Cross section measurements in H->4l channel at CMS

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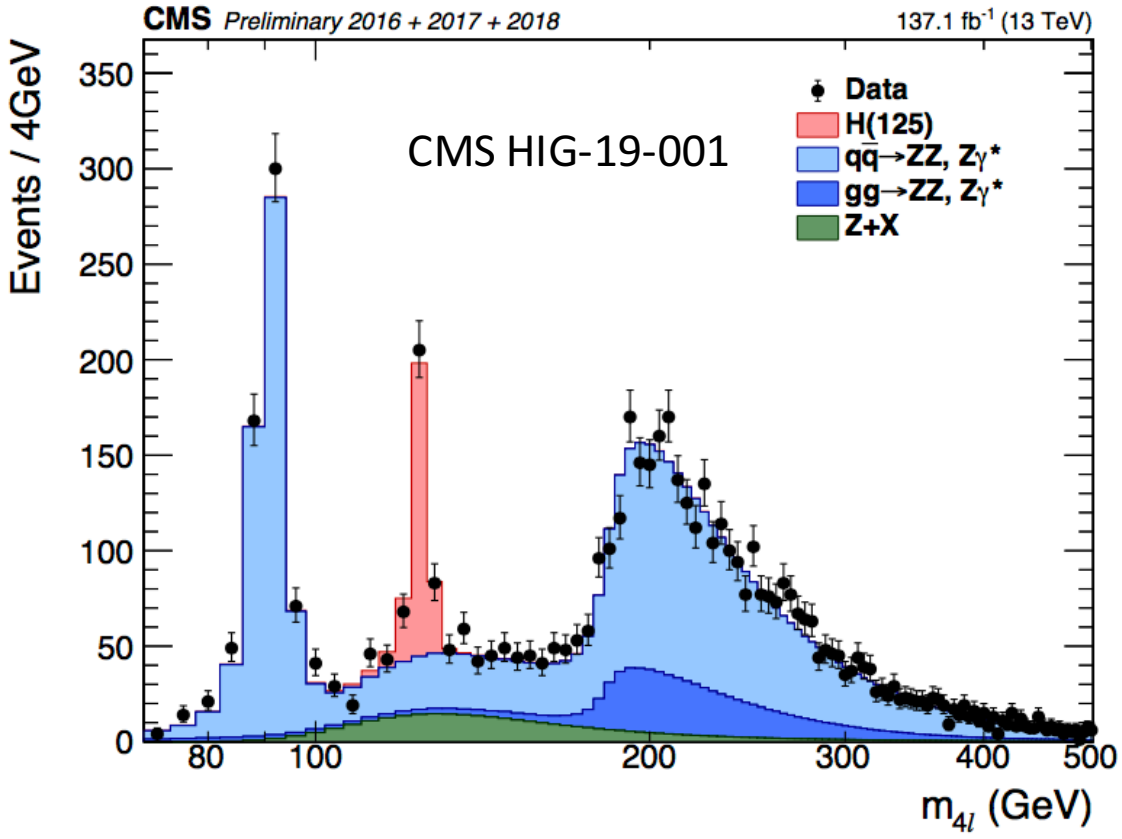
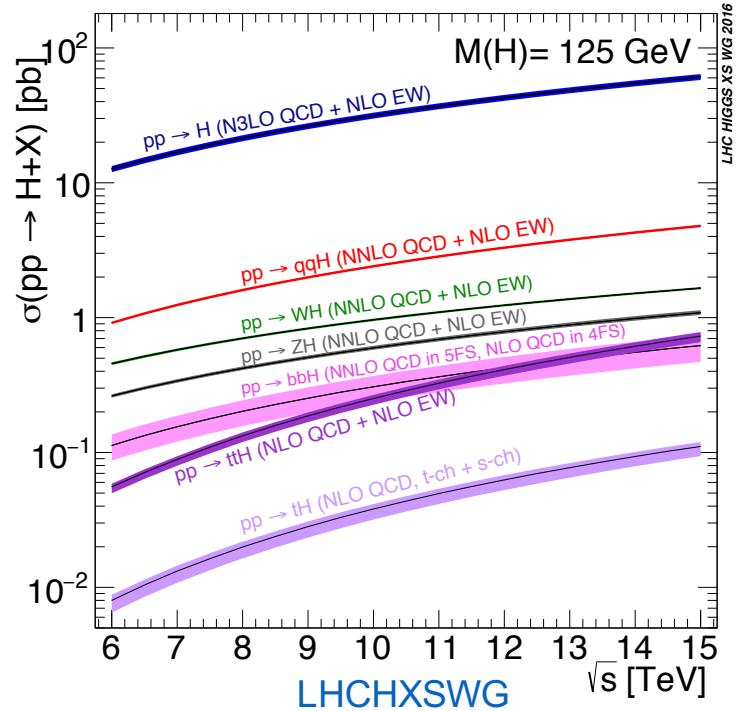
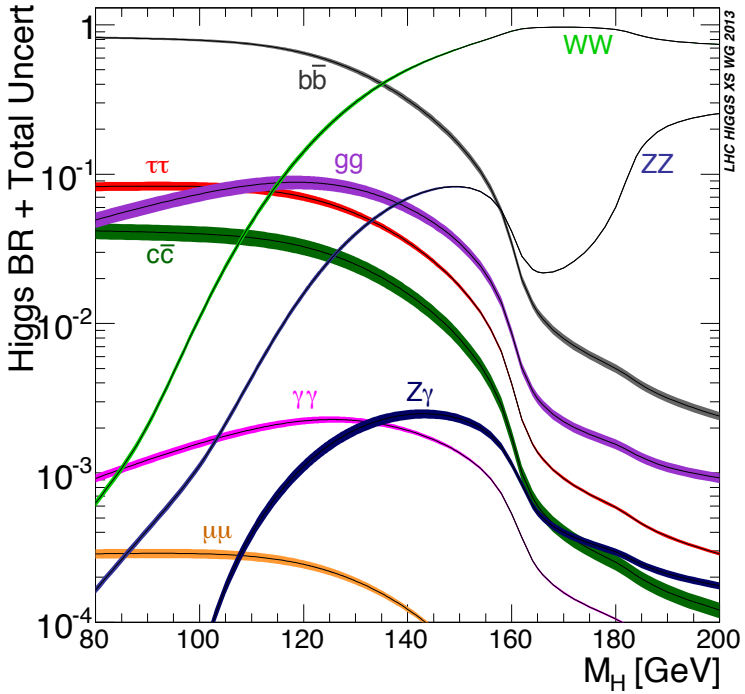
On behalf of CMS collaboration

The 6th China LHC Physics Workshop (CLHCP2020)

Introduction







- 4l channel is one of the most important channel for Higgs boson search
- A large signal-to-background ratio
- Complete reconstruction of final state decay products
- Excellent lepton momentum reconstruction

Objects

➢ Selected electrons

- Loose electrons
  - $P_T > 7\text{GeV}; |\eta| < 2.5$
  - $d_{xy} < 0.5\ cm;\ d_z < 1\ cm; SIP_{3D} < 3$
- BDT ID+Iso in 6 ($|\eta|$, P_T)bins
- Reduction of fakes for same signal efficiency when witch from TMVA(V1) to **xgboost**(V2) library for BDT training

➢ FSR photon

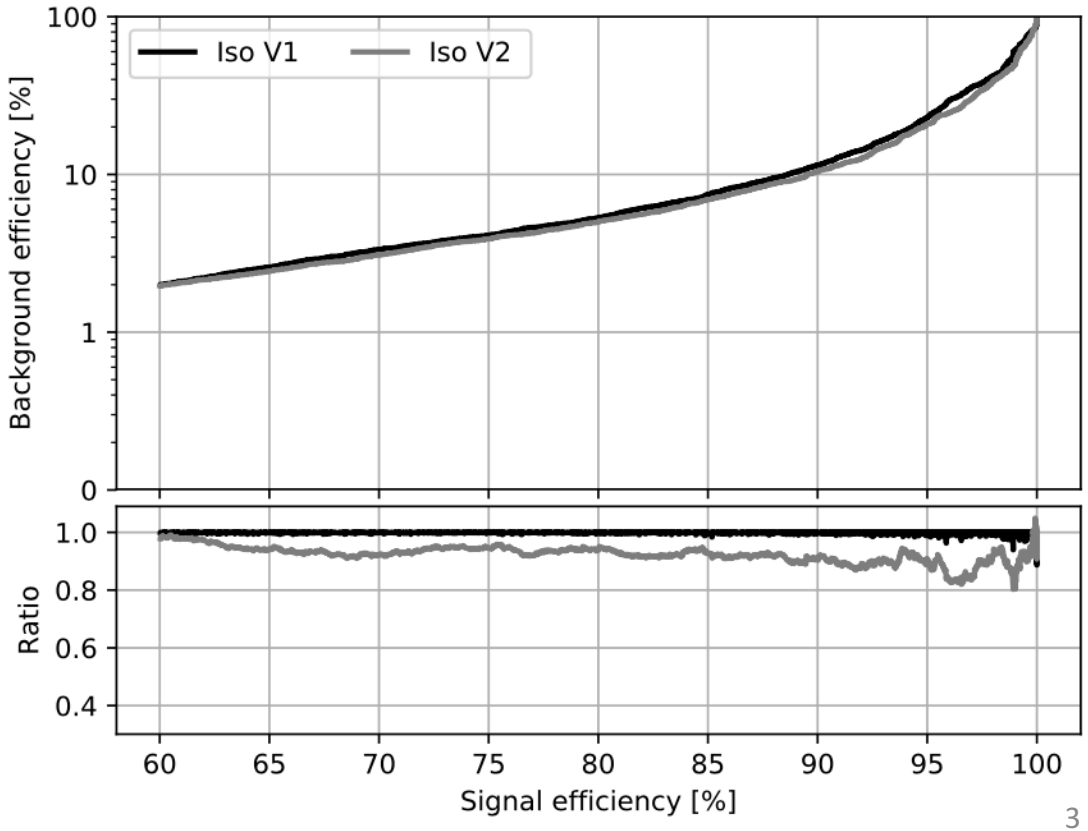
- $P_{T,\gamma} > 2$ GeV;$|\eta^{\gamma}| < 2.4$;relPFIso<1.8
- Electron SC veto by PF reference
- Associated γ to the closest loose lepton
- $\Delta R(\gamma, l) < 0.5$; $\frac{\Delta R(\gamma,l)}{E^2_{T,\gamma}} < 0.012$; choose photon with lowest $\frac{\Delta R(\gamma,l)}{E^2_{T,\gamma}}$
- Remove selected FSRs from lepton isolation cone for all loose leptons

➢ JETS

- AK4 PFCHs jets
- $P_T > 30$ GeV; $|\eta| < 4.7$; Tight PF jet ID
- Cleaned $\Delta R(jet, l/\gamma) > 0.4$
- Tight PU Jet ID
- B-tagger:
  - DeepCSV medium WP
  - B-tagging SF applied

➢ Selected muons

- Loose muons
  - $P_T > 5\text{GeV}; |\eta| < 2.4$
  - $d_{xy} < 0.5\ cm;\ d_z < 1\ cm; SIP_{3D} < 3$
- PF μ ID and tracker high P_T ID
- RelPFIso($\Delta R = 0.3$) < 0.35



Event reconstruction and selections

- Z candidate
  - Any OS-SF pair that satisfy $12 < m_{ll(\gamma)} < 120$ GeV

- Build all possible ZZ candidates defined as pairs of non-overlapping Z candidate; define Z_1 candidate with $m_{ll(\gamma)}$ closest to the POG m(Z) mass
  - $m_{Z1} > 40$ GeV; $P_T(l1) > 20$ GeV; $P_T(l2) > 10$ GeV
  - $\Delta R > 0.02$ between each of the four leptons
  - $m_{ll} > 4$ GeV for OS pairs (regardless of flavour)
  - Reject 4μ and 4e candidates where the alternative pair Z_aZ_b satisfies $|m_{Z_a} - m_Z| < |m_{Z_1} - m_Z|$ and $m_{Z_b} < 12$ GeV
  - $m_{4l} > 70$ GeV
- If more than one ZZ candidate is left, choose the one of highest $\mathcal{D}_{\mathrm{bkg}}^{\mathrm{kin}}$.
- If $\mathcal{D}_{\mathrm{bkg}}^{\mathrm{kin}}$ is the same, take the one with Z_1 mass closest to m_Z.

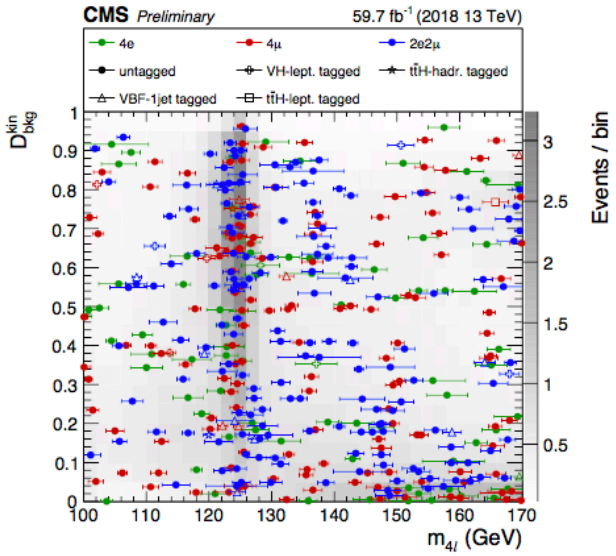
Observables

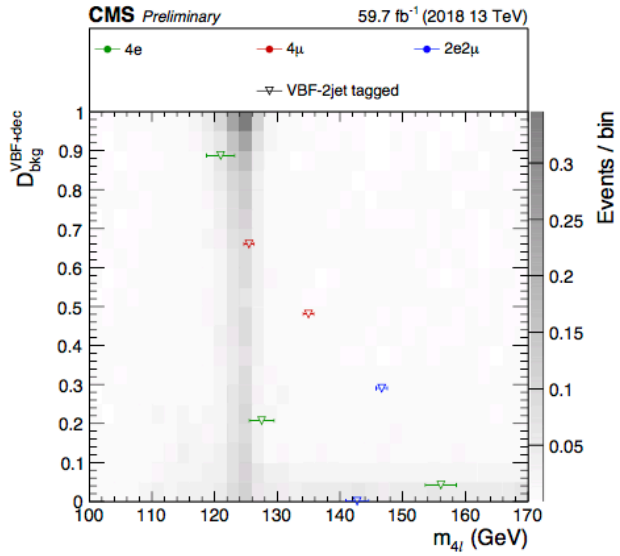
- Two observables used: m_{4l}; kd
- Three different kd discriminant applied.
  - Discriminant sensitive to $gg/q\bar{q} \to 4l$ kinematics
  - Dedicated production-dependent $\mathcal{D}_{kgd}$ discriminants used in VBF-2jet tagged and hadronic VH tagged categories
  - Four discriminants calculated are used to enhance the purity of event categories

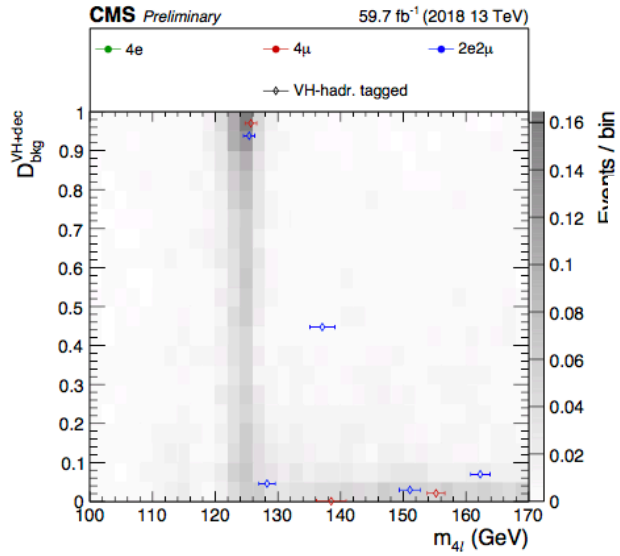
$$\mathcal{D}_{bkg}^{kin} = \left[1 + \frac{\mathcal{P}_{bkg}^{q\bar{q}}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}{\mathcal{P}_{sig}^{gg}(\vec{\Omega}^{H\to 4\ell}|m_{4\ell})}\right]^{-1} \quad (1)$$

$$\mathcal{D}_{bkg}^{VBF+dec} = \frac{\mathcal{P}_{sig}^{VBF+VH+dec}(\vec{\Omega})}{\mathcal{P}_{sig}^{VBF+VH+dec}(\vec{\Omega}) + c^{VBF2jet}(m_{4\ell}) \times (\mathcal{P}_{bkg}^{VBS+VVV}(\vec{\Omega}) + \mathcal{P}_{bkg}^{QCD+dec}(\vec{\Omega}))} \quad (2)$$

$$\mathcal{D}_{bkg}^{VH+dec} = \frac{\mathcal{P}_{sig}^{VBF+VH+dec}(\vec{\Omega})}{\mathcal{P}_{sig}^{VBF+VH+dec}(\vec{\Omega}) + c^{had.VH}(m_{4\ell}) \times (\mathcal{P}_{bkg}^{VBS+VVV}(\vec{\Omega}) + \mathcal{P}_{bkg}^{QCD+dec}(\vec{\Omega}))},$$







$$\mathcal{D}_{2jet} = \left[1 + \frac{\mathcal{P}_{HJJ}(\vec{\Omega}^{H+JJ}|m_{4\ell})}{\mathcal{P}_{VBF}(\vec{\Omega}^{H+JJ}|m_{4\ell})}\right]^{-1}$$

$$\mathcal{D}_{ZH} = \left[1 + \frac{\mathcal{P}_{HJJ}(\vec{\Omega}^{H+JJ}|m_{4\ell})}{\mathcal{P}_{ZH}(\vec{\Omega}^{H+JJ}|m_{4\ell})}\right]^{-1} \quad (3)$$

$$\mathcal{D}_{WH} = \left[1 + \frac{\mathcal{P}_{HJJ}(\vec{\Omega}^{H+JJ}|m_{4\ell})}{\mathcal{P}_{WH}(\vec{\Omega}^{H+JJ}|m_{4\ell})}\right]^{-1}$$

$$\mathcal{D}_{1jet} = \left[1 + \frac{\mathcal{P}_{HJ}(\vec{\Omega}^{H+J}|m_{4\ell})}{\int d\eta_J \mathcal{P}_{VBF}(\vec{\Omega}^{H+JJ}|m_{4\ell})}\right]^{-1}$$

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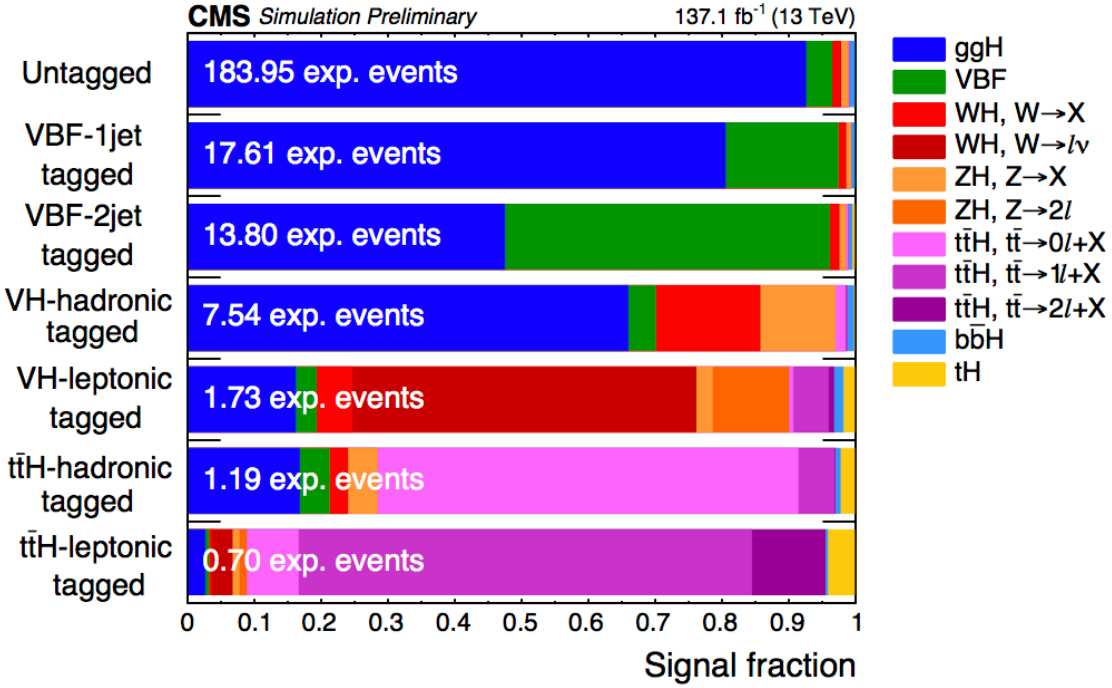
Event categorization – Stage0

- Selected events are classified into seven exclusive categories to improve the sensitivity to the Higgs boson production mechanisms.



- **VBF-2jet-tagged category** requires exactly 4 leptons. In addition there must be either 2 or 3 jets of which at most 1 is b-tagged, or at least 4 jets and no b-tagged jets. Finally, $\mathcal{D}_{2\text{jet}} > 0.5$ is required.
- **VH-hadronic-tagged category** requires exactly 4 leptons. In addition there must be 2 or 3 jets, or at least 4 jets and no b-tagged jets. Finally, $\mathcal{D}_{\text{VH}} > 0.5$ is required.
- **VH-leptonic-tagged category** requires no more than 3 jets and no b-tagged jets in the event, and exactly 1 additional lepton or 1 additional pair of opposite sign same flavor leptons. This category also includes events with no jets and at least 1 additional lepton.
- **$\text{t}\bar{\text{t}}$H-hadronic-tagged category** requires at least 4 jets of which at least 1 is b-tagged and no additional leptons.
- **$\text{t}\bar{\text{t}}$H-leptonic-tagged category** requires at least 1 additional lepton in the event.
- **VBF-1jet-tagged category** requires exactly 4 leptons, exactly 1 jet and $\mathcal{D}_{1\text{jet}} > 0.7$.
- **Untagged category** consists of the remaining events.

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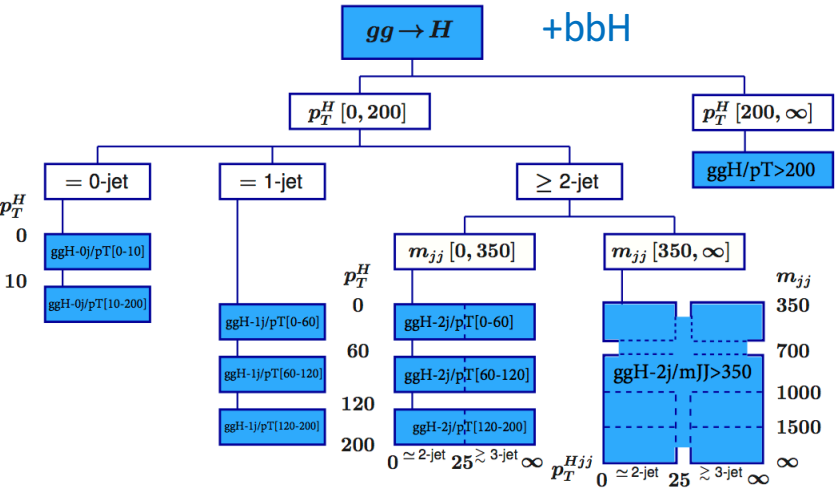
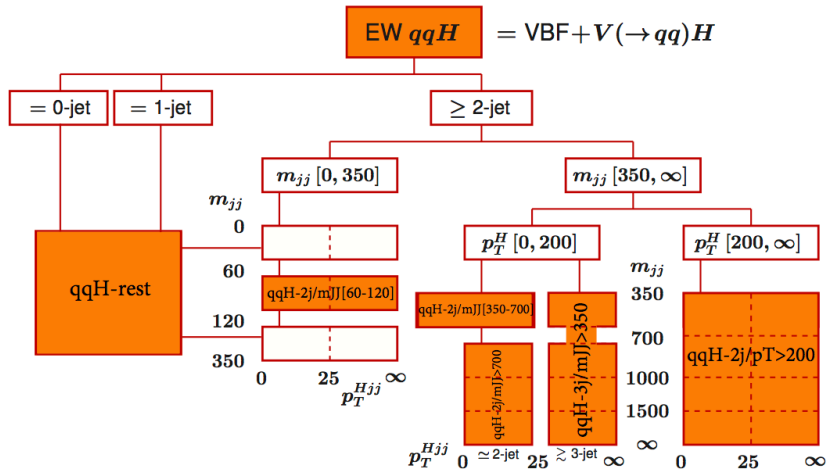
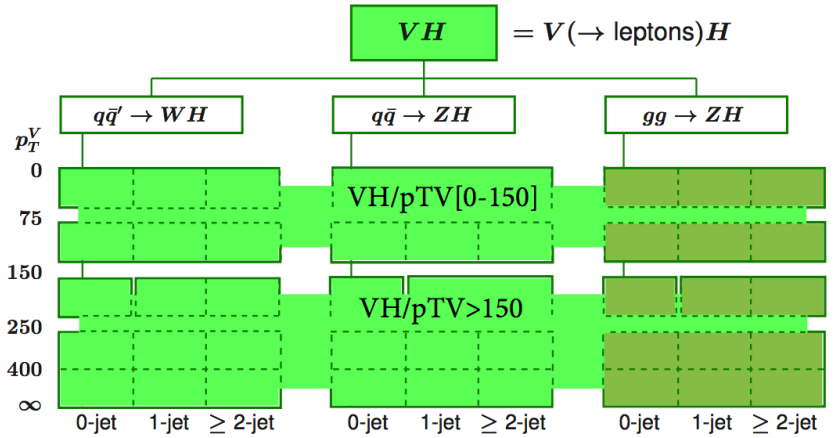
Event categorization -- STXS1.1 bins

- The events are further binned within ggH, VBF, and VH in order to study deeper structure within each production mechanisms. (10+6+2+1)
- The primary goals of the STXS framework are to maximize the sensitivity of the measurements while at the same time to minimize their dependence on the theory predictions.







ttH + tH

Event categorization -- STXS1.1 categories

- Untagged, VBF-2jet-tagged, VH-had-tagged, VH-lep-tagged category are further split. 22 sub-categories are designed to match the STXS Bins defined.

- **Untagged category**:

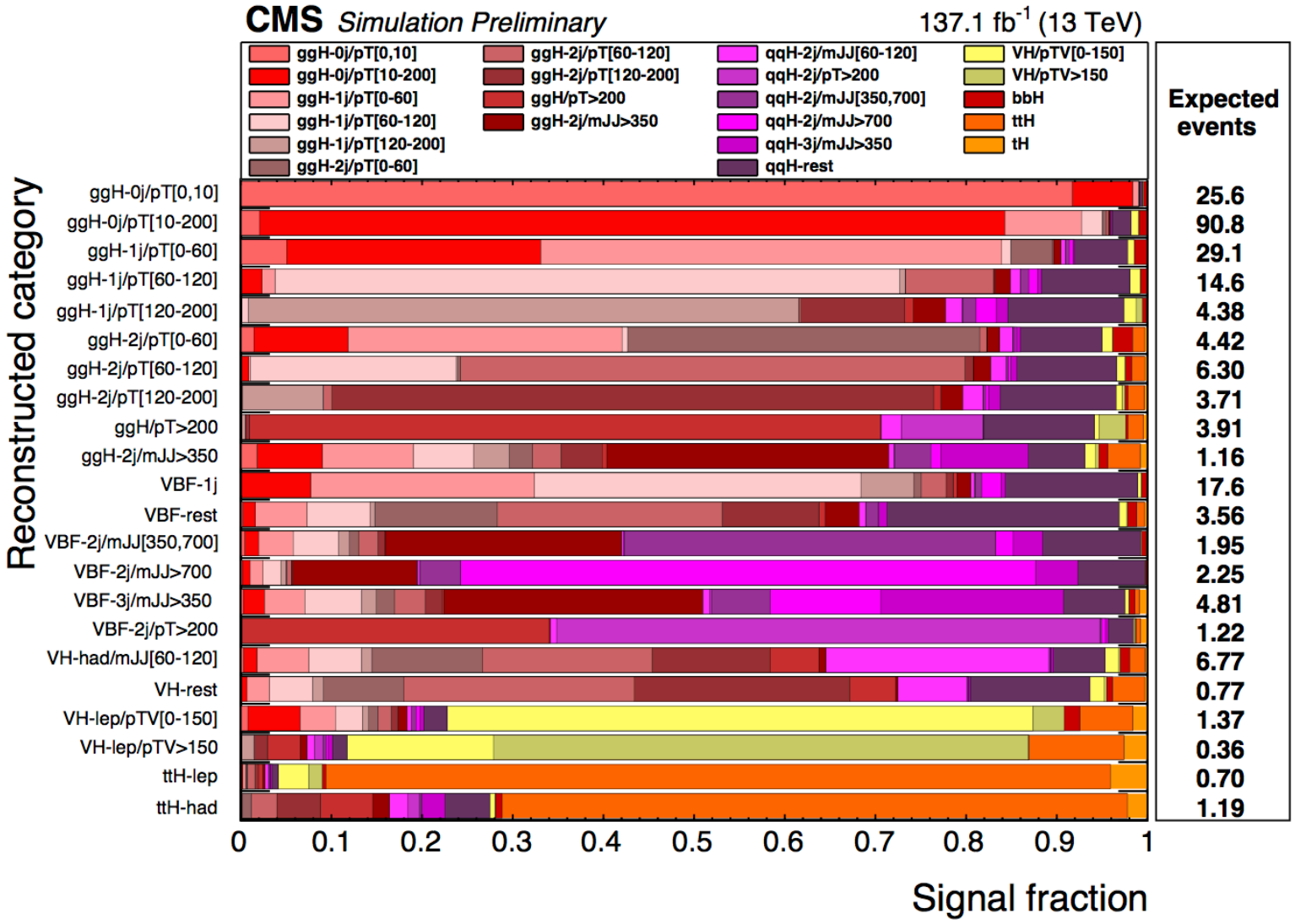
1. `ggH/pT>200`: the Higgs boson has $p_{\mathrm{T}}^{\mathrm{H}} > 200$ GeV;
2. `ggH-0j/pT[0,10]`: 0 jet reconstructed and $0 < p_{\mathrm{T}}^{\mathrm{H}} < 10$ GeV;
3. `ggH-0j/pT[10-200]`: 0 jet reconstructed and $10 < p_{\mathrm{T}}^{\mathrm{H}} < 200$ GeV;
4. `ggH-1j/pT[0-60]`: 1 jet reconstructed and $0 < p_{\mathrm{T}}^{\mathrm{H}} < 60$ GeV;
5. `ggH-1j/pT[60-120]`: 1 jet reconstructed and $60 < p_{\mathrm{T}}^{\mathrm{H}} < 120$ GeV;
6. `ggH-1j/pT[120-200]`: 1 jet reconstructed and $120 < p_{\mathrm{T}}^{\mathrm{H}} < 200$ GeV;
7. `ggH-2j/mJJ>350`: 2 jets reconstructed and $m_{jj} > 350$ GeV;
8. `ggH-2j/pT[0-60]`: 2 jets reconstructed, $0 < p_{\mathrm{T}}^{\mathrm{H}} < 60$ GeV, and $m_{jj} < 350$ GeV;
9. `ggH-2j/pT[60-120]`: 2 jets reconstructed, $60 < p_{\mathrm{T}}^{\mathrm{H}} < 120$ GeV, and $m_{jj} < 350$ GeV;
10. `ggH-2j/pT[120-200]`: 2 jets reconstructed, $120 < p_{\mathrm{T}}^{\mathrm{H}} < 200$ GeV, and $m_{jj} < 350$ GeV.

Event categorization -- STXS1.1 categories

- Untagged, VBF-2jet-tagged, VH-had-tagged, VH-lep-tagged category are further split. 22 sub-categories are designed to match the STXS Bins defined.

- **VBF-1jet-tagged category**: `VBF-1j`
- **VBF-2jet-tagged category**:
  1. `VBF-2j/pT>200`: $p_{\mathrm{T}}^{\mathrm{H}} > 200$ GeV and $m_{jj} > 350\,\mathrm{GeV}$;
  2. `VBF-2j/mJJ[350,700]`: $p_{\mathrm{T}}^{\mathrm{H}} < 200\,\mathrm{GeV}$, $p_{T}^{Hjj} < 25\,\mathrm{GeV}$, and $350 < m_{jj} < 700\,\mathrm{GeV}$;
  3. `VBF-2j/mJJ>700`:$p_{\mathrm{T}}^{\mathrm{H}} < 200\,\mathrm{GeV}$, $p_{\mathrm{T}}^{Hjj} < 25\,\mathrm{GeV}$, $m_{jj} > 700\,\mathrm{GeV}$;
  4. `VBF-3j/mJJ>350`:$p_{\mathrm{T}}^{\mathrm{H}} < 200\,\mathrm{GeV}$, $p_{\mathrm{T}}^{Hjj} > 25\,\mathrm{GeV}$, $m_{jj} > 350\,\mathrm{GeV}$;
  5. `VBF-rest`: if not above.
- **VH-hadronic-tagged category**
  1. `VH-had/mJJ[60-120]`: $60 < m_{jj} < 120\,\mathrm{GeV}$;
  2. `VH-rest`: not above.
- **VH-leptonic-tagged category**
  1. `VH-lep/pT[0-150]`: $p_{\mathrm{T}}^{\mathrm{H}} < 150\,\mathrm{GeV}$;
  2. `VH-lep/pT>150`: $p_{\mathrm{T}}^{\mathrm{H}} > 150\,\mathrm{GeV}$.
- **$t\bar{t}H$-hadronic-tagged category**: `ttH-had`.
- **$t\bar{t}H$-leptonic-tagged category**: `ttH-lep`.

Event categorization – Stage1.1



- Signal relative purity of the 22 event sub-categories in terms of the STXS Stage 1.1 Bins in a 118 < *m*4l < 130 GeV mass window.

Background estimation

- Irreducible background
  - Production of ZZ via $q\bar{q}$ annihilation or gluon fusion
  - Estimated using simulation

- Two dependent methods used to estimated Z+X background: OS and SS
- Fake rates calculated in Z+l control region
- Z+X yields estimated in 2 orthogonal regions of Z+ll control region
- Final estimate combination of 2 methods

- Reducible background
  - Secondary leptons produced by heavy-flavor jets
  - Misidentified as leptons from decay of heavy-flavor hadron, in-flight decays of light mesons within jets, or (for electrons) decay of charged hadrons overlapping with π^0 decays.

(Main prosesses of producting these background: Z+jets, $t\bar{t}$+jets, Zγ+jets, WW+jets, WZ+jets)

Channel	4e	4μ	2e2μ	4ℓ
$q\bar{q} \to ZZ$	333^{+57}_{-53}	622^{+31}_{-44}	815 ± 73	1770^{+98}_{-101}
$gg \to ZZ$	$75.1^{+14.3}_{-13.5}$	$116.6^{+11.7}_{-12.8}$	176.9 ± 23.0	$368.5^{+29.5}_{-29.6}$
$Z + X$	19.3 ± 7.2	50.8 ± 15.2	64.6 ± 15.6	134.7 ± 22.9
Sum of backgrounds	$428^{+59.2}_{55.2}$	$790^{+36.4}_{-48.3}$	1057 ± 78.1	$2274^{+104.9}_{-107.7}$
Signal ($m_H = 125$ GeV)	$19.6^{+3.3}_{-3.1}$	$40.8^{+2.5}_{-2.9}$	50.7 ± 5.6	$111.1^{+6.9}_{-7.0}$
Total expected	$447^{+59.3}_{55.2}$	$830^{+36.5}_{-48.4}$	1108 ± 78.3	$2385^{+105.1}_{-107.9}$
Observed	462	850	1130	2442

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Systematics Uncertainties

- The experimental uncertainties
  - depending on the year of data taking
  - Integrated luminosity
  - Lepton identification and reconstruction efficiency
- Theoretical uncertainties
  - renormalization and factorization scale and choice of PDF set
- In combination of the three-year data, the theoretical uncertainties and experimental ones related to leptons or jets are treated as correlated while all other ones from experimental sources are taken as uncorrelated.

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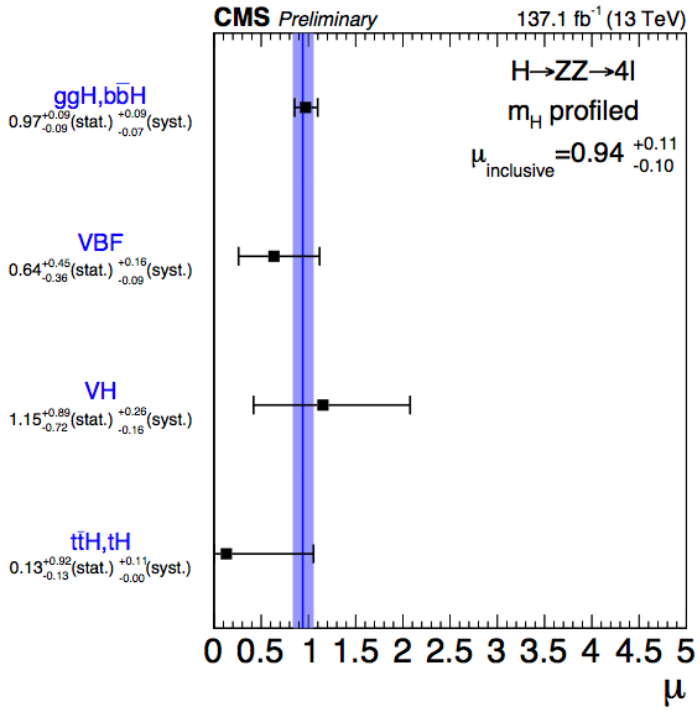
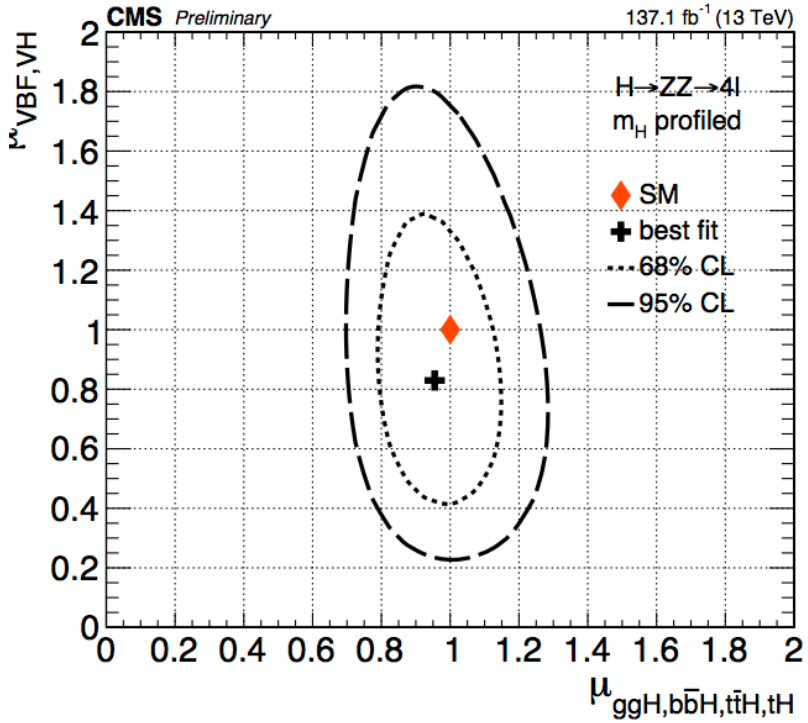
	2016	2017	2018
Luminosity	2.6%	2.3%	2.5%
Lepton eff.	2.5 – 9%	3 - 12.5%	2.2 - 16.1%

Summary of inclusive theory uncertainties	
$BR(H \to ZZ \to 4\ell)$	2 %
QCD scale ($q\bar{q} \to ZZ$)	+3.2/-4.2 % %
PDF set ($q\bar{q} \to ZZ$)	+3.1/-3.4 %
Electroweak corrections ($q\bar{q} \to ZZ$)	$\pm$ 0.1 %

Signal Strength – Production Models





	Expected	Observed
$\mu_{\text{inclusive}}$	$1.00^{+0.08}_{-0.08}(\text{stat.})^{+0.09}_{-0.07}(\text{syst.})$	$0.94^{+0.07}_{-0.07}(\text{stat.})^{+0.08}_{-0.07}(\text{syst.})$
μ_{ggH}	$1.00^{+0.10}_{-0.10}(\text{stat.})^{+0.09}_{-0.07}(\text{syst.})$	$0.97^{+0.09}_{-0.09}(\text{stat.})^{+0.09}_{-0.07}(\text{syst.})$
μ_{VBF}	$1.00^{+0.54}_{-0.45}(\text{stat.})^{+0.27}_{-0.14}(\text{syst.})$	$0.64^{+0.45}_{-0.36}(\text{stat.})^{+0.16}_{-0.09}(\text{syst.})$
μ_{VH}	$1.00^{+0.91}_{-0.72}(\text{stat.})^{+0.29}_{-0.16}(\text{syst.})$	$1.15^{+0.89}_{-0.72}(\text{stat.})^{+0.26}_{-0.16}(\text{syst.})$
$\mu_{\text{t}\bar{\text{t}}\text{H,tH}}$	$1.00^{+1.16}_{-0.73}(\text{stat.})^{+0.19}_{-0.04}(\text{syst.})$	$0.13^{+0.92}_{-0.13}(\text{stat.})^{+0.11}_{-0.00}(\text{syst.})$

$$\mu_{ggH,t\bar{t}H,b\bar{b}H,tH} = 0.96^{+0.11}_{-0.12}$$

$$\mu_{VBF,VH} = 0.83^{+0.29}_{-0.35}$$

- Perform multidimensional maximum likelihood fit to (m_{4l},KD) templates in 66channels (3×22)
- Total PDF is defined as: $\mathcal{L}_{2D}(m_{4\ell}, \mathcal{D}^{\text{kin}}_{\text{bkg}}) = \mathcal{L}(m_{4\ell})\mathcal{L}(\mathcal{D}^{\text{kin}}_{\text{bkg}}|m_{4\ell})$.

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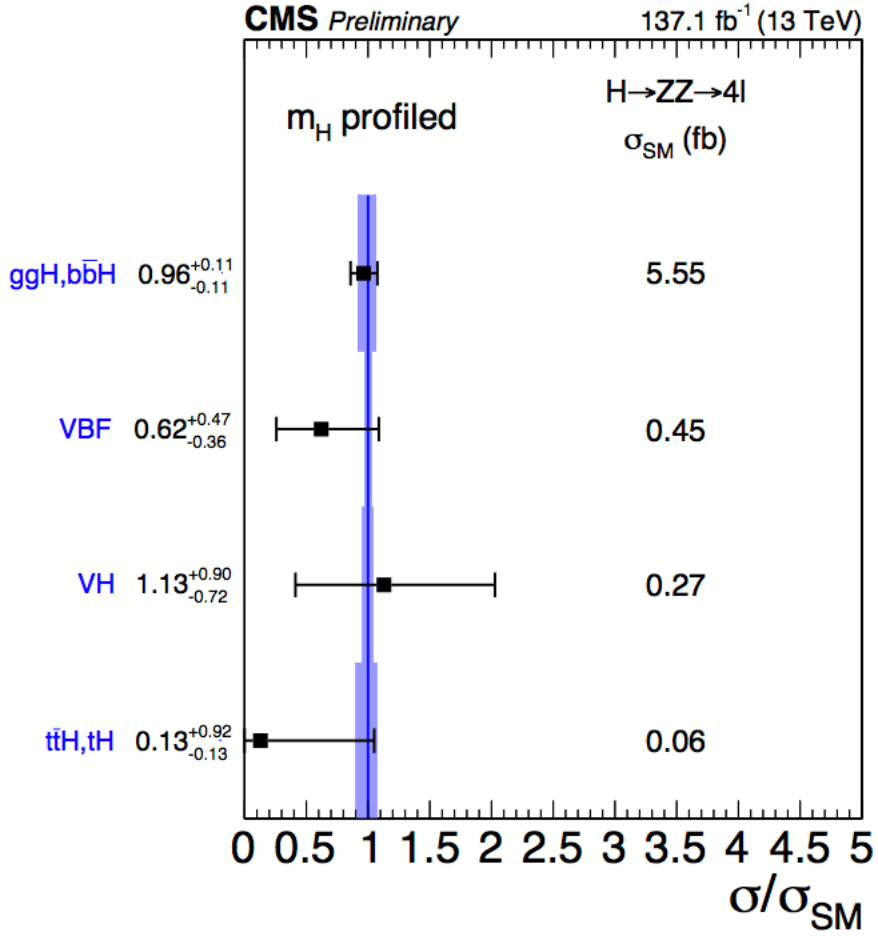
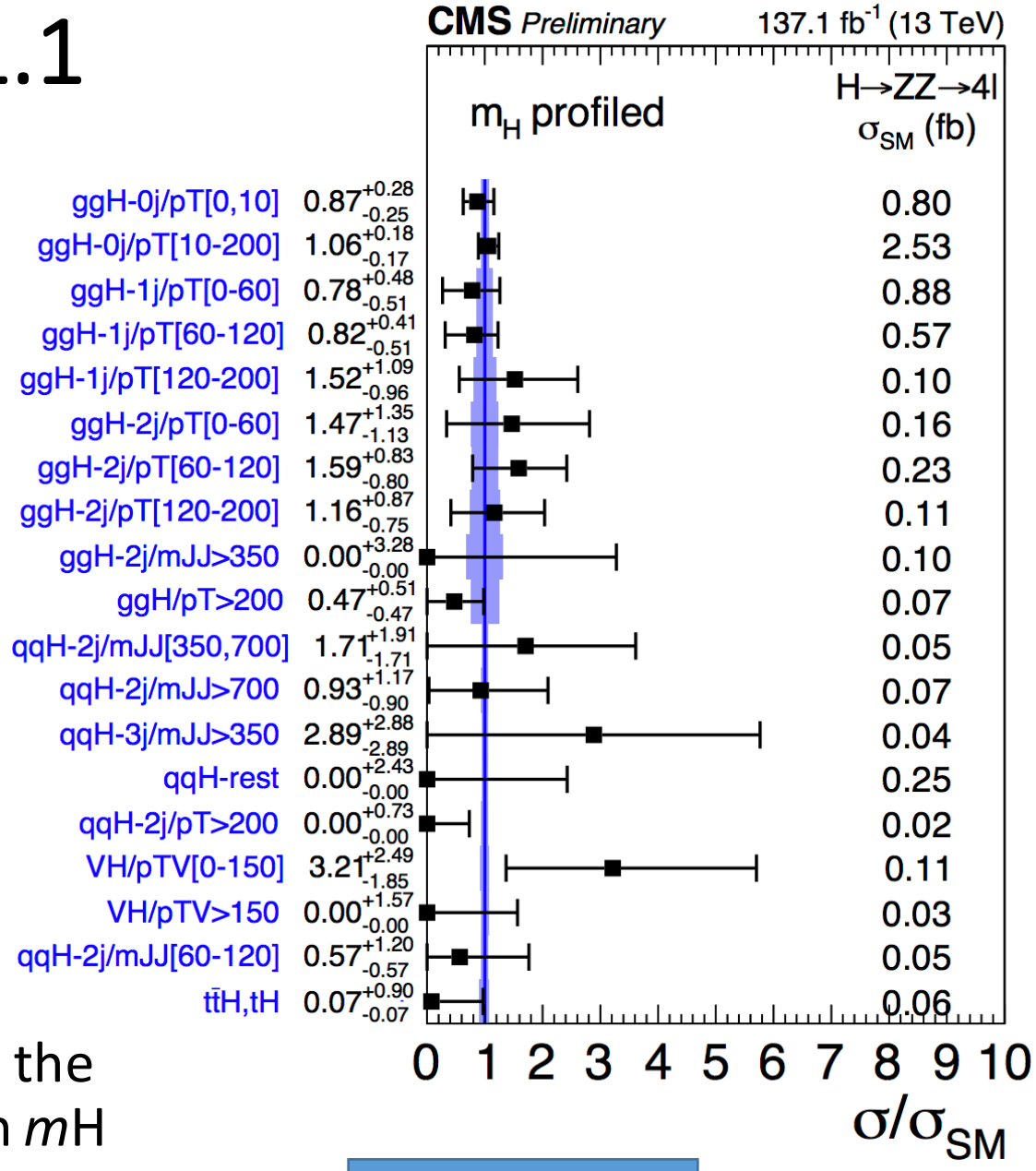
STXS – Stage 0 & Stage1.1





- The ratios between measured cross sections and the SM prediction for Stage 0 and Stage 1.1 Bins with *m*H profiled in the fit.

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Fiducial/Differential Cross Section

- This measurement has minimal dependence on the assumptions of the relative fraction or kinematic distributions of the separate production modes.

Requirements for the H $\to 4\ell$ fiducial phase space	
Lepton kinematics and isolation	
Leading lepton p_T	$p_T > 20$ GeV
Next-to-leading lepton p_T	$p_T > 10$ GeV
Additional electrons (muons) p_T	$p_T > 7(5)$ GeV
Pseudorapidity of electrons (muons)	$\lvert\eta\rvert < 2.5(2.4)$
Sum of scalar p_T of all stable particles within $\Delta R < 0.3$ from lepton	$< 0.35 \cdot p_T$
Event topology	
Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above	
Inv. mass of the Z_1 candidate	40 GeV $< m_{Z_1} <$ 120 GeV
Inv. mass of the Z_2 candidate	12 GeV $< m_{Z_2} <$ 120 GeV
Distance between selected four leptons	$\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$
Inv. mass of any opposite sign lepton pair	$m_{\ell^+\ell^-} > 4$ GeV
Inv. mass of the selected four leptons	105 GeV $< m_{4\ell} <$ 140 GeV

Signal process	$\mathcal{A}_{\text{fid}}$	ϵ	f_{nonfid}	$(1+f_{\text{nonfid}})\epsilon$
Individual Higgs boson production modes				
gg→H (POWHEG)	0.402 ± 0.001	0.592 ± 0.002	0.053 ± 0.001	0.624 ± 0.002
VBF (POWHEG)	0.444 ± 0.002	0.605 ± 0.003	0.043 ± 0.001	0.631 ± 0.003
WH (POWHEG+MINLO)	0.325 ± 0.002	0.588 ± 0.003	0.075 ± 0.002	0.632 ± 0.004
ZH (POWHEG+MINLO)	0.340 ± 0.003	0.594 ± 0.005	0.081 ± 0.004	0.643 ± 0.006
ttH (POWHEG)	0.314 ± 0.003	0.585 ± 0.006	0.169 ± 0.006	0.684 ± 0.007

$$
\begin{aligned}
N^{f,i}_{\text{obs}}(m_{4\ell}) &= N^{f,i}_{\text{fid}}(m_{4\ell}) + N^{f,i}_{\text{nonfid}}(m_{4\ell}) + N^{f,i}_{\text{nonres}}(m_{4\ell}) + N^{f,i}_{\text{bkg}}(m_{4\ell}) \\
&= \epsilon^{f}_{i,j} \cdot \left(1 + f^{f,i}_{\text{nonfid}}\right) \cdot \sigma^{f,j}_{\text{fid}} \cdot \mathcal{L} \cdot \mathcal{P}_{\text{res}}(m_{4\ell}) \\
&\quad + N^{f,i}_{\text{nonres}} \cdot \mathcal{P}_{\text{nonres}}(m_{4\ell}) + N^{f,i}_{\text{bkg}} \cdot \mathcal{P}_{\text{bkg}}(m_{4\ell}),
\end{aligned}
$$

$$\sigma_{fid.} = 2.73^{+0.30}_{-0.29} = 2.73^{+0.23}_{-0.22}(stat.)^{+0.24}_{-0.19}(syst.)fb$$

$$\sigma^{SM}_{fid} = 2.76 \pm 0.14 fb$$

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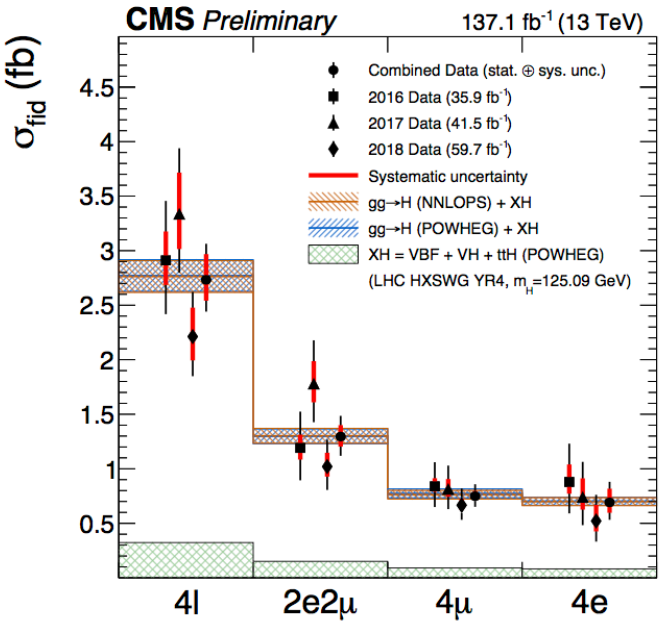
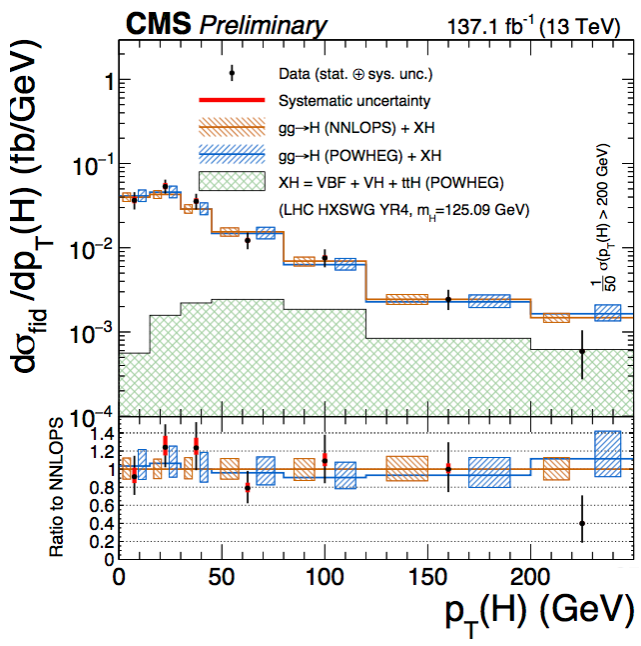
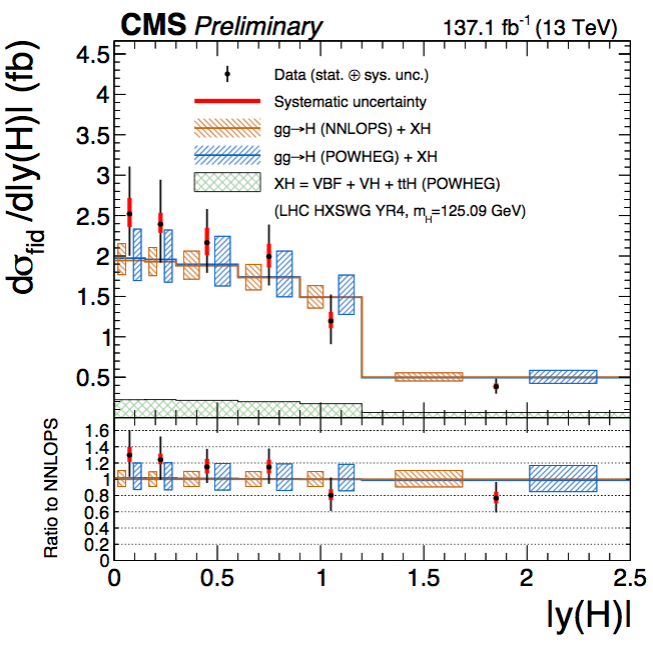
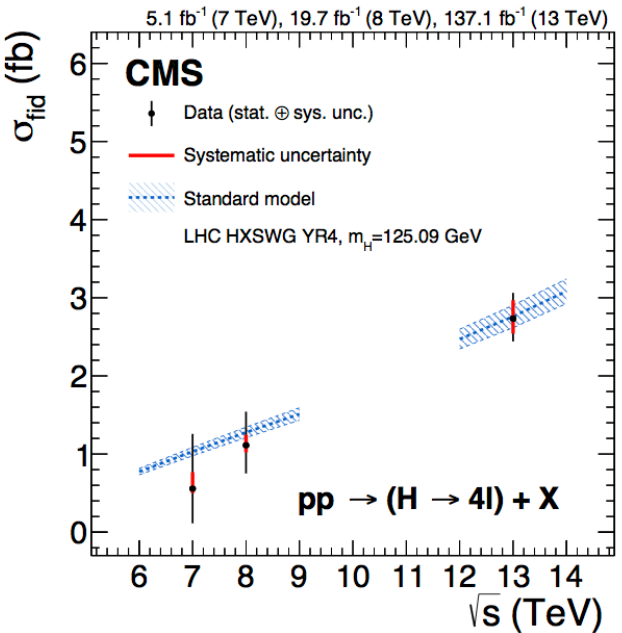
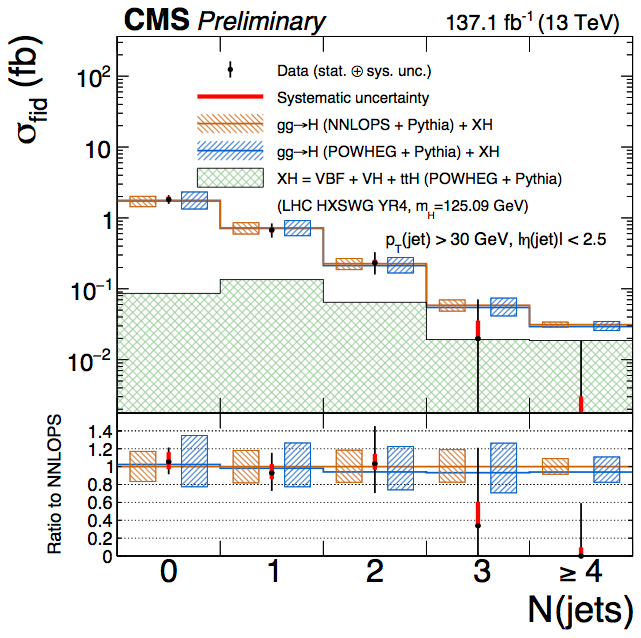
Fiducial/Differential Cross Section

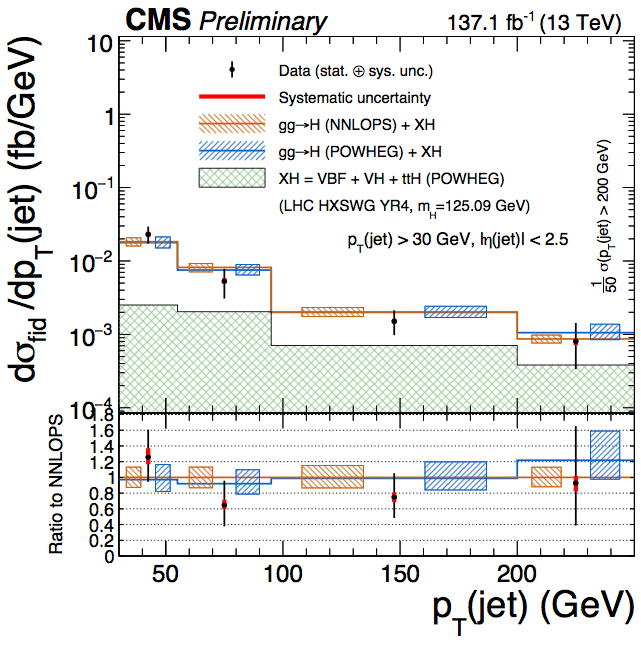












- The measured inclusive fiducial cross section in different final states and as a function of $\sqrt{s}$. (left)
- Differential cross sections as a function of the p_T and rapidity of the H boson, the number of associated jets, and the p_T of the leading associated jet are determined. (right)
- The sub-dominant component of the the signal (VBF + VH + $t\bar{t}H$) is denoted as XH.

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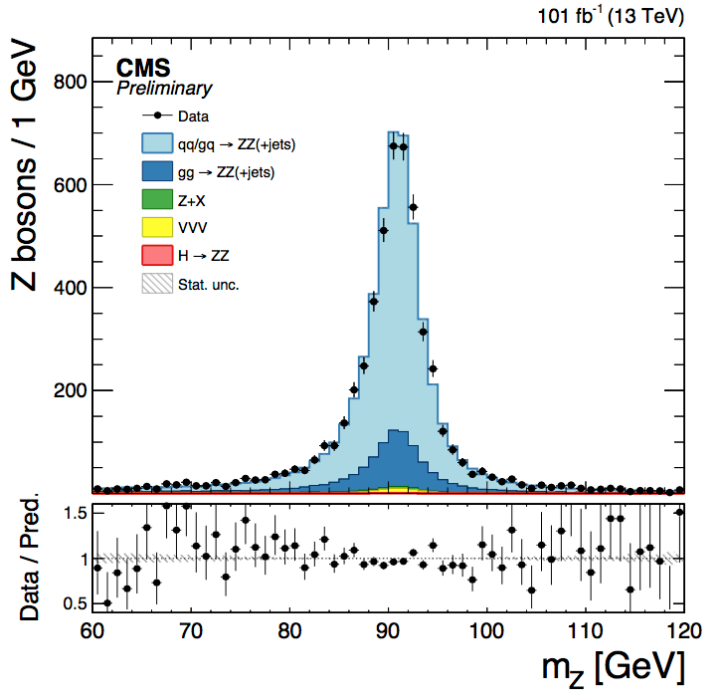
Measured total σ(pp → ZZ) cross section

- Based on similar event selection, the total cross section of pp -> ZZ is measured with 2017 and 2018 data, combining with previous 2016 results.
- $\sigma_{tot}(pp \rightarrow ZZ) = 17.1 \pm 0.3\,(stat) \pm 0.4\,(syst) \pm 0.4\,(theo) \pm 0.3\,(lumi)$ pb

Year	Total cross section, pb
2016 [5]	$17.5^{+0.6}_{-0.5}\,(stat) \pm 0.6\,(syst) \pm 0.4\,(theo) \pm 0.4\,(lumi)$
2017	$16.8 \pm 0.5\,(stat) \pm 0.5\,(syst) \pm 0.4\,(theo) \pm 0.4\,(lumi)$
2018	$16.8 \pm 0.4\,(stat) \pm 0.6\,(syst) \pm 0.4\,(theo) \pm 0.4\,(lumi)$
Combined	$17.1 \pm 0.3\,(stat) \pm 0.4\,(syst) \pm 0.4\,(theo) \pm 0.3\,(lumi)$

Fiducial phase space for ZZ -> 4l	
Lepton kinematics and isolation	
Leading lepton p_T Next-to-leading lepton p_T Additional electrons (muons) p_T Pseudorapidity of electrons (muons)	$p_T > 20$ GeV $p_T > 10$ GeV $p_T > 5$ GeV $\|\eta\| < 2.5$
Event topology	
Existence of at least two same-flavor OS lepton pairs, where leptons satisfy criteria above Inv. mass of the Z_1 candidate Inv. mass of the Z_2 candidate Inv. mass of any opposite sign lepton pair Inv. mass of the selected four leptons	 60GeV<mZ1, mZ2<120GeV $\Delta m_{l+l'-}$ >4GeV



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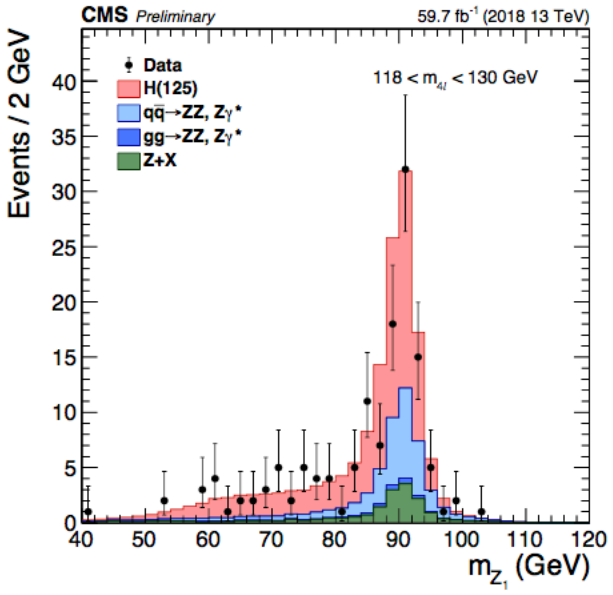
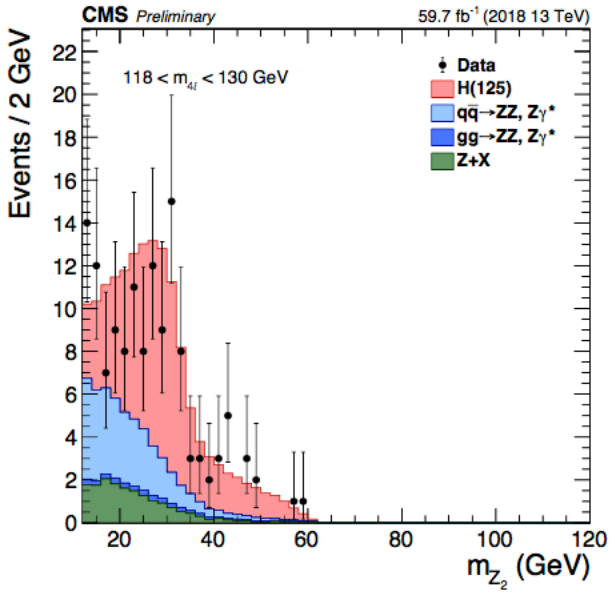
Conclusion

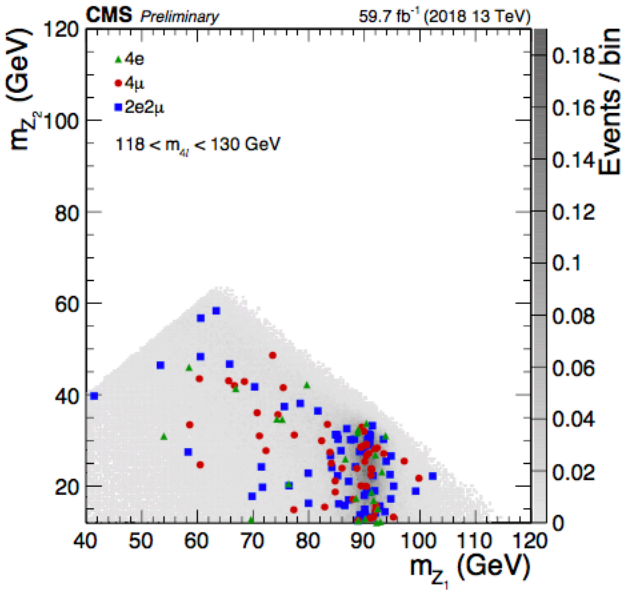
- Several measurements of Higgs boson production in four-lepton final state at $\sqrt{s} = 13TeV$ are presented, using data sample corresponding to an integrated luminosity of 137.1 fb^{-1}.
  - It is the STXS measurement of so-called stage 1.1. For the paper, it is updated with stage1.2.
  - New observables and improved bins are applied for differential XS. For further study, additional theoretical prediction(s) and more observables will be studied.
- Measured cross section of pp -> ZZ process is 17.1 ± 0.3 (stat) ± 0.4 (syst) ± 0.4 (theo) ± 0.3 (lumi) pb when combining 3-year data.
- All results are consistent, within their uncertainties, with the expectations for the Standard Model H boson.

Backup

Distribution of Z_1 and Z_2







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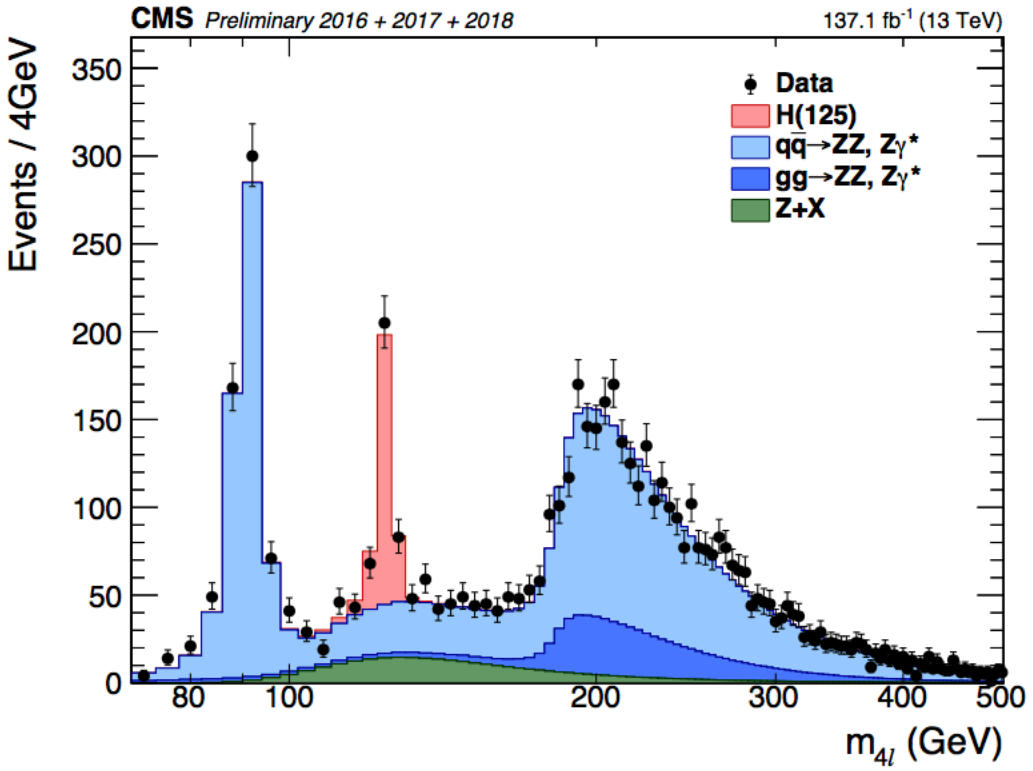
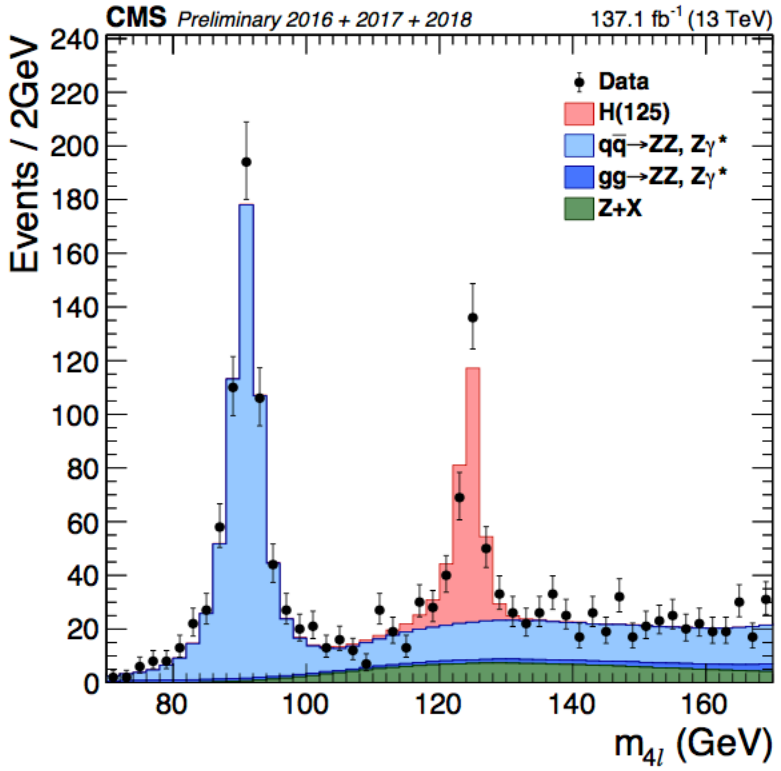
Distribution of m_{4l} of Run-2 data





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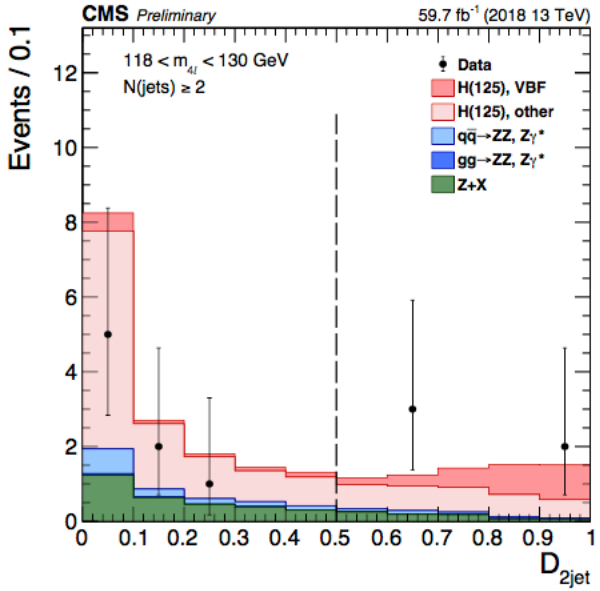
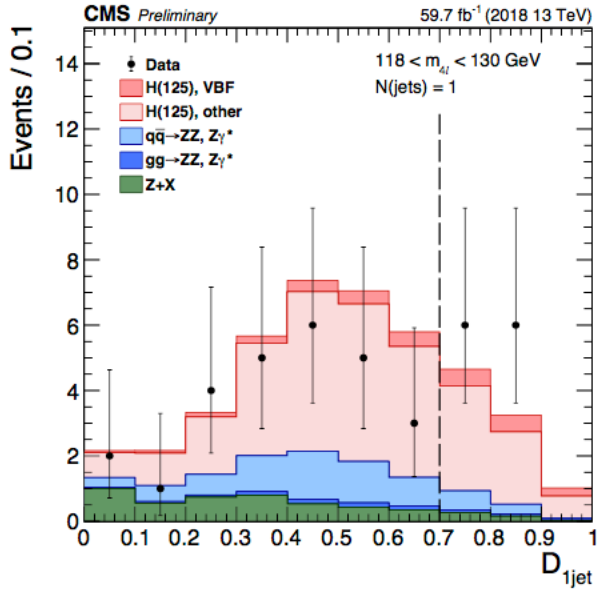
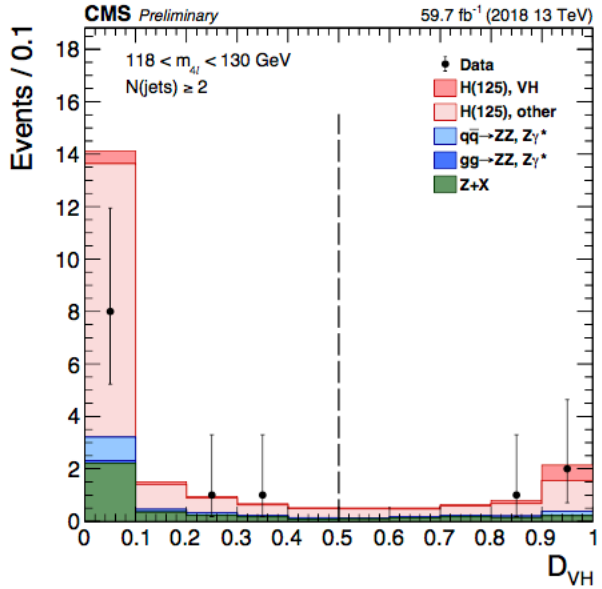
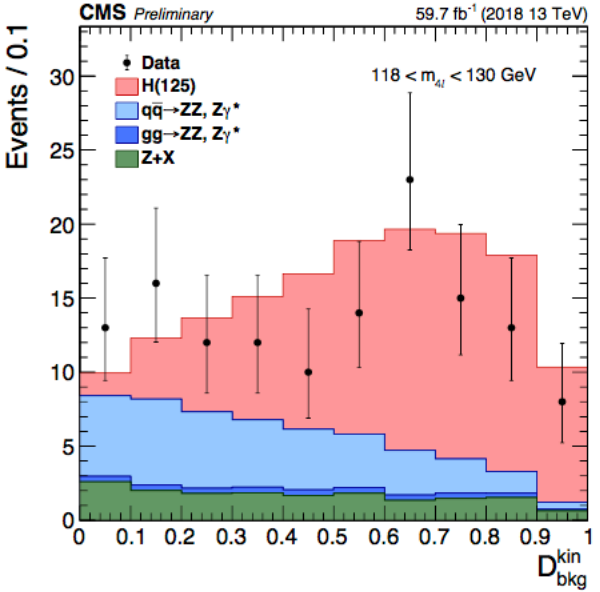
Distribution of discriminant

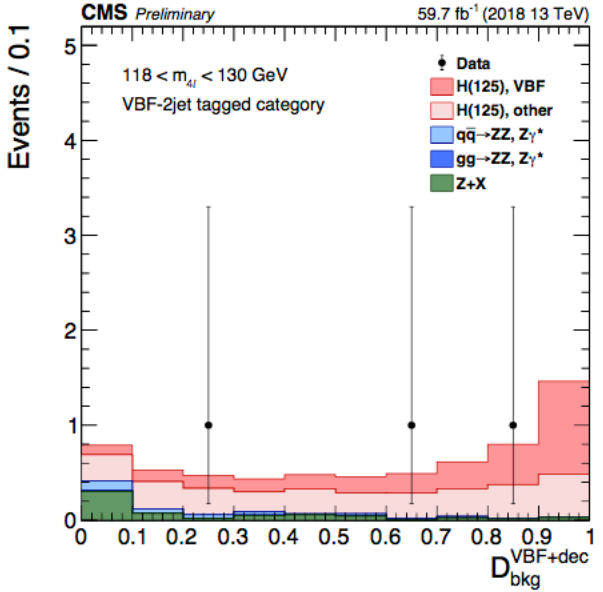


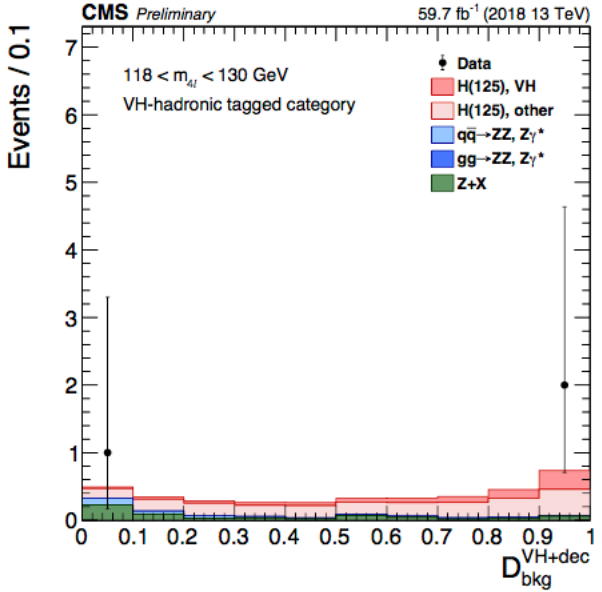




Category discriminant







Kinematic discriminant

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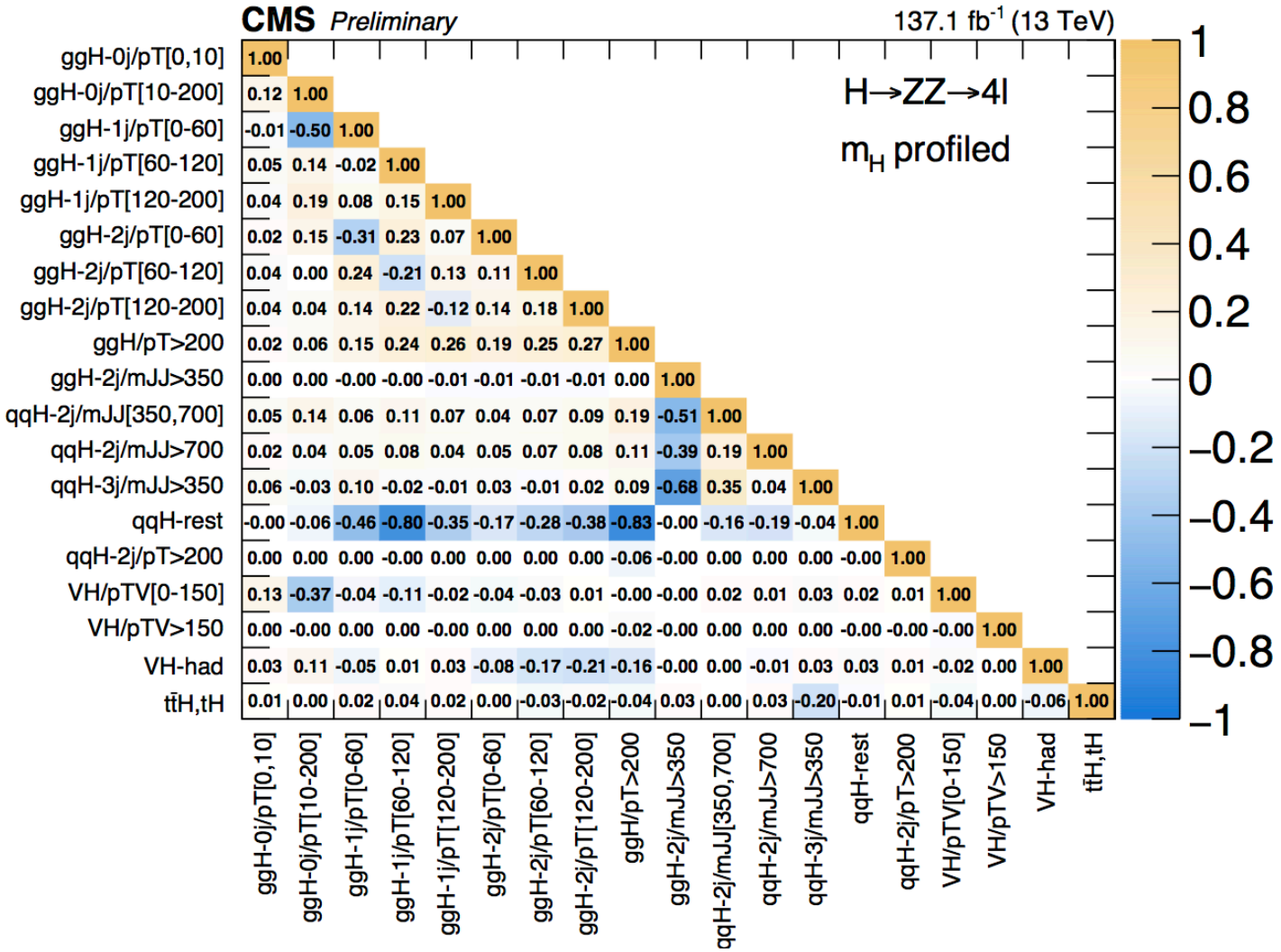
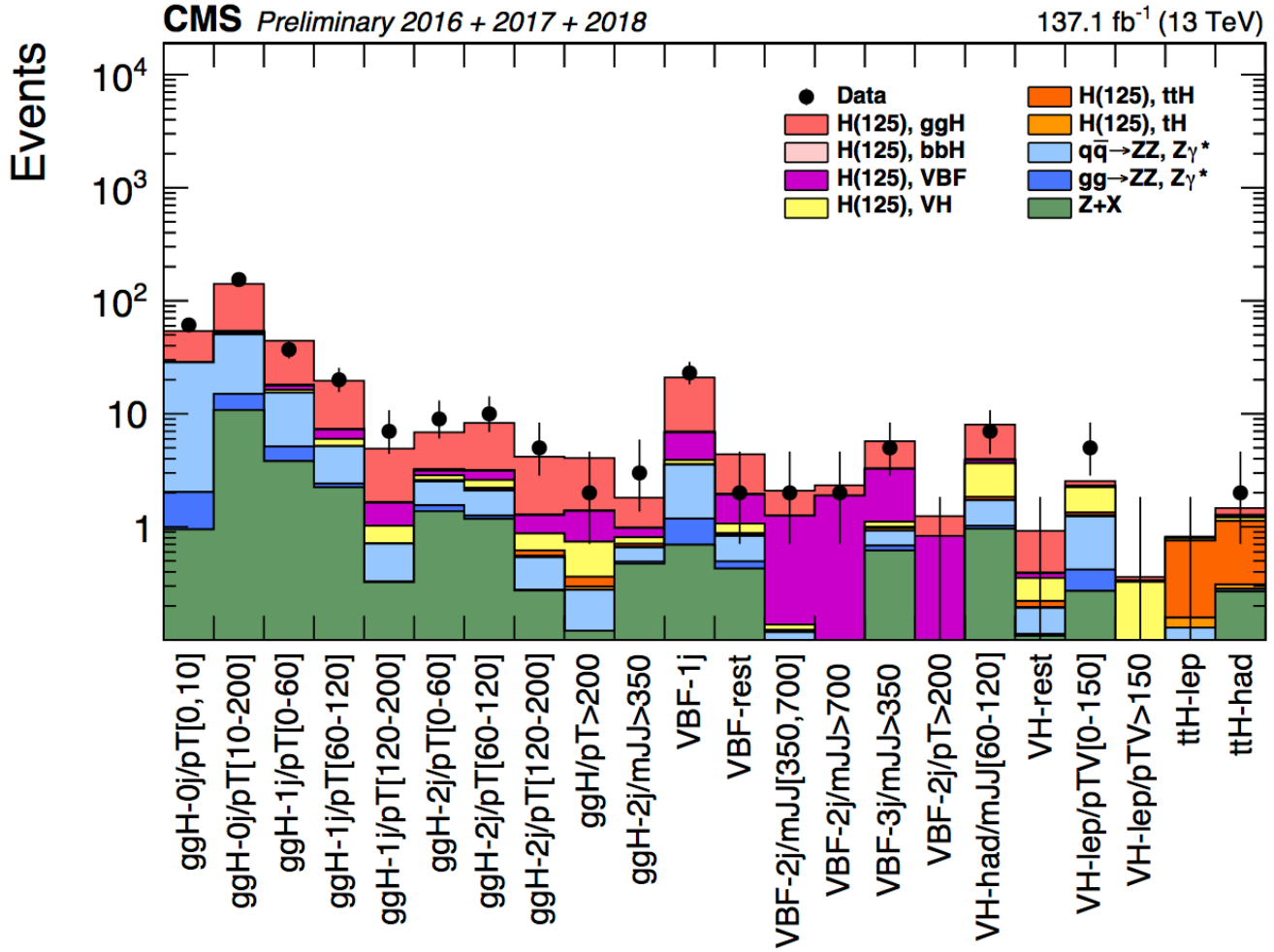
Correlation matix of the fitted signal strengths of Stage1.1 bins



Expected Yields

Event category	Signal ggH	VBF	WH	ZH	ttH	bbH	tqH	Total signal	Background $q\bar{q} \to ZZ$	$gg \to ZZ$	$Z + X$	Total expected	Observed
ggH-0j/pT[0,10]	25.3	0.08	0.02	0.02	0.00	0.14	0.00	25.6	26.5	0.97	1.19	54.2	61
ggH-0j/pT[10-200]	86.8	1.69	0.54	0.86	0.00	0.90	0.00	90.8	35.4	3.79	15.5	145	153
ggH-1j/pT[0-60]	26.2	1.43	0.50	0.45	0.01	0.43	0.01	29.1	10.3	1.19	5.54	46.1	40
ggH-1j/pT[60-120]	12.4	1.24	0.45	0.47	0.01	0.10	0.01	14.6	2.76	0.16	3.21	20.8	17
ggH-1j/pT[120-200]	3.31	0.62	0.17	0.26	0.00	0.02	0.00	4.38	0.38	0.00	0.52	5.28	6
ggH-2j/pT[0-60]	3.68	0.29	0.14	0.14	0.06	0.09	0.02	4.42	0.97	0.15	2.07	7.60	9
ggH-2j/pT[60-120]	5.17	0.54	0.22	0.22	0.09	0.04	0.02	6.30	0.84	0.07	1.86	9.06	12
ggH-2j/pT[120-200]	2.90	0.40	0.15	0.17	0.07	0.01	0.02	3.71	0.26	0.00	0.40	4.37	5
ggH/pT>200	2.72	0.65	0.21	0.24	0.06	0.01	0.02	3.91	0.16	0.00	0.21	4.28	2
ggH-2j/mJJ>350	0.82	0.17	0.06	0.05	0.04	0.01	0.01	1.16	0.16	0.02	0.65	1.98	3
VBF-1j	14.2	2.94	0.20	0.18	0.00	0.12	0.01	17.6	2.37	0.43	1.05	21.5	20
VBF-2j/mJJ[350,700]	0.80	1.11	0.01	0.01	0.00	0.01	0.00	1.95	0.08	0.02	0.04	2.09	2
VBF-2j/mJJ>700	0.43	1.80	0.00	0.00	0.00	0.00	0.00	2.25	0.02	0.01	0.03	2.31	2
VBF-3j/mJJ>350	2.43	2.15	0.06	0.07	0.02	0.03	0.05	4.81	0.24	0.06	0.96	6.07	6
VBF-2j/pT>200	0.42	0.76	0.01	0.01	0.01	0.00	0.01	1.22	0.01	0.00	0.03	1.26	0
VBF-rest	2.40	0.87	0.11	0.10	0.03	0.04	0.01	3.56	0.34	0.06	0.74	4.70	2
VH-lep/pTV[0-150]	0.24	0.04	0.71	0.25	0.08	0.02	0.02	1.37	0.82	0.14	0.40	2.72	5
VH-lep/pTV>150	0.02	0.01	0.21	0.08	0.04	0.00	0.01	0.36	0.01	0.00	0.02	0.40	0
VH-had/mJJ[60-120]	4.11	0.25	1.01	1.20	0.11	0.07	0.02	6.77	0.70	0.05	1.36	8.89	8
VH-rest	0.56	0.04	0.08	0.07	0.03	0.00	0.00	0.77	0.08	0.00	0.15	1.01	1
ttH-had	0.19	0.05	0.03	0.06	0.82	0.01	0.03	1.19	0.01	0.00	0.45	1.66	2
ttH-lep	0.02	0.00	0.02	0.02	0.60	0.00	0.03	0.70	0.03	0.00	0.12	0.85	0

Distributions of the expected and observed number of events for all Stage 1.1 sub-categories



Mass region $118 < m_{4l} < 130$ GeV with Run 2 data