Prospects on HH production at the HL-LHC with the CMS experiment

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Double Higgs production

- Direct access to Higgs self-coupling \( \lambda \)
- Probe scalar potential structure!

Destructive interference
- Small cross-section: 40 fb @ 14 TeV
- Strong variations if \( \lambda \neq \lambda_{SM} \)

- Dominated by gluon fusion:

Current CMS double Higgs results

- Variety of final states probed
  - Maximise sensitivity
- Run I result: \( \exp./\text{obs.}\) limit \( \sigma < 47 \pm 43 \times \sigma_{SM} \)
- Run II: no excess seen, limits on \( \mu \sigma_{SM} \)

Final state: \( b \bar{b}VV (l\nu l\nu) \)

- Expression obs./exp.: 16/19
- Search for deviations from SM signal kinematics
- Dependence on \( \kappa_l = \lambda/\lambda_{SM} \)

- Need much more data to constrain \( \lambda \)!

CMS Phase II Upgrade

- HL-LHC: 3000 fb\(^{-1}\) with \( L_{\text{int}} \approx 5 \times 10^{33} \text{cm}^{-2}\text{s}^{-1} \)
- Run I - II - III radiation damage
  - New detector needed
- Maintain current performances despite <PU> ~ 140 - 200
- Extended acceptance

Dedicated upgrade studies

Follow upgrade Technical Proposal (TP) – <PU> = 140, 3000 fb\(^{-1}\)

1) \( b \bar{b}VV \) final state:
- Backgrounds: multi-jet + photons, \( t\bar{t}(\gamma) \), single Higgs
- MC truth smeared & re-weighted
- 2D parametric fit on signal vs. background
- 1.6 sigma signal significance, 67% precision on \( \sigma_{SM} \)

2) \( \ell\ell\ell \) final state:
- Backgrounds: \( Z+V, Z+\ell, VV \), single Higgs, multi-jet assumed negligible
- DELPHES fast simulation tuned to full sim.
- Crucial: jet PU (incl. M_{t\ell}, resolution), track trigger
- Signal extraction: MT variable, (t_{MT}, bDT (t_{MT}))
- 0.9 sigma, 105% precision on \( \sigma_{SM} \)

Combine \( b \bar{b}VV \) and \( \ell\ell\ell \): 1.9 sigma, 54% prec. on \( \sigma_{SM} \)

3) \( b \bar{b}VV \) final state (l\nu l\nu and l\nu l\nu):
- Only \( \ell \) dominant background considered
- DELPHES simulation tuned to full sim.
- BDT (l\nu l\nu) and ANN (l\nu l\nu) discriminant
- Promising channels for combination

Conclusions

- Double Higgs production: Crucial channel at HL-LHC
- Dedicated studies, projections of existing analyses
  - Estimate ultimate sensitivity & identify bottlenecks
- Even with 3000 fb\(^{-1}\), observation challenging! Will require:
  - Combination of several final states (new channels being considered)
  - Maximised signal acceptance
  - Keeping theory & experimental systematics in check

References

- CMS-PAS-TOP-15-002: Higgs pair production at the High Luminosity LHC
- CMS-PAS-TOP-16-002: Projected performance of Higgs analyses at the HL-LHC for 2016 CMS-TOP-15-001: A search for Higgs boson pair production in the diboson final state in proton-proton collisions at \( \sqrt{s} = 13 \text{ TeV} \)
- CMS-PAS-HIG-17-002: Search for non-resonant and resonant Higgs pair production in the diboson final state in proton-proton collisions at \( \sqrt{s} = 13 \text{ TeV} \)
- CMS-PAS-HIG-17-001, Search for non-resonant production of Higgs bosons in the diboson final state with 13 TeV CMS data
- CMS-PAS-HIG-17-001, Search for Higgs boson pair production in the final state containing two photons and two bottom quarks in proton-proton collisions at \( \sqrt{s} = 13 \text{ TeV} \)
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- CMS-PAS-EXO-14-002, Search for direct Production of a long-lived spin-2 object in the diboson final state with 20 fb\(^{-1}\) of 8 TeV LHC data
- CMS-PAS-EXO-14-001, Search for a long-lived spin-2 object in the diboson final state with 300 fb\(^{-1}\) of 8 TeV LHC data
- CMS-PAS-EXO-13-001, Search for a long-lived spin-2 object in the diboson final state with 470 fb\(^{-1}\) of 8 TeV LHC data
- CMS-PAS-EXO-12-001, Search for direct Production of a long-lived vectorlike lepton in diboson final state with 416 fb\(^{-1}\) of 7 TeV LHC data

Extrapolation of Run II analyses

- Results on 2015 data @ 13 TeV (2.3 - 2.7 fb\(^{-1}\)) projected to \( L_{\text{int}} \approx 3000 \text{ fb}^{-1} \)
- > 13 - 14 TeV: \( \sigma_{SM} \) increase by 18%, scale backgrounds same factor (pessimistic)
- Increased acceptance not considered (pessimistic)
- Scenarios assumed for systematic uncertainties:
  1) Static only: 2 scale yields with \( \lambda_{SM} \) variations
  2) ECA16 S5:
    - Theory uncertainties reduced by 50% on efficiency
    - Experiment systematic:
      - Reduced with luminosity
      - Lower limit on estimated detector performance
  3) ECA16 S5 = \( b \bar{b}VV \) only:
    - \( S2 \) Impact of <PU> ~ 200 & detector upgrades on photon performance (efficiency, resolution, fake rate)
    - Explicitly taken into account

Photon reconstruction:
- Majority of signal in top, balance
- Performance similar to current detector
- Timing capabilities
- Vertex finding degradation (PU) mitigated
- Material/HL resolution

Main backgrounds: Est. from data
- Stat. uncertainty only (scaled with L)

Vehicle Tracking:
- Inner Tracker:
  - High granularity, low material budget
  - Coverage up to 0.9
- Triggering capability at 1.3

References

- CMS-PAS-TOP-15-002: Higgs pair production at the High Luminosity LHC
- CMS-PAS-TOP-16-002: Projected performance of Higgs analyses at the HL-LHC for 2016 CMS-TOP-15-001: A search for Higgs boson pair production in the diboson final state in proton-proton collisions at \( \sqrt{s} = 8 \text{ TeV} \)
  - ATLAS 17010350 [hep-ex]
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