# Search for the Higgs Boson Decaying into tau pairs
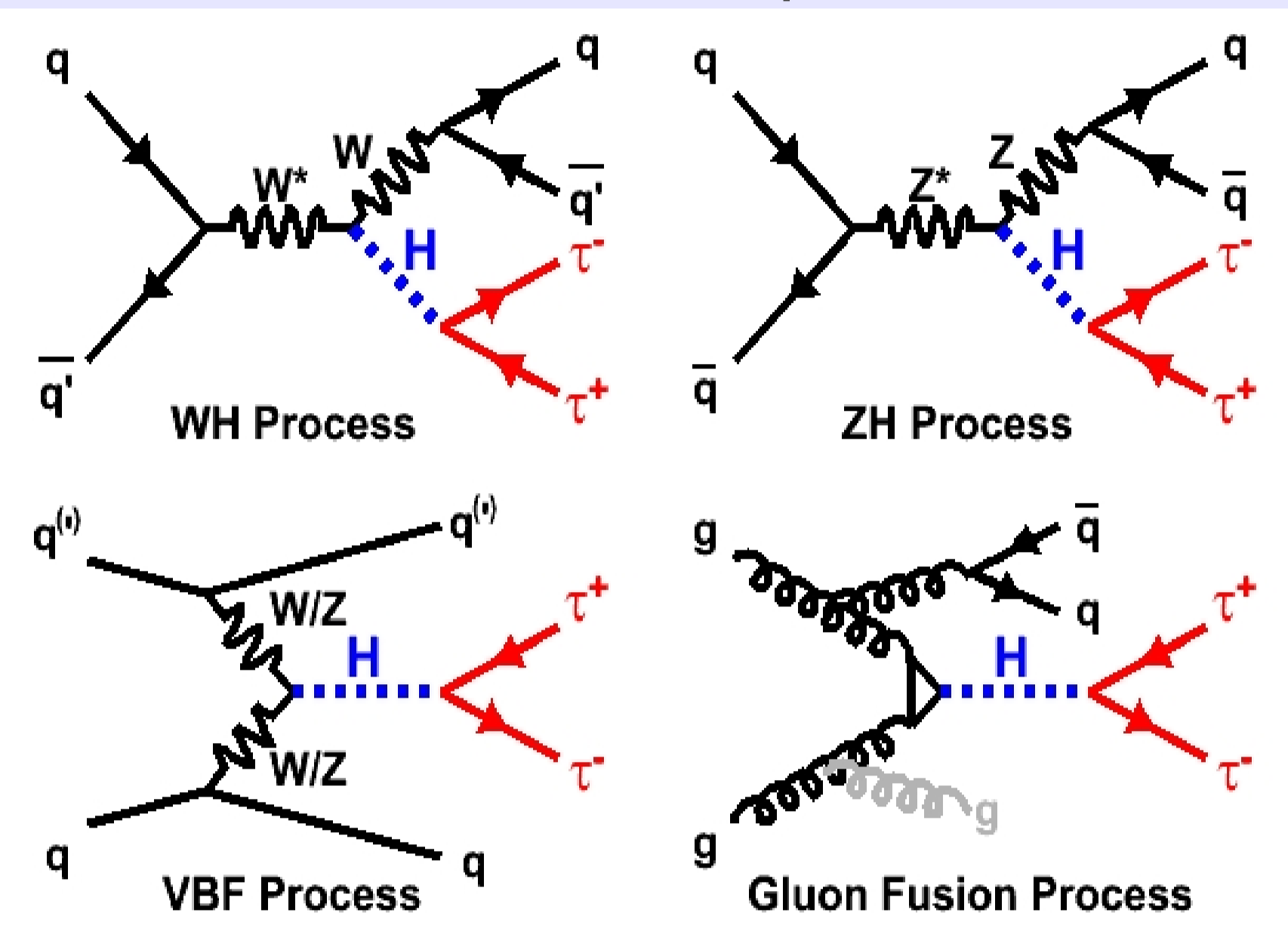
## Abstract

A search for the standard-model Higgs boson decaying to τ pairs is performed using events recorded by the CMS experiment at the LHC in 2011 and 2012 at a centre-of-mass energy of 7 and 8 TeV respectively. The dataset corresponds to an integrated luminosity of 4.9 fb⁻¹ at a centre-of-mass energy of 7 TeV and 19.4 fb⁻¹ at 8 TeV. The τ-pair invariant mass spectrum is studied in five different final states corresponding to the decay modes of the two τ leptons. An excess of events is observed over a broad range of Higgs mass hypotheses, with a maximum local significance of 2.93 standard deviations at $m_H$ = 120 GeV. The excess is compatible with the presence of a standard-model Higgs boson of mass 125 GeV.

## Higgs production mechansims

- Analysis exploits most of the Higgs production mechanisms[1]

- Most sensitive to VBF production



WH Process / ZH Process / VBF Process / Gluon Fusion Process

1) W and Z assiciated Higgs production are not discussed in detail

## H->ττ decay channels covered



3%, 3%, 6%, $\tau_\mu\tau_\mu$ $\tau_e\tau_e$ $\tau_e\tau_\mu$
41%, $\tau_h\tau_h$
23% $\tau_h\tau_e$
23%, $\tau_h\tau_\mu$

$$\tau^- \rightarrow \nu_\tau + \begin{cases} e^- & \mu^- & d \\ \bar{\nu}_e & \bar{\nu}_\mu & \bar{u} \end{cases}$$

Both τ-leptons decay subsequently into hadrons, muons or electrons + genuine MET from neutrinos

| | |
|---|---|
| $\tau_h\tau_h$ | Both τ-leptons into hadrons |
| $\mu\tau_h$ | τ-leptons into μ and hadrons |
| $e\tau_h$ | τ-leptons into e and hadrons |
| $e\mu$ | τ-leptons into e and μ |
| $\mu\mu$ | Both τ-leptons into μ |

## Background estimation

| | |
|---|---|
| QCD | Shape, normalization from same-sign sample |
| W+Jets | Normalization from sideband |
| TTJets | Normalization from sideband |
| Z+Jets | MC corrected for fake rate (μμ-channel: shape and normalization from sideband) |
| Z->ττ | From Z->ττ embedded sample |

The Z->ττ background is estimated via a Data MC hybrid sample. Z->μμ Data events are selected for all run periods. For the embedded sample the muons are then replaced by decaying MC τ-leptons.
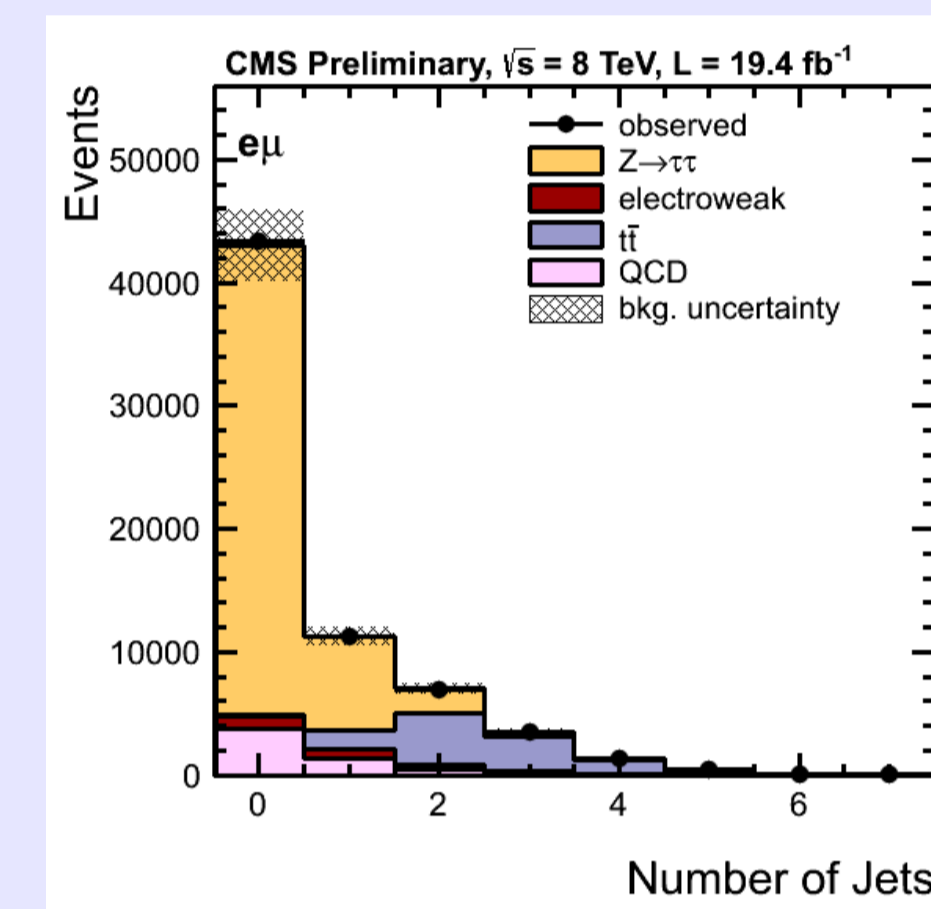
## Event selection

Events are recorded via the CMS L1 and HLT trigger system and reconstructed using the Particle Flow algorithm. Physics Objects are required to pass refined identification criteria and to be within the acceptance of the corresponding sub-detectors.

## Event categorization

- Events are classified wrt jet multiplicity

- Probes different Higgs production mechanisms
- Enhances Sensitivity



| | |
|---|---|
| VBF | At least two jets with $p_T$>30 GeV, invariant mass of $m_{jj}$>500 GeV and separated in pseudorapidity by $\eta_{jj}$>3.5. No additional jet in eta gap, no b-tagged jets |
| 1-Jet | At least one jet with $p_T$>30 GeV Not in VBF category No b-tagged jets ($e\tau_h$-channel: MET>30 GeV) |
| 0-Jet | Anything not in other categories No b-tagged jets ($\tau_h\tau_h$-channel: omitted due to trigger) |

## Topological selection

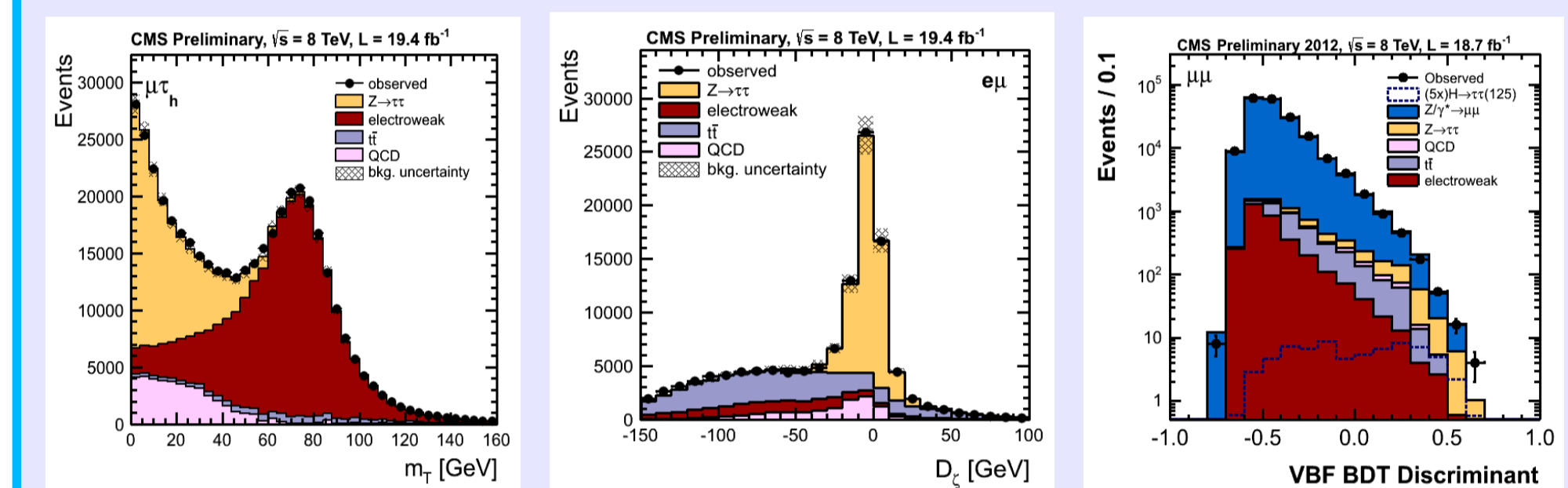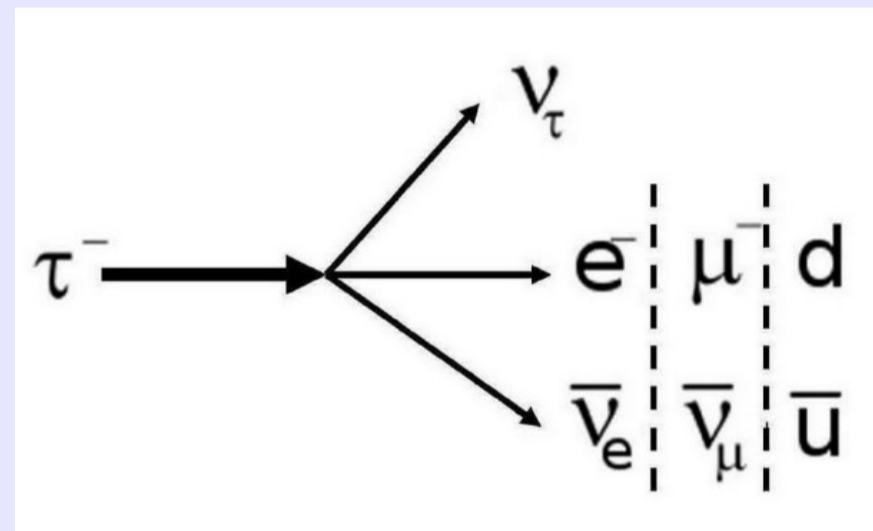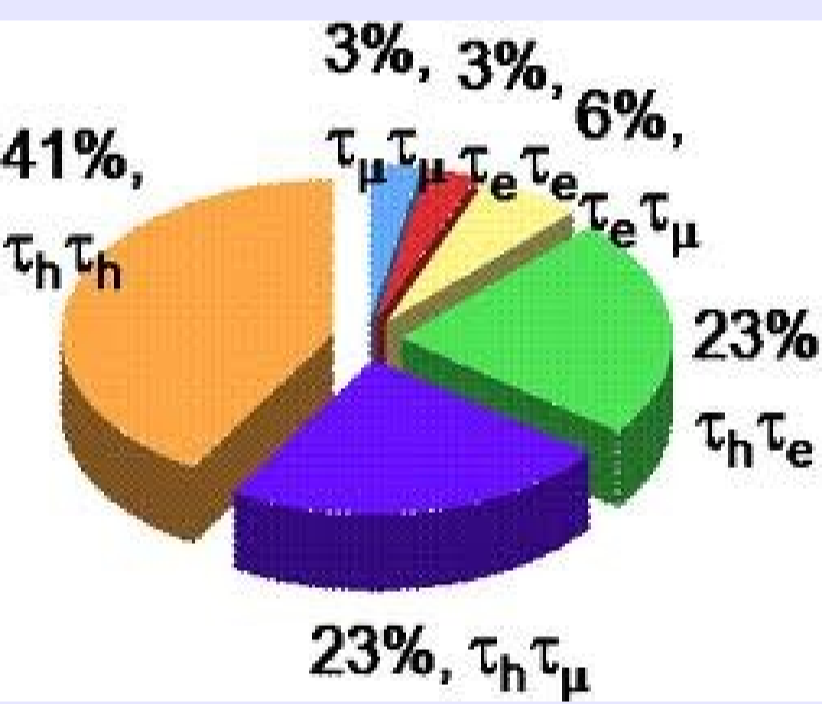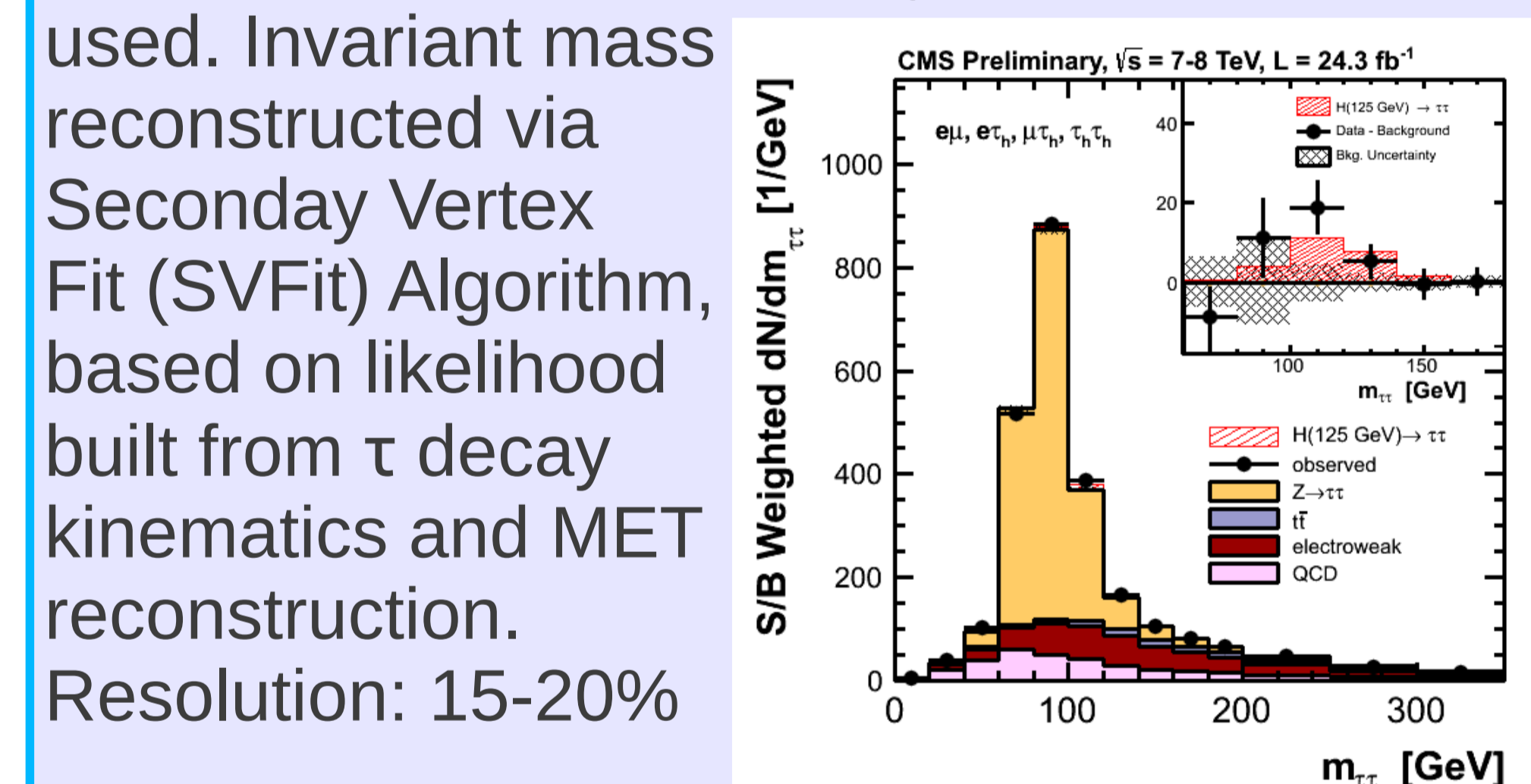| | |
|---|---|
| $e\tau_h$, $\mu\tau_h$ | Cut on: $$m_T = \sqrt{2p_T E_T^{miss}(1 - cos(\Delta\phi))}$$ |
| $e\mu$ | Cut on: (ζ: bisector of lepton $p_T$ directions) $$D_\zeta = p_\zeta - 0.85 \cdot p_\zeta^{vis} > -20\text{GeV}$$ $$p_\zeta = \vec{p}_{T,1} \cdot \hat{\zeta} + \vec{p}_{T,2} \cdot \hat{\zeta} + \vec{E}_T^{miss} \cdot \hat{\zeta}$$ $$p_\zeta^{vis} = \vec{p}_{T,1} \cdot \hat{\zeta} + \vec{p}_{T,2} \cdot \hat{\zeta}$$ |
| $\mu\mu$ | Cut on boosted decision tree |



## M$_{\tau\tau}$ reconstruction

For **statistical inference** the reconstructed invariant mass of the di-τ system is used. Invariant mass reconstructed via Seconday Vertex Fit (SVFit) Algorithm, based on likelihood built from τ decay kinematics and MET reconstruction. Resolution: 15-20%
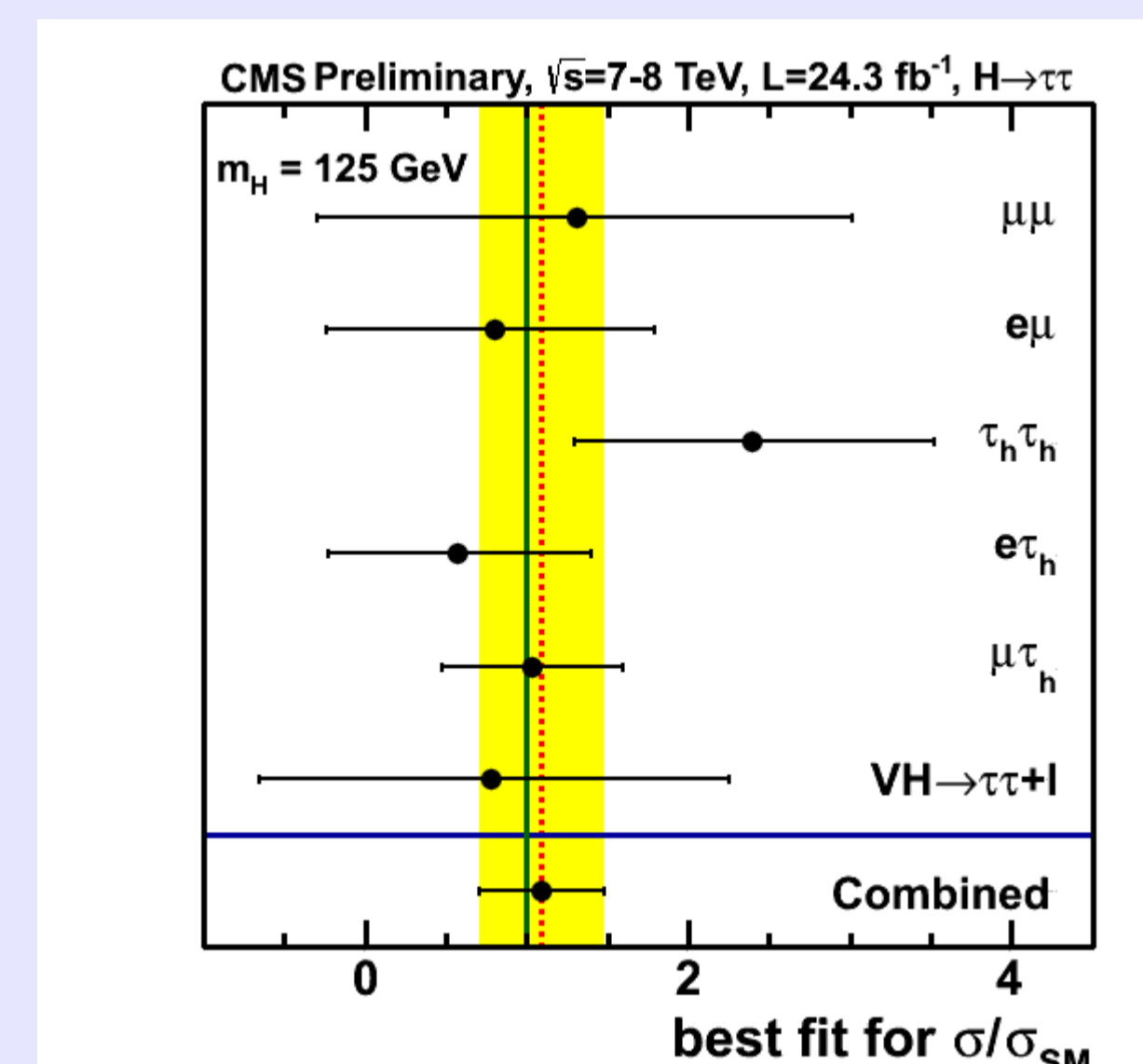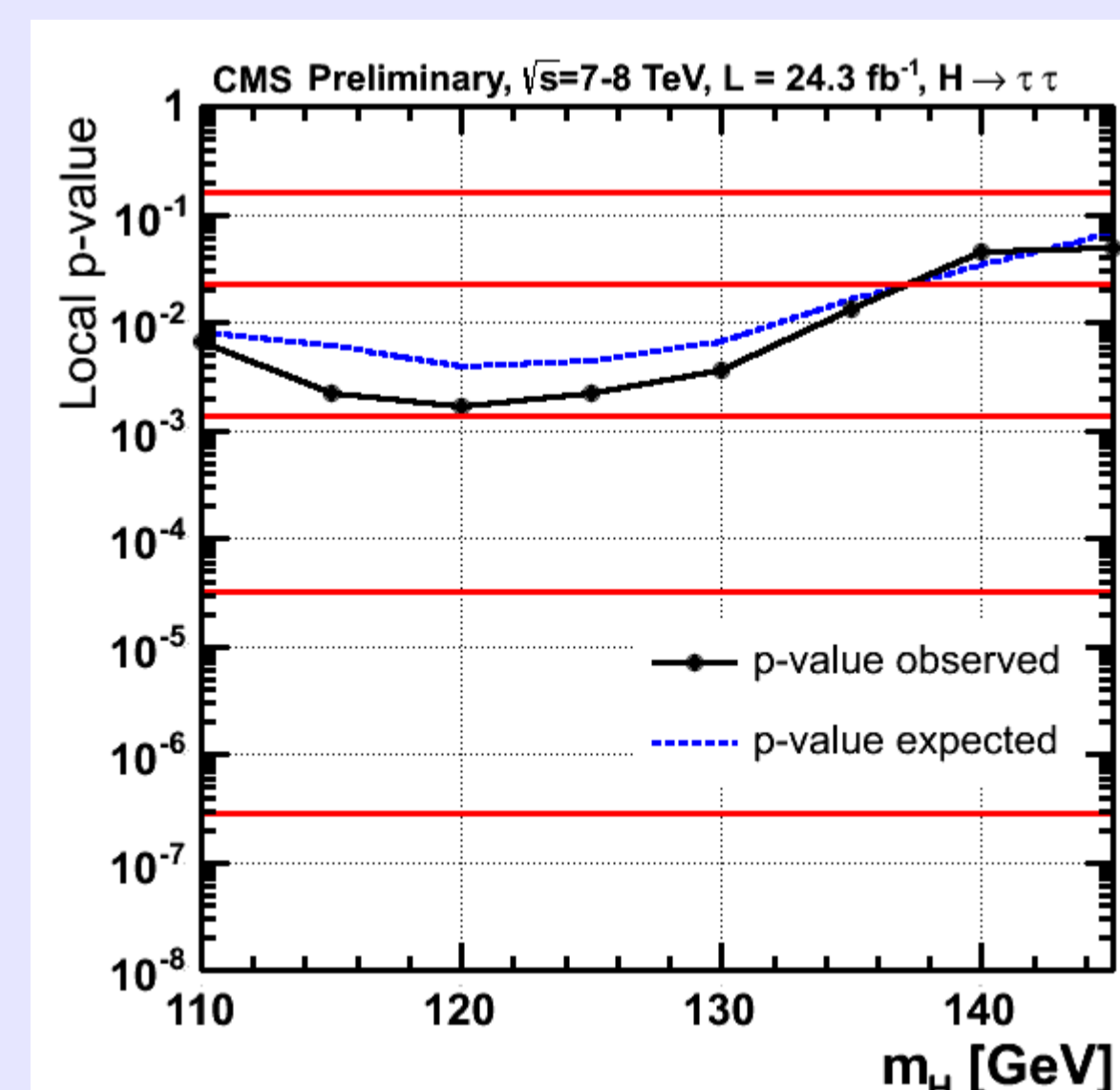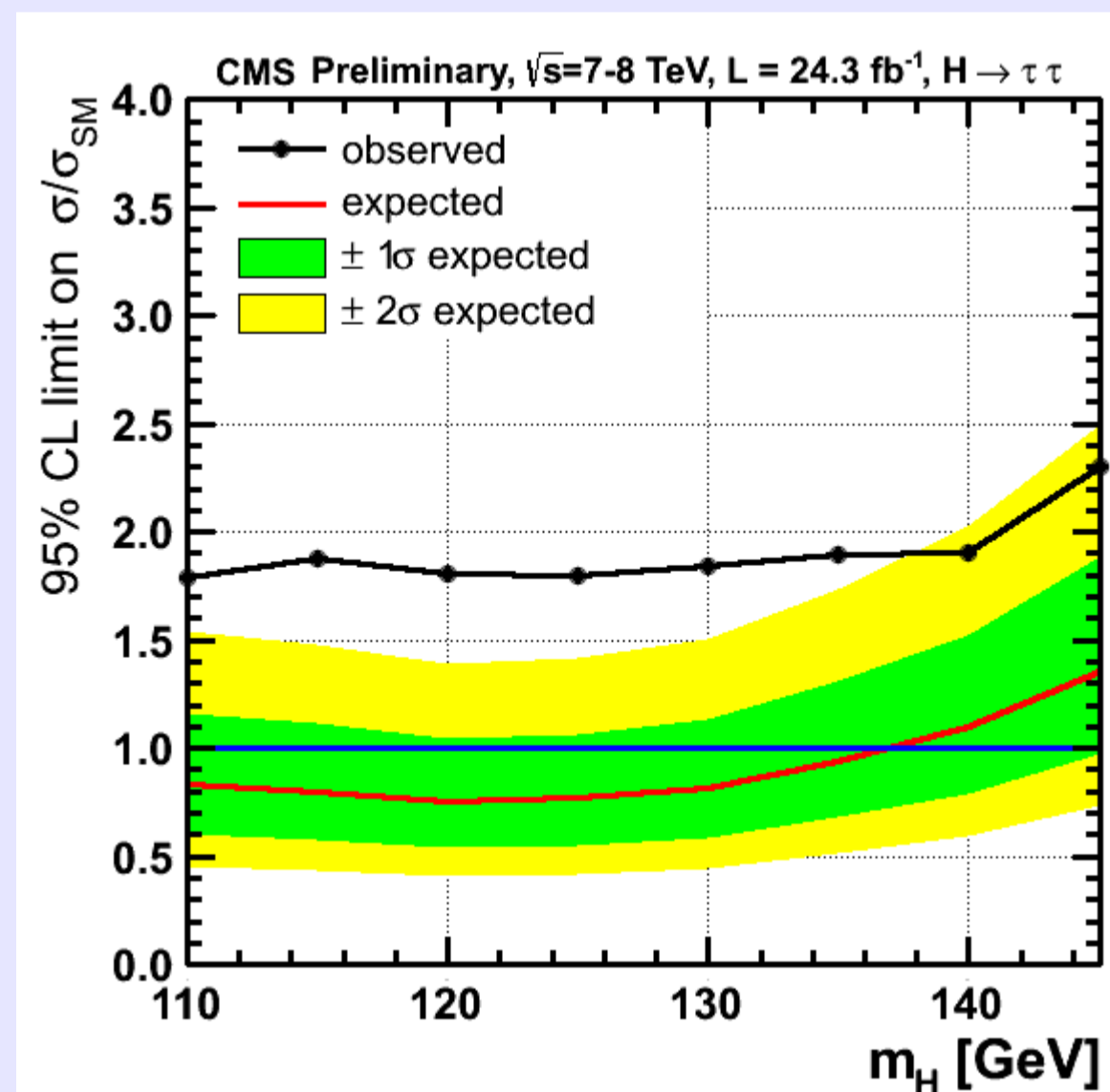


## Results



Simultaneous fit on $m_{\tau\tau}$ in all channels and all categories. Best combined fit for signal strength μ=1.1±0.4 at $m_H$= 125 GeV. Minimum local p-value of observed limit at $m_H$=120 GeV, corresponding to significance of 2.93 standard deviations. For $m_H$=125.8 GeV, significance is 2.85σ.

Number of expected and observed event yields in $\mu\tau_h$-channel (7 & 8 TeV merged)

| Process | 0-Jet | 1-Jet (high) | VBF |
|---|---|---|---|
| Z->ττ | 84833±1927 | 4686±232 | 109±11 |
| QCD | 18313±478 | 481±38 | 48±7 |
| EWK | 8841±653 | 1585±153 | 63±9 |
| ttbar | 11±1 | 155±11 | 5±1 |
| Background | 111998±2090 | 6908±281 | 225±16 |
| Signal | - | 73±13 | 11±2 |
| Observed | 112279 | 7011 | 240 |