Measurements of differential and integrated fiducial cross sections for Higgs Boson production in the four-lepton decay channel using run 2 data with the CMS detector

Alessandro Tarabini on behalf of the CMS collaboration
Laboratoire Leprince-Ringuet (IPP - École Polytechnique)
alessandro.tarabini@cern.ch

We are entering in the precision era of the Higgs physics where the comparison between theory and experiment is becoming crucial to spot any sign of new physics. Fiducial cross section measurements are one of the tools we have to pursue this task, allowing a precise inspection of the scalar sector of the Standard Model (SM). Evaluating fiducial cross sections in bins of kinematic variables allows to probe interesting phase space regions.

Decay channel: $H \rightarrow ZZ \rightarrow 4\ell$

- High S/B (~2)
- Complete reconstruction of the final state
- Excellent momentum resolution
- Small BR (0.028%)
- Three different final states: $2e2\mu$, $4e$, $4\mu$

Workflow of the analysis

Unfolding

Physics model

Results

Accepted for publication in Eur. Phys. J. C.
arXiv:2103.04956
Cross section is measured by **unfolding** experimental data to the **fiducial phase space** at **generator level**

- High-longevity of the measurement
- Direct comparison with theoretical models
- Combination with different decay channel and experiments

**MC simulation of a process**

- **Partonic process**: Powheg, Madgraph, JHUGen, MiNLO, etc.
- **Parton shower**: Pythia
- **Hadronisation**
- **Detector**: Geant4

**gen-level**

- generator level
- What one would measure with an ideal detector

**reco-level**

- reconstruction level
- What one actually measures

**UNFOLDING**

**Unfolding**

- High-longevity of the measurement
- Direct comparison with theoretical models
- Combination with different decay channel and experiments

**Total phase space**

- Experimental selections
- Fiducial phase space

- Model independent measurement
\[ \forall \text{ year} \rightarrow N_{\text{obs}}^{f,i}(m_{4\ell}) = N_{\text{fid}}^{f,i}(m_{4\ell}) + N_{\text{nonfid}}^{f,i}(m_{4\ell}) + N_{\text{nonres}}^{f,i}(m_{4\ell}) + N_{\text{redirred}}^{f,i}(m_{4\ell}) \]

**Fiducial resonant contribution**
Selected four leptons associated to the decay of the $Z$ bosons coming from the decay of the $H$ **inside** the fiducial volume

\[ N_{\text{fid}}^{f,i}(m_{4\ell}) = \sum_{\text{genBin}} e_{i,j}^f \cdot \sigma_{\text{fid}}^i \cdot \mathcal{P}_{\text{res}}^f(m_{4\ell}) \]

$\mathcal{P}_{\text{res}}^f(m_{4\ell}) \rightarrow$ Double-sided Crystal Ball

\[ e_{i,j} = \frac{N(\text{fid} \rightarrow \text{reco}_i)}{N(\text{fid}_j)} \]

**Non-fiducial resonant contribution**
Selected four leptons associated to the decay of the $Z$ bosons coming from the decay of the $H$ **outside** the fiducial volume

\[ N_{\text{nonfid}}^{f,i}(m_{4\ell}) = \sum_{\text{genBin}} e_{i,j}^f \cdot f_{\text{nonfid}}^i \cdot \sigma_{\text{fid}}^i \cdot \mathcal{P}_{\text{res}}^f(m_{4\ell}) \]

$\mathcal{P}_{\text{res}}^f(m_{4\ell}) \rightarrow$ Double-sided Crystal Ball

\[ f_{i,j}^{\text{nonfid}} = \frac{N(\text{nonFid} \rightarrow \text{reco}_i)}{N(\text{fid} \rightarrow \text{reco}_j)} \]

**Non-resonant background**
Selected four leptons not associated to the decay of the $H$

\[ N_{\text{nonres}}^{f,i}(m_{4\ell}) = N_{\text{nonres}}^f \cdot \mathcal{P}_{\text{nonres}}(m_{4\ell}) \]

$\mathcal{P}_{\text{nonres}}(m_{4\ell}) \rightarrow$ Landau

Fraction of these events
- WH $\sim$ 5%
- ZH $\sim$ 22%
- ttH $\sim$ 17%

**Reducible and irreducible background**

\[ N_{\text{redirred}}^{f,i}(m_{4\ell}) = \sum_{b} N_{b}^{f,i} \cdot \mathcal{P}_{\text{nonres}}^i(m_{4\ell}) \]

**Irreducible backgrounds**
- $qq \rightarrow ZZ$
- $gg \rightarrow ZZ$

**Reducible backgrounds**
- $ZX = Z+jets \& \ tt+jets \& \ Z\gamma+jets$
- $WW+jets \& \ ...$

Legend
- $f=$ final state, $i=$ reco bin, $j=$ gen bin

Physics model
Results

- All results are in agreement with SM predictions
- Once fiducial results are provided, they can be used for further analyses:
  - Test different Beyond-Standard-Model theories and tune SM computations
  - Extraction of parameters (e.g. $k_b$, $k_c$, $k_\lambda$) and interpretations in a specific framework (e.g. EFT)
  - Combination with other channels

Integrated fiducial cross section
- Measured value
  \[ \sigma_{fid} = 2.84^{+0.34}_{-0.31} = 2.84^{+0.23}_{-0.22} \text{ (stat)}^{+0.26}_{-0.21} \text{ (sys)} \text{ fb} \]
- SM expectation
  \[ \sigma_{SM}^{fid} = 2.84 \pm 0.14 \text{ fb} \]