Improving the sensitivity of the trilinear Higgs boson self-coupling measurement in the bbττ decay channel at the HL-LHC and FCC-hh

Bastien Voirin Supervised by Claude Charlot at LLR

> LLR Interns Seminar June 2025

Anderson-Brout-Englert-Guralnik-Hagen-Higgs-Kibble-'t Hooft mechanism (1964)

- masses of W^{\pm} and Z^0 gauge bosons (+ quarks + charged leptons)
- electroweak unification/symmetry breaking at the Fermi scale ($\sim 10^2 \, {
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SM Higgs field (4 degrees of freedom)

 $\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \varphi_1 + \mathrm{i}\varphi_2 \\ \varphi_3 + \mathrm{i}\varphi_4 \end{pmatrix}$

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- $\lambda = m_h^2/2v^2 \approx 0.129$ is **fully determined** by the
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- How? λ shows up in
 - *hhh* self-coupling $\lambda_{hhh}^{\mathrm{SM}} = \lambda v = m_h^2/2v$
 - *hhhh* self-coupling $\lambda_{hhhh}^{\text{SM}} = \lambda/4 = m_h^2/8v^2$

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Direct measurement through the **rate of** hh **production** as some of them come from $h \rightarrow hh$

Status of Higgs boson pair production at CMS (https://arxiv.org/abs/2207.00043)



 $h \rightarrow b\overline{b}$ has the largest branching ratio

 $b\overline{b} b\overline{b}, b\overline{b} \tau\tau, b\overline{b} \gamma\gamma, b\overline{b} WW, b\overline{b} ZZ$, and multilepton $WWWW, WW\tau\tau, \tau\tau\tau\tau$

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HL-LHC (3000 fb^{-1}) is expected to "establish the SM Higgs boson pair production with a significance of 4 s.d."

Gluon-gluon fusion (ggF) Higgs boson pair (*hh*) production at the leading order

Dominant *hh* production mode compared to vector boson fusion (VBF), WH/ZH (VH), ttH...



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Exploit kinematic characteristics to purify the "triangle" contribution from the total $gg \rightarrow hh$ process so that the number of observed $gg \rightarrow hh$ events becomes more sensitive to λ

Sample production

- MadGraph5_aMC@NLO (Monte Carlo event generator) for the
 - $gg \rightarrow hh \rightarrow b\bar{b}\tau^-\tau^+$ total process (triangle + box + interference)
 - $gg \rightarrow h^* \rightarrow hh \rightarrow b\bar{b}\tau^-\tau^+$ triangle contribution
 - $gg \rightarrow hh \rightarrow b\bar{b}\tau^-\tau^+$ box contribution (forbidden *s*-channel *h**)

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 - $gg \rightarrow bbZ(\tau\tau)$ background
 - $gg \rightarrow tt \rightarrow bW(\tau\nu) \, bW(\tau\nu)$ background

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- DelphesPythia for the hadronization and fast parametric detector simulation













Work In Progress (until August 8)

- Preselection (2 *b*-tagged jets, 2 τ leptons, $\tau_{had}\tau_{had}$ or $\tau_{had}\tau_{lep}$, p_{T}^{bb} , $p_{T}^{\tau\tau}$, ΔR ...)
- Fit and scan of negative log-likehood $-2\Delta \ln(L)$ over κ_{λ}
- *hh* vs. backgrounds discriminant
- *hh* triangle vs. other contributions (box, interference) discriminant

Testing the silicon readout electronics of the High-Granularity Calorimeter (HGCAL) endcaps for the CMS experiment at the HL-LHC

Bastien Voirin Supervised by **Amina Zghiche** at **CERN**

> LLR Interns Seminar June 2025

The High-Granularity Calorimeter (HGCAL) endcaps for CMS at the HL-LHC

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- **HL-LHC**, major upgrade of the LHC for the 2030s (way more data, finer η and ϕ segmentation)
- **HGCAL**, state-of-the-art electromagnetic and hadronic sampling calorimeter to replace the current CMS endcaps (seen below)





The High-Granularity Calorimeter (HGCAL) endcaps for CMS at the HL-LHC

- **CE-E** (electromagnetic) Silicon sensors
- **CE-H** (hadronic)

Silicon sensors (close to the interaction point) and plastic scintillators (far from the interaction point)





HGCAL silicon readout electronics

- 27,000 hexaboards and modules to assemble and test
 - in numerous hexaboard assembly facilities
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 - at the 2 cassette assembly factories (CERN and Fermilab)



Contribution 1/2 — development of the GUI from Alabama University

Hexaboard Testing GUI CERN Test Flow Live Outputs Test Area Board Identification Passed Current Time 2024-12-17 17:19:04.027768 The power supply should be disabled. Board Verification and HGCROCs Scanning Passed 320XLF42QH0000-20241217_171735 DUT Wait for Kria Passed Wait for Power Supply DAQ Client active (running) Passed Wait for BV Power Supply Passed I2C: active (OK) Kria DAQ: active (OK) Power Supply Enable Passed Power Supply Uninitialized I-V Curve / BV Power Supply Enable Passed Power (Default) 0.762W Kria Enable Passed Power (Configured) 3.415W Load Firmware Passed I2C Checker (Default) Passed Restart Services Passed I2C Checker (Configured) Passed Create Sockets Passed Pedestal Run Success Passed Check Power (Default) Passed Pedestal Run Corruntion Passed I2C Checker (Default) Passed Pedestal Run Dead Channels 0 Configure HGCROCs Passed Pedestal Run Noisy Channels 0 I2C Checker (Configured) Passed Pedestal Run Data Pedestal Run Plots Pedestal Scan Data vrefinv Data vrefnoinv Data I-V Curve Check Power (Configured) Passed Chip 0 Chip 1 Initialize Sockets Passed Normal channels Normal channels Pedestal Run 1 Passed Calibration channels Calibration channels Pedestal Scan Passed Common mode channe Common mode channel • vrefinf Dassed vrefnoinv Passed ومحرفته فتسترج ويترجون Pedestal Run 2 Passed . •. • Check BV Current Passed . . Check BV Voltage Dassed Check BV Result Passed 40 Channel Kria Dicable Daccord Chip 2 Power Supply Disable Passed Normal channels Cleanup + Upload Uninitialized Calibration channels Common mode cha • • Ongoing... Thread Finished ←←← check the Test Flow panel and the Timeout Abort Thread Continue...

Contribution 2/2 — module multiplexer board





return;