Contribution ID: **18** Type: **not specified**

A novel implementation of the Matrix Element Method at next-to-leading-order (NLO) for the measurement of the Higgs tri-linear coupling in di-Higgs production at the LHC (20+10)

Monday 17 March 2025 17:00 (30 minutes)

One of the LHC's priorities, following the discovery of the Higgs boson, is to observe the production of Higgs pairs and to measure the Higgs tri-linear coupling λ_{3H}.
Due to the rarity of di-Higgs production, measuring λ_{3H} has proven to be highly challenging. Exclusion limits have been observed using a variety of approaches, including cut-based methods and boosted decision trees (BDTs).
To address this difficulty from a new perspective, our work explores the application of the Matrix Element Method (MEM), a technique that has demonstrated its effectiveness in multiple analyses in which measurements were performed in processes that were rare (at the time). One can mention the primordial role of the MEM in measuring the top-quark mass at Tevatron, or its role in the first evidence for single top production in the s-channel at the LHC for example.
The MEM is a statistically optimal multivariate method that maximizes the utilization of both the experimental and theoretical information available to an analysis, making it inherently well-suited to rare process searches and Standard Model measurements at particle accelerators like the LHC.
The MEM avoids the application of strict selection requirements to the data. It accounts for the entire dataset (with minimal preselection), which is very important when dealing with such rare processes.
Most MEM studies have been limited to leading-order (LO) accuracy, with extensions to next-to-leading-order (NLO) explored only in specific cases due to the additional complexities introduced by virtual and real contributions. Building a MEM at LO is already a highly challenging task, and incorporating NLO formalism substantially amplifies this difficulty due to the increased computational demands and complex theoretical requirements.
To contribute to the measurement of λ_{3H} from LHC data in the $gg \to HH \to b\bar{b}\gamma\gamma$ channel, we developed a MEM framework by working on a new NLO implementation (which can be applied in many more analyses).
This MEM framework utilizes state-of-the-art Matrix Elements at NLO from the POWHEG-BOX-V2 [1] and MG5_@NLO software packages, and can be extended to include Higgs boson pair production at full NLO QCD in SMEFT [2].
The framework is implemented within a modified version of MoMEMta, a software designed for managing multi-variable phase-space integration, which has been extended to incorporate this new NLO implementation.
To our knowledge, this work marks the first application of the MEM at NLO accuracy to the search for HH and the measurement of λ_{3H}. This also represents the first application of the MEM using this new NLO formalism.
We have demonstrated that this NLO framework is functional and effective.
We also applied this framework to Monte Carlo (MC) simulated samples in a search for λ_{3H}, achieving promising results. This study aims to introduce this new approach to the community and position the MEM (at NLO) as a competitive alternative to other established methods to determine the Higgs self-coupling λ_{3H}.

References:
[1] G. Heinrich, S.P. Jones , M. Kerner, G. Luisoni , L. Scyboz
Probing the trilinear Higgs boson coupling in di-Higgs production at NLO QCD including parton shower effects ,
JHEP 06 (2019) 066 [https://inspirehep.net/literature/1725744]
[2] G. Heinrich, J, Lang
Renormalisation group effects in SMEFT for di-Higgs production ,[https://arxiv.org/pdf/2409.19578]

Track/session

Plenary track

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Session Classification: Early career scientists presentations