

The background features a 3D cutaway view of the ATLAS detector, showing its complex cylindrical structure with various internal components. Overlaid on this are several particle collision events, depicted as starburst patterns of lines radiating from a central point, representing the paths of particles produced in the collisions. The colors used for the detector and events include shades of blue, purple, green, and yellow.

# The indirect measurement on Charm quark and Higgs boson interaction with the ATLAS detector at the LHC

Qassem Awayies  
Supervised by,  
Petar Bokan and Valentina Cairo

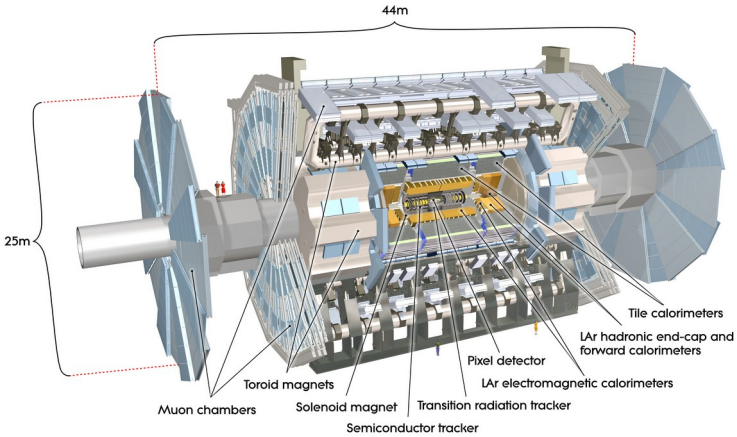


Run: 309092

Event: 4866214607

2016-07-16 06:20:19 CEST

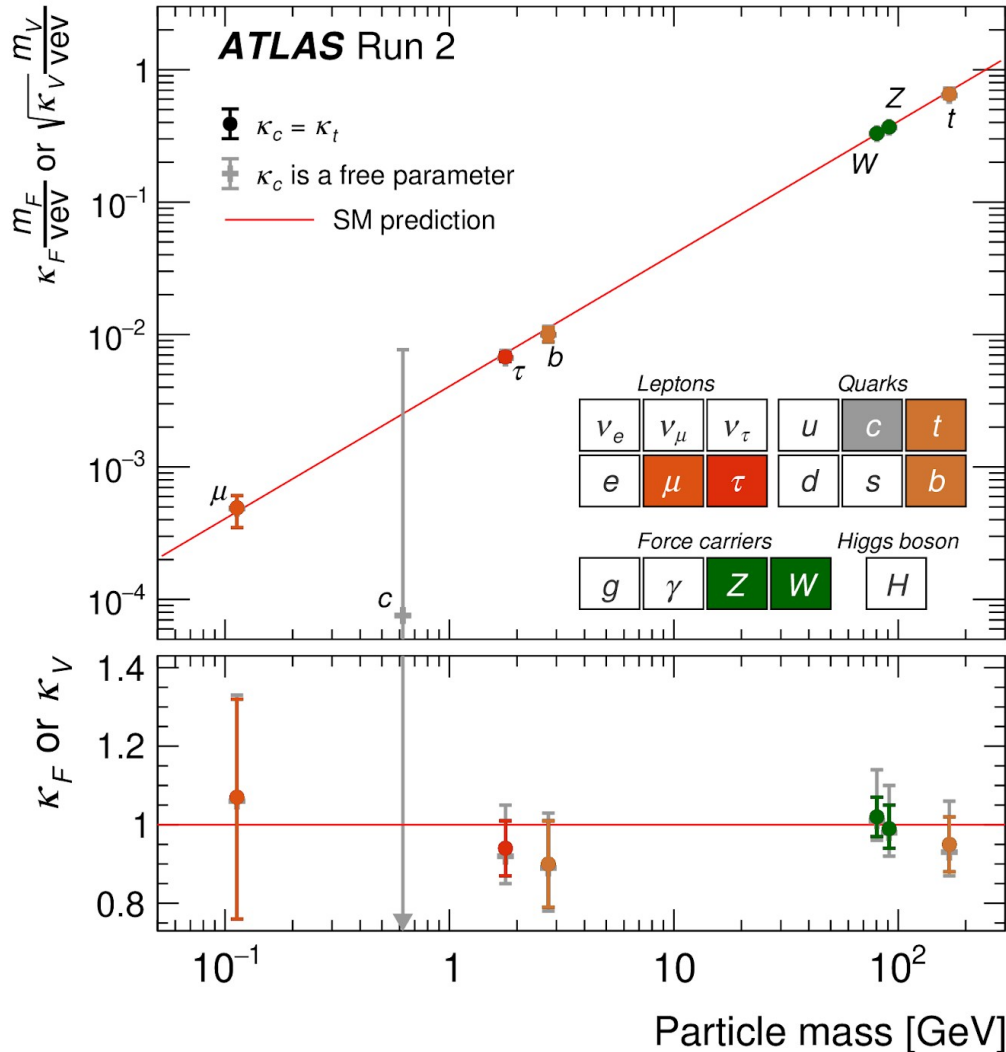
# Intro: ATLAS and the Standard Model of Particle physics



== ?

mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 125 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
<b>QUARKS</b>	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
<b>LEPTONS</b>	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	$\pm 1$	
	$1/2$	$1/2$	$1/2$	1	
	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	
					<b>GAUGE BOSONS</b>

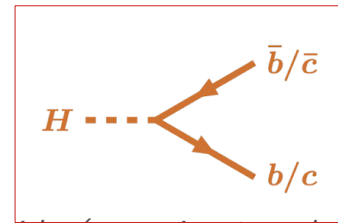
Do we observe the physics the standard model predicts?



**Higgs coupling strength is proportional to the mass of the particle it couples to.**

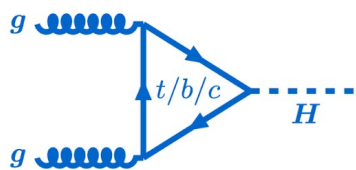
The lighter the particle the more difficult it is to measure its coupling strength.

A direct yet a challenging way to measure the Charm-Yukawa coupling:

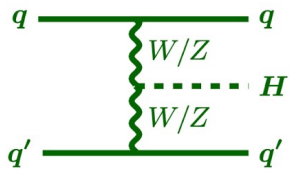


ATLAS  $H \rightarrow c \bar{c}$  analysis sets an upper limit on the  $y_c < 4.2 \times y_c^{SM}$  at 95% CL [HIGG-2020-20]

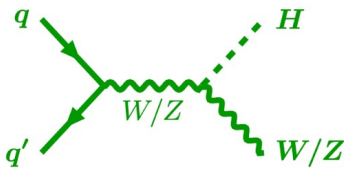
# Indirect Charm-Yukawa coupling



Gluon-gluon fusion (ggF)

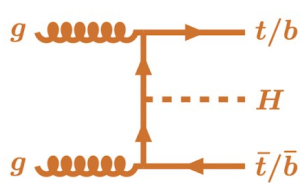
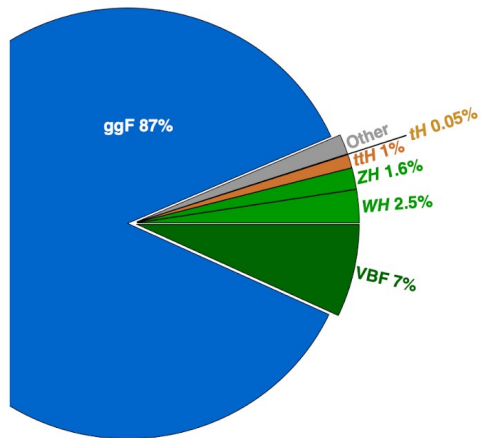


Vector boson fusion (VBF)

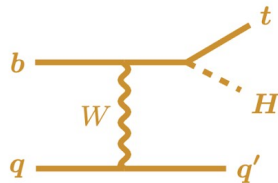


ZH/WH production

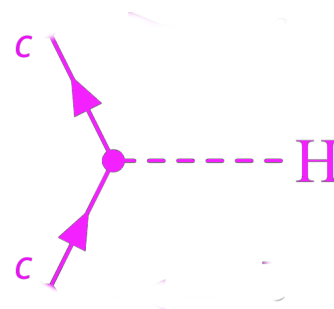
Charm Yukawa interaction affects the Higgs boson cross section



ttH production



tH production

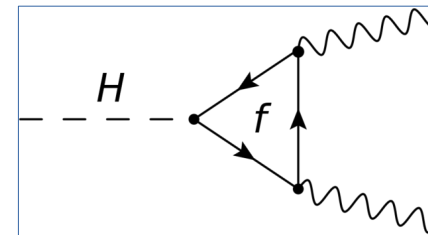


4 / 17

$$K_p = \frac{y_p}{y_p^{SM}}$$

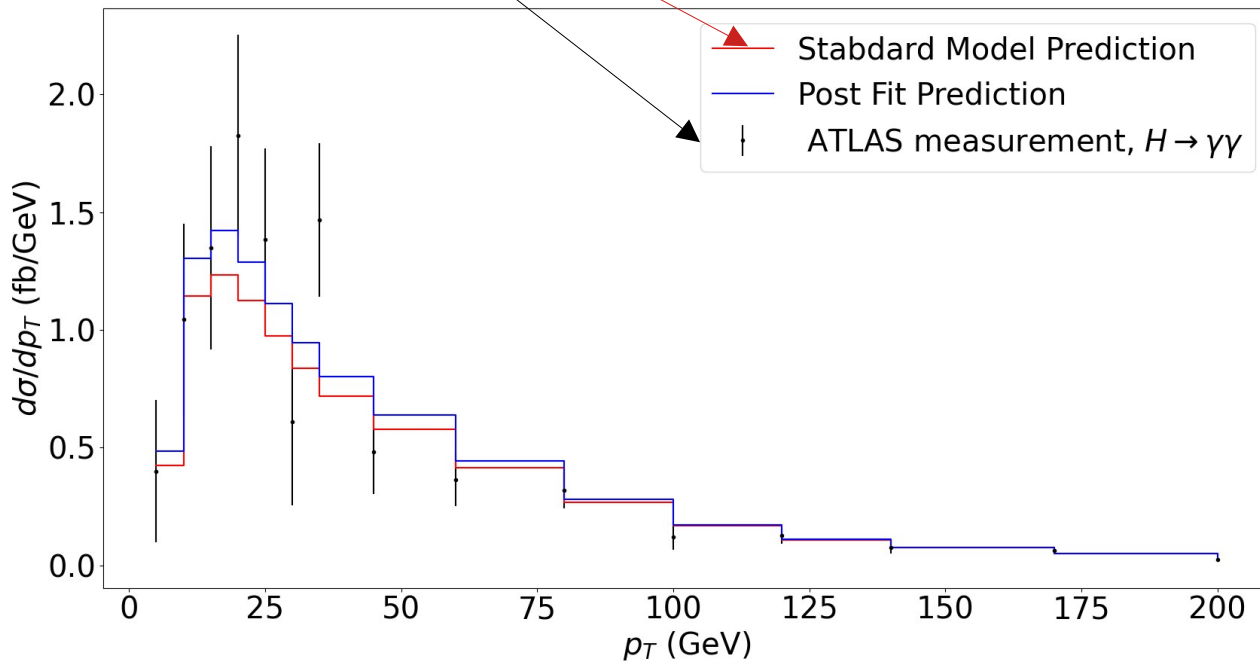
$$\begin{aligned} \sigma_{pp \rightarrow H}(K_b, K_c) &= \sigma_{ggF}(K_b, K_c) + \sigma_{b\bar{b} \rightarrow H}(K_b) + \sigma_{c\bar{c} \rightarrow H}(K_c) + \sigma_{ttH} + \sigma_{\text{other}} \\ &= K_t^2 \cdot (\sigma_{ggF}^{tt} + \sigma_{ttH}) + K_t \cdot K_b \cdot \sigma_{ggF}^{tb} + \underline{K_t \cdot K_c \cdot \sigma_{ggF}^{tc}} + K_b \cdot K_c \cdot \sigma_{ggF}^{bc} \\ &\quad + K_b^2 \cdot (\sigma_{ggF}^{bb} + \sigma_{b\bar{b} \rightarrow H}) + \underline{K_c^2 \cdot (\sigma_{ggF}^{cc} + \sigma_{c\bar{c} \rightarrow H})} + \sigma_{\text{other}} \end{aligned}$$

# Using differential Higgs boson cross-section measurements to constrain charm-Yukawa coupling

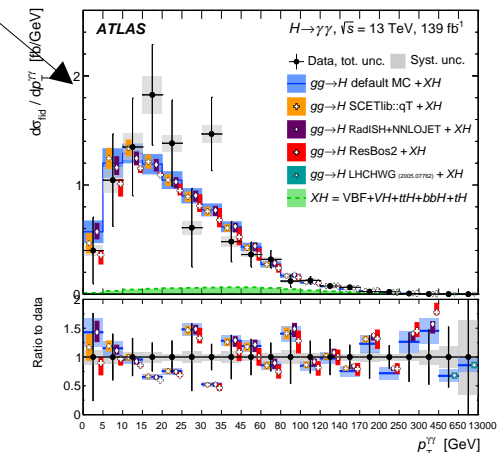


$$L(\kappa, \theta) = \exp\left(-\frac{1}{2} (x - \sigma(\kappa, \sigma))^T V^{-1} (x - \sigma(\kappa, \theta))\right) \times \prod_i \text{Gauss}(\theta_i; 0, 1)$$

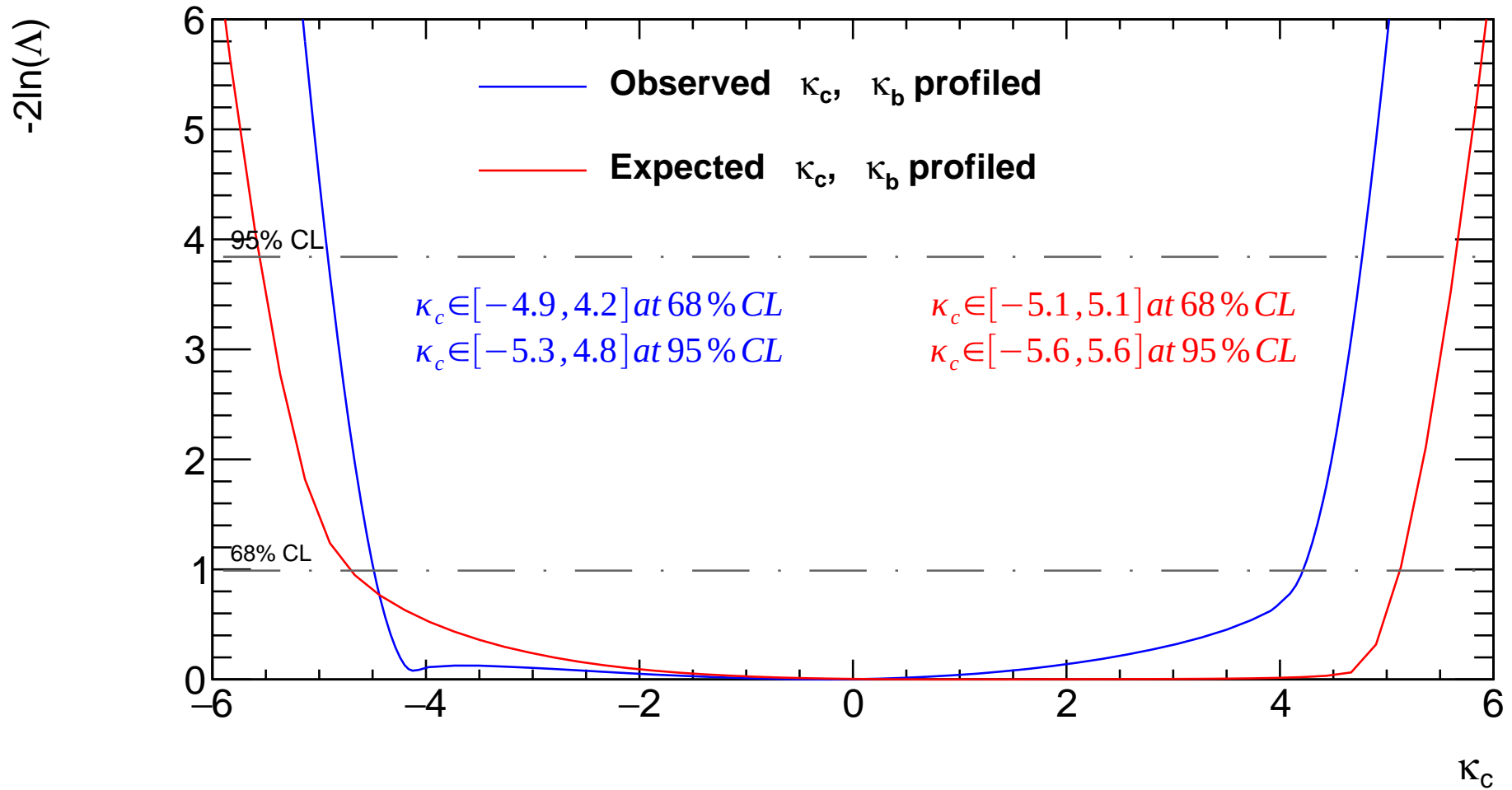
Measurement covariance matrix



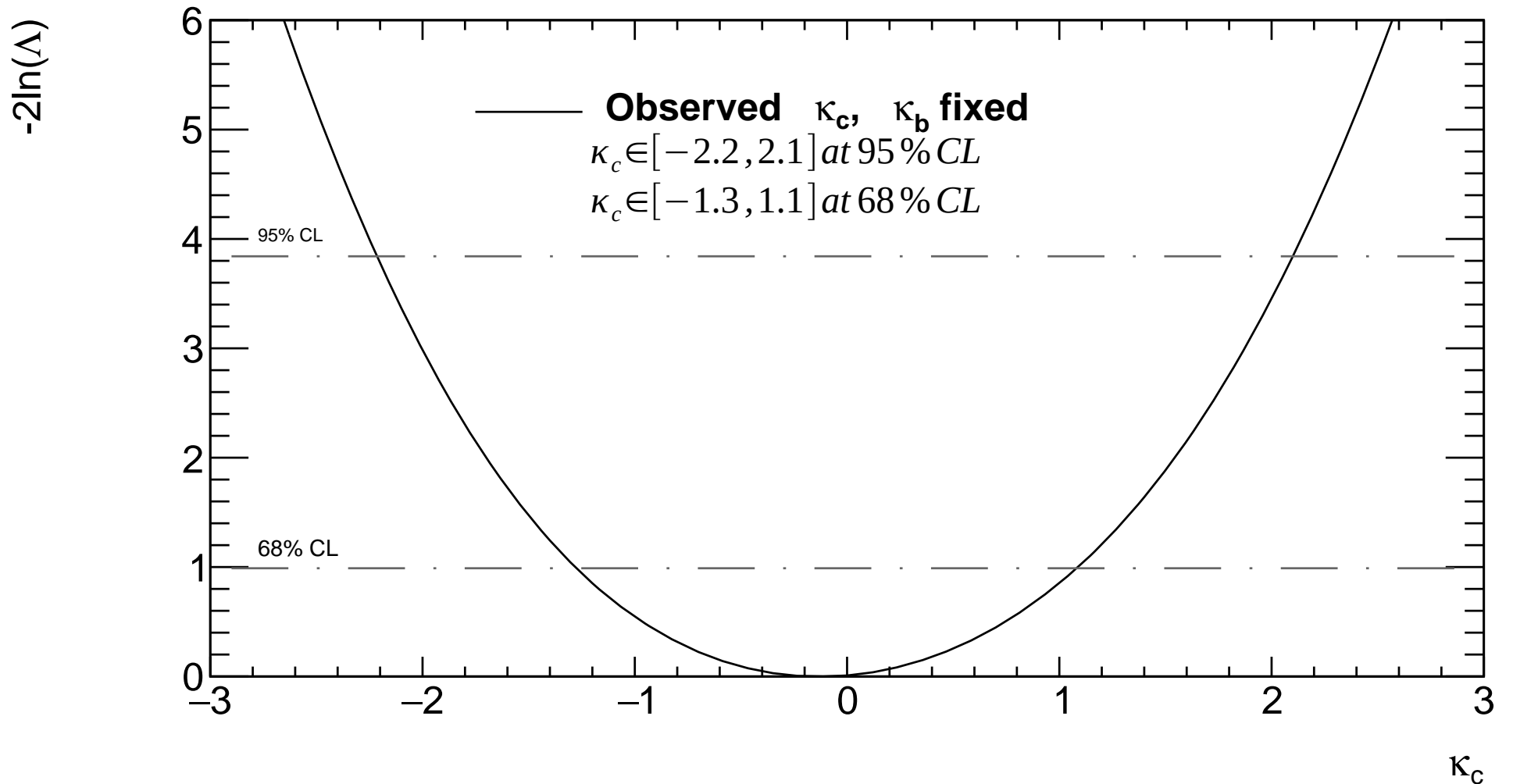
[https://doi.org/10.1007/JHEP08\(2022\)027](https://doi.org/10.1007/JHEP08(2022)027)



# Negative Log Likelihood scans (NLL)



# Negative Log Likelihood scans (NLL)



systematic uncertainties not implemented\*

# Conclusion

- The coupling strength of the Higgs boson to other particles depend on the mass, and hence the difficulty of studying the Charm Yukawa coupling, especially with its challenging decay channel.
- I investigate how to set indirect constraints on the interaction between charm quarks and Higgs bosons by carrying a detailed analysis of the Higgs boson differential cross-section measurements in the  $H \rightarrow \gamma\gamma$  final state
- When we assume  $\kappa_b=1$  and  $\kappa_t=1$ (Standard Model prediction), the constraints, we obtain  $[-2.2, 2.1]$  at 95% CL.
- When we treat also  $\kappa_b$  as a free parameter, we obtain  $[-5.3, 4.8]$  at 95% CL.
- Next steps are to study further the model dependence of our results, the impact of systematic uncertainties and to understand how the results are expected to improve with more data.