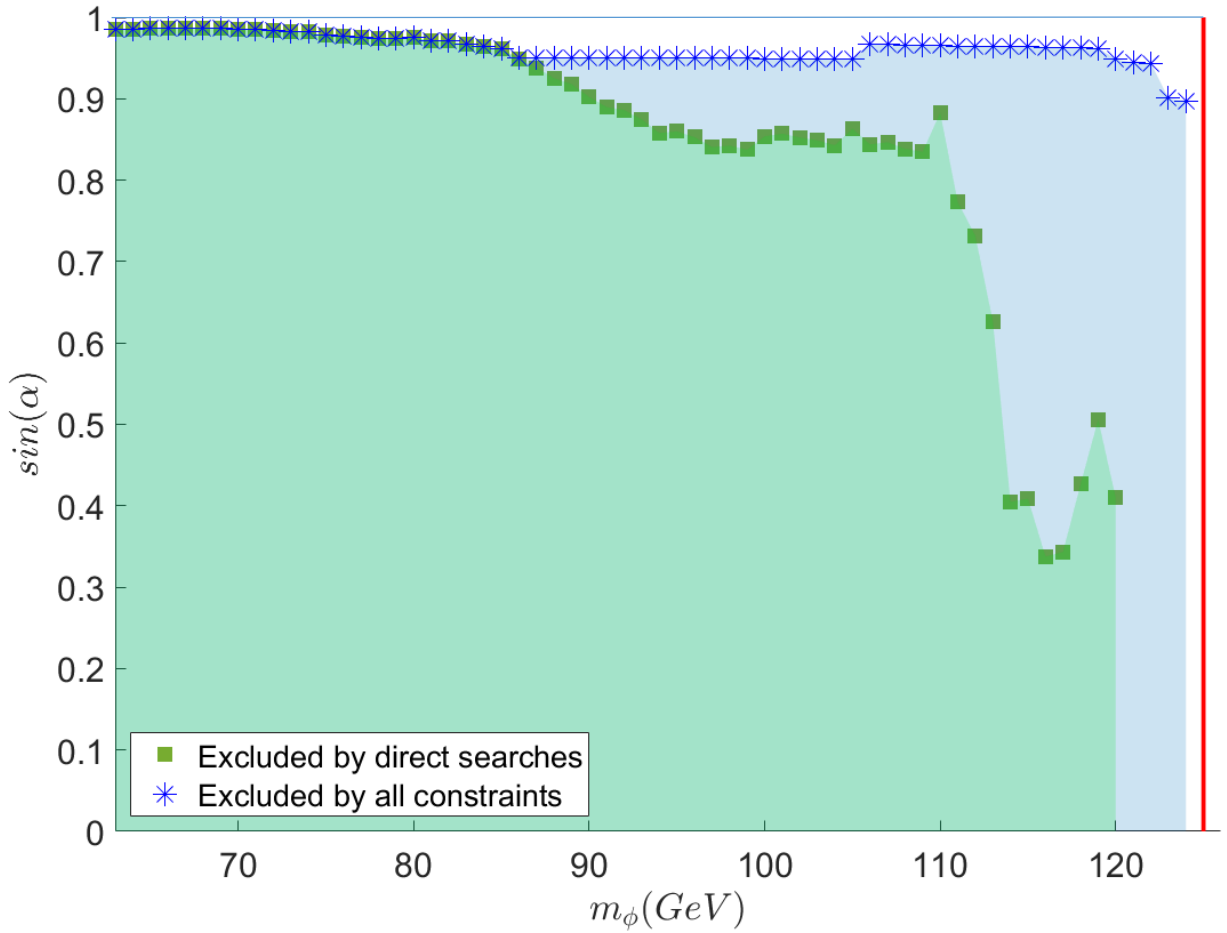
HxSM: $V(\Phi, S) = -m^2 \Phi^\dagger \Phi - \mu^2 S^2 + \begin{pmatrix} \Phi^\dagger \Phi & S^2 \end{pmatrix} \begin{pmatrix} \lambda_1 & \frac{\lambda_3}{2} \\ \frac{\lambda_3}{2} & \lambda_2 \end{pmatrix} \begin{pmatrix} \Phi^\dagger \Phi \\ S^2 \end{pmatrix}$

$$= -m^2 \Phi^\dagger \Phi - \mu^2 S^2 + \lambda_1 (\Phi^\dagger \Phi)^2 + \lambda_3 S^2 \Phi^\dagger \Phi + \lambda_2 S^4$$

$$\Phi \equiv \begin{pmatrix} 0 \\ \frac{\tilde{h}+v}{\sqrt{2}} \end{pmatrix} \qquad S \equiv \frac{h' + x}{\sqrt{2}}$$

$$\begin{pmatrix} \phi \\ h \end{pmatrix} = \begin{pmatrix} cos(\alpha) & -sin(\alpha) \\ sin(\alpha) & cos(\alpha) \end{pmatrix} \begin{pmatrix} \tilde{h} \\ h' \end{pmatrix}$$

Range of free parameters



Mass range:

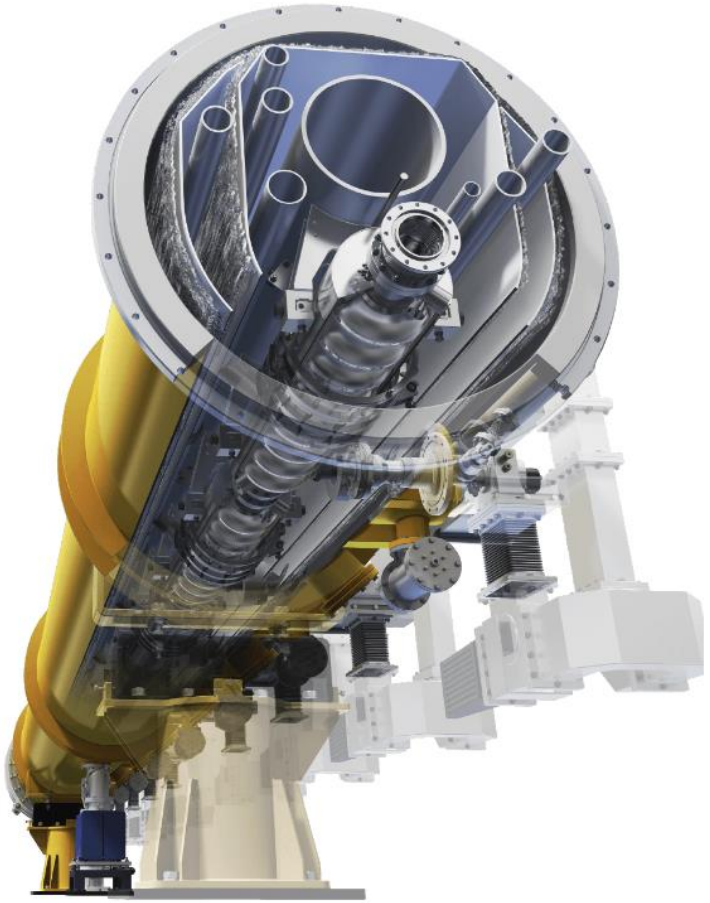
$$m_\Phi \in [63\ 123]\ GeV$$

Green: Values excluded by previous direct searches at LEP

Blue: Values excluded by measurements of the 125 GeV Higgs at LHC

We thank Tania Robens for providing the data

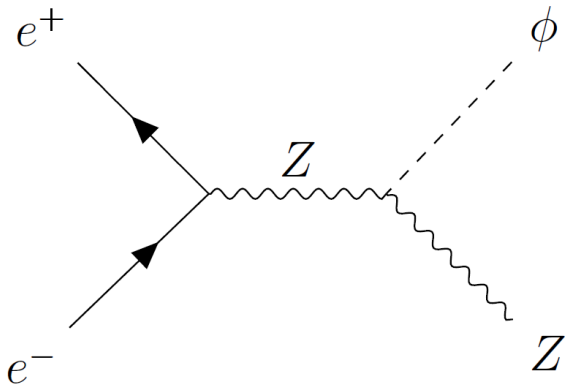
International linear collider (ILC)



Source: ILC International Development Team
https://linearcollider.org/

Advantages over LHC:

- Cleaner events
- Better precision



Objectives and tools

- Motivations:
  - First step to analyse a new particle
  - Evaluate to which model it adjusts
  - Possibly allow to distinguish between models

- Evaluation method:
  - Statistical study of the experimental uncertainties of the couplings of a light Higgs boson relative to the SM Higgs.
  - The couplings (g) are a measurement of the force at which the Higgs interacts with the rest of the particles (fermions and bosons).
    higher coupling strength → more frequent process

Evaluation method: Couplings I

Decay mode

$$\frac{\left(\frac{\Delta g_x}{g_x}\right)_\phi}{\left(\frac{\Delta g_x}{g_x}\right)_h} = \sqrt{\frac{D+f_h}{1+f_h}}\sqrt{\frac{\sigma(e^+e^- \to Zh)}{\sigma(e^+e^- \to Z\phi)}}\sqrt{\frac{BR(h \to xx)}{BR(\phi \to xx)}\frac{(1-BR(h \to xx))}{(1-BR(\phi \to xx))}}$$

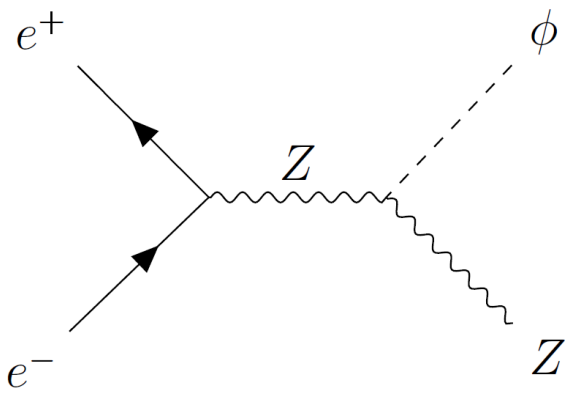
- Branching Ratio : BR
- Cross section: σ
- D factor:

$$D \equiv \frac{f_h}{f_\phi} = \frac{\left(\frac{N_S}{N_B}\right)_h}{\left(\frac{N_S}{N_B}\right)_\phi}, \qquad D \propto \frac{1}{cos^2(\alpha)}$$

Everything relative to the values of the 125 GeV Higgs

Evaluation method: Couplings II

Production mode



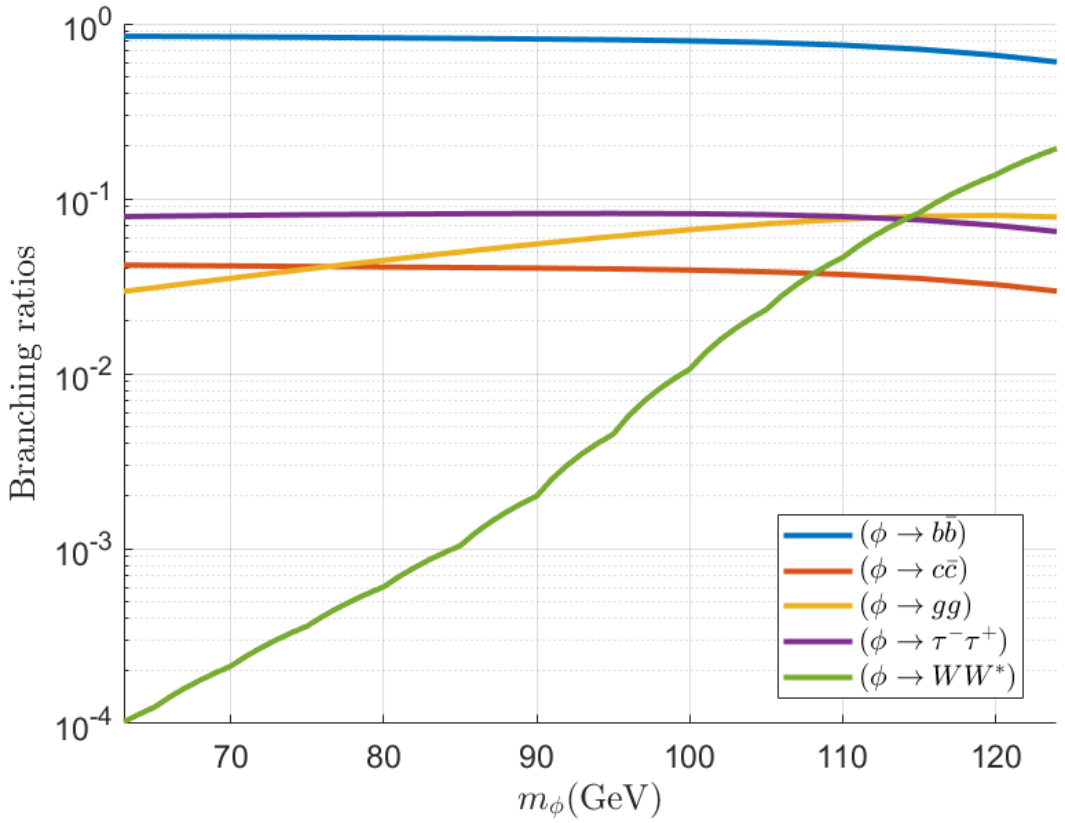
$$\frac{\left(\frac{\Delta g_Z}{g_Z}\right)_\phi}{\left(\frac{\Delta g_Z}{g_Z}\right)_h} = \sqrt{\frac{\sigma(e^+e^- \to Zh)}{\sigma(e^+e^- \to Z\phi)}}$$

- Cross section : σ

Relative to the known values of 125 GeV Higgs

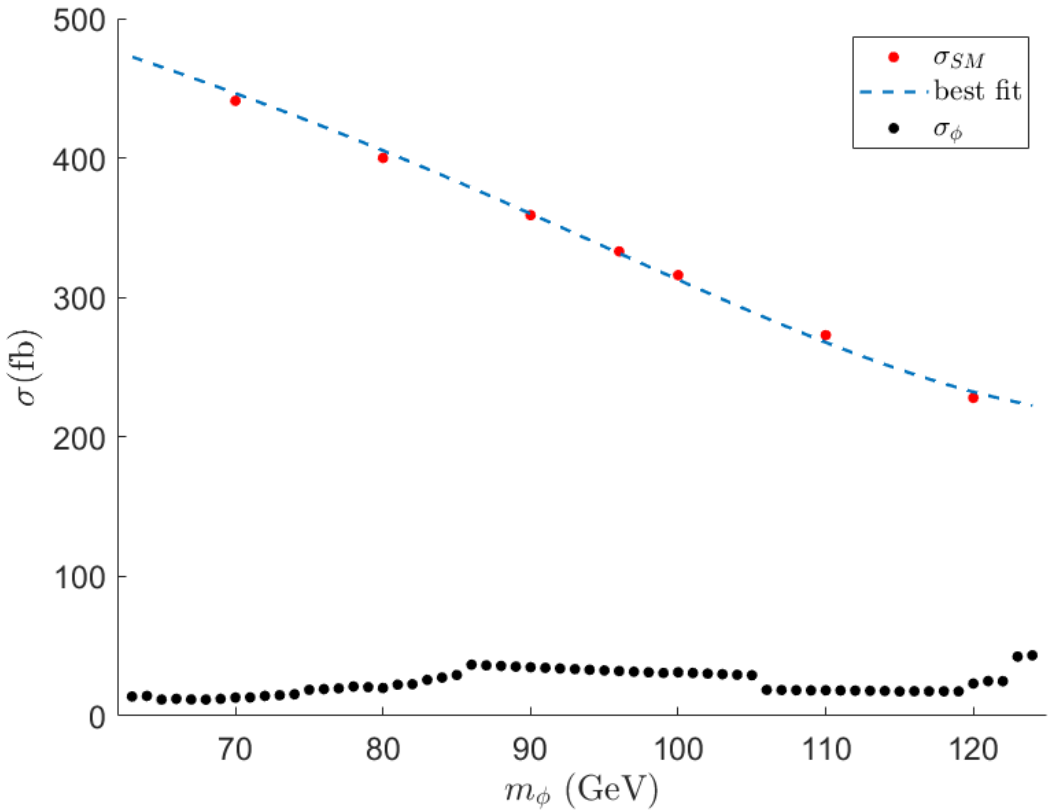
Evaluation method: BR and Cross Section

$$BR(h \to xx') \equiv \frac{\Gamma(h \to xx')}{\Gamma_{h,TOT}}$$



Source: LHC Higgs Working Group
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGBRs

$$\sigma(e^+e^- \to Z\phi) = \sigma^{\phi}_{SM}(e^+e^- \to H^{\phi}_{SM}Z) \times cos^2\alpha$$

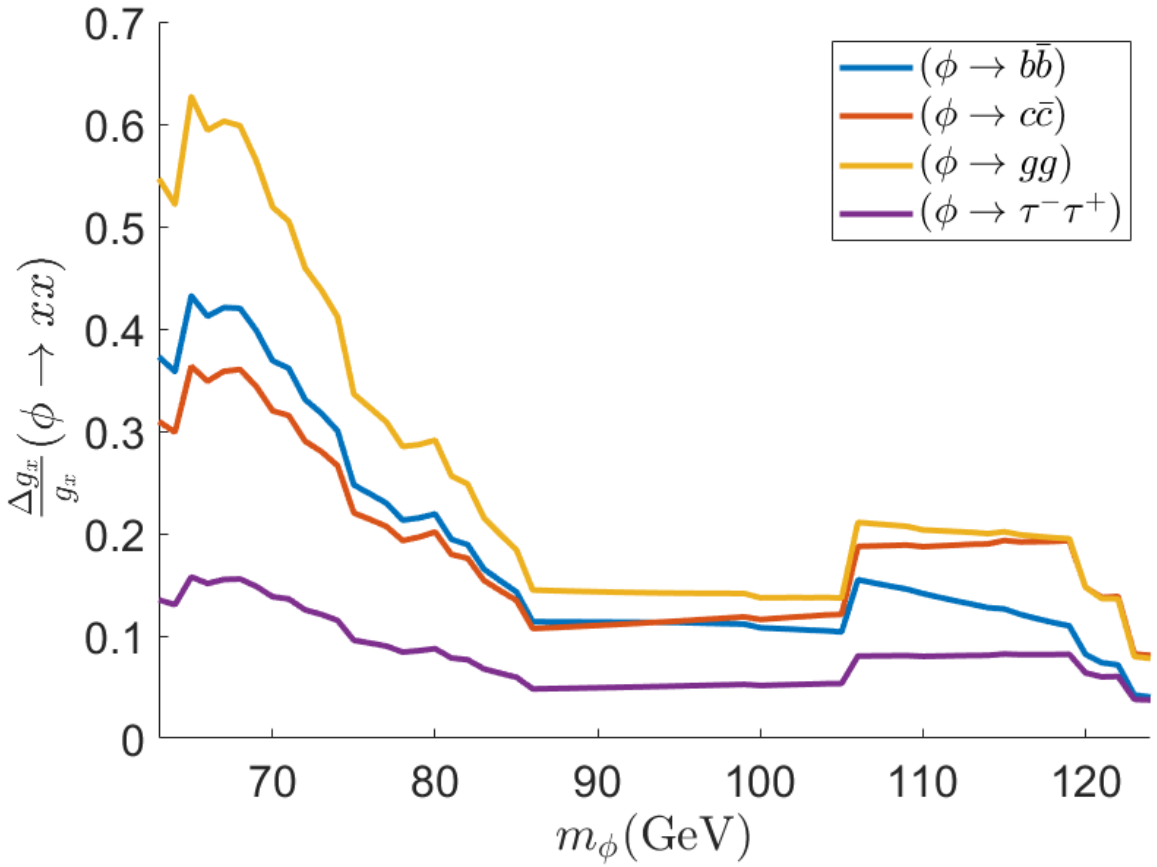


We thank Christian Schappacher for the evaluation of $\sigma_{SM}(e^+e^- \to Z\, H_{SM})$ at the full one-loop level including soft and hard QED radiation

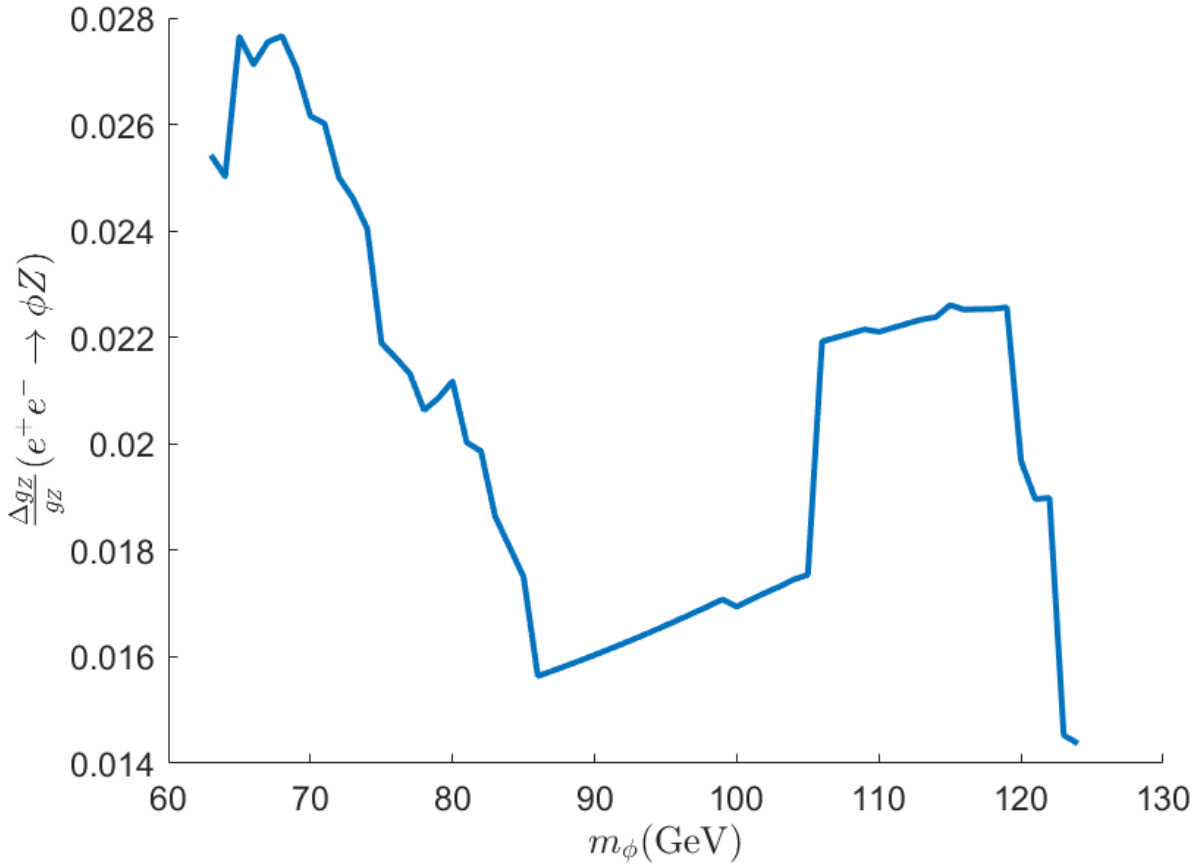
Results: Best case

Minimum sin(α)

Decay mode

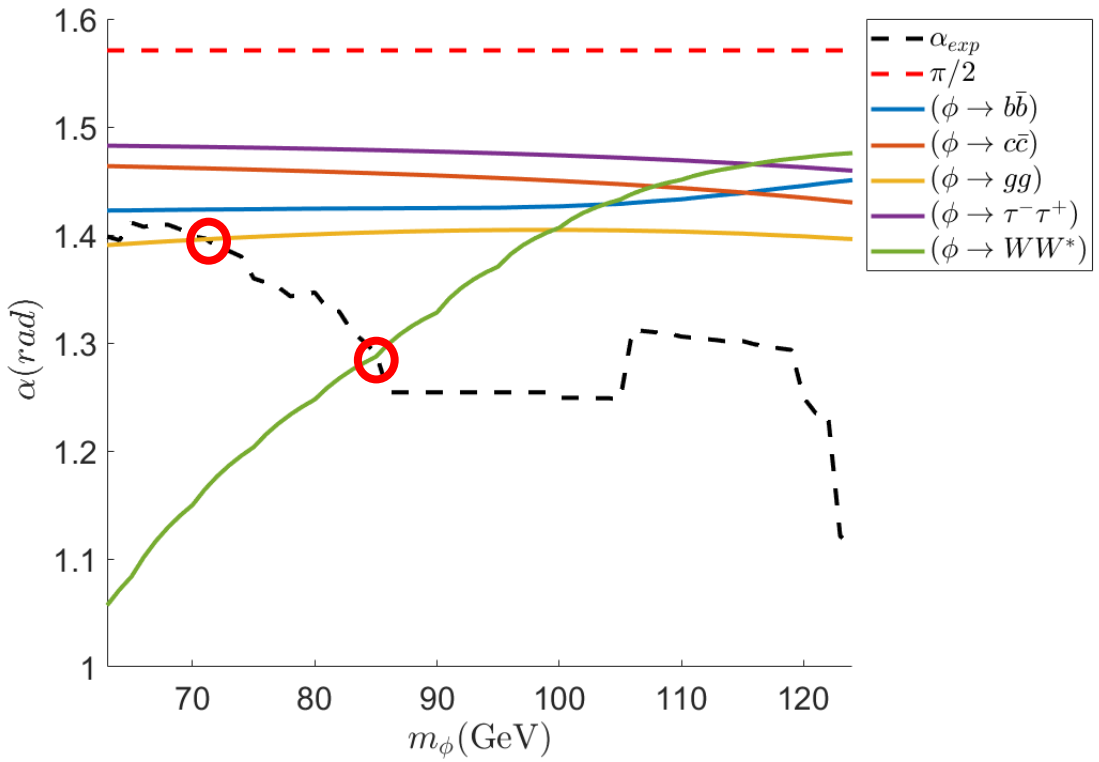


Production mode

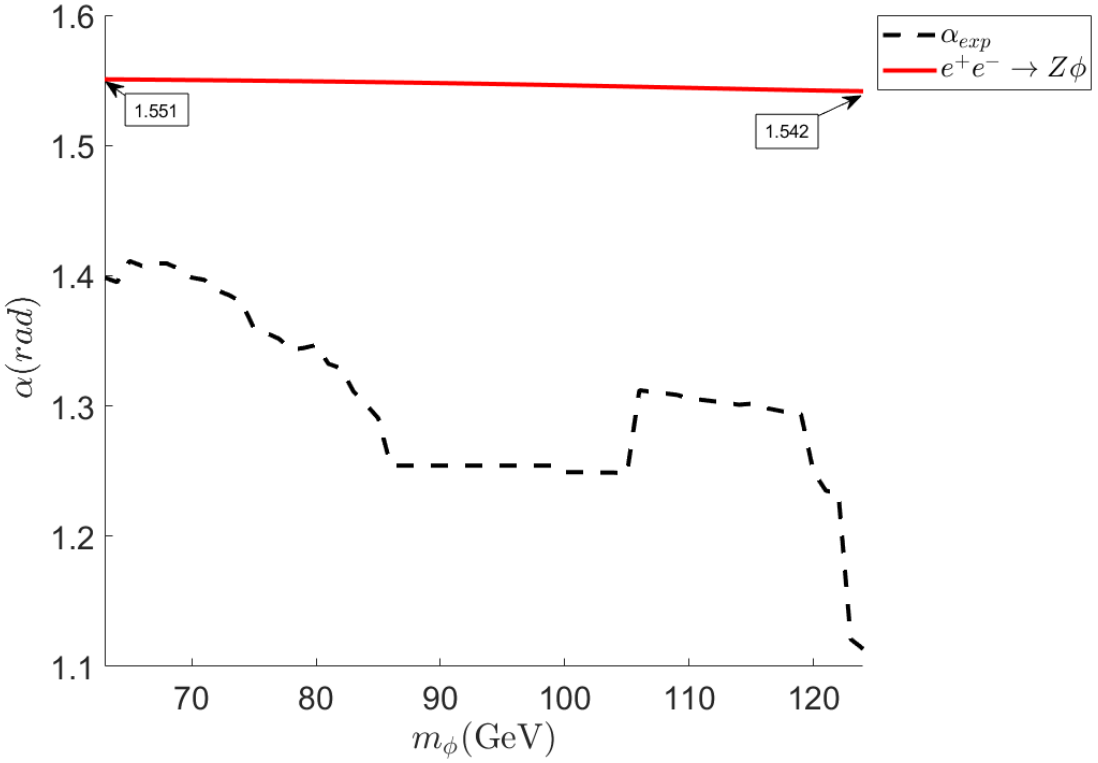


Results: Worst case

Decay mode



Production mode

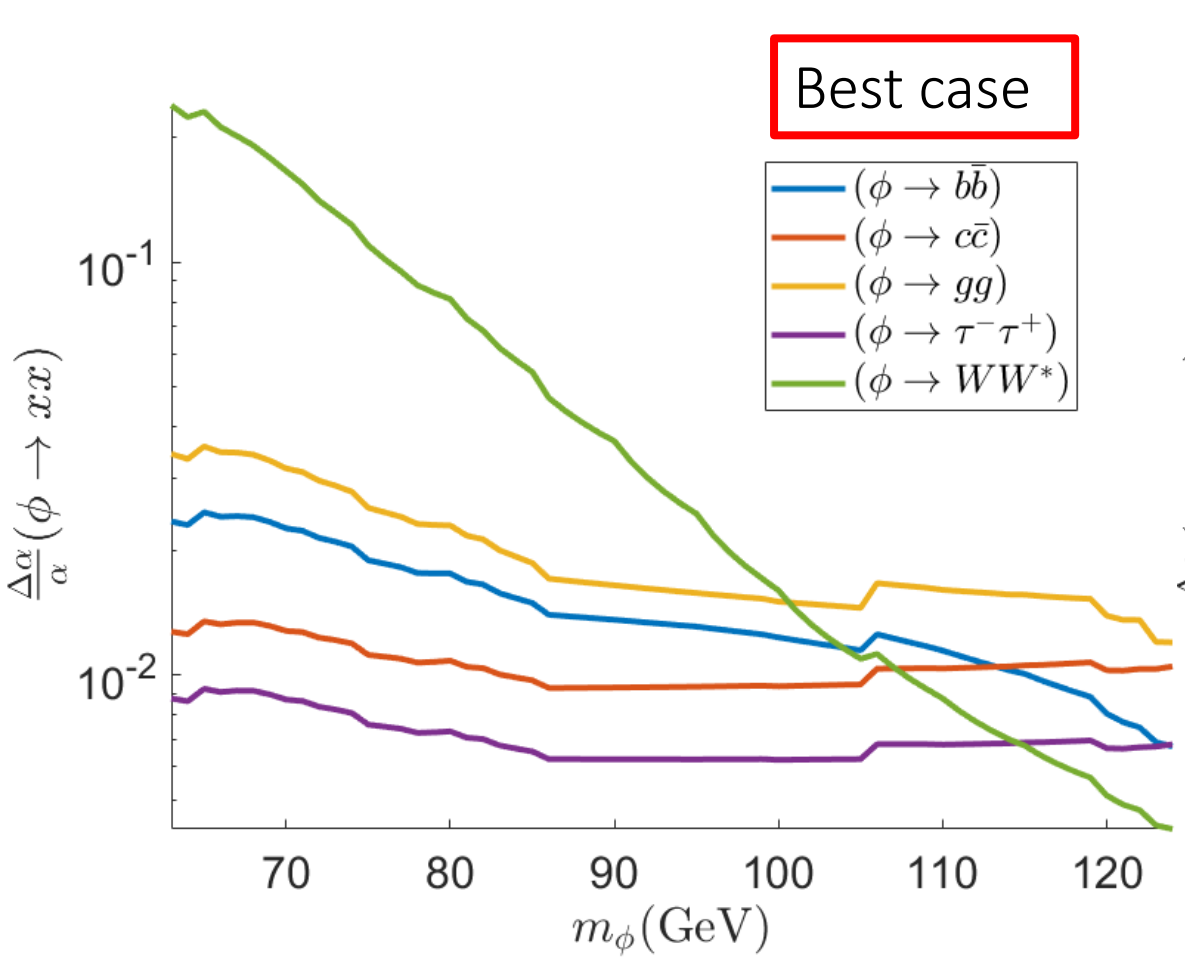


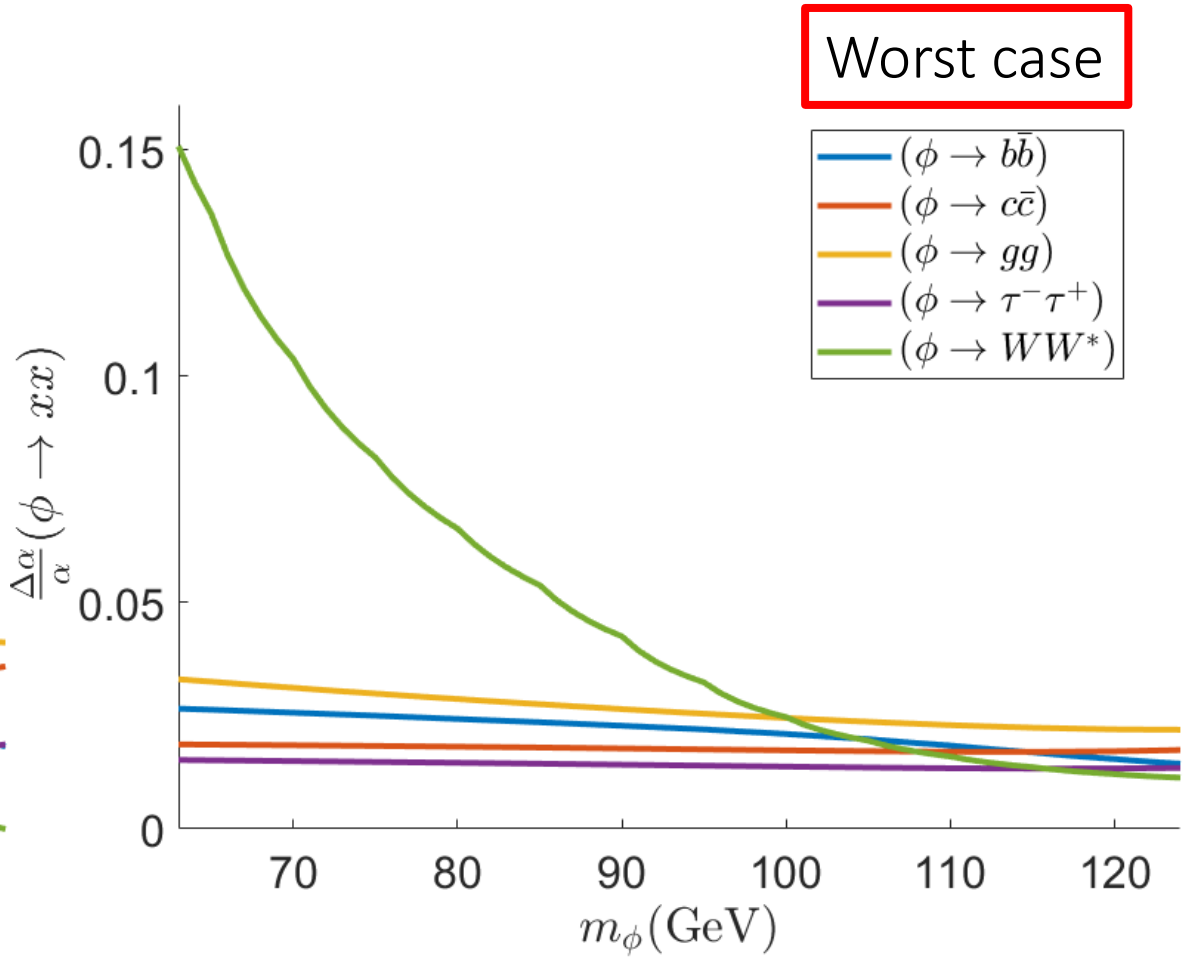
We consider an uncertainty higher than 2σ: This means at this point the meaurement of the coupling is in 2σ accordance with a null value.

O Loss of sensitivity in this chanels at this mass threshold

Results: Precision of α I

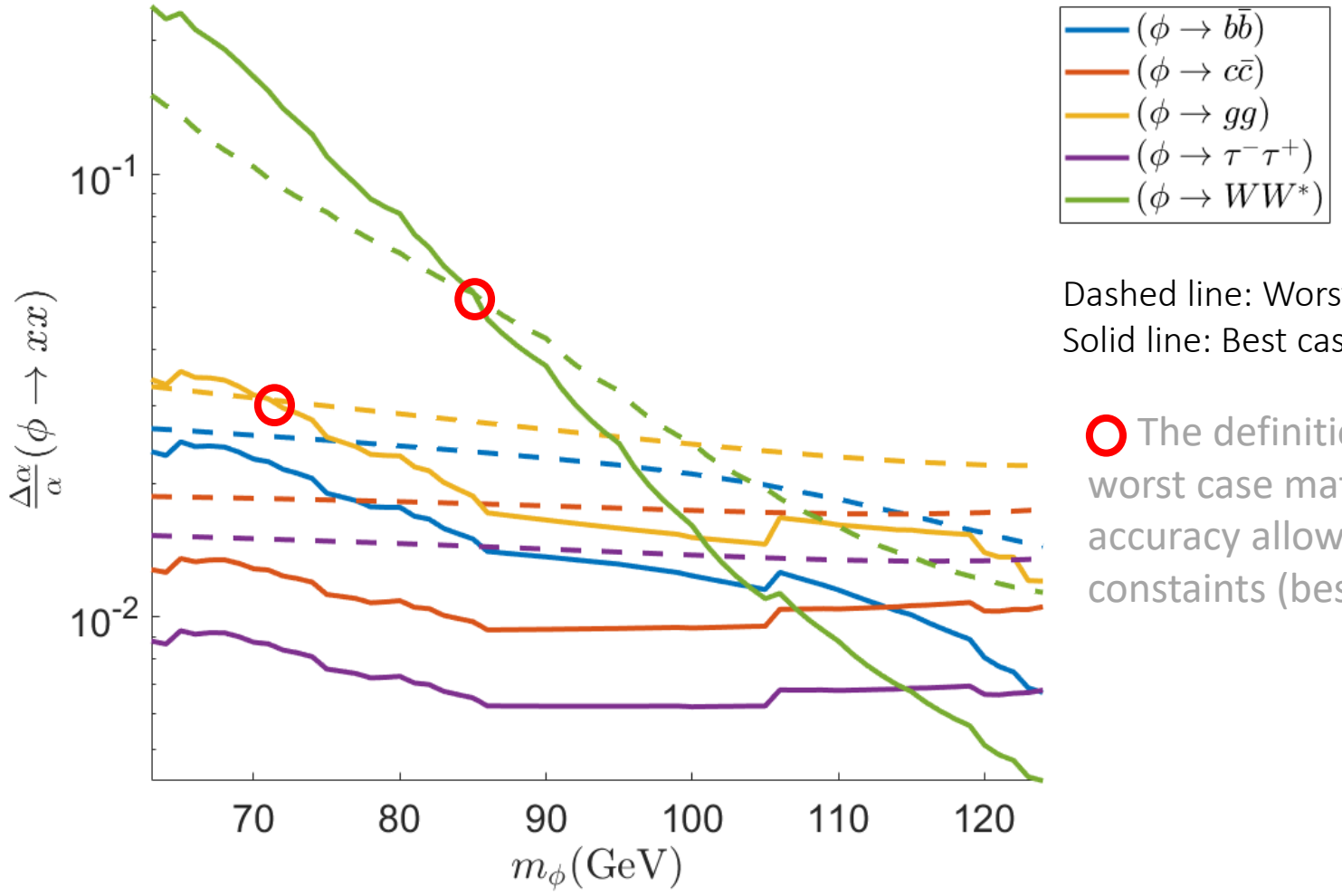
Decay mode





Results: Precision of α II

Decay mode: Comparison

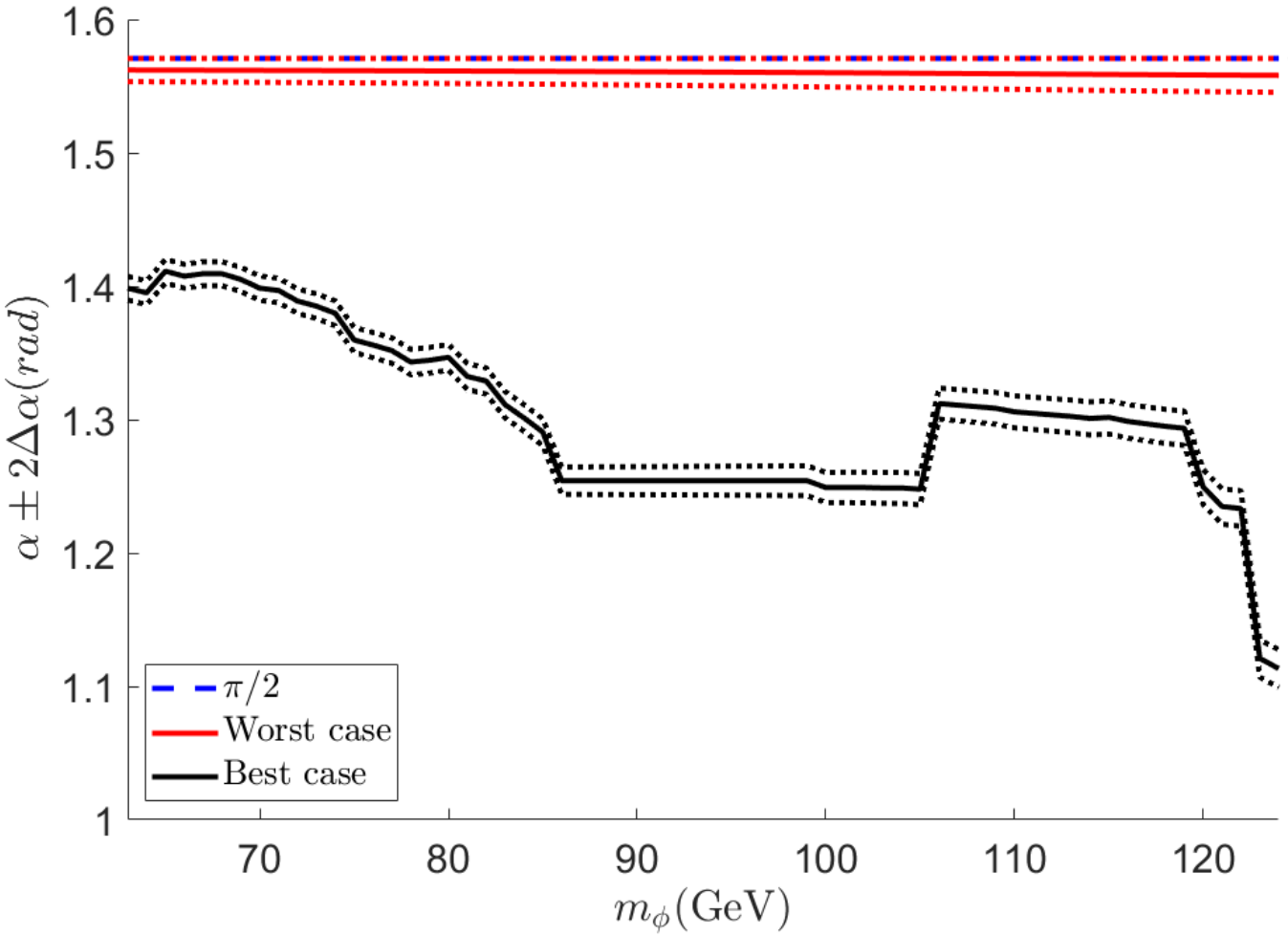


Dashed line: Worst case
Solid line: Best case

The definition of the worst case matches the accuracy allowed by constaints (best case)

Results: Precision of α III

Production mode



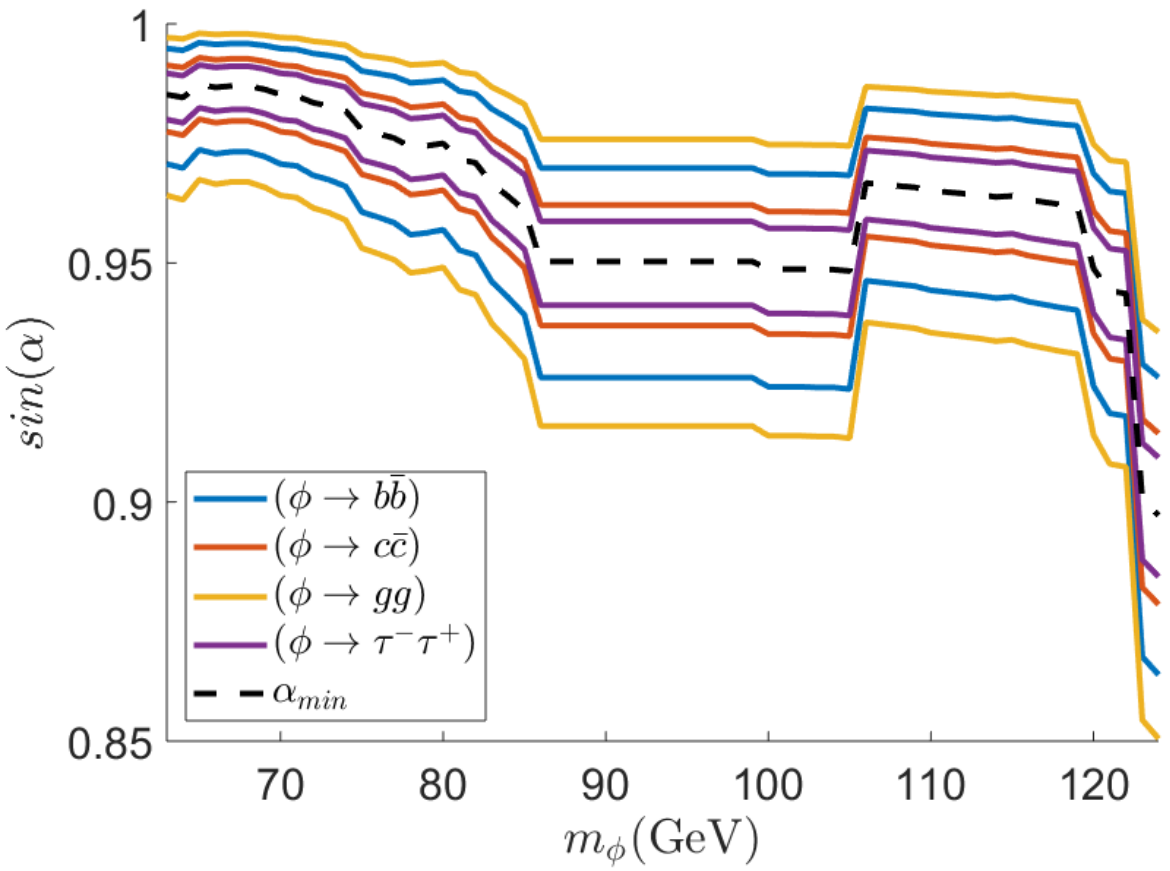
Better precision than for any decay mode!

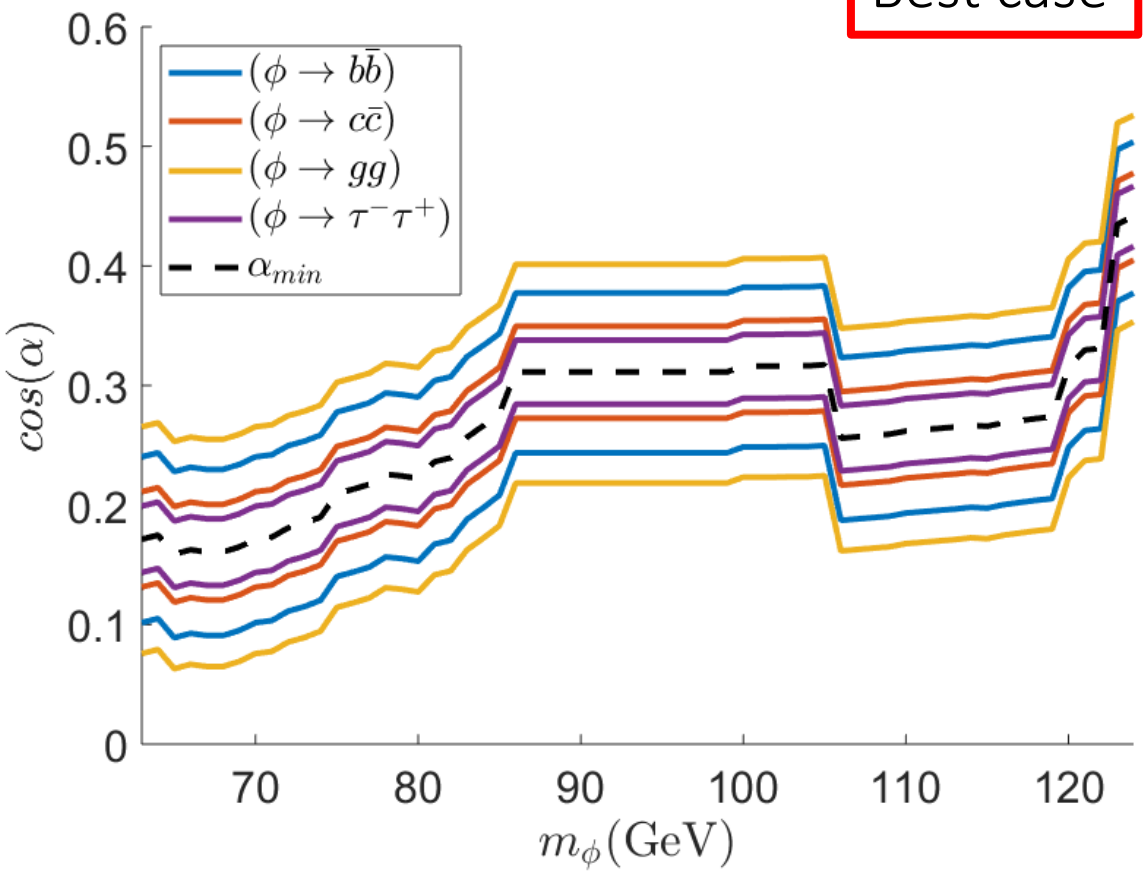
Recover the definition of the worst case

Results: Couplings precision

Decay mode

Best case





Conclusions

- The ILC offers a future possibility to validate the existence of an additional lighter Higgs boson in the parameter range still available by all the constraints and previous measurements.
- The precision of the couplings of the lighter Higgs boson is considerable to determine its existence if it is given in nature.

Questions

Appendix I: Uncertainties of the angle

- Decay:

$$\Delta\alpha = K\left[2cos\alpha sin\alpha\left(\frac{1}{\sqrt{1+caf_h}} - \frac{caf_h}{2\sqrt{(1+caf_h)^3}}\right)\right]^{-1}, \quad \text{where:} \quad cos^2\alpha \equiv ca$$

$$K = \left(\frac{\Delta g_x}{g_x}\right)_h \sqrt{\frac{\sigma(e^+e^- \to Zh)}{\sigma^{\phi}_{SM}(1+f_h)}} \sqrt{\frac{BR(h \to xx)}{BR(\phi \to xx)} \frac{(1-BR(h \to xx))}{(1-BR(\phi \to xx))}}$$

- Production:

$$\Delta\alpha = \left(\frac{\Delta g_Z}{g_Z}\right)_h \sqrt{\frac{\sigma(e^+e^- \to Zh)}{\sigma^{\phi}_{SM}}} \frac{1}{sin\alpha}$$

Appendix II: Data relative to the 125 GeV Higgs

$$\sigma(e^+e^- \to Zh) = 206 \text{ fb}$$

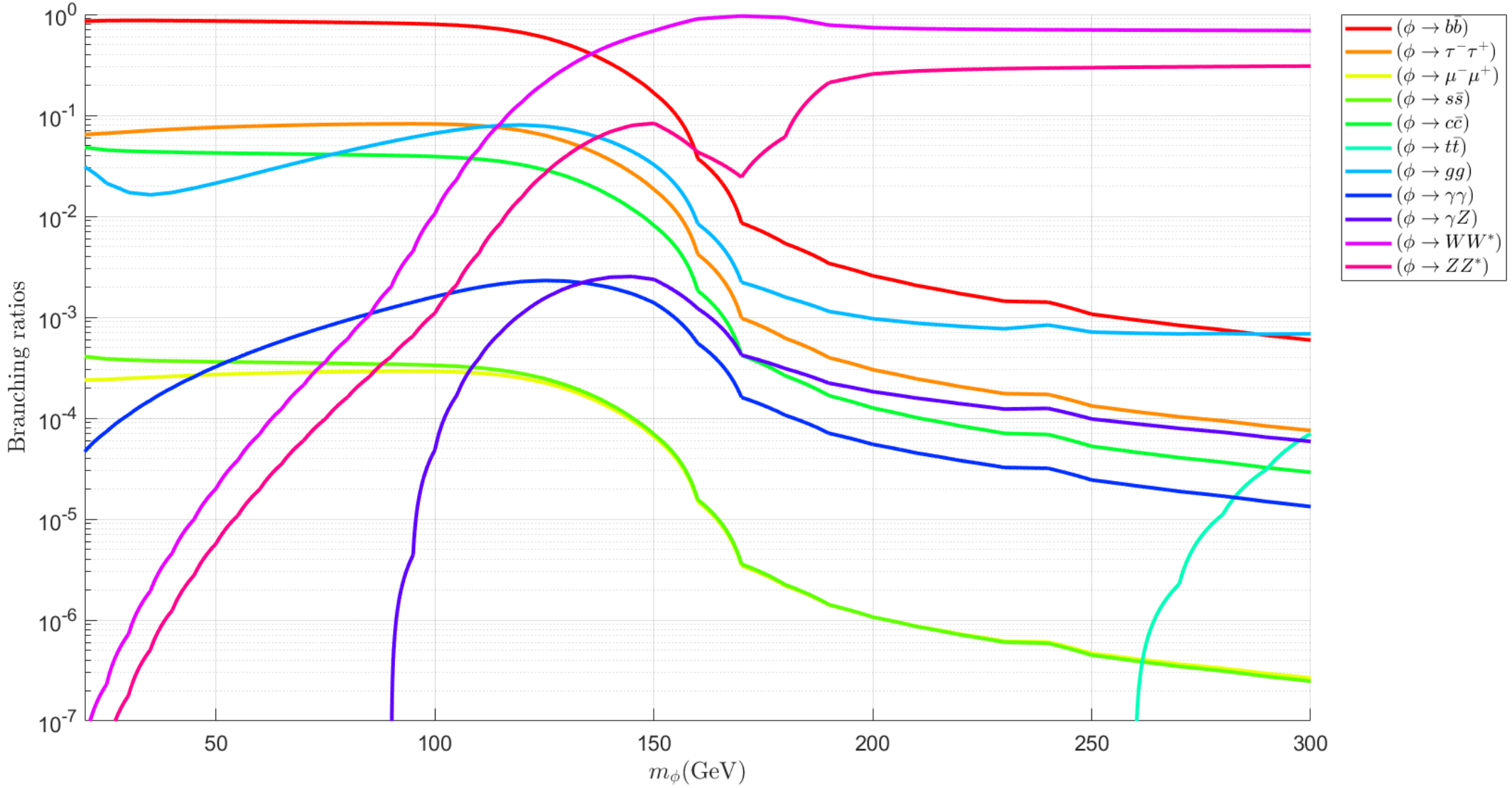
- Decay:

Decay mode	$b\bar{b}$	$c\bar{c}$	gg	$\tau^-\tau^+$	WW^*
Branching ratio	0.582	0.029	0.082	0.063	0.214
$(\Delta g_x/g_x)_h$ [%]	1.04	1.79	1.60	1.16	0.65
S/B	1/0.89	1/4.7	1/13	1/0.44	1/0.96

- Production:

Production mode	ZZ
$(\Delta g_Z/g_Z)_h$ [%]	0.66
S/B	1/2.0

Appendix III: Branching Ratios



Source: LHC Higgs Working Group. https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWGBRs