

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

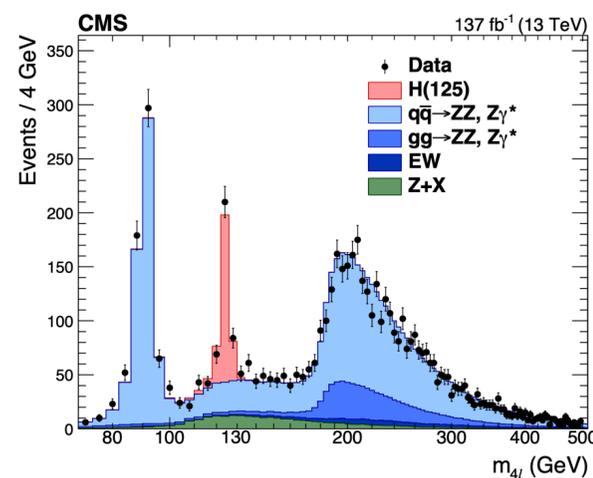


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We are entering in the **precision era** of the Higgs physics where the comparison between theory and experiment is becoming crucial to spot any sign of new physics. **Fiducial cross section** measurements are one of the tools we have to pursue this 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.

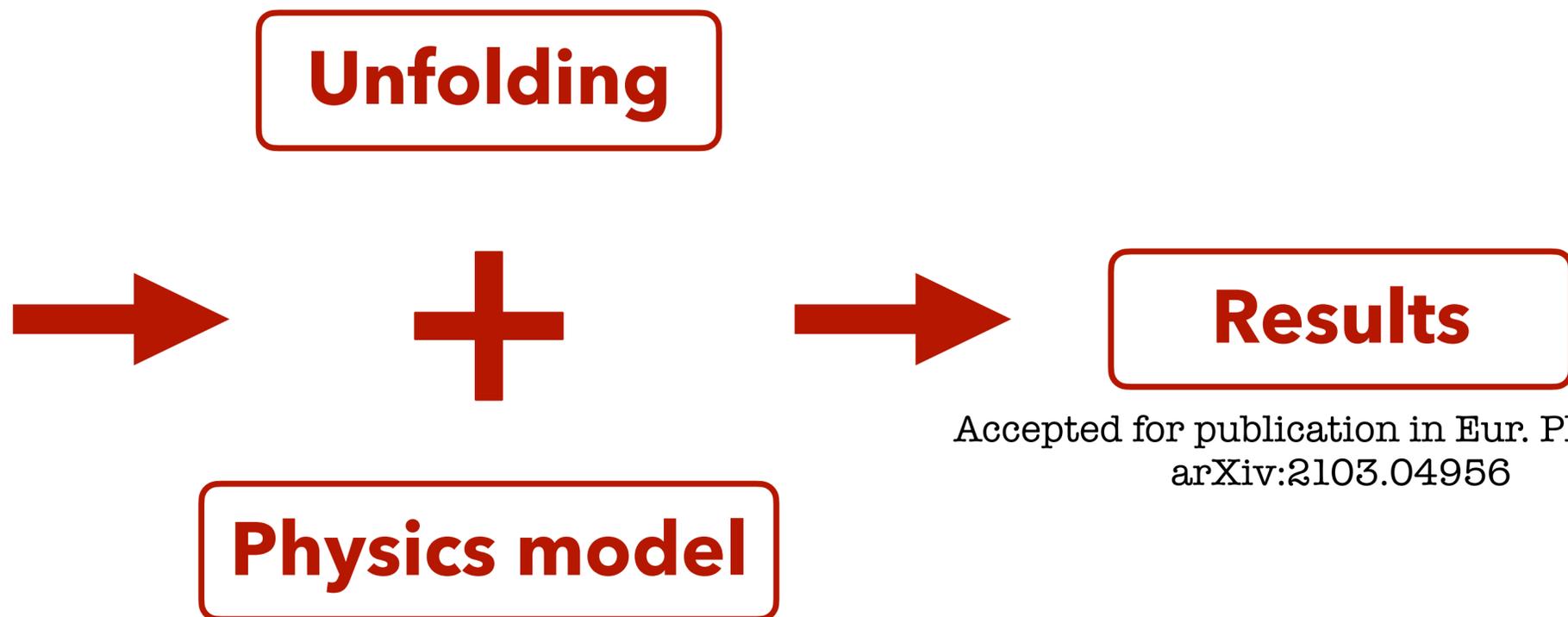
Workflow of the analysis

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: $2e2\mu$, $4e$, 4μ

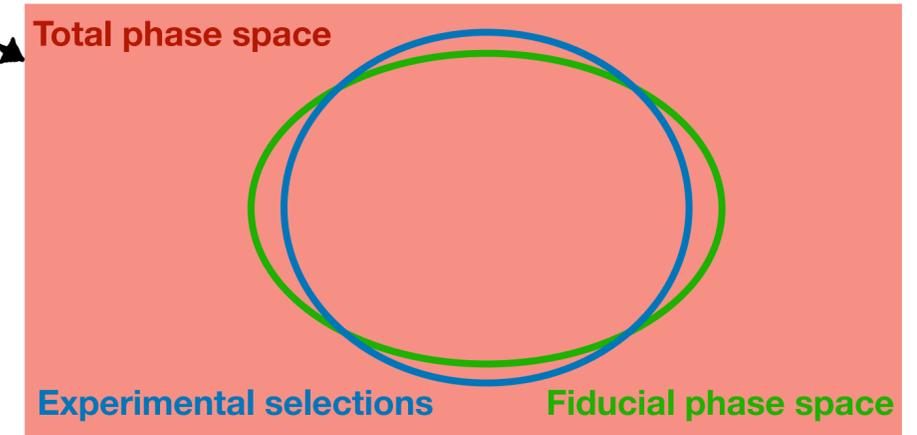


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Unfolding

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

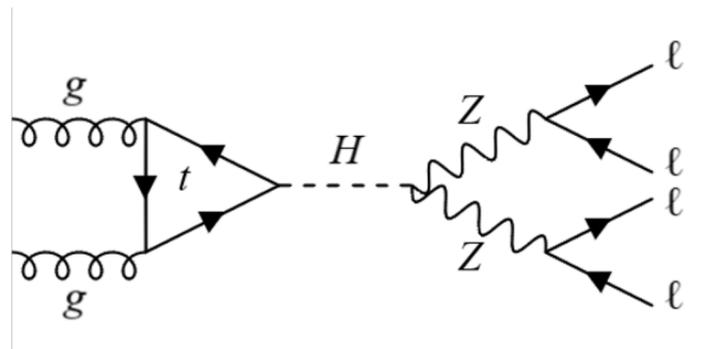


👍 Model independent measurement

MC simulation of a process

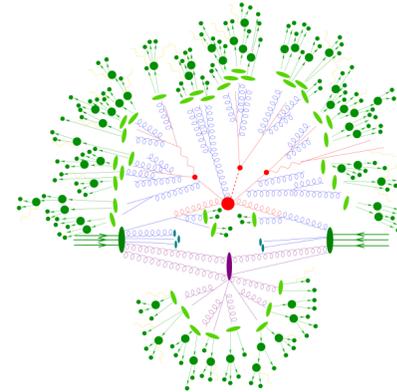
Partonic process

Powheg, Madgraph, JHUGen, MiNLO, etc.



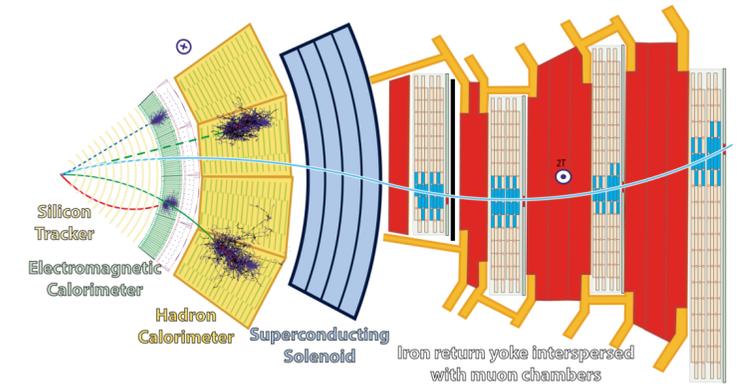
Parton shower Hadronisation

Pythia



Detector

Geant4



— Muon — Electron — Charged hadron (e.g. pion)
 - - - Neutral hadron (e.g. neutron) - - - Photon

gen-level

generator level

What one would measure with an ideal detector

reco-level

reconstruction level

What one actually measures

UNFOLDING

Physics model

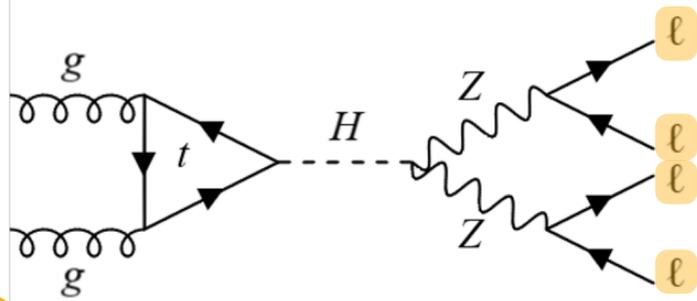
$$\forall \text{ year} \rightarrow N_{obs}^{f,i}(m_{4\ell}) = N_{fid}^{f,i}(m_{4\ell}) + N_{nonfid}^{f,i}(m_{4\ell}) + N_{nonres}^{f,i}(m_{4\ell}) + N_{redlirred}^{f,i}(m_{4\ell})$$

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

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

$$N_{fid}^{f,i}(m_{4\ell}) = \sum_j^{genBin} \epsilon_{i,j}^f \cdot \sigma_{fid}^j \cdot \mathcal{L} \cdot \mathcal{P}_{res}^f(m_{4\ell})$$



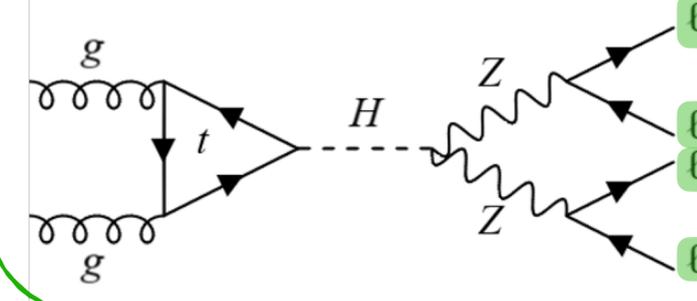
$\mathcal{P}_{res}(m_{4\ell}) \rightarrow$ Double-sided Crystal Ball

$$\epsilon_{i,j} = \frac{N(\text{fid}_j \rightarrow \text{reco}_i)}{N(\text{fid}_j)}$$

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

$$N_{nonfid}^{f,i}(m_{4\ell}) = \sum_j^{genBin} \epsilon_{i,j}^f \cdot f_{nonfid}^{f,i} \cdot \sigma_{fid}^j \cdot \mathcal{L} \cdot \mathcal{P}_{res}^f(m_{4\ell})$$



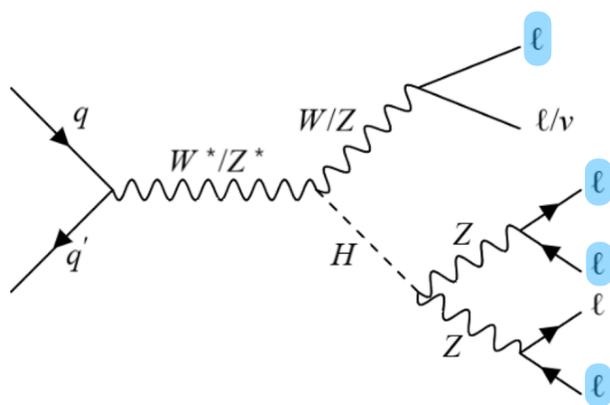
$\mathcal{P}_{res}(m_{4\ell}) \rightarrow$ Double-sided Crystal Ball

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

Non-resonant background

Selected four leptons not associated to the decay of the H

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



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

Fraction of these events

- WH ~ 5%
- ZH ~ 22%
- ttH ~ 17%

Reducible and irreducible background

$$N_{redlirred}^{f,i}(m_{4\ell}) = \sum_b^{bkgs} N_b^{f,i} \cdot \mathcal{P}_{nonres}^{f,i}(m_{4\ell})$$

Irreducible backgrounds

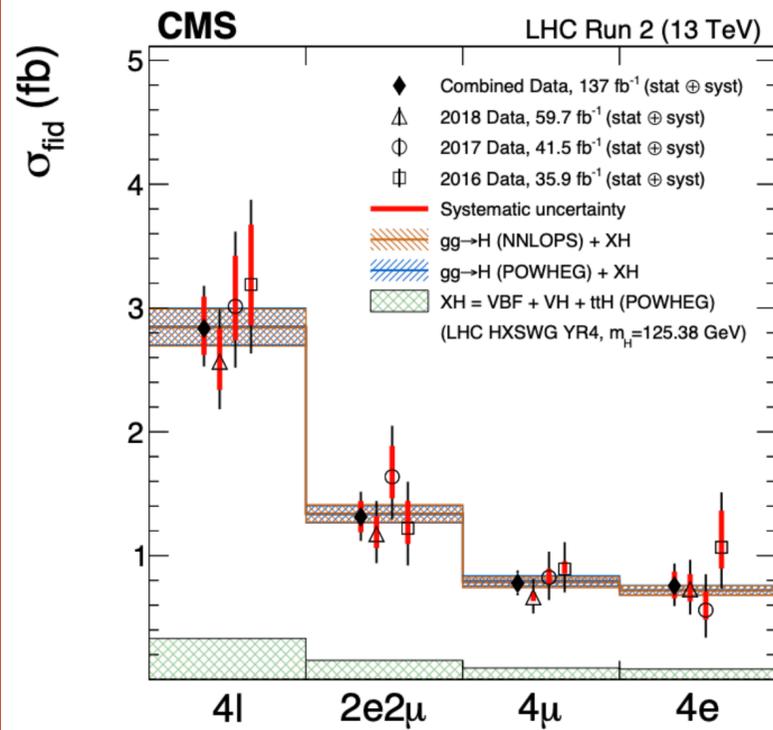
- qq \rightarrow ZZ
- gg \rightarrow ZZ

Reducible backgrounds

- ZX = Z+jets & tt+jets & Z γ +jets & WW+jets & ...

$\mathcal{P}_{nonres}(m_{4\ell}) \rightarrow$ Template from Monte Carlo or Control Region in data

Results



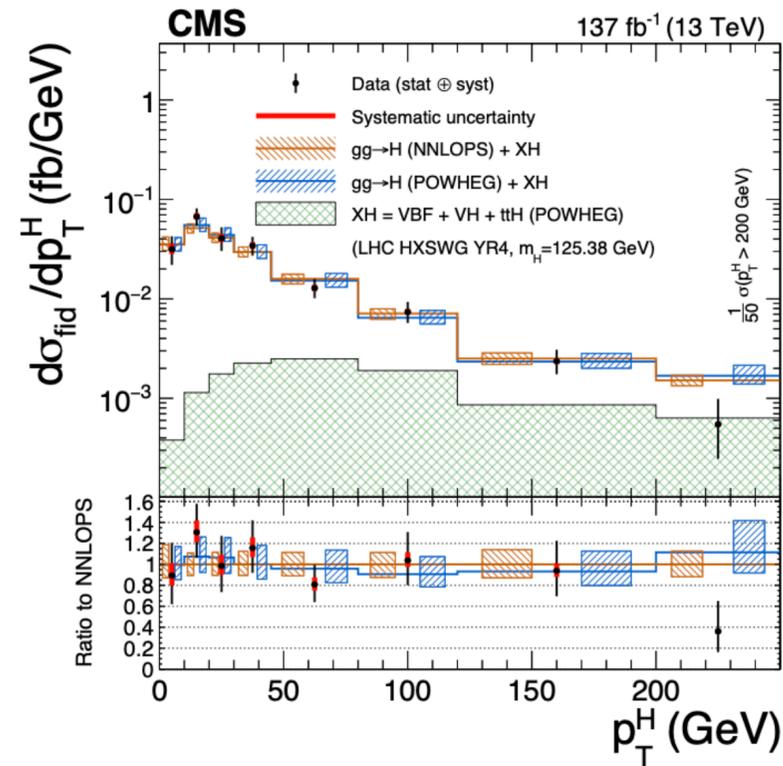
Integrated fiducial cross section

- Measured value

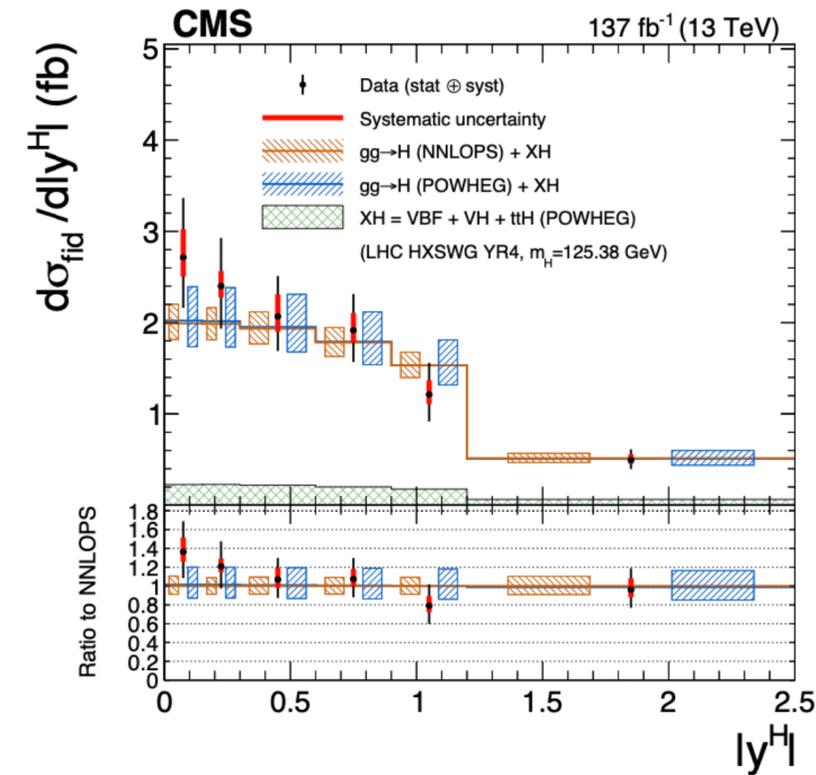
$$\sigma_{fid} = 2.84^{+0.34}_{-0.31} = 2.84^{+0.23}_{-0.22} (\text{stat})^{+0.26}_{-0.21} (\text{syst}) \text{ fb}$$

- SM expectation

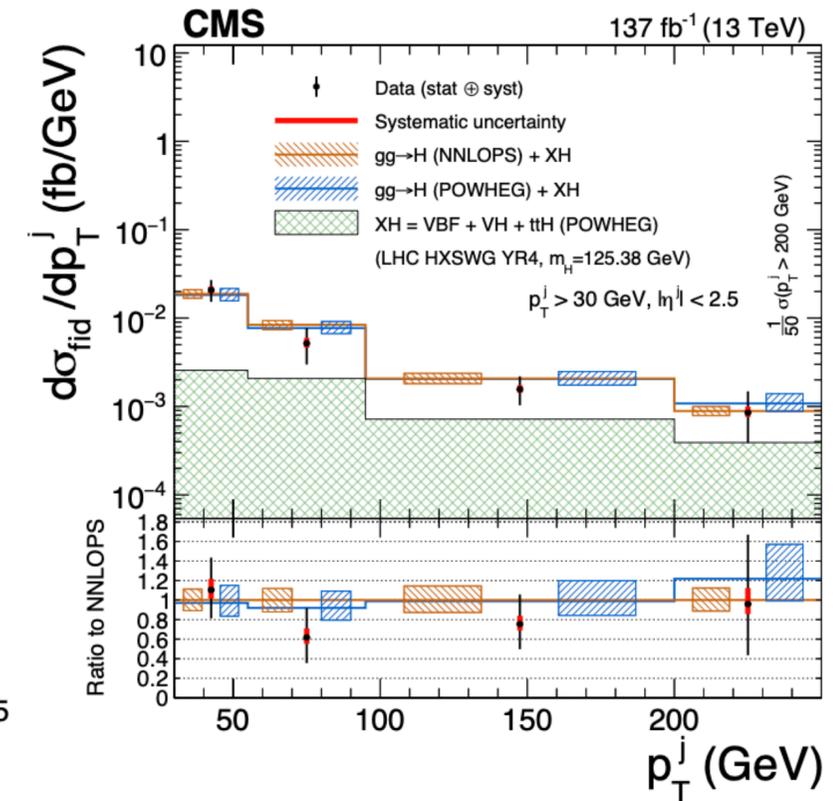
$$\sigma_{fid}^{SM} = 2.84 \pm 0.14 \text{ fb}$$



- Test pQCD calculations
- Sensitive to b-/c-quark Yukawa coupling
- Sensitive to Higgs trilinear coupling effects
- Cross section computed with high accuracy



- Sensitive probe to PDFs of protons
- Influenced by QCD radiative corrections



- Probe pQCD radiation effects and the Higgs boson production mechanisms
- Effects of QCD resummation

- 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_λ) and **interpretations** in a specific framework (e.g. EFT)
 - **Combination** with other channels