Measurement of the transverse momentum spectrum of the Higgs boson decaying into WW at 8 TeV with the CMS detector

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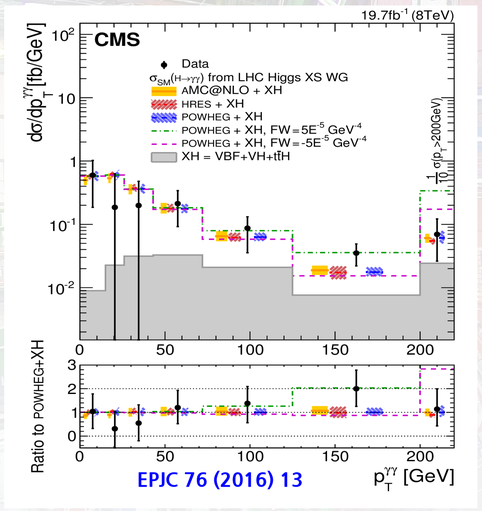
Reference: CMS-PAS-HIG-15-010

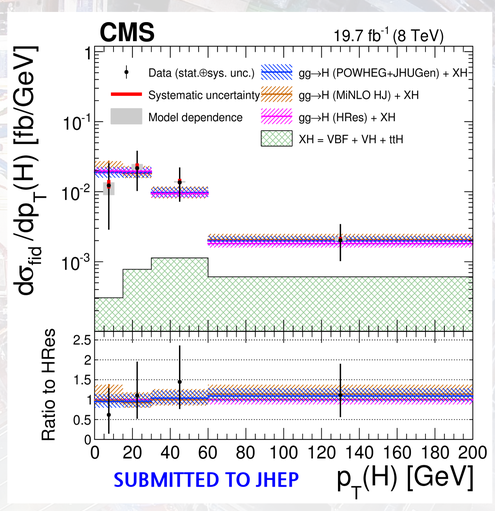
1 - State of the art

- Measurements of the production cross section and kinematic properties of the Higgs boson represent an **important test for possible deviations from the Standard Model (SM)**.
- The Higgs boson transverse momentum (p_T^H) spectrum can be affected by the presence of new physics phenomena and its measurement allows **testing the existing theoretical calculations in the SM Higgs sector.**
- Higgs p_T differential and fiducial measurements at 8 TeV have been reported by ATLAS and CMS in the H→ZZ→4ℓ and H→γγ decay channels.

Higgs transverse momentum spectrum from the CMS H→γγ analysis



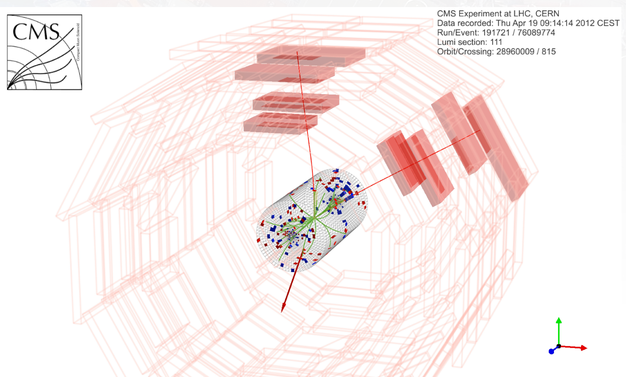
Higgs transverse momentum spectrum from the CMS H→ZZ→4ℓ analysis



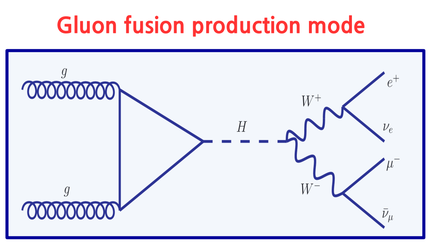
2 - Measurement basics

- The **measurement of the fiducial integrated cross section and transverse momentum spectrum for the Higgs boson production in H→WW→2ℓ2ν** decays is performed.
- The results are based on 19.4 fb^{-1} of data collected by the CMS detector at 8 TeV.

Candidate H →WW event into 2 muons



Gluon fusion production mode



- **H→WW→2ℓ2ν signature:**
  - Two isolated high p_T electrons or muons with opposite charge;
  - Moderate MET.

- Analysis performed looking at **opposite flavour leptons (*eμ*) in the final state**.

- **With respect to H→ZZ→4ℓ or H→γγ:**
  - Significantly higher σ×BR;
  - Worst p_T^H resolution due to the presence of neutrinos.

$$p_T^H = |\vec{p}_T^{\,\ell\ell} + \vec{E}_T^{miss}|$$

3 - Analysis strategy

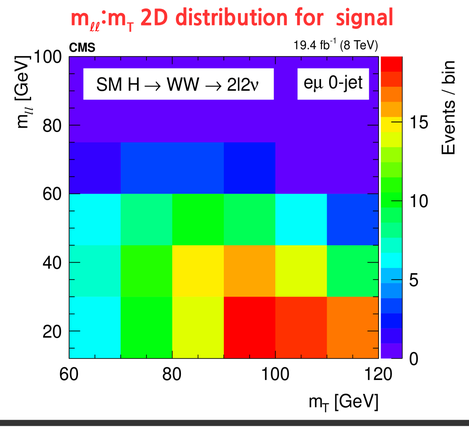
- Event selection based on the previously published H→WW→2ℓ2ν measurements.
  - Important difference: **this analysis is performed inclusively in jets multiplicity**.
- To measure the differential cross section the p_T^H spectrum is binned.
  - accurate binning definition is needed to avoid too large bin migration effects
- 2D template fit used to measure signal strengths in each bin:
  - **di-lepton mass ($m_{\ell\ell}$)** and **transverse mass (m_T)** used to discriminate signal and backgrounds.

Estimation methods used for the various background processes

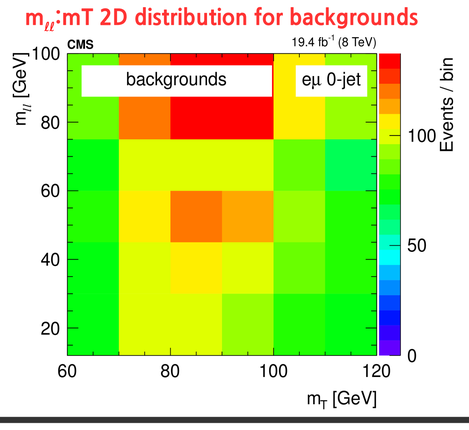
Process	Normalization	Shape	Control/template sample
WW	data	simulation	events at high $m_{\ell\ell}$ and m_T^H
Top	data	simulation	top-enriched control region
W+jets	data	data	events with loosely identified leptons
Wγ	simulation	data	events with an identified γ
Wγ*	data	simulation	Wγ* → 3μ sample
Z/γ* → ττ	data	data	τ embedded sample

- Main backgrounds: **qq→W⁺W⁻** and **tt̄+jets**.
- Backgrounds estimated using **data driven methods** whenever possible.

$m_{\ell\ell}$:m_T 2D distribution for signal



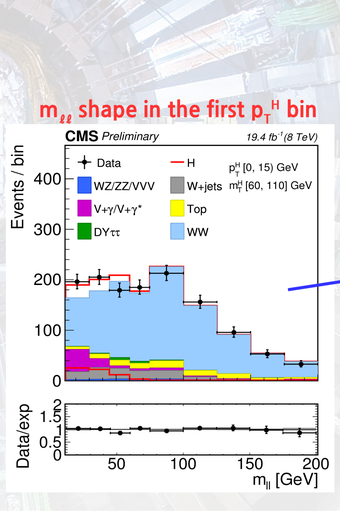
$m_{\ell\ell}$:mT 2D distribution for backgrounds



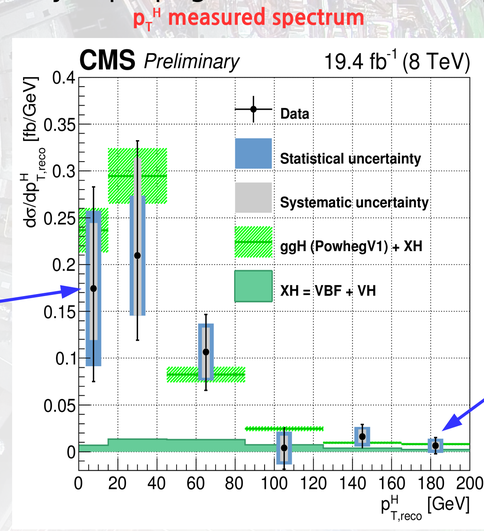
4 - Measured spectrum

- Signal extracted subtracting backgrounds with a Maximum Likelihood fit.
- Sources of uncertainty divided in three categories:
  - **Experimental uncertainties**: luminosity, lepton momentum scale and resolution, **MET scale and resolution**, jet energy scale, b tagging uncertainty.
  - **Background estimation uncertainties**: related to the normalization estimation of each background, e.g. tt̄ background.
  - **Theoretical uncertainties**: related to the theoretical models used for simulating signal and background events.
- Each source of uncertainty is propagated as a nuisance parameter through the fit.

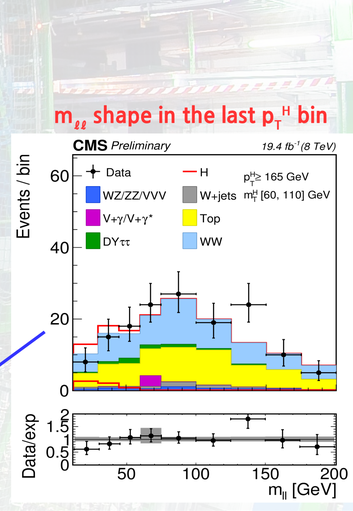
$m_{\ell\ell}$ shape in the first p_T^H bin



p_T^H measured spectrum

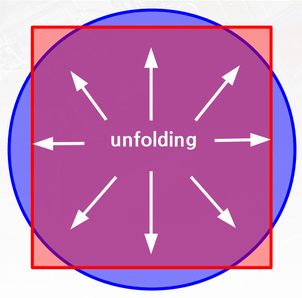


$m_{\ell\ell}$ shape in the last p_T^H bin



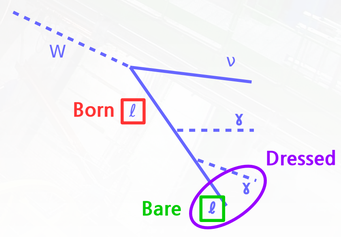
5 - Fiducial phase space and unfolding

Reco phase space | Fiducial phase space



Fiducial & reconstructed
Fiducial & non-reconstructed
Non-fiducial & reconstructed

- **Results extrapolated to a fiducial phase space**, defined using Born level leptons, with a regularized unfolding procedure.
- Direct comparison with theoretical predictions and other experimental results.



Kinematic requirements for the fiducial phase space	
Leading lepton transverse momentum	$p_T > 20$ GeV
Sub-leading lepton transverse momentum	$p_T > 10$ GeV
Pseudorapidity of electrons and muons	$\|\eta\| < 2.5$
Invariant mass of the two leptons	$m_{\ell\ell} > 12$ GeV
Transverse momentum of the lepton pair	$p_T^{\ell\ell} > 30$ GeV
Invariant mass of the leptonic system in the transverse plane	$m_T^H > 50$ GeV
No MET cut applied	

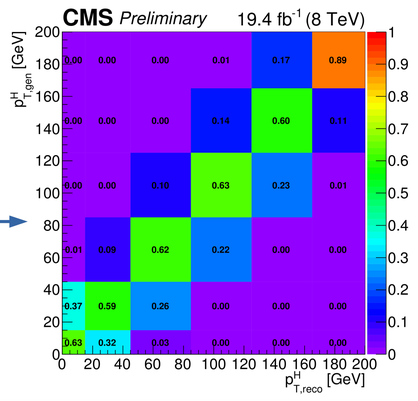
- **Basic principle**: use the MC signal samples to make the distribution of the variable of interest before and after the full GEANT4 simulation of the CMS detector and the event reconstruction.

MC distribution at particle level

MC distribution at reconstructed level (after the full CMS simulation)

$$R_i^{MC} = M_{ij} T_j^{MC}$$

Response matrix

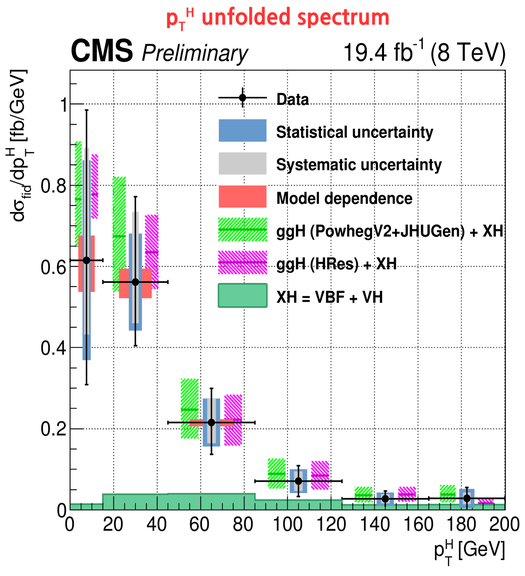


- Unfolding with **SVD method** and Tikhonov **regularization function**.

6 - Comparison with theory predictions

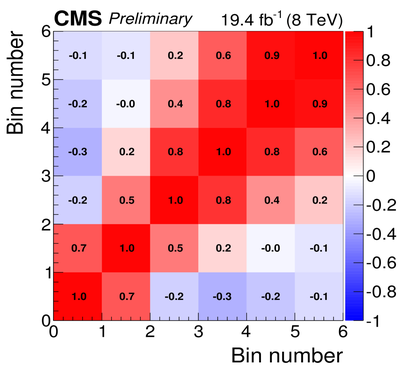
- **Unfolded spectrum** of the Higgs boson transverse momentum shown with statistical, systematic and theoretical uncertainty contributions reported as separated error bands.
- Spectrum compared to two SM-based theory predictions:
  - ggH production simulated using the **HRes** or **PowhegV2** programs.

p_T^H unfolded spectrum



- Very **good level of agreement between data and theory predictions** within the uncertainties.

Correlation matrix



- **Large level of correlation** between neighbouring bins after the unfolding.

- **Inclusive cross section** in the fiducial phase space obtained integrating the measured spectrum and correcting for the selection efficiency.

$$\sigma_{\text{fid}} = 39 \pm 8\ (\text{stat}) \pm 9\ (\text{syst})\ \text{fb}$$

$$\sigma_{theory} = 48 \pm 8\ \text{fb}$$