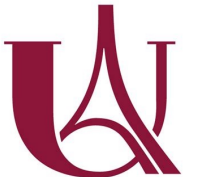


Higgs Physics at Complementary Collider, with the **search at LHC for double-Higgs production for the measurement of the Higgs self-coupling**, and **prospects for Higgs mass and self-coupling measurements at the Future Circular Collider in e^+e^- collision**

Tom Fournier

Supervised by Gregorio Bernardi

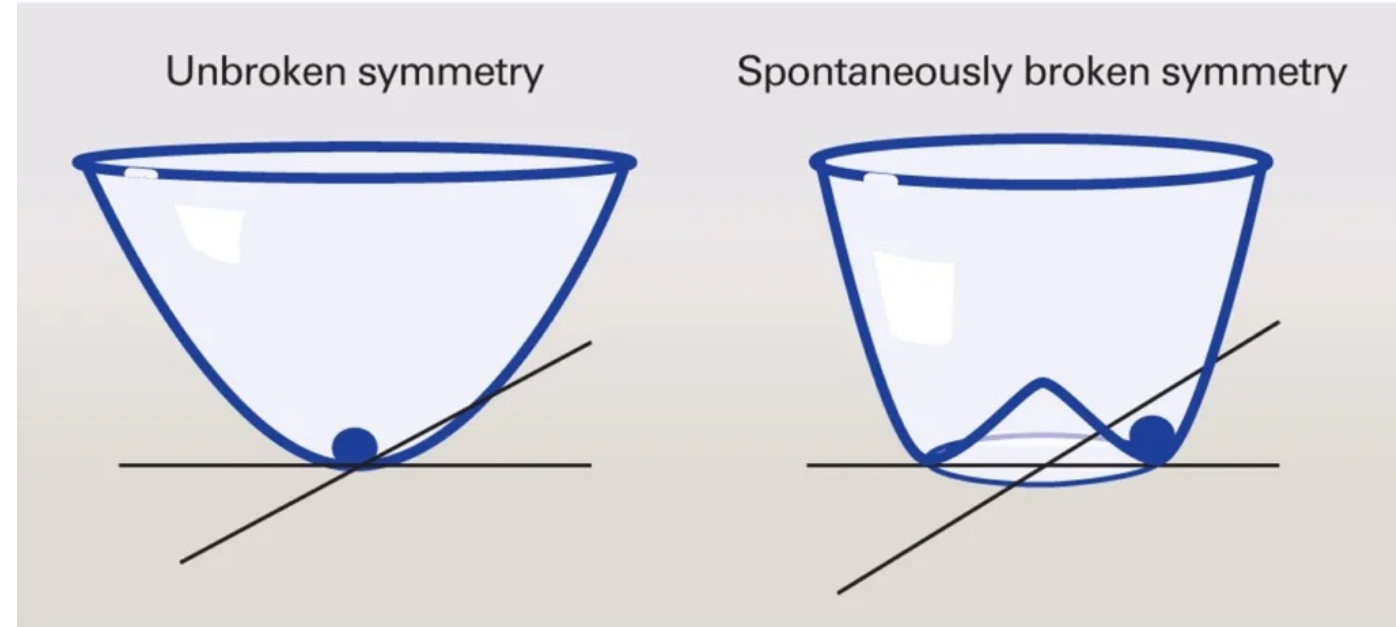
Thesis presentation: Biennale



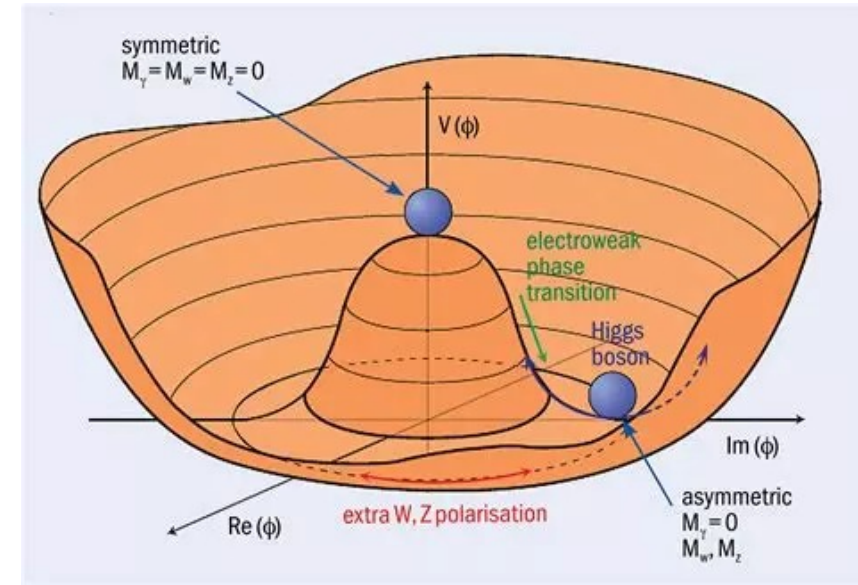
Introduction

Standard Model of Elementary Particles

| three generations of matter (fermions) | | | interactions / force carriers (bosons) | |
|--|---|---|---|--|
| | | | SCALAR BOSONS | |
| I mass $\approx 2.16 \text{ MeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ u up | II mass $\approx 1.273 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ c charm | III mass $\approx 172.57 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ t top | 0 0 1 g gluon | $\approx 125.2 \text{ GeV}/c^2$ 0 0 H higgs |
| QUARKS mass $\approx 4.7 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ d down | mass $\approx 93.5 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ s strange | mass $\approx 4.183 \text{ GeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ b bottom | 0 0 1 γ photon | |
| mass $\approx 0.511 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ e electron | mass $\approx 105.66 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ μ muon | mass $\approx 1.77693 \text{ GeV}/c^2$ charge -1 spin $\frac{1}{2}$ τ tau | 0 1 Z Z boson | |
| LEPTONS mass $< 0.8 \text{ eV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_e electron neutrino | mass $< 0.17 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_μ muon neutrino | mass $< 18.2 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_τ tau neutrino | $\approx 80.3692 \text{ GeV}/c^2$ ± 1 W W boson | GAUGE BOSONS VECTOR BOSONS |



Higgs potential after EWSB:
$$V(h) = \frac{1}{2} m_H h^2 + \lambda_3 v h^3 + \frac{1}{4} \lambda_4 h^4$$



- m_H : already measured at 125 GeV
- λ_3 : not measured yet but constrained in LHC
- λ_4 : not measured, very poorly constrained in LHC

Introduce the coupling modifier: $\kappa_\lambda = \frac{\lambda_\lambda}{\lambda_\lambda^{SM}}$ (in the SM, $\kappa_\lambda = 1$)

One of the main goals in Higgs physics is to measure κ_λ

Why do we want to measure κ_λ ?

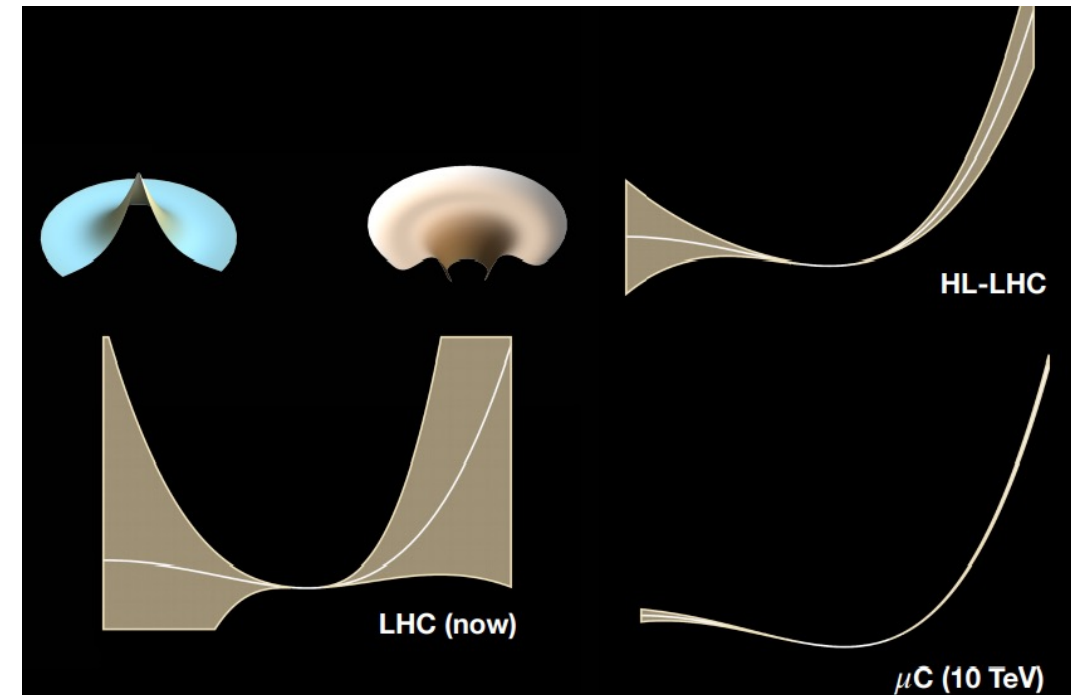
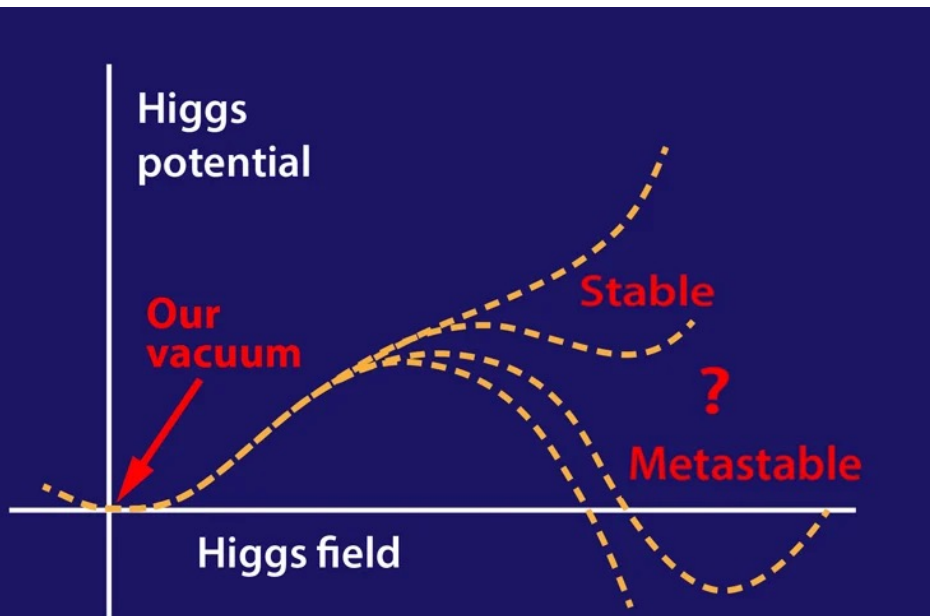
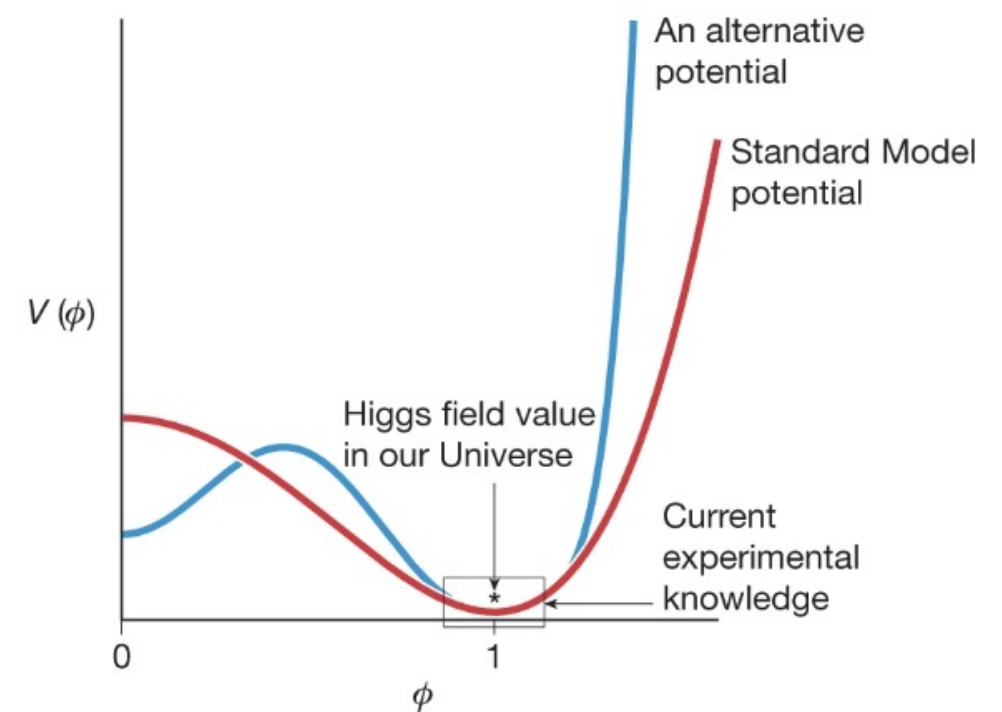
Obvious answer: To test the Standard Model predictions

Less obvious answer:

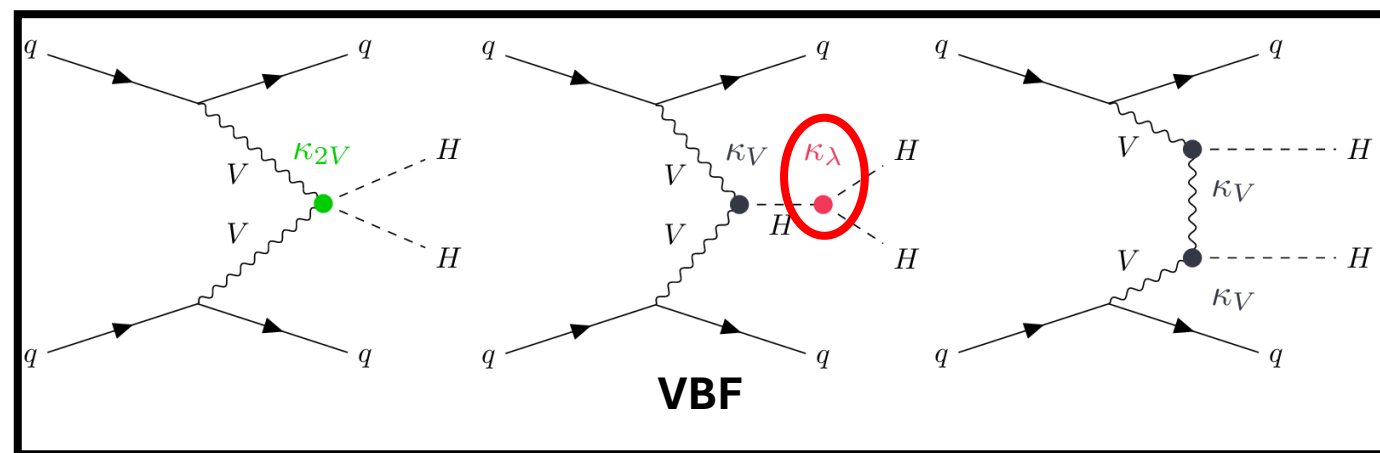
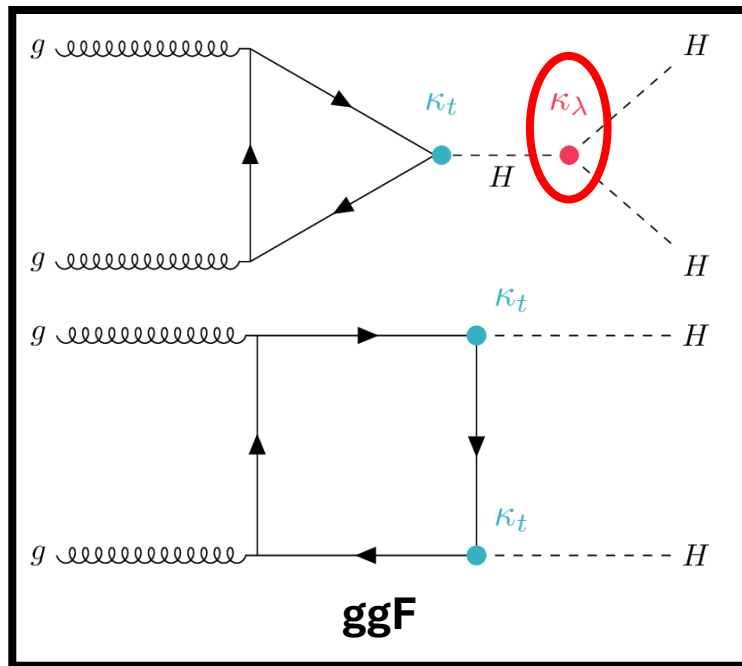
Open questions in the Standard Model

- Origin of mass
- Baryogenesis
- Hierarchy problem
- Stability of the vacuum
- Dark matter

Measuring κ_λ and the other Higgs properties could answer these questions



ATLAS part of the thesis



Analysis separated in different channels:

$HH \rightarrow b\bar{b}b\bar{b}$, $HH \rightarrow b\bar{b}\tau^+\tau^-$, $HH \rightarrow b\bar{b}\gamma\gamma$

| | bb | WW | $\tau\tau$ | ZZ | $\gamma\gamma$ |
|----------------|-------|-------|------------|--------|----------------|
| bb | 34% | | | | |
| WW | 25% | 4.6% | | | |
| $\tau\tau$ | 7.3% | 2.7% | 0.39% | | |
| ZZ | 3.1% | 1.1% | 0.33% | 0.069% | |
| $\gamma\gamma$ | 0.26% | 0.10% | 0.028% | 0.012% | 0.0005% |

$HH \rightarrow b\bar{b}b\bar{b}$:

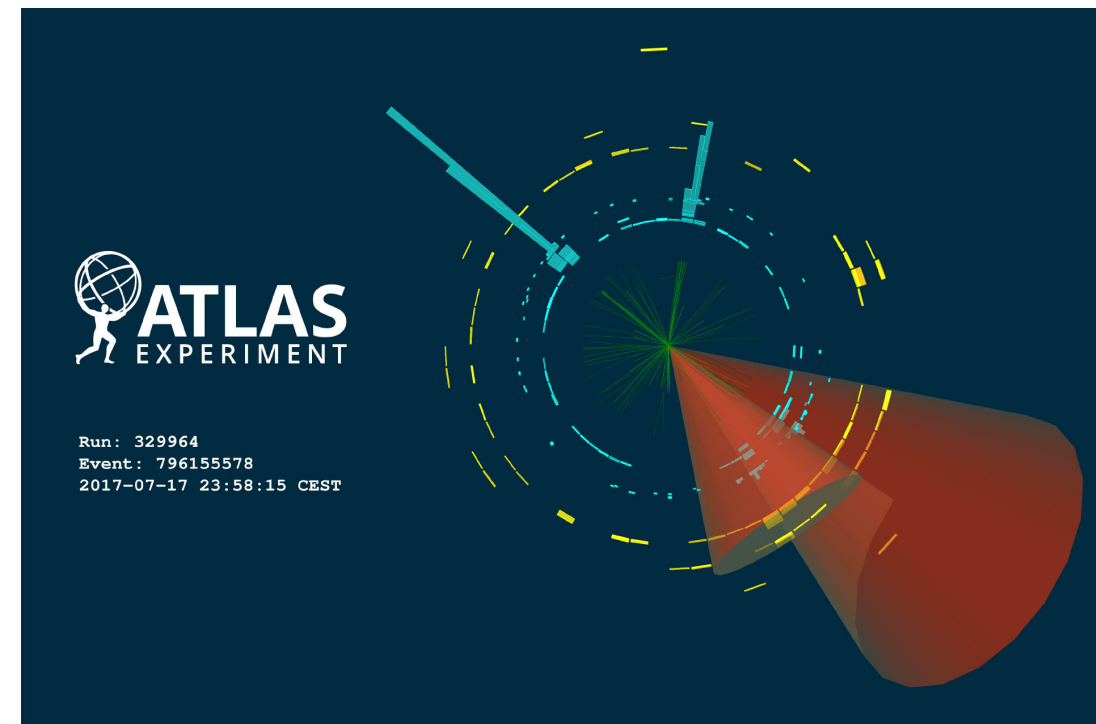
- High branching ratio
- High background

$HH \rightarrow b\bar{b}\tau^+\tau^-$:

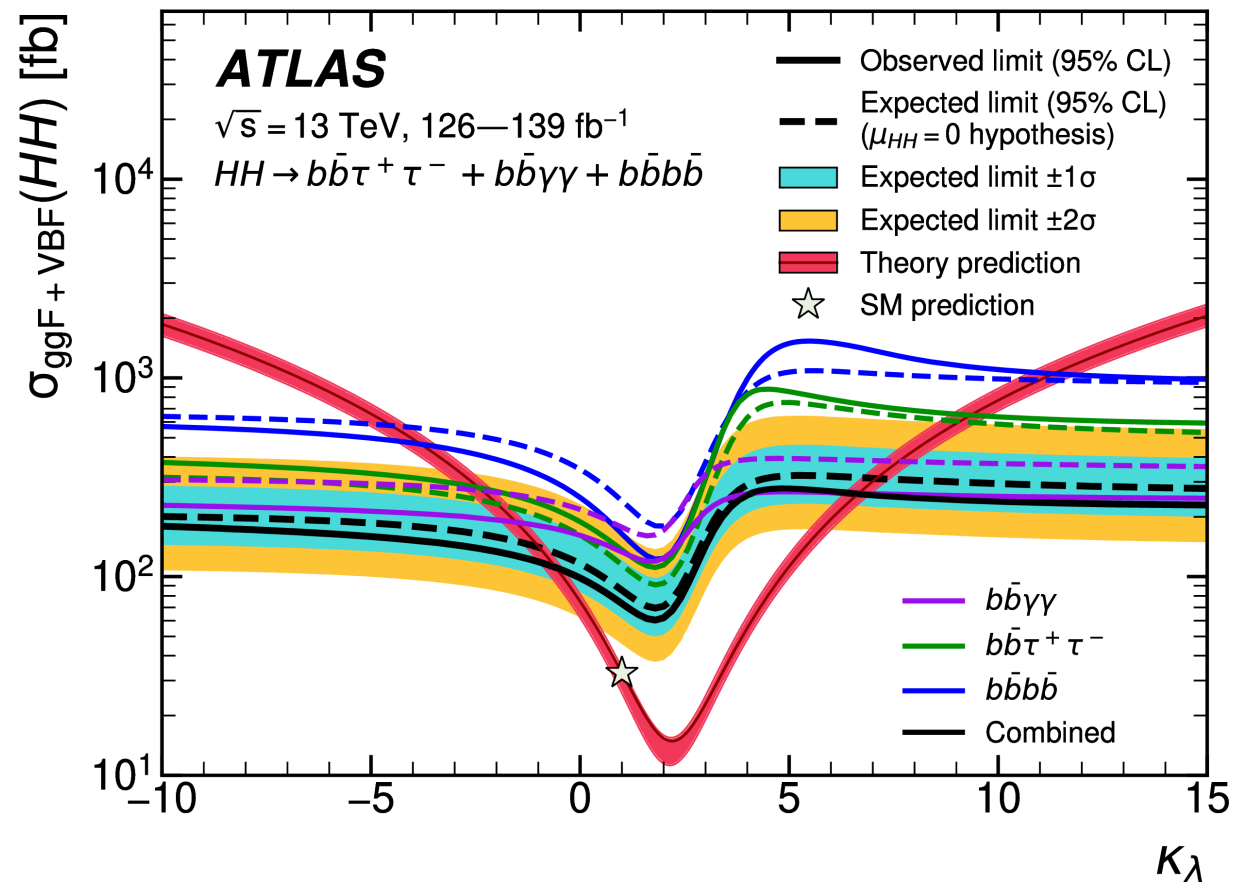
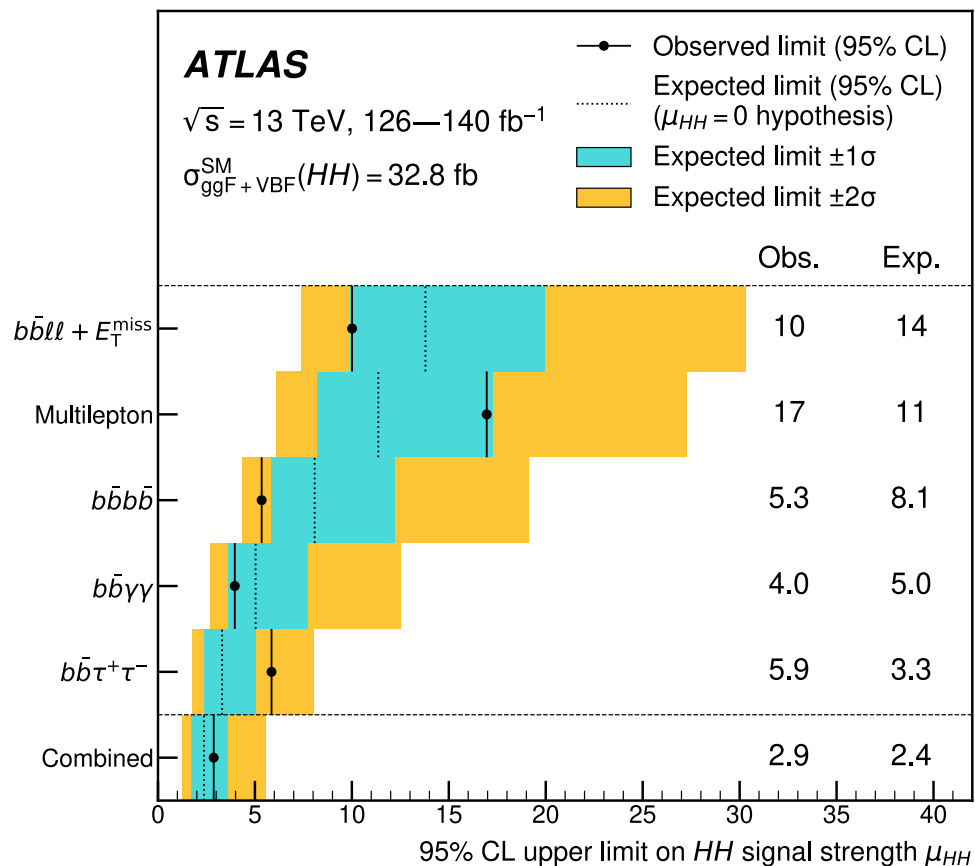
- Medium branching ratio
- Medium background

$HH \rightarrow b\bar{b}\gamma\gamma$:

- Low branching ratio
- Low background



ATLAS part of the thesis



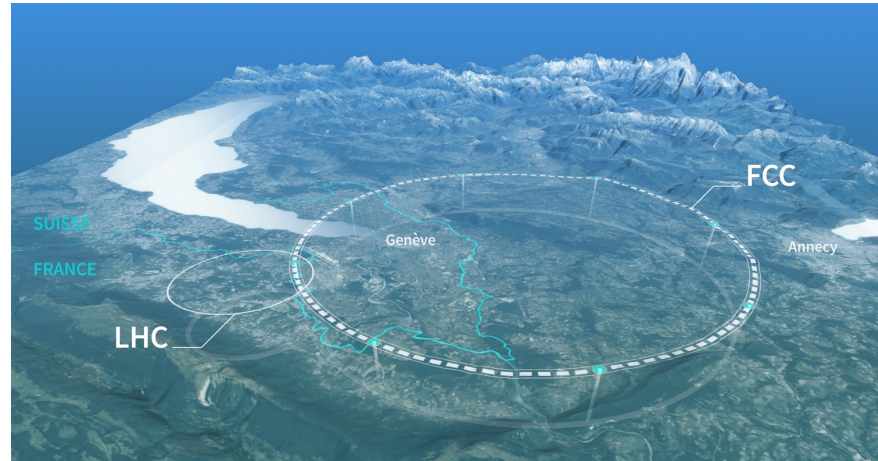
Currently:

- Di-Higgs production not currently observed
- Can only put upper limit on the production cross-section
 - Current limit: $\mu_{HH} < 2.9(2.4)$
- This limit can constrain κ_λ
 - Current constrain: $-1.2 < \kappa_\lambda < 7.2$ ($-1.6 < \kappa_\lambda < 7.2$)

My works is to contribute to the $HH \rightarrow b\bar{b}\tau^+\tau^-$ analysis

- Will start contributing next year
- Currently doing a qualification task to become an ATLAS author

FCC part of the thesis



| Working point | Z pole | WW thresh. | ZH | t \bar{t} | |
|--|----------------------|----------------------|---|--|------|
| \sqrt{s} (GeV) | 88, 91, 94 | 157, 163 | 240 | 340–350 | 365 |
| Lumi/IP ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$) | 140 | 20 | 7.5 | 1.8 | 1.4 |
| Lumi/year (ab^{-1}) | 68 | 9.6 | 3.6 | 0.83 | 0.67 |
| Run time (year) | 4 | 2 | 3 | 1 | 4 |
| Integrated lumi. (ab^{-1}) | 205 | 19.2 | 10.8 | 0.42 | 2.70 |
| Number of events | 6×10^{12} Z | 2.4×10^8 WW | 2.2×10^6 ZH + 65k WW \rightarrow H | 2×10^6 t \bar{t} + 370k ZH + 92k WW \rightarrow H | |

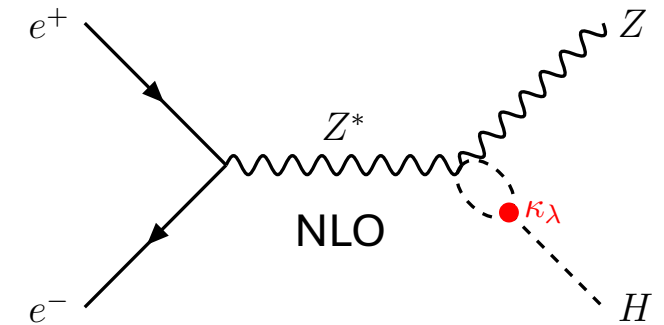
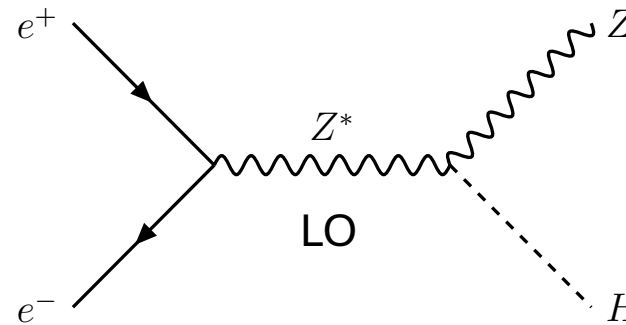
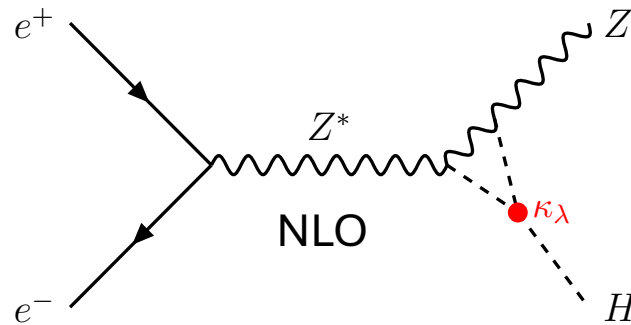
FCC is a candidate to replace LHC, it is separated in 2 phases:

- FCC-ee: e^+e^- collisions at different \sqrt{s}
- FCC-hh: pp collisions at $\sqrt{s} = 85 \text{ TeV}$

Higgs properties measurable through ZH production cross-section

- Higgs coupling g_{HXX}
- Higgs width: Γ_H
- Higgs mass m_H
- Higgs self-coupling κ_λ

- **Future Circular Collider (FCC)**
Circumference: 90 -100 km
Energy: 100 TeV (pp) 90-350 GeV (e^+e^-)
- **Large Hadron Collider (LHC)**
Large Electron-Positron Collider (LEP)
Circumference: 27 km
Energy: 14 TeV (pp) 209 GeV (e^+e^-)
- **Tevatron**
Circumference: 6.2 km
Energy: 2 TeV (pp)



FCC part of the thesis

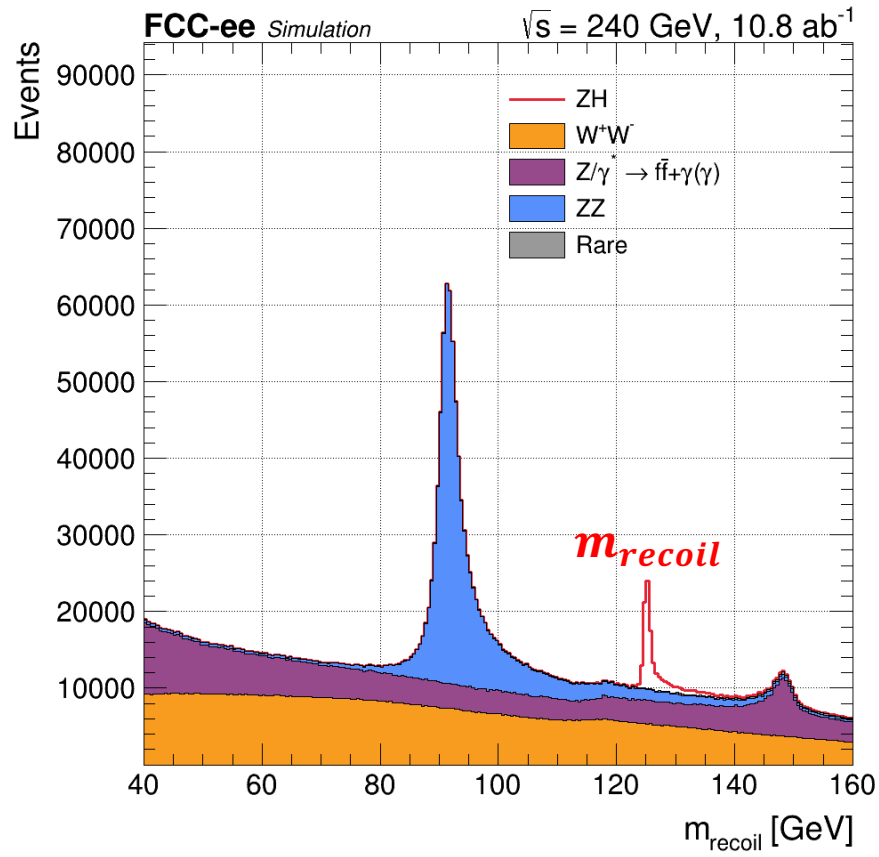
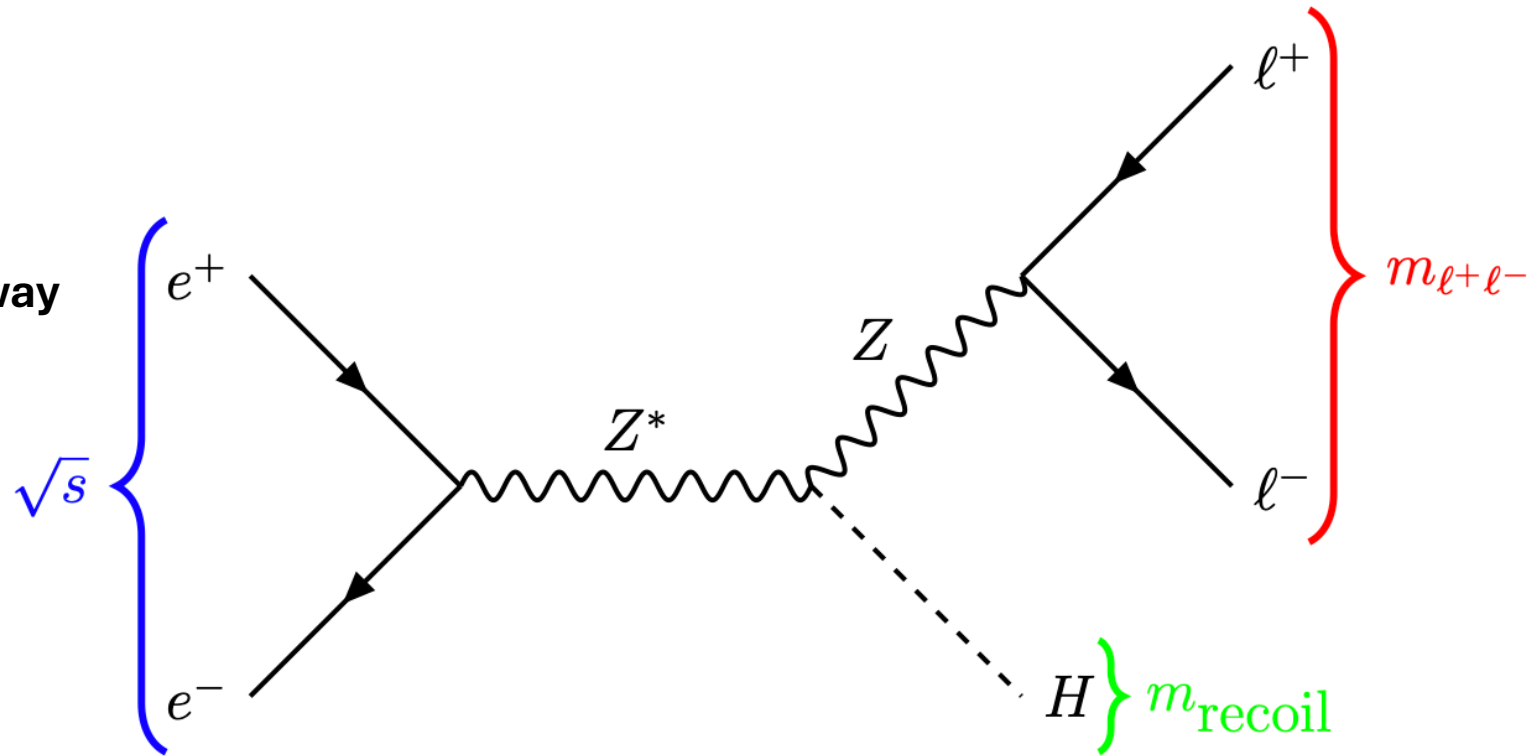
Initial state known → can use recoil mass

method: $m_{recoil}^2 = s - 2\sqrt{s}E_{\ell^+\ell^-} + m_{\ell^+\ell^-}^2$ to

reconstruct the Higgs in **model-independent way**

Analysis separated in three channels:

- $Z(\mu^+\mu^-)H, Z(e^+e^-)H \rightarrow$ leptonic channel
- $Z(q\bar{q})H \rightarrow$ hadronic channel



My work consists in improving this selection

- Done for the leptonic channel ($\sim 20\%$ improvement)
- Currently doing the hadronic channel

After this:

- Work with full simulation
 - To reconstruct the detector's effect
 - To optimize the detector's design
- Improve the Higgs mass measurement analysis

Thanks for listening