The latest results of the measurement of the Higgs boson decaying to a pair of tau leptons

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for CMS collaboration

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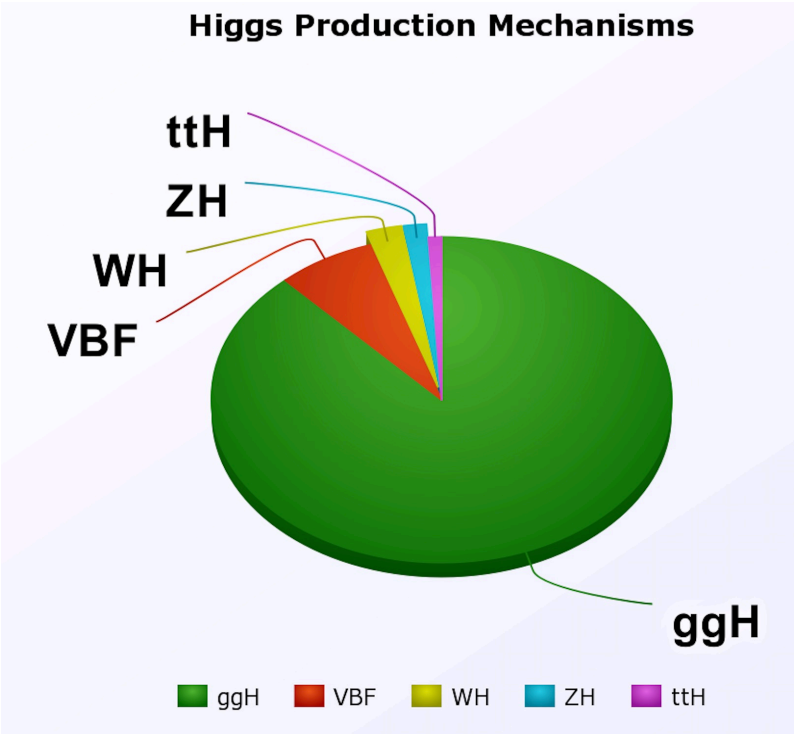
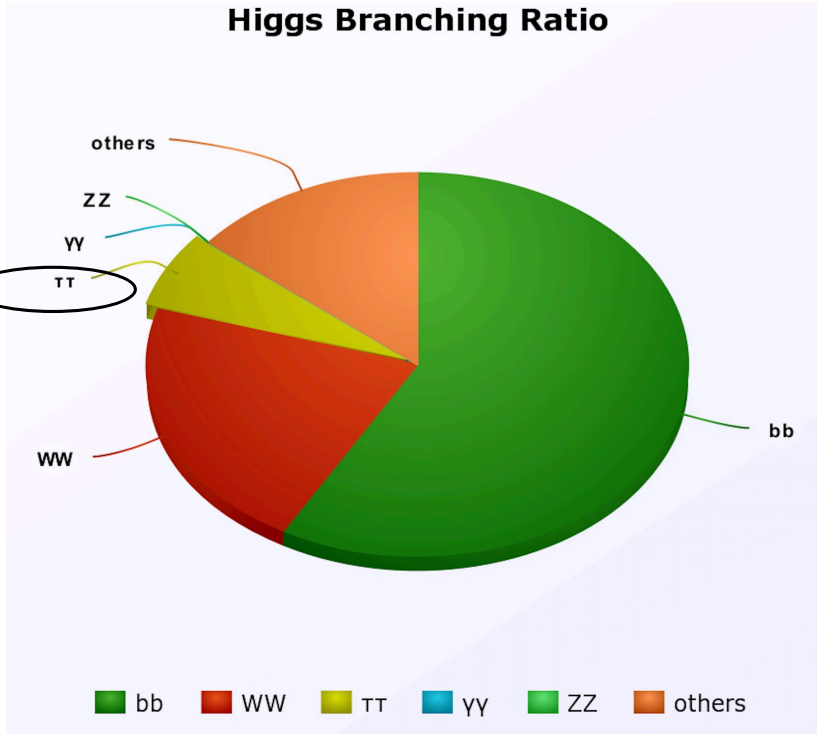
Introduction

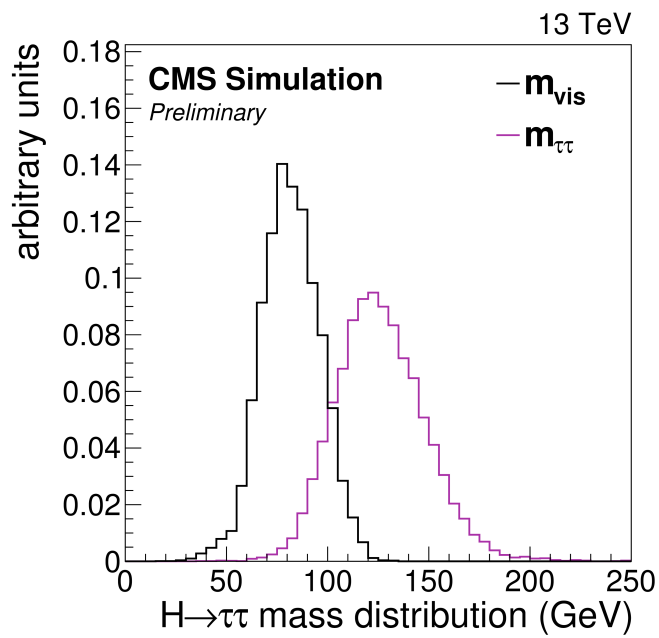


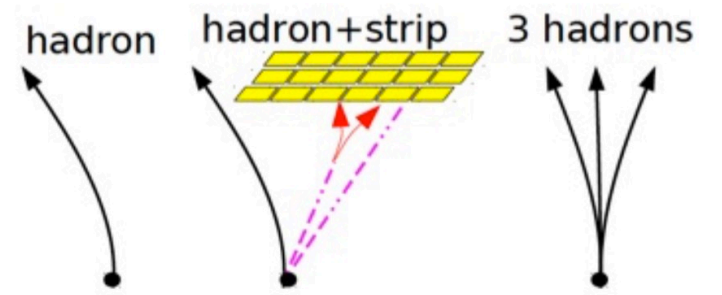


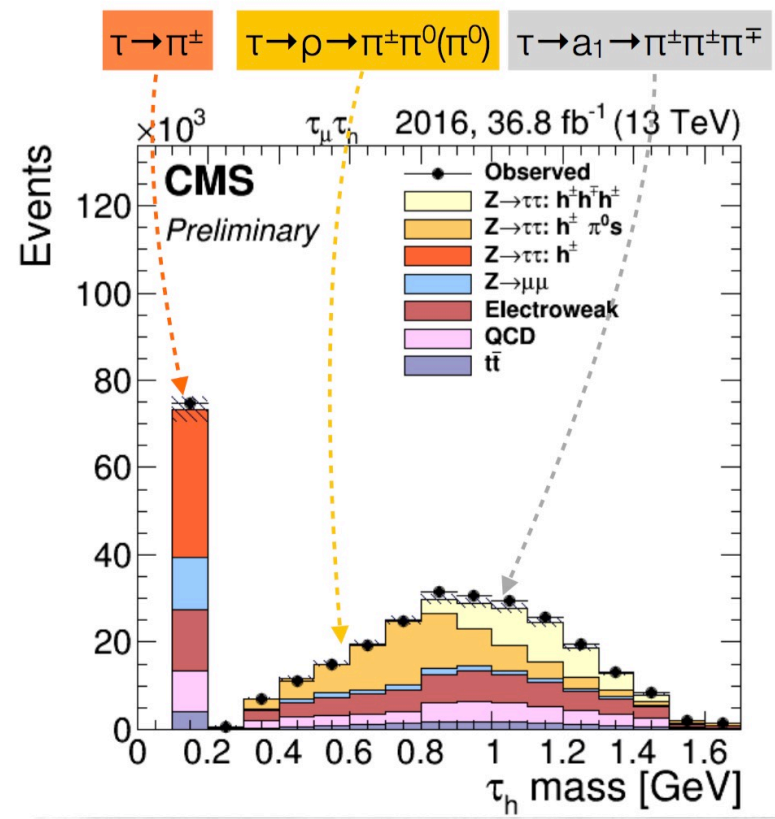
- Higgs boson in ττ decay mode is the most promising channel to explore the Higgs Yukawa coupling to fermions(decay rate to ττ is less than bb, but this channel has much less background)
- Analyzing run1 data, in 4 production modes led to the first evidence of Higgs coupling to fermions (Observed(expected) significance of 3.2(3.7) σ)
- In this presentation the results for 4 highest production cross section modes will be presented. (ttH results will be presented in a dedicated talk)

(di-)Tau reconstruction overview

- Hadron Plus Strips (HPS) algorithm updated for run2 with dynamic strip reconstruction
- Taus are reconstructed either in 1 prong or 3 prong modes
- Developed MVA based discriminators to suppress mis-identification of the taus by jets, electrons and muon
- DiTau mass is reconstructed using svFit



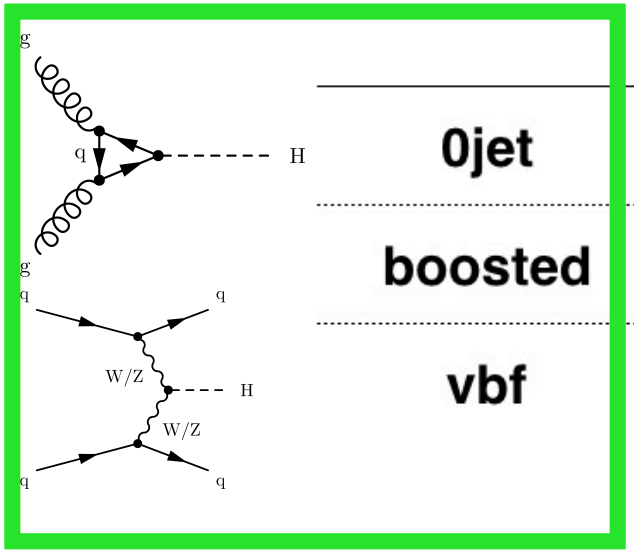




Part I
ggH + VBF production modes
[CMS-HIG-16-043]

Run 2 categorization

- Event categorization has been changed in Run2
  - 4 different final states (based on tau decays)
  - 3 main categories (mainly) based on the jet multiplicity
  - In each category, events are further split depending on tau decay modes/muon p_T (in 0jet), p_T of the Higgs boson(in boosted) and mass of the two forward jets(in VBF mode)

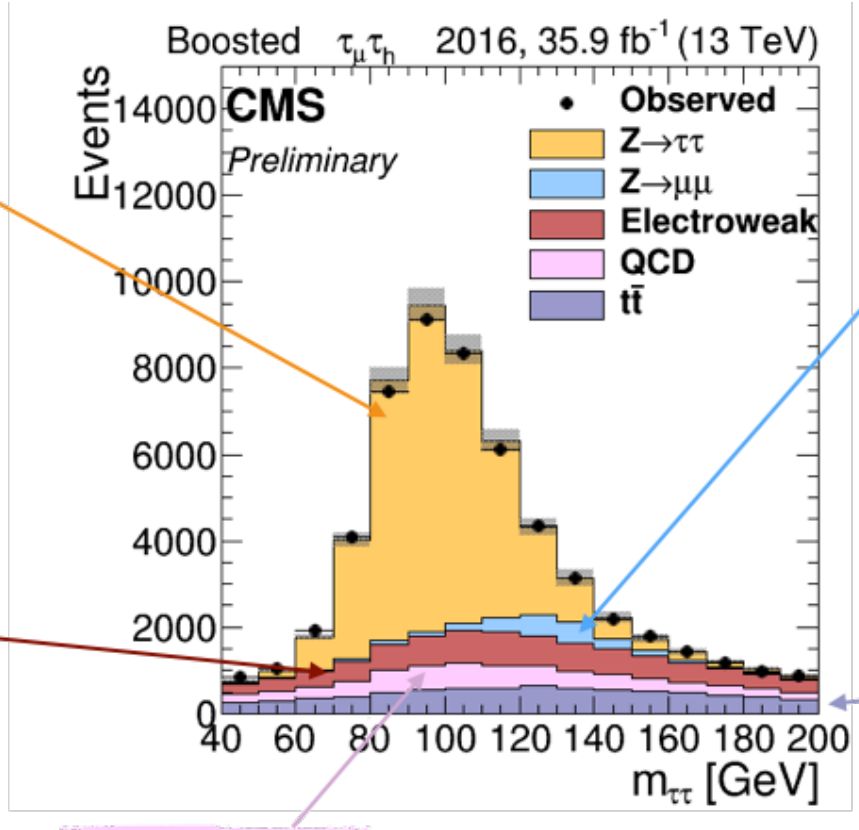


	ττ	μτ	eτ	eμ
0jet	$m_{\tau\tau}$	m_{vis}:τ DM	m_{vis}:τ DM	m_{vis} : μ pT
boosted	$m_{\tau\tau}$: H pT	$m_{\tau\tau}$: H pT	$m_{\tau\tau}$: H pT	$m_{\tau\tau}$: H pT
vbf	$m_{\tau\tau}$: m_{jj}	$m_{\tau\tau}$: m_{jj}	$m_{\tau\tau}$: m_{jj}	$m_{\tau\tau}$: m_{jj}

- 2D distributions are then unrolled to1D distributions which will be the input for the statistical interpretations

Background Anatomy

Z->ττ simulation: Madgraph N-Jet binned Drell-Yan Samples, corrections derived from Z(μμ) CR and applied



DY ℓ->τ fakes simulation: Madgraph N-Jet binned Drell-Yan Samples, corrections derived from Z(μμ) CR and applied. Additional ℓ->τ fake corrections.

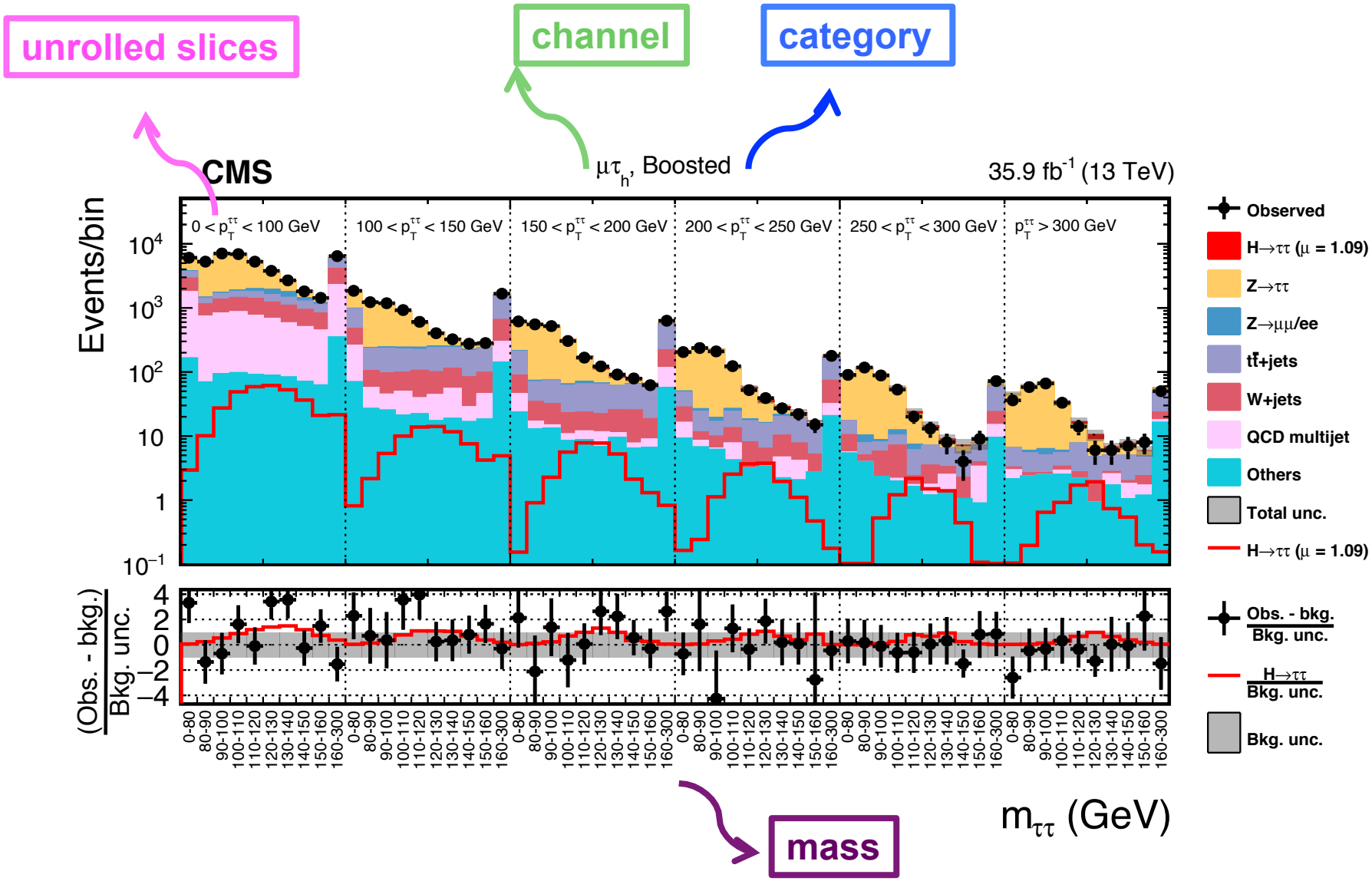
W+Jets/VV: datadriven in control region for ℓτ

TTbar: powheg MC eμ, ℓτ, ττ: datadriven all channels

QCD: datadriven in control region, for ℓτ, ττ, eμ

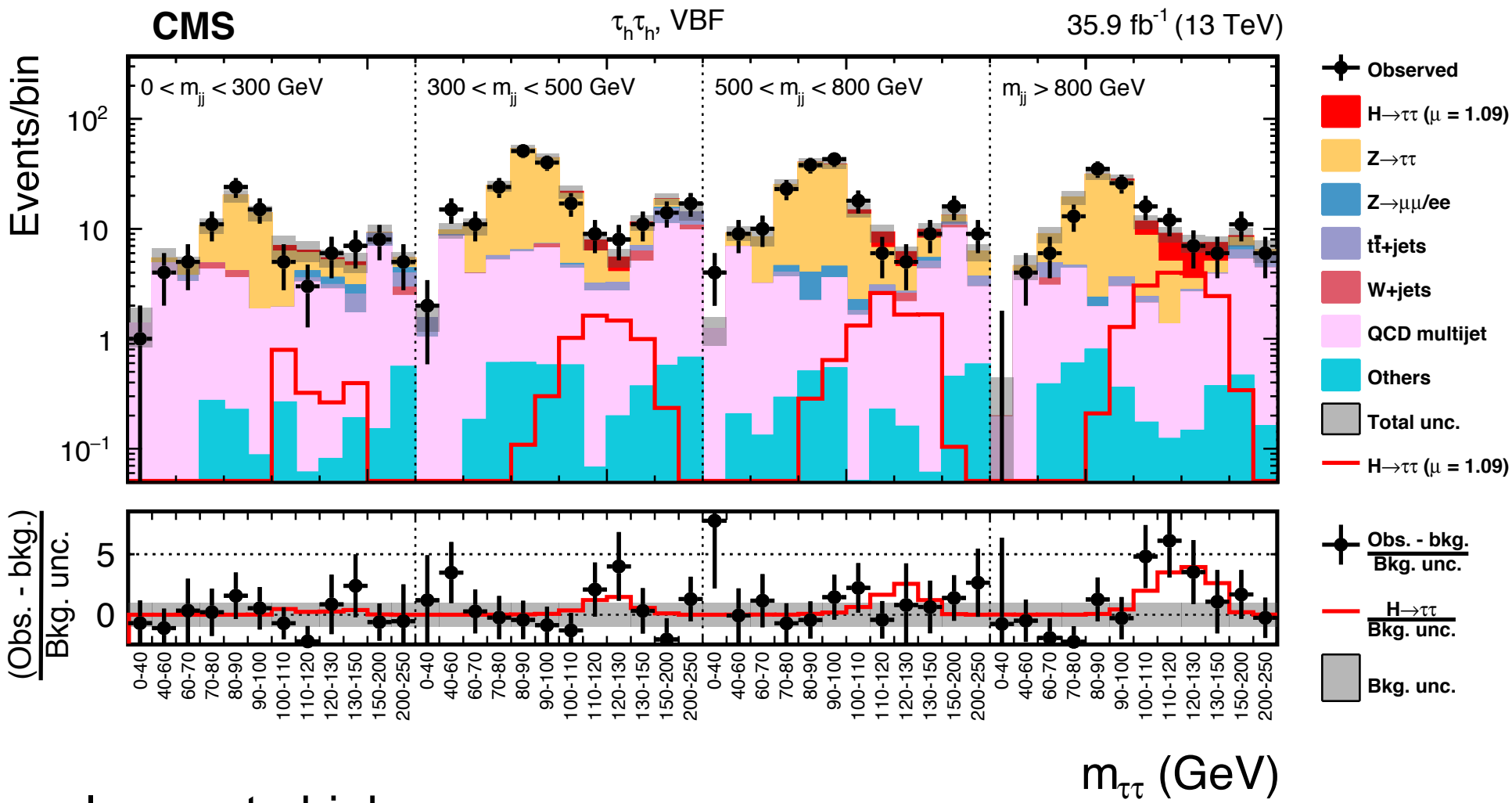
- Introduce several control regions (i.e. same sign dilepton , high-TransverseMass, …) to constrain the normalization of the backgrounds
- These control regions are fitted simultaneously with signal region

Final distributions



- Background composition and signal sensitivity varies in each slices

Final distributions

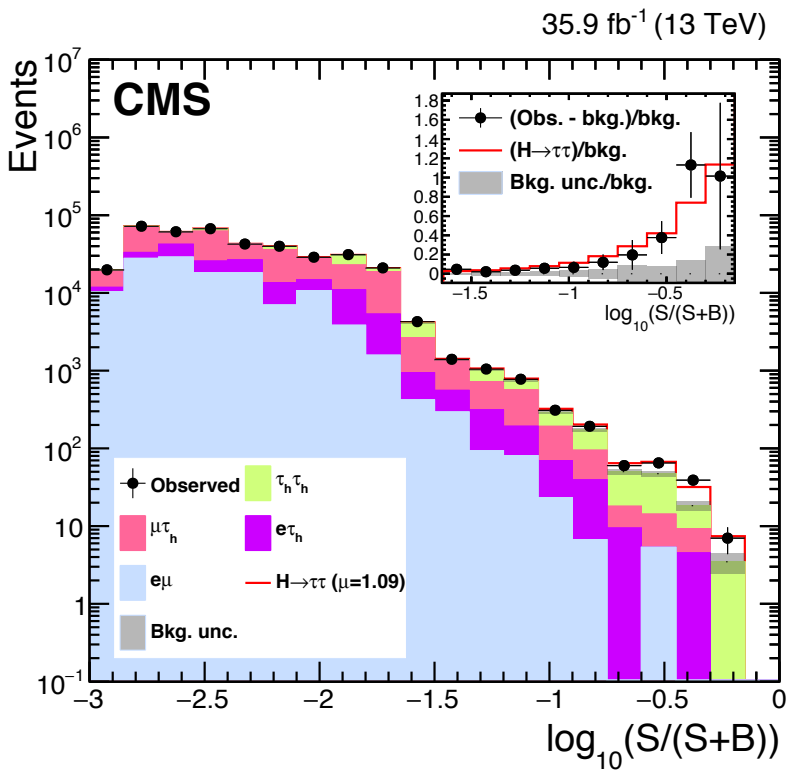


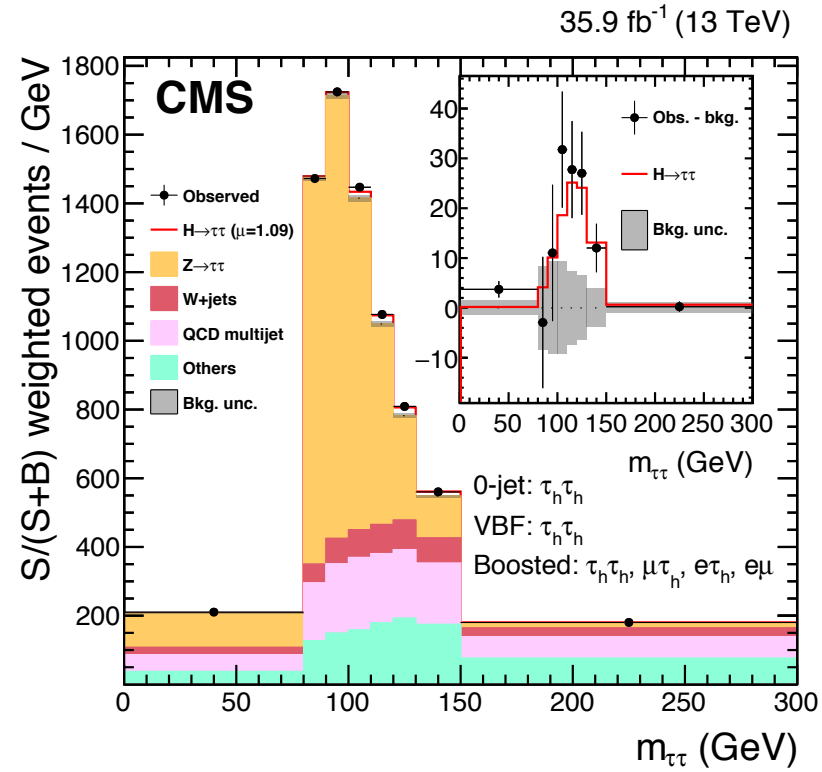
- From low m_{jj} to high m_{jj}:

Higher S/B & higher purity for VBF production w.r.t ggH production mode

- Visible excess of data on top of the SM prediction

Visualizing the excess

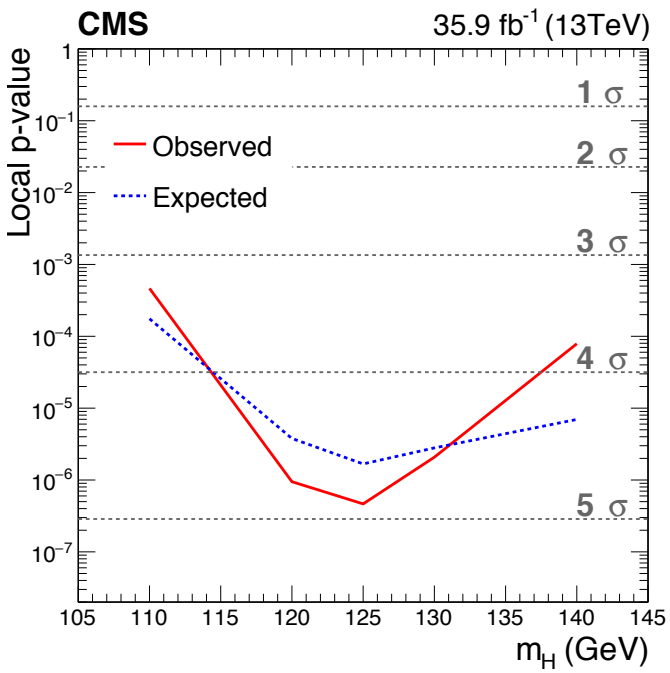


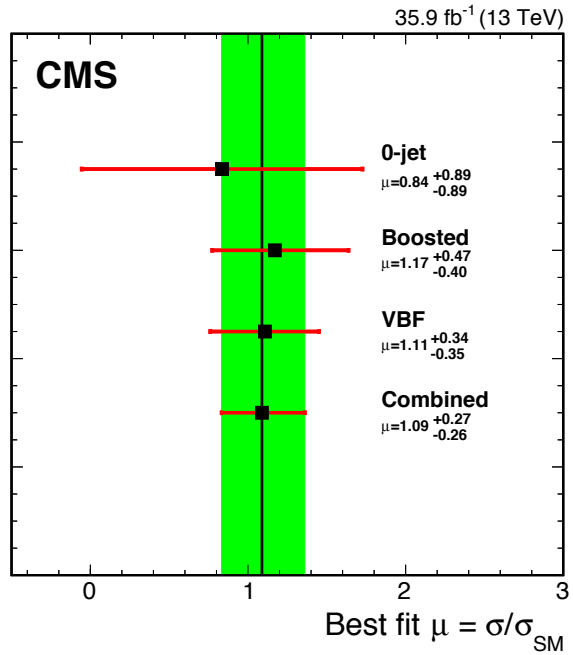


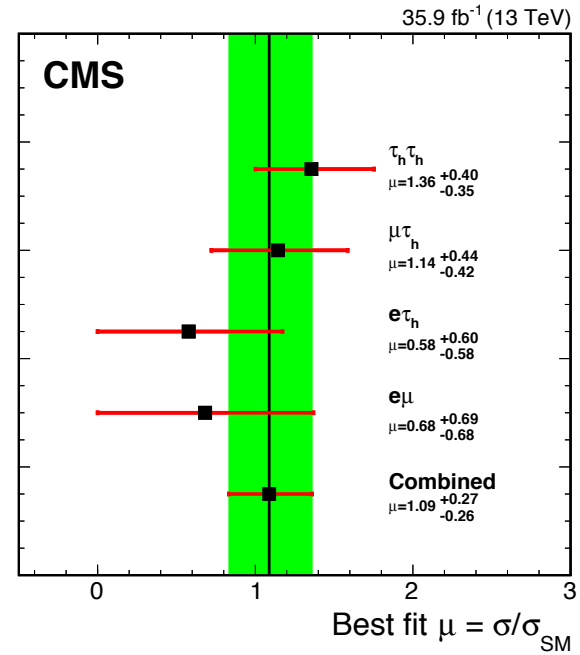
- Reorder the bins based on the log(S/S+B)
- Sensitive bins are shifted to the right-side of the distribution and less sensitive to the left-side

- Bins are weighted according to S/S+B
- Higgs signal peaks around 125 GeV

Significance & best fit value







- 4.9 (4.7) σ observed (expected) significance
- Combining with run1 we would have 5.9 σ **(the first observation of the Higgs coupling to tau leptons in a single experiment**)
- Signal strength of 1.09 +- 0.26
- $\tau_h\tau_h$ is the most sensitive channel
- VBF is the most sensitive category

Part II
VH(V→leptons) production mode
[CMS-PAS-HIG-18-007]

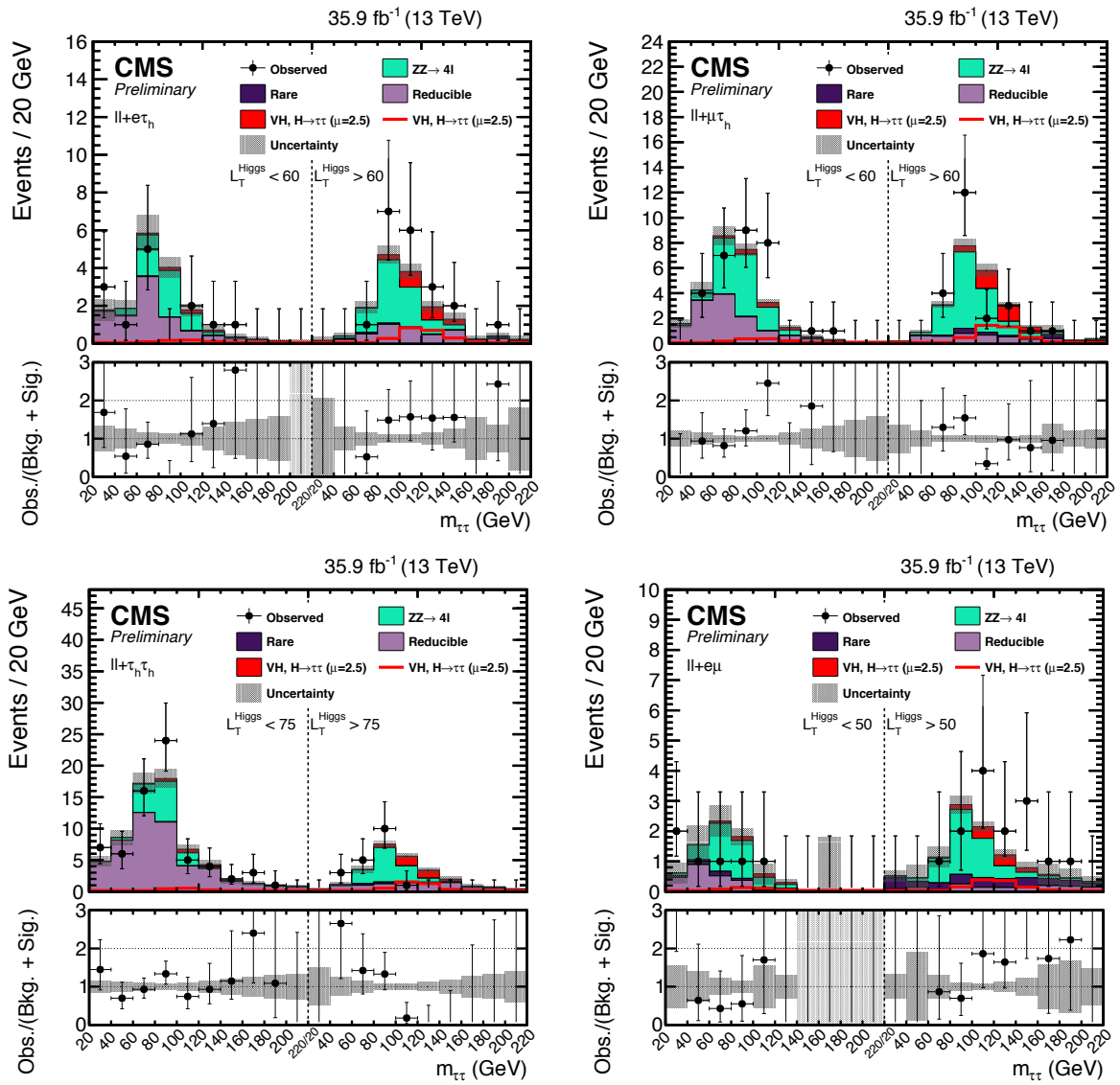
VH (ZH leptonic)

- 8 final states are explored

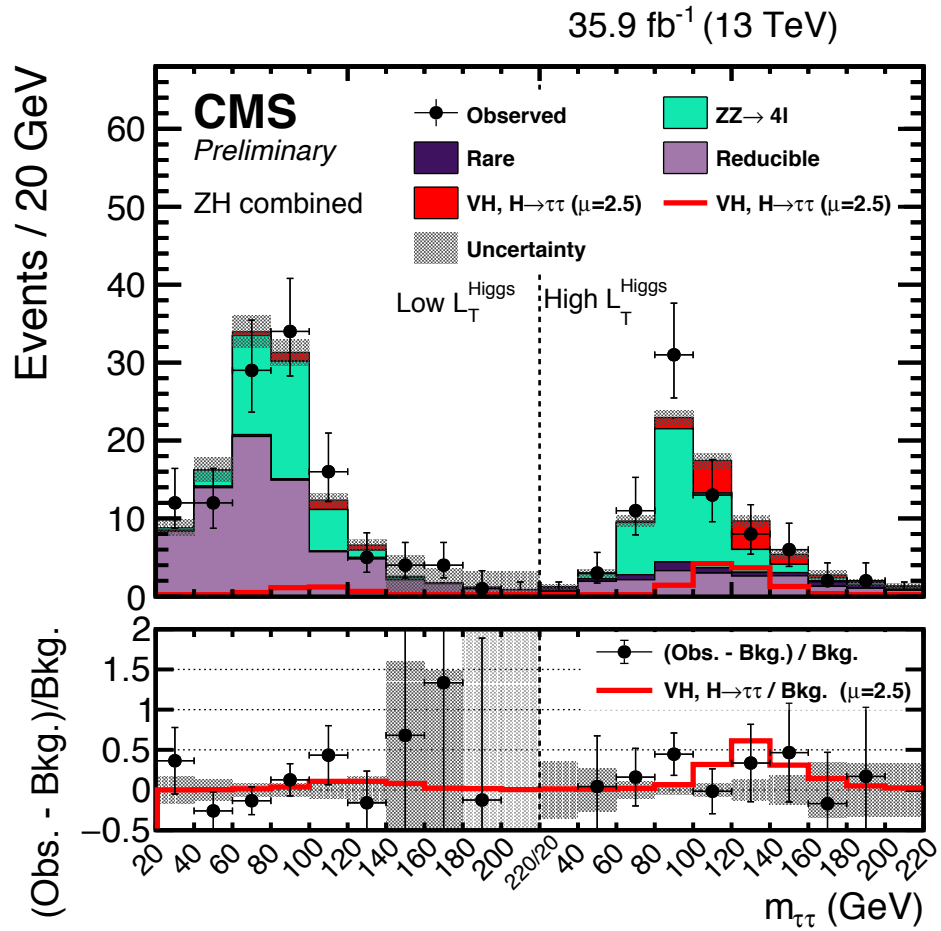
$eee\mu, eee\tau_h, ee\mu\tau_h, ee\tau_h\tau_h,$

$\mu\mu e\mu, \mu\mu e\tau_h, \mu\mu\mu\tau_h, \mu\mu\tau_h\tau_h$

- Clean signatures with ZZ as irreducible background. Other are WZ and Z+jets
- L_T (scalar sum of the lepton p_T from H decay) is used to improve the sensitivity
  - $ll e\tau_h$: L_T = 60GeV
  - $ll\mu\tau_h$: L_T= 60GeV
  - $ll\tau_h\tau_h$: L_T= 75GeV
  - $ll e\mu$: L_T = 50 GeV



ZH combined



- High L_T category is more sensitive
- The excess of data in most of the bins near Higgs mass
- This plot is just for visualization purpose. To extract the limit, all 8 ZH channels are fitted simultaneously

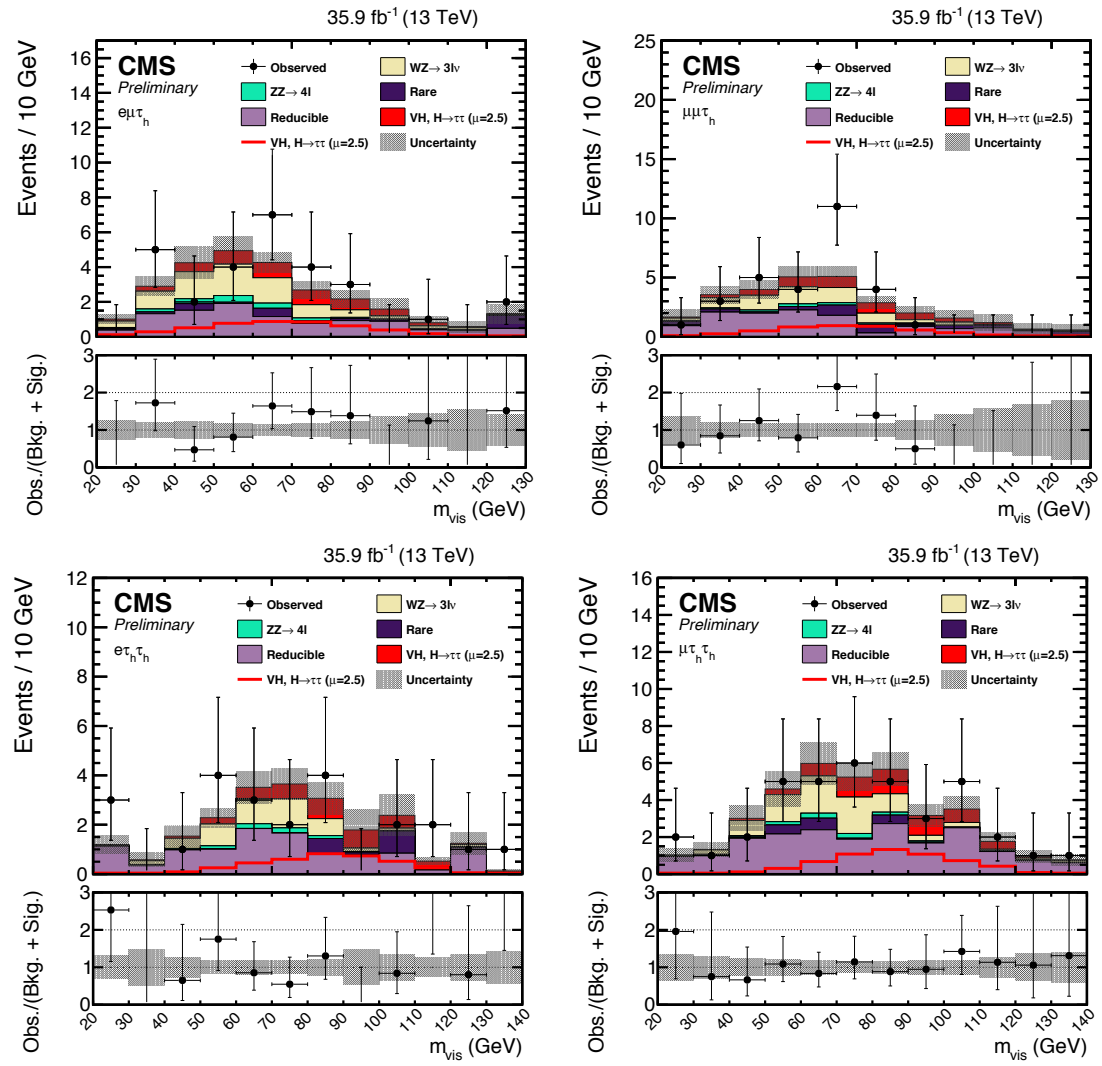
VH (WH)

WH semi-leptonic

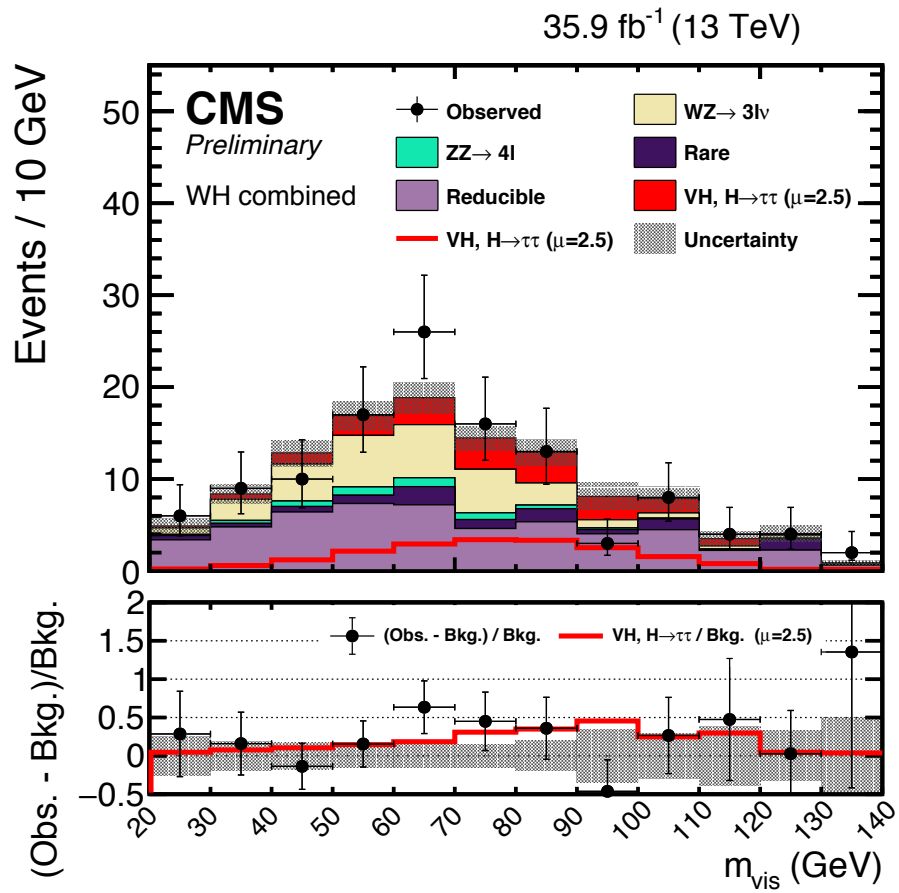
- $e\mu\tau_h, \mu\mu\tau_h$ channels
- $L_T > 100$ GeV
- $|\Delta\phi(l_1, H)| > 2.0$
- $|\Delta\eta(l_1, H)| < 2.0$
- WZ is the irreducible background. Other backgrounds like Z+jets & ttbar are highly suppressed by requiring 2 leptons to be same sign

WH hadronic

- $e\tau_h\tau_h, \mu\tau_h\tau_h$ channels
- $L_T > 130$ GeV
- $|\Delta\eta(\tau_h, \tau_h)| < 2.0$
- Larger background w.r.t other VH channels

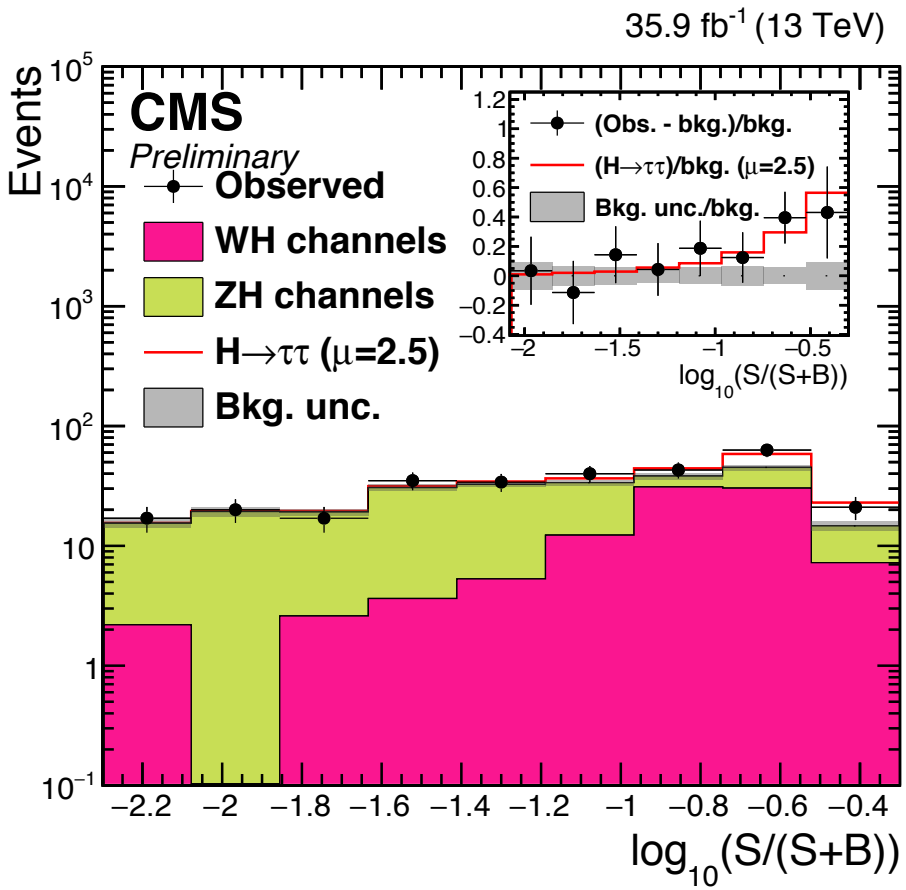


WH combined



- The excess of data in most of the bins near Higgs mass
- Similar to ZH, this plot is just for visualization. To extract the limit, all 4 WH channels are fitted simultaneously

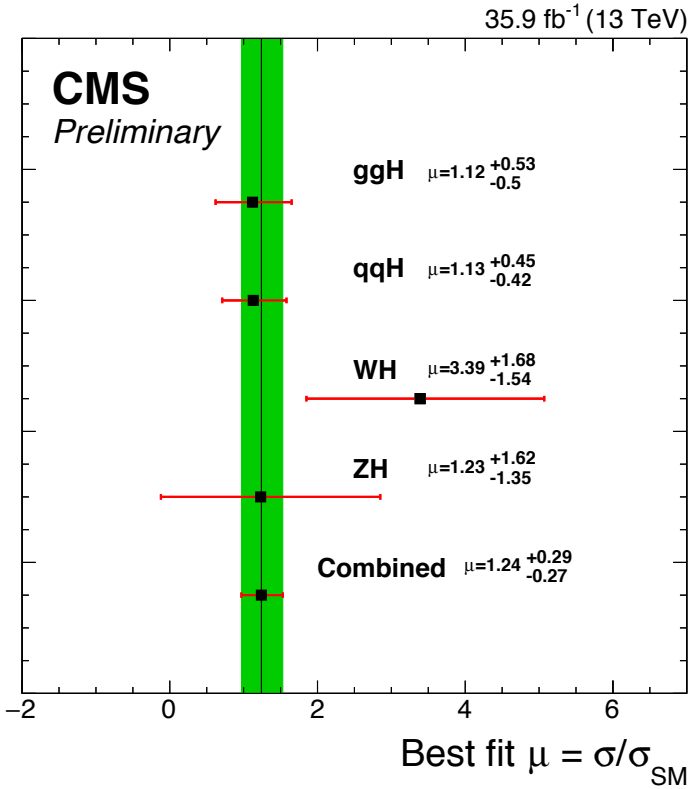
Visualizing the excess (VH)

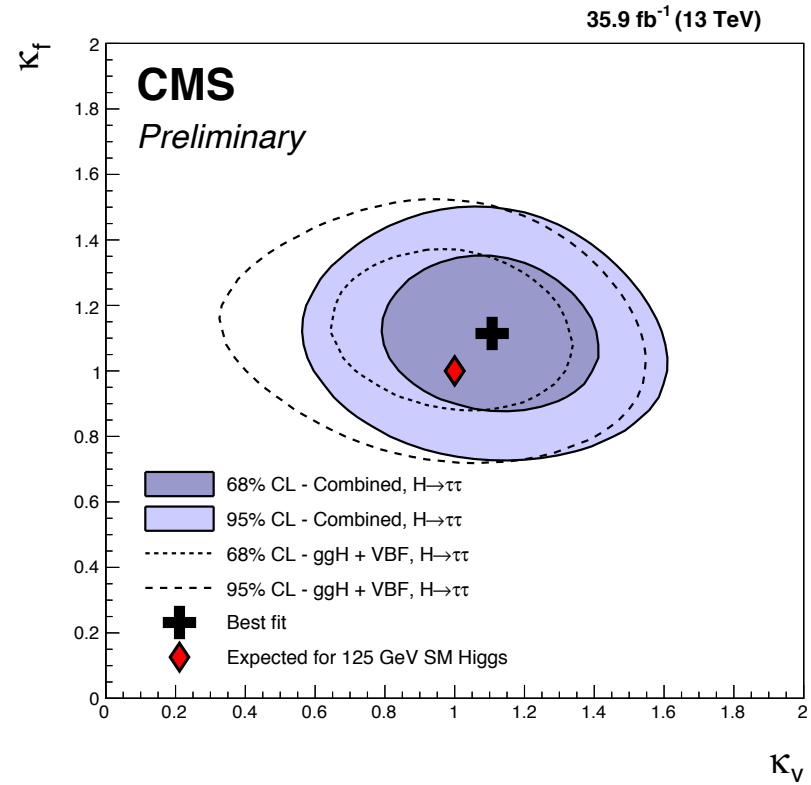


- 2.3 (1.0) σ observed (expected) significance
- The signal strength is 2.5±1.4
- ZH and WH production modes have similar sensitivity

Part III
$H \rightarrow \tau\tau$ combination
[CMS-PAS-HIG-18-007]

Coupling compatibility





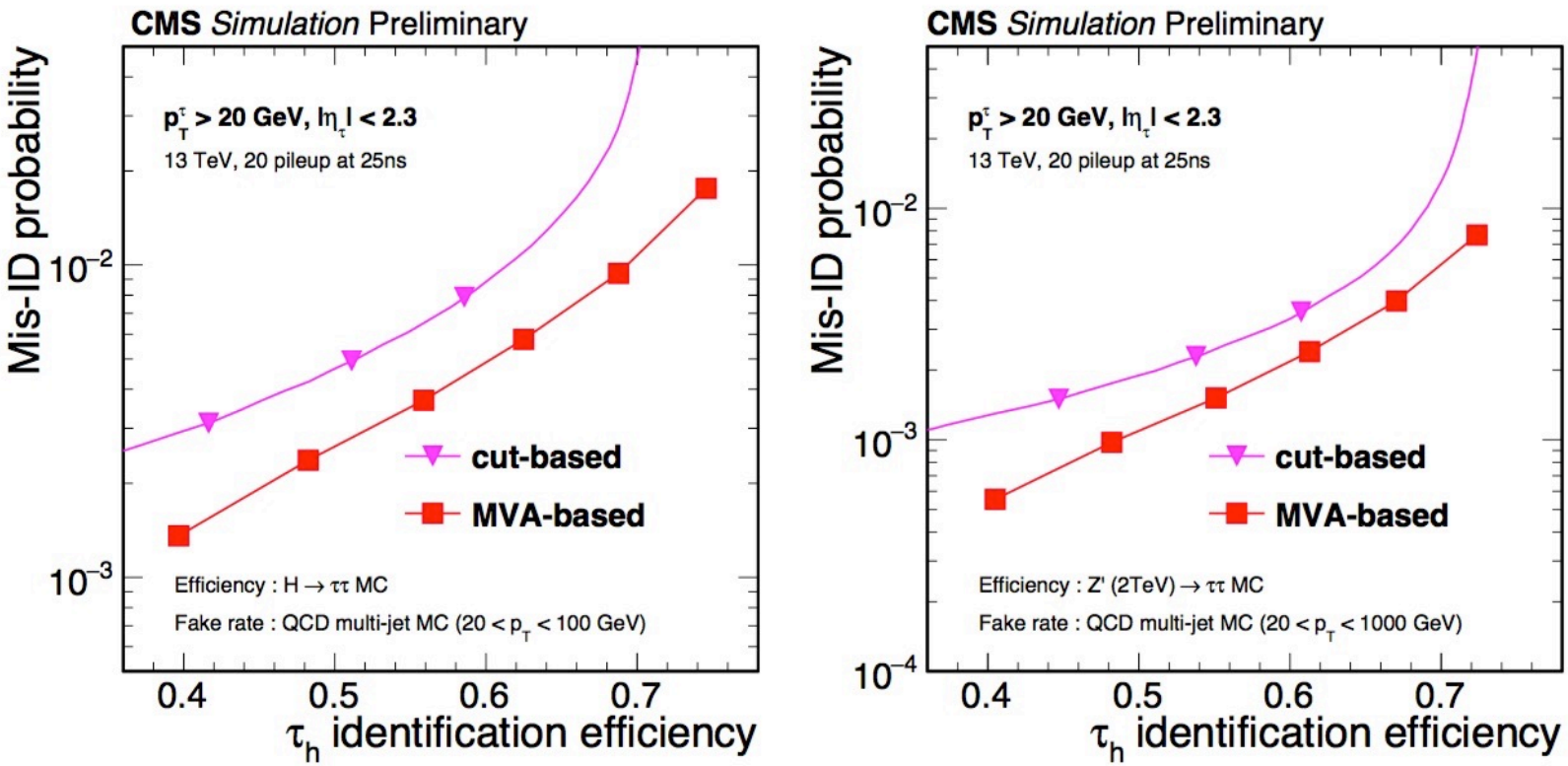
- **Observation of the Higgs boson in ττ final state with 2016 data**
  - **5.5 (4.8) σ observed (expected) significance**
- The combined signal strength is 1.24±0.28
- Higgs couplings to both bosons and fermions are compatible with the SM expectation
- Higgs boson decays to pairs of W or Z bosons, H → WW or H → ZZ, are considered as part of the signal

Summary

- First observation of the SM Higgs boson to a pair of tau leptons with a single experiment
  - 5.9 observed significance by combining 2016 (excluding VH) + run 1 data
  - 5.5 observed significance by 2016 data
- The best fit value is consistent with 1.0 within one standard deviation
- The coupling to both fermions and bosons are compatible with those predicted by SM
- Next steps:
  - Measuring the Higgs coupling to tau lepton more precisely, as we accumulate more data
  - Measuring the Higgs anomalous coupling in $\tau\tau$ final state
  - …
- New results will appear soon!

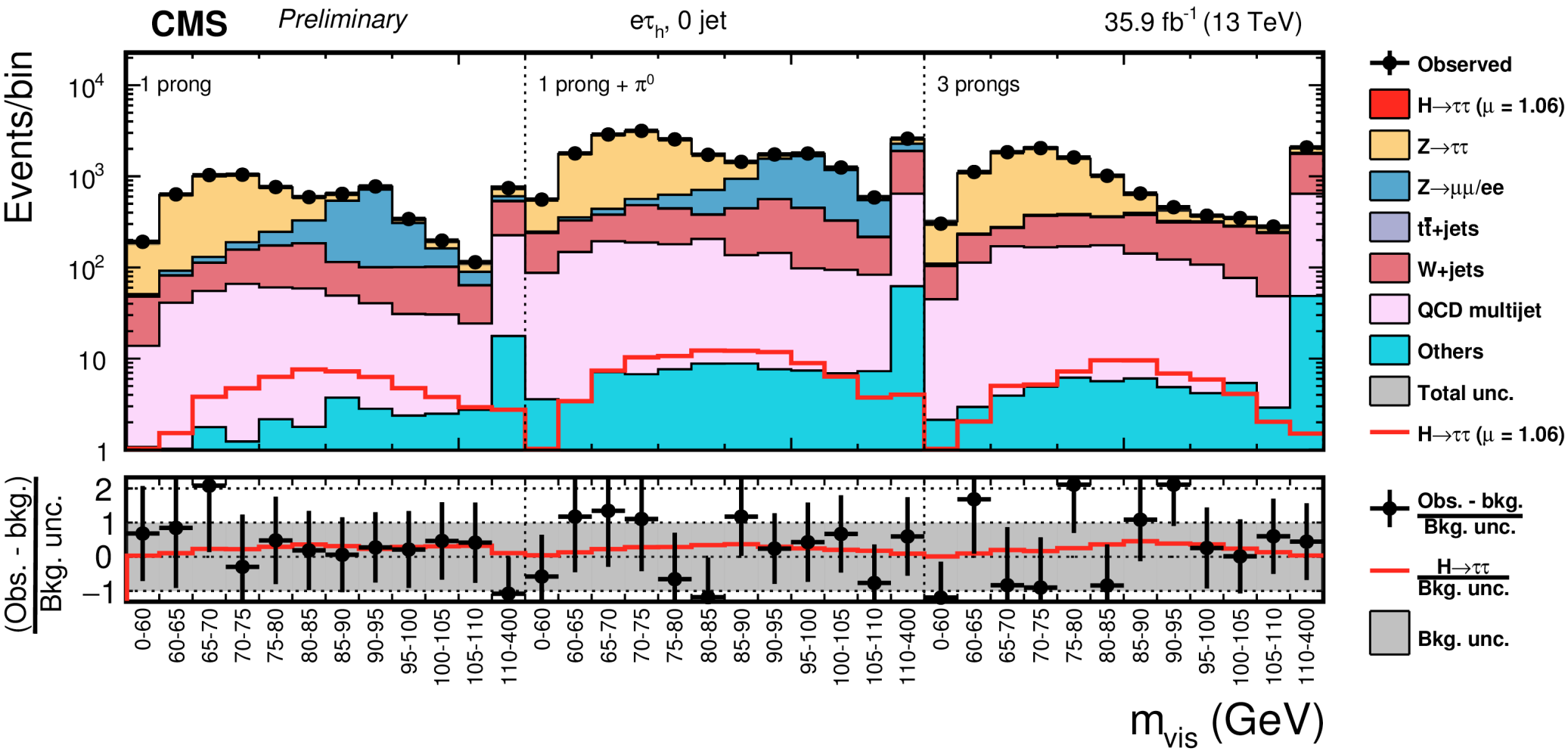
Backup

Discrimination against jets, electrons and muons

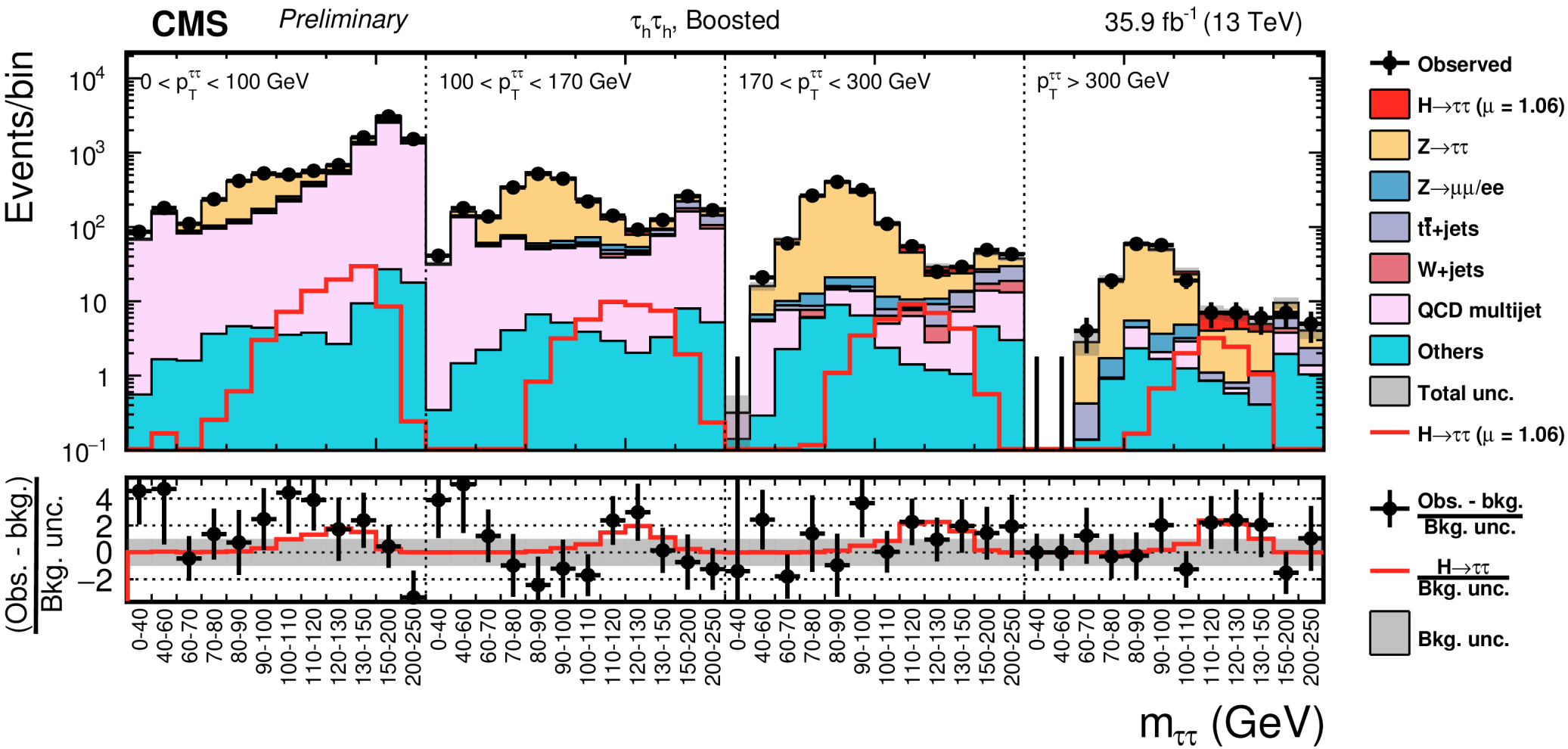


- Whatever comes out of pp collision can fake taus !
- Developed MVA based discriminators to suppress mis-identification of the taus by jets, electrons and muon
- MVA based isolation exploited the tau decay life as well

Final distributions

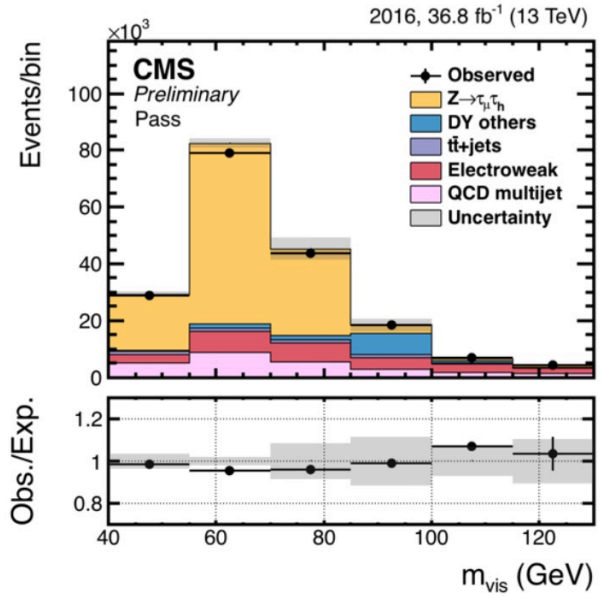


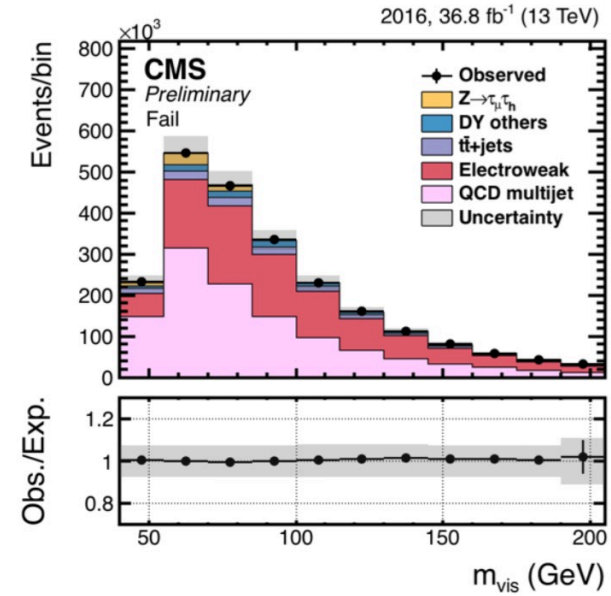
Final distributions

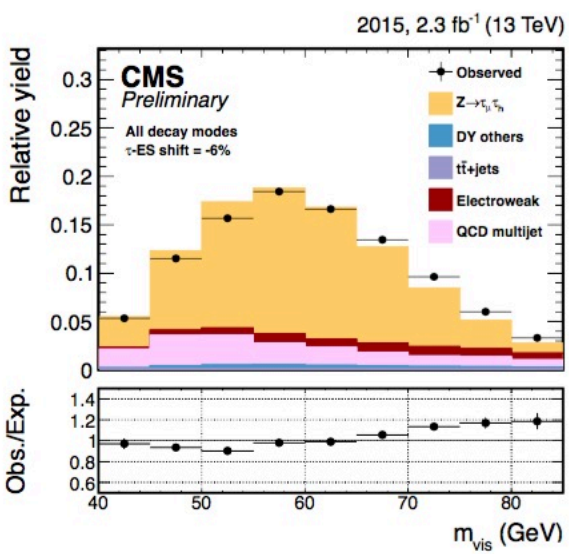


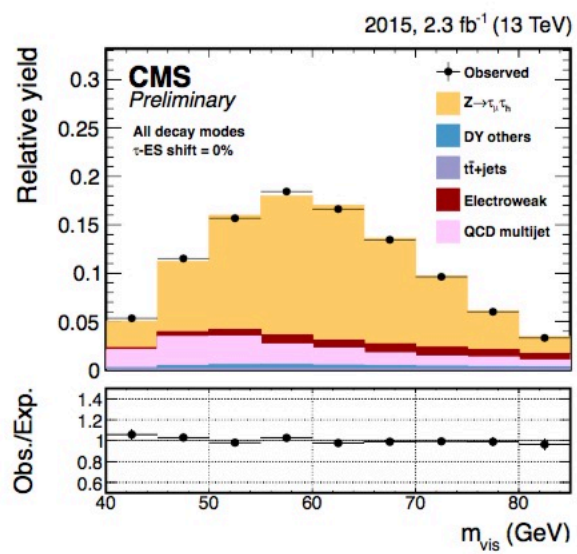
Major systematics (Tau Id efficiency and Tau ES)

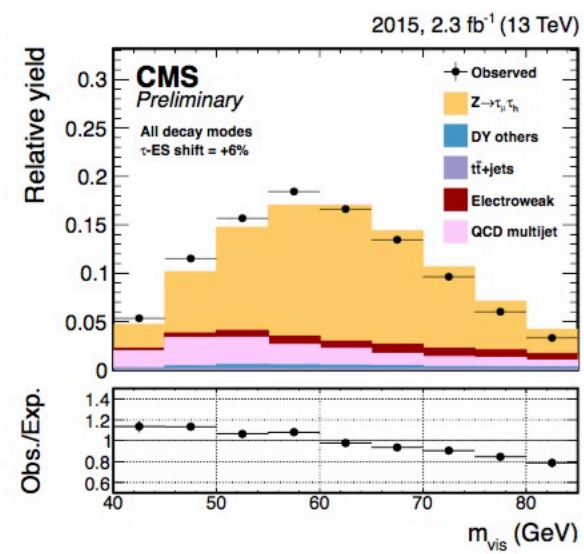
Tau Id efficiency is measured using Tag&Probe technique (SF=0.95+- 0.05)





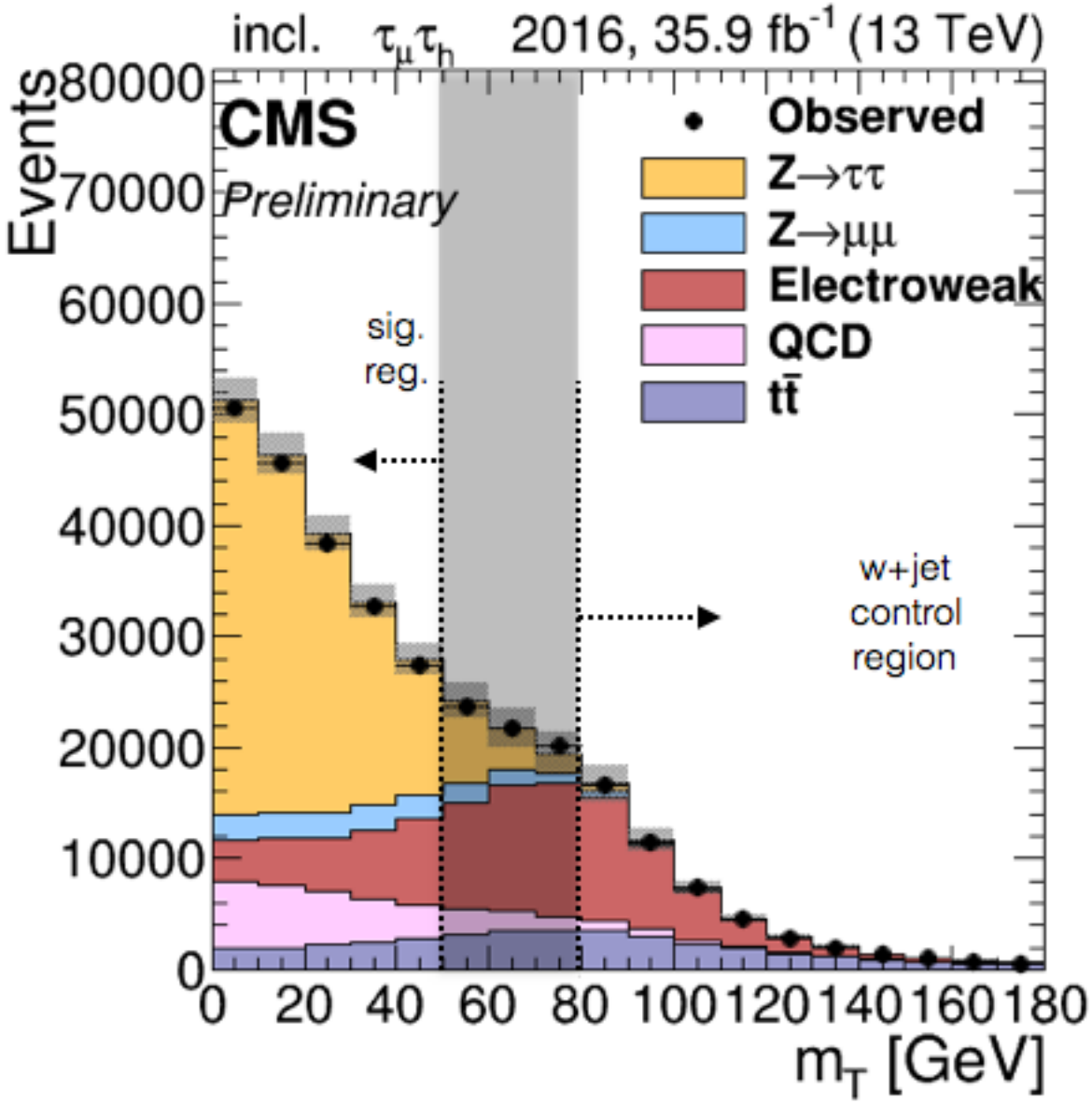




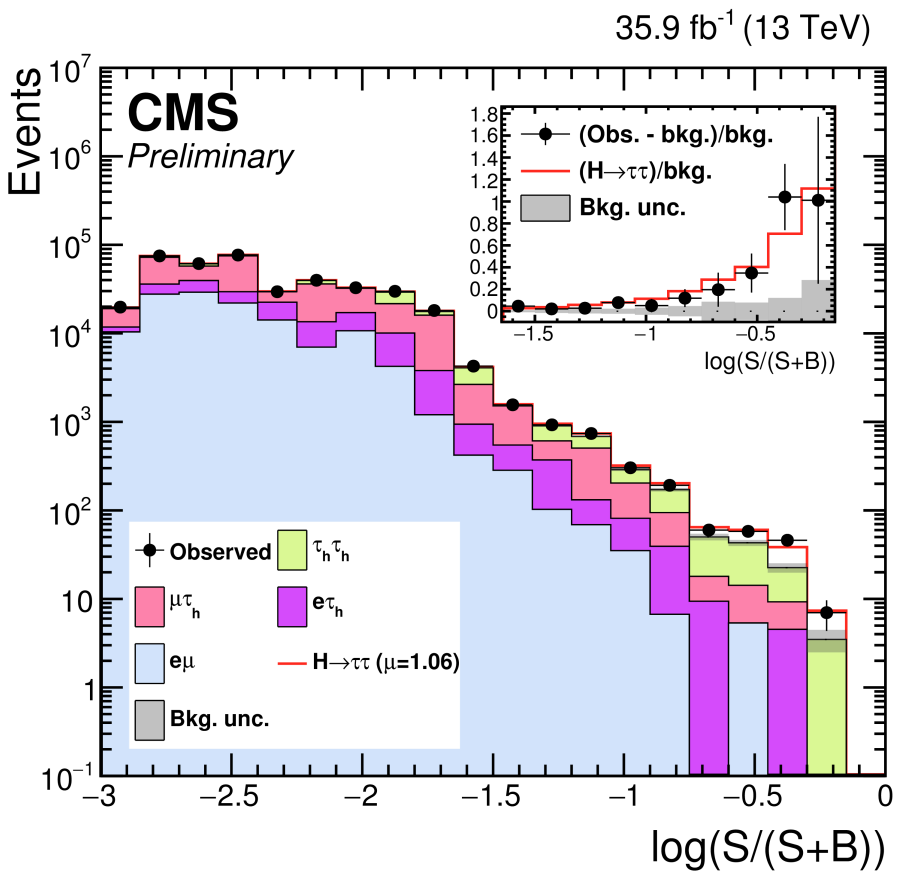


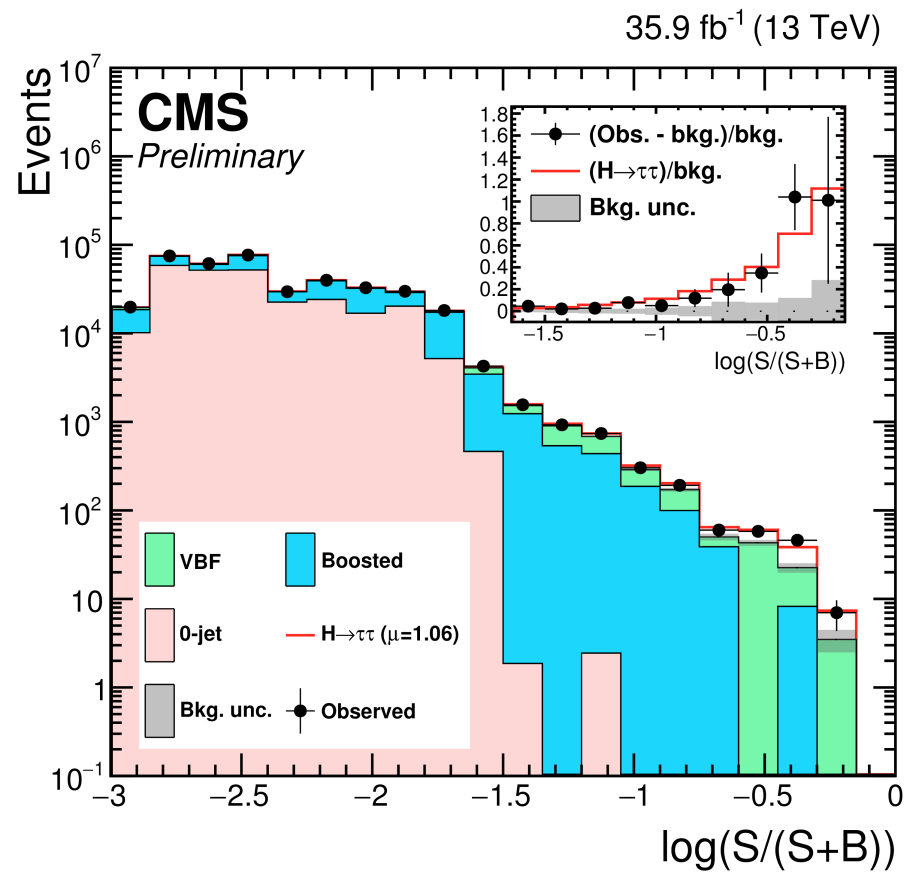
W+Jet background estimation

- Subtract all non_w backgrounds from high-MT CR region in data
- Apply a low-MT to high-MT scale factor (driven from simulation)
- Validate the above scale factor from Zmumu selection(data and simulation) when one muon is replaced by a neutrino



Weighted distributions I

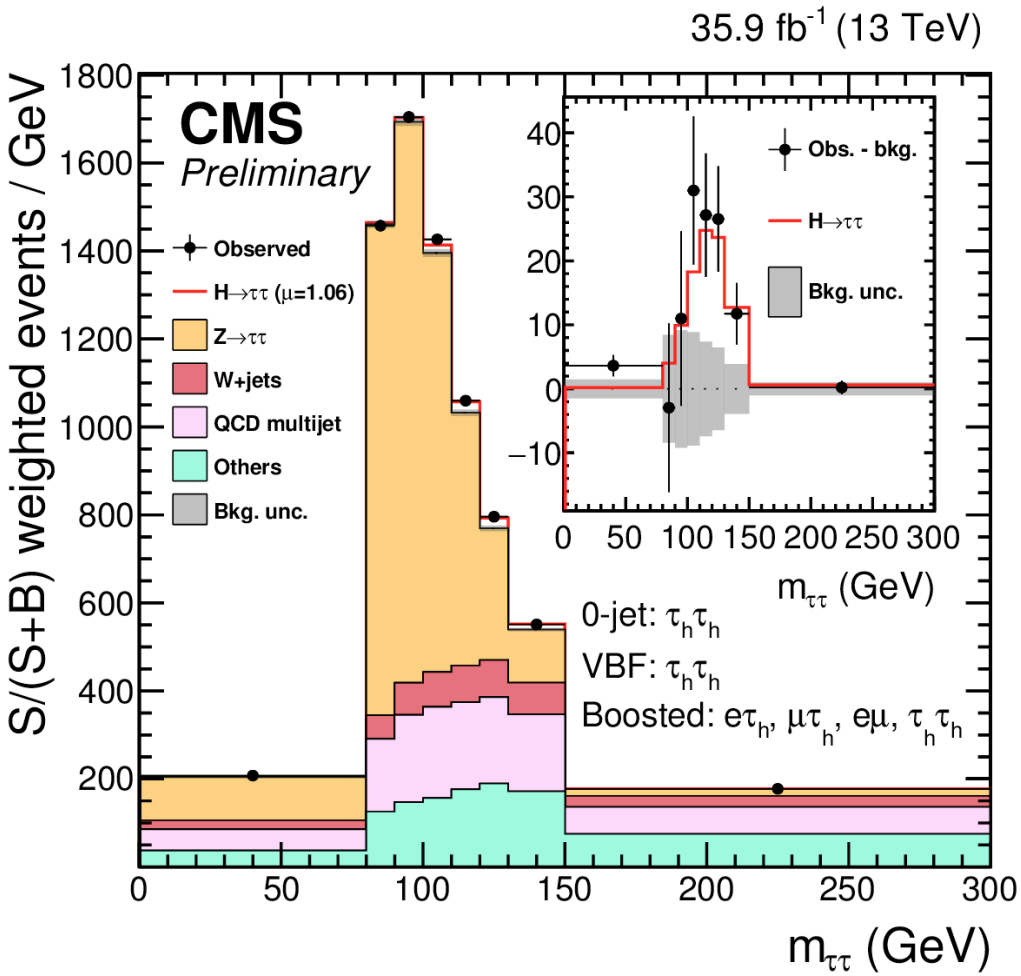


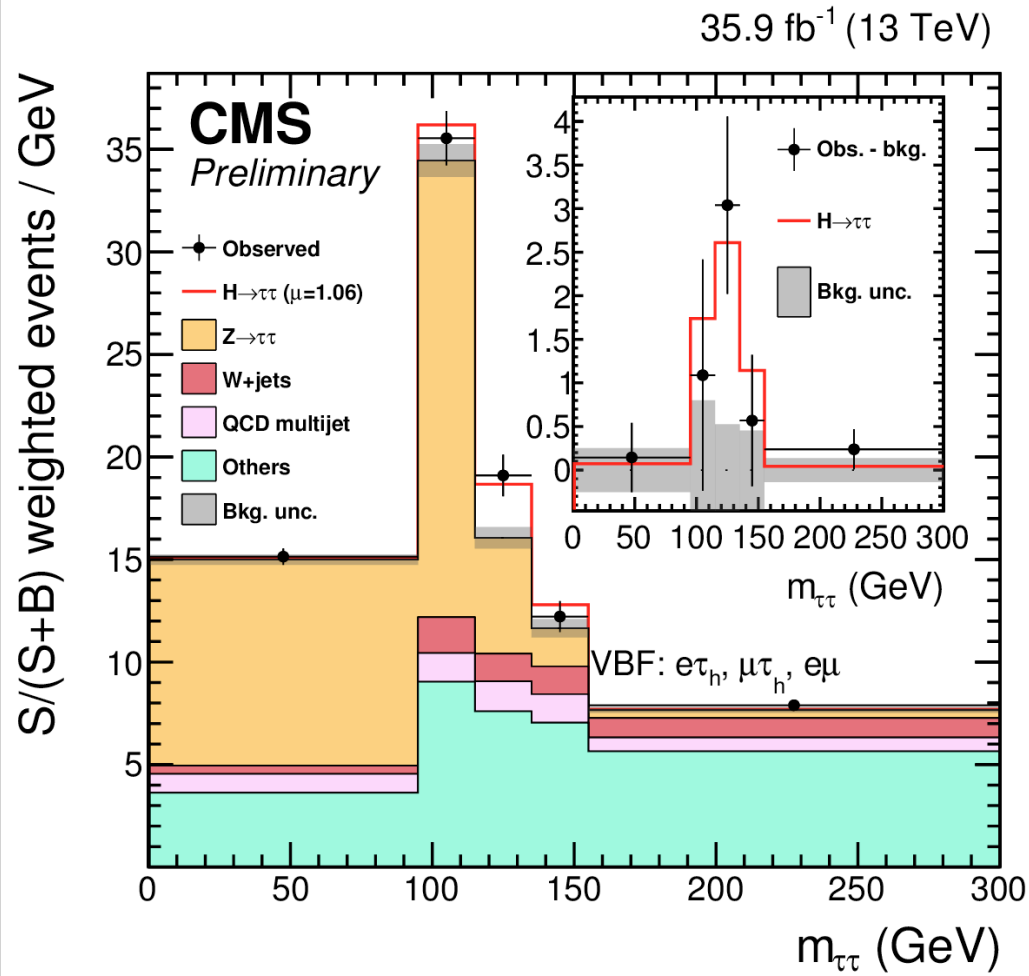


Reorder the bins based on the log(S/S+B)

Sensitive bins are shifted to the right-side of the distribution and less sensitive to the left-side

Weighted distributions II



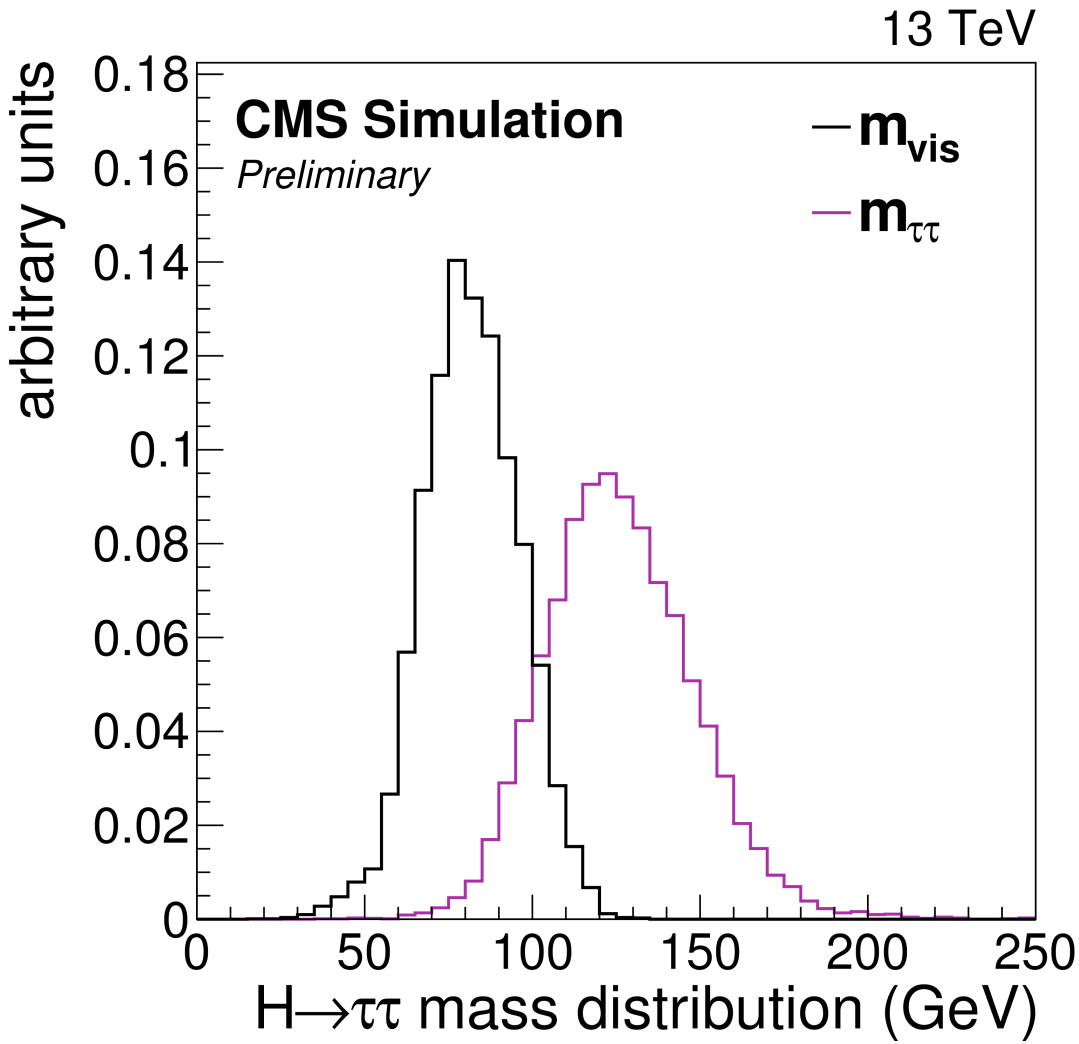


Not possible to make similar weighted-mass plot (money plot) as run 1, due to the different binning.

Weight the distributions in each category and final state based on the S/S +B with similar binnings

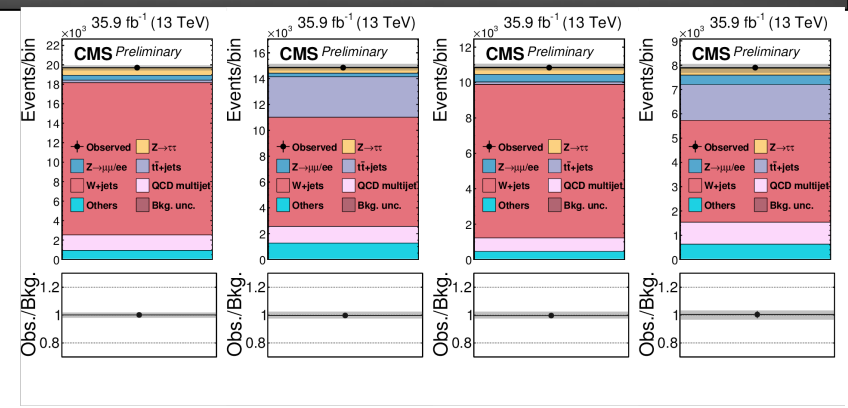
Ditau mass reconstruction (svFit algorithm)

- SvFit takes 4 momenta of both tau leptons, MET and and MET uncertainty and develop a likelihood to marginalize the degrees of freedom
- Has a better separation betwee Htautau and Ztautau
- Shift the Htautau peak to 125 GeV
- Thus, better performance

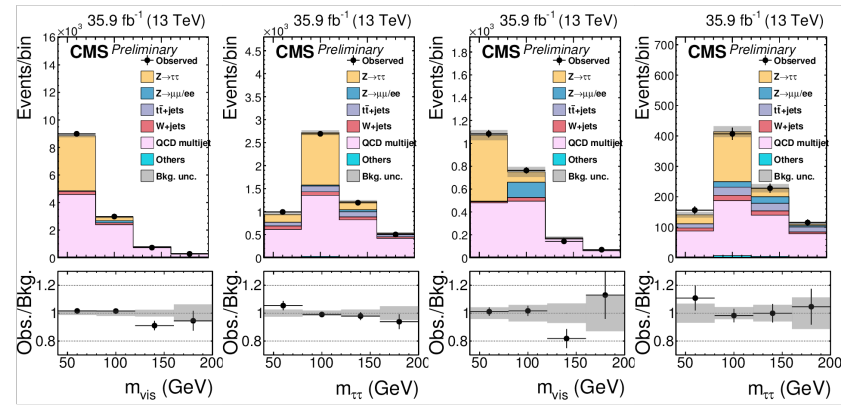


CRs in the fit

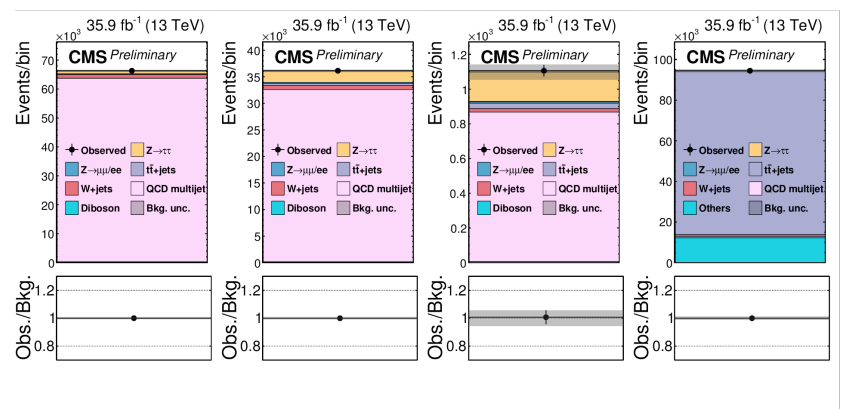
- Introduce several control regions (i.e. SS, high-MT) to constraint the normalization of the backgrounds
- These control regions are fitted simultaneously with signal region in combine



(a) $\mu\tau_h$, 0 jet (b) $\mu\tau_h$, boosted (c) $e\tau_h$, 0 jet (d) $e\tau_h$, boosted



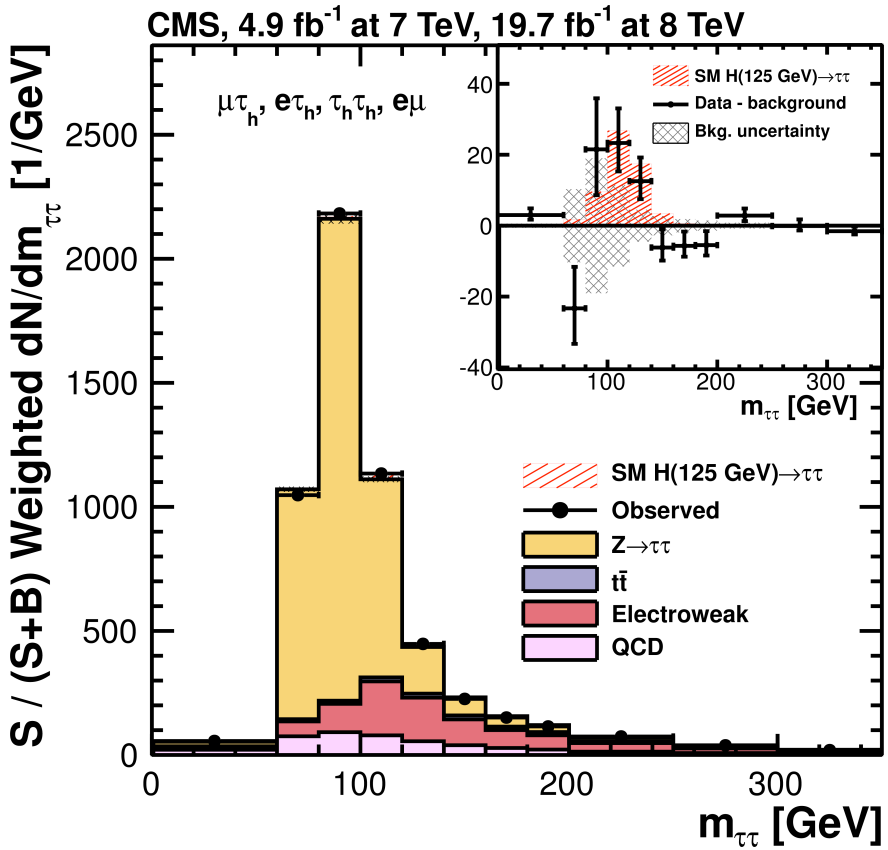
(e) $\mu\tau_h$, 0 jet (f) $\mu\tau_h$, boosted (g) $e\tau_h$, 0 jet (h) $e\tau_h$, boosted

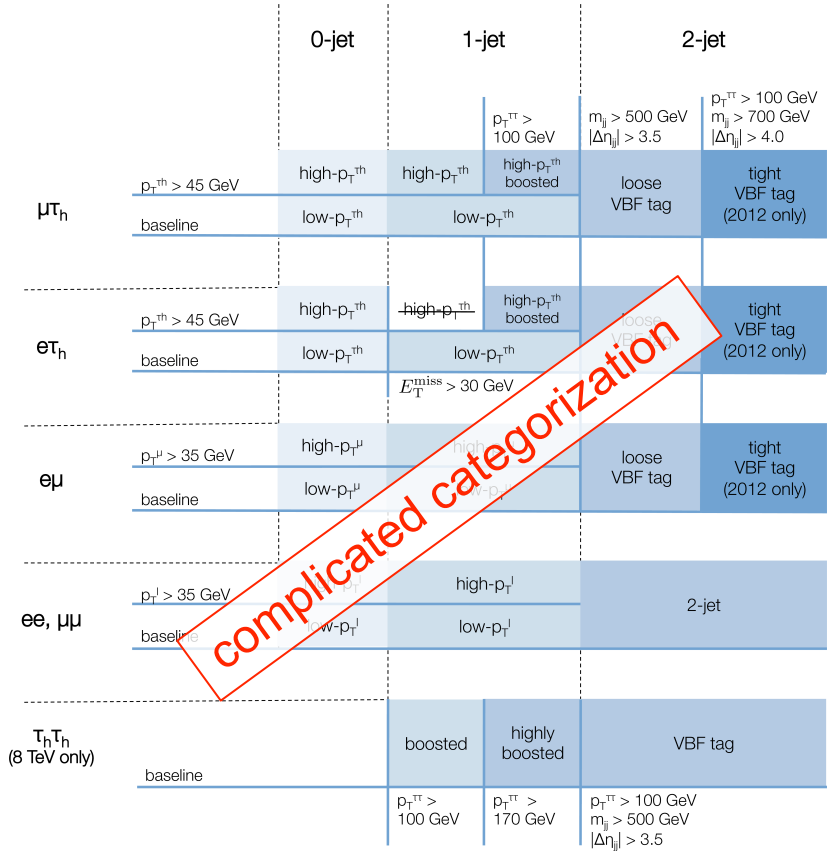


(i) $\tau_h\tau_h$, 0 jet (j) $\tau_h\tau_h$, boosted (k) $\tau_h\tau_h$, VBF (l) $e\mu$, ≥ 1 jet

Abdollah Mohammadi (KSU)

CMS Run1 legacy results: “Evidence”





- Analyzing data in all(6) final states and 3 production modes
- Observed(expected) significance of 3.2(3.7) σ
- Best fit value of 0.78 ± 0.27