Higgs CP property measurement via Higgs-Vector boson coupling in high energy collider

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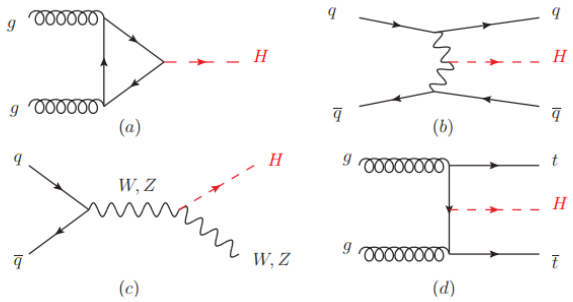
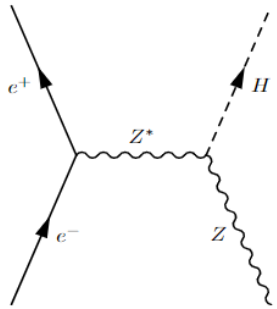
Introduction

Higgs production in LHC and CEPC

- At LHC(pp collider):

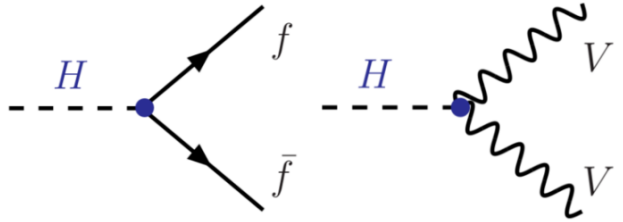


- At CEPC(e^+e^- collider):

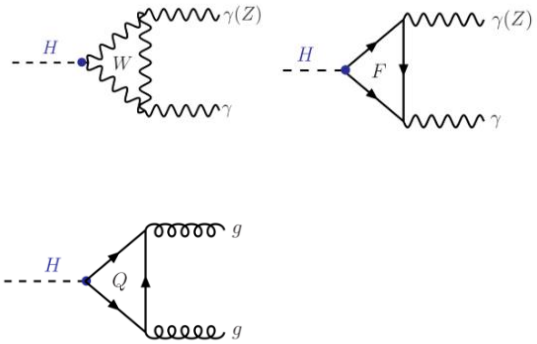


Higgs Decay

- Higgs decay to fermion pair and vector boson pair (Leading order)



- Higgs decay to $\gamma\gamma, Z\gamma, gg$



Introduction background

Standard Model Higgs: $J^{PC} = 0^{++}$.

Relative experiments in LHC:

- The hypothesis of spin-1 or spin-2 Higgs has been excluded by ATLAS and CMS at >99% CL in $\sqrt{s} = 7\&8$ TeV, 25fb-1 data.
- Totally CP-even Higgs also has been excluded, the CL depends on theory model (>95%). Ref: ATLAS Run1 Higgs spin/CP in H->VV
- SM+BSM Higgs CP mixing model is still under testing.

All in inclusive Higgs production mode(i.e. ggF dominant). Present results show the great agreement with SM Higgs.

VBF mode provides a glance for finding CP violation in Higgs-vector boson coupling.

First look for VBF Higgs: VBF $H \to \tau\tau$ analysis.

Introduction Theory

6-dimension Effective Lagrangian framework

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{f_{\tilde{B}B}}{\Lambda^2}\mathcal{O}_{\tilde{B}B} + \frac{f_{\widetilde{W}W}}{\Lambda^2}\mathcal{O}_{\widetilde{W}W} + \frac{f_{\tilde{B}}}{\Lambda^2}\mathcal{O}_{\tilde{B}}$$

$\mathcal{O}_{\tilde{B}}$ term is neglected based on LEP

$$= \mathcal{L}_{SM} + \boxed{\tilde{g}_{HAA}HAA + \tilde{g}_{HAZ}HAZ + \tilde{g}_{HZZ}HZZ + \tilde{g}_{HWW}HWW}$$

CP-odd operator

Only 2 of $\tilde{g}$ are independent due to constraints imposed by U(1)×SU(2) invariance, so express $\tilde{g}$ to $\tilde{d}$ and $\tilde{d}_B$:

$$\tilde{g}_{HAA} = \frac{g}{2m_W}(\tilde{d}sin^2\theta_W + \tilde{d}_B cos^2\theta_W),\ \tilde{g}_{HAZ} = \frac{g}{2m_W}sin2\theta_W(\tilde{d} - \tilde{d}_B),$$

$$\tilde{g}_{HZZ} = \frac{g}{2m_W}(\tilde{d}cos^2\theta_W + \tilde{d}_B sin^2\theta_W),\ \tilde{g}_{HWW} = \frac{g}{2m_W}\tilde{d}$$

In HIGZ basis: $\tilde{d} = \tilde{d}_B$, so that $\tilde{g}_{HAA} = \tilde{g}_{HZZ} = \frac{1}{2}\tilde{g}_{HWW} = \frac{g}{2m_W}\tilde{d},\ \tilde{g}_{HAZ} = 0$

Other Higgs interactions (fermion and gluon) are as predicted in SM.

Analysis in ATLAS

VBF Higgs CP test in $H \rightarrow \gamma\gamma$ channel in ATLAS experiment

- Study in $H \rightarrow \gamma\gamma$ final state

  Relatively clean background in p-p collider

  Good Higgs mass resolution

  Developed analysis framework and toolkit

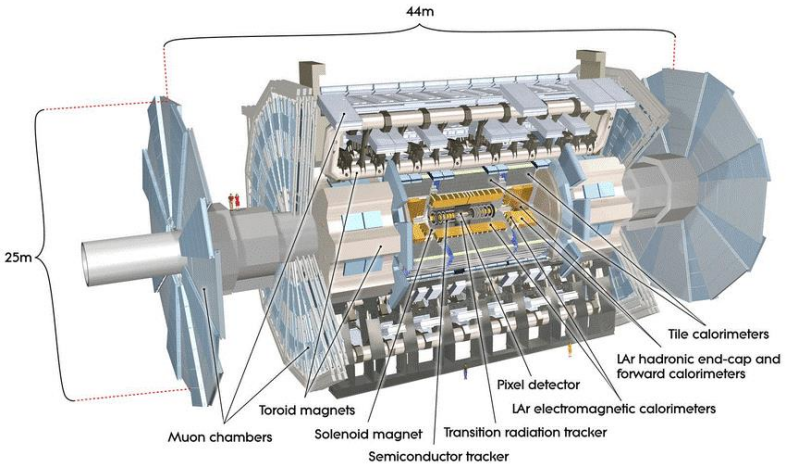
  Can probe Higgs-Vector boson coupling both in production and decay mode.

- Data and particle reconstruction

  Data in full ATLAS Run2 period ($139fb^{-1}$)

  Reconstructed with ATLAS software (athena)

  At least 2 photons and 2 jets in final state.



Analysis in ATLAS

BSM Effect in VBF $H \to \gamma\gamma$:

- VBF Higgs production:

  Increase VBF cross section.

  Some kinematic distribution, e.g. $\Delta\Phi_{jj}$, Optimal Observable.

  Independent CP-even observable *Optimal Observable* $OO_1 = \frac{2\Re(\mathcal{M}^*_{SM}\mathcal{M}_{CP-odd})}{|\mathcal{M}_{SM}|^2}$, which can be calculated with 4-vector of Higgs and 2 VBF jets by HAWK

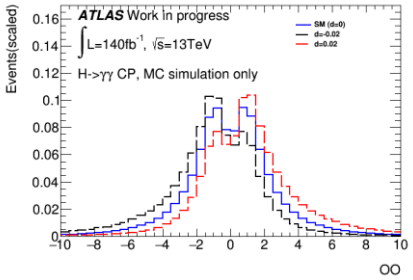
- $Br(H \to \gamma\gamma)$

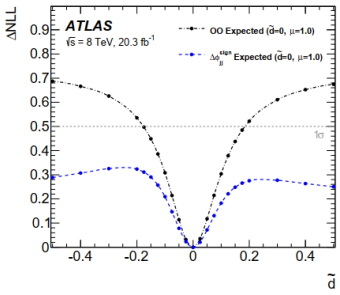
  Direct BSM Higgs-photon vertex.

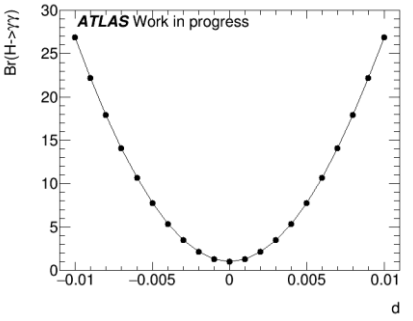
- Basic strategy:

  Only use shape to avoid other operator effects.

  Use shape + normalization for full EFT test.



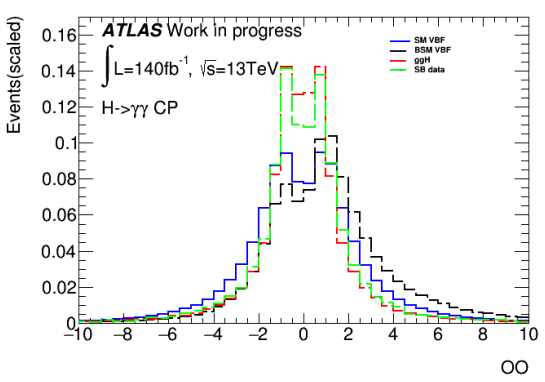




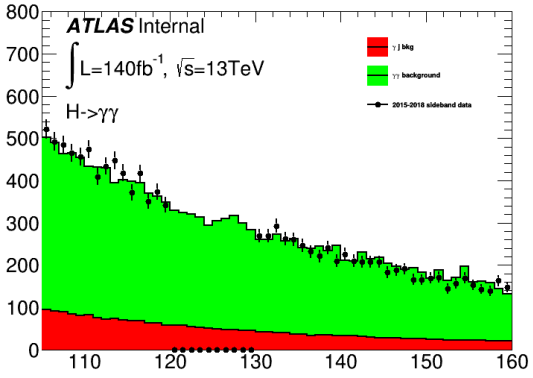
Analysis in ATLAS

Analysis strategy

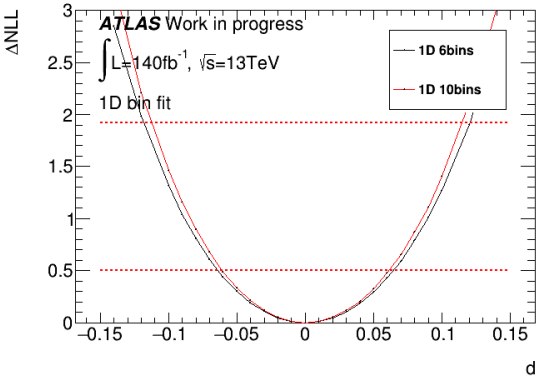
- Divide events into several bins based on *Optimal Observable.*
- Model $m_{\gamma\gamma}$ shape with Monte Carlo and control region data.
- Perform a maximum likelihood fit in CP-mixing parameter $\tilde{d}$.



Optimal Observable distribution for SM VBF, BSM VBF, ggF, background process.



$m_{\gamma\gamma}$ distribution for side-band data and MC simulation.



NLL curve for maximum likelihood fit.

Analysis in ATLAS

Facing challenge

- Analysis optimization: binning, modelling, etc.
- Background modelling: restricted by CR data statistics.
- Systematic uncertainty from new model and new observable.

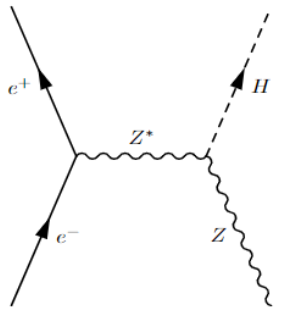
Expect result

- Without normalization: a reasonable result with full Run2 data.
- With normalization: the most precise restriction in BSM Higgs-Vector Boson coupling ($Br(H \to \gamma\gamma)$ provides most contribution).

Analysis in CEPC

Similar strategy could be performed in CEPC

- Dominant Higgs production in CEPC: $ee \rightarrow ZH$
- Introduce *Optimal Observable* in CEPC analysis, see it's performance.
- Use Monte Carlo simulation to get an expected measurement precision in future CEPC experiment.



Working list

- Migrate HAWK to CEPC condition.
- Choose one(or more) best channel for CP study.
- Perform analysis like did in ATLAS experiment.
- Combine the result in different channels.