Exotic-spin and anomalous coupling study of the H boson with the \( H \rightarrow ZZ \rightarrow 4l \) channel

Can You (Johns Hopkins University), for CMS collaboration

**Introduction**

The observation of a new boson with a mass around 125 GeV and properties consistent with the standard model (SM) Higgs boson was reported by the ATLAS and CMS Collaborations in 2012. The discovery was followed by a comprehensive set of measurements of its properties to determine if the new boson follows the SM predictions or if there are indications for physics beyond the SM (BSM).

- **Decay of spin-zero resonance**
  \[ A(HVV) \sim [1 + \epsilon_{HVV}^{\gamma\gamma} \epsilon_{HVV}^{\gamma\gamma} + \epsilon_{HVV}^{\gamma\gamma}(1 + \epsilon_{HVV}^{\gamma\gamma})] \]
  - The tree-level SM-like contribution corresponds to \( a_0 \).
  - Small values of other couplings can be generated through loop effects in the SM, and can be ascribed to anomalous couplings.
  - \( A_1 \) is the scale of BSM physics and is a free parameter of the model.
  - The parity-conserving interaction of a pseudoscalar (CP-odd state) corresponds to the \( a_4 \) terms, while the other terms describe the parity-conserving interaction of a scalar (CP-even state).
  - The anomalous couplings are parameterized in terms of effective fractional cross sections \( f_{a_i} \), \( f_{a_2} \) and \( f_{a_4} \), and the phases \( \phi_{a_1}, \phi_{a_2} \) and \( \phi_{a_4} \).

- **Decay of spin-one resonance**
  \[ A(ZV+V) \sim [1 + \epsilon_{ZV+V}^{\gamma\gamma} \epsilon_{ZV+V}^{\gamma\gamma} + \epsilon_{ZV+V}^{\gamma\gamma}(1 + \epsilon_{ZV+V}^{\gamma\gamma})] \]
  - In the case of a spin-one resonance, the amplitude of its interaction with a pair of massive gauge bosons consists of two independent terms. Here the \( a_0 \) coupling corresponds to a vector particle, while the \( a_4 \) coupling corresponds to a pseudovector.
  - An effective fractional cross section \( f_{a_2} \) is defined to test some particular mixture of the vector and pseudovector states.

**Analysis Techniques**

**Matrix Element Likelihood Approach (MELA)**

- **Observables**
  - Five production and decay angles
  - Invariant masses of dilepton pairs
  - Invariant mass of the four-lepton system

- **Kinematic Discriminants**
  - Probabilities are calculated using the LO matrix elements as a function of angular and mass observables.

- **Spin-one results**
  - Two scenarios are tested: \( qq \) production and using only decay information (production-independent)
  - Hypothesis testing is performed for a discrete set of values of the parameter \( f_{a_2} \)
  - The input observables are \( \Delta m_{a_2} \), \( \Delta \theta_{a_2} \), \( \Delta \theta_{a_2} \)

**Spin-two results**

- Three scenarios are tested: \( gg \), \( q\bar{q} \) production and using only decay information (production-independent)
- The input observables are \( \Delta m_{a_2} \), \( \Delta \theta_{a_2} \)

**References**

CMS Collaboration, “Constraints on the spin-parity and anomalous HVV couplings of the Higgs boson in proton collisions at 7 and 8 TeV”, arXiv:1411.3441