Search for the SM Higgs boson in the WH production with the $e^{\pm}\tau^{+}\tau^{-}$ and $\mu^{\pm}\tau^{+}\tau^{-}$ final states

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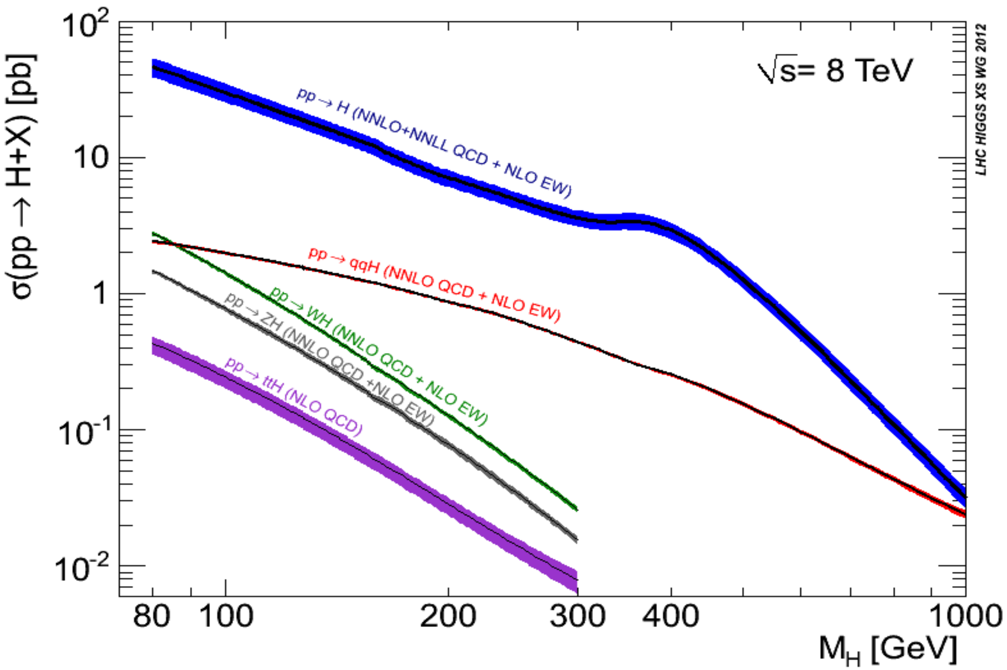
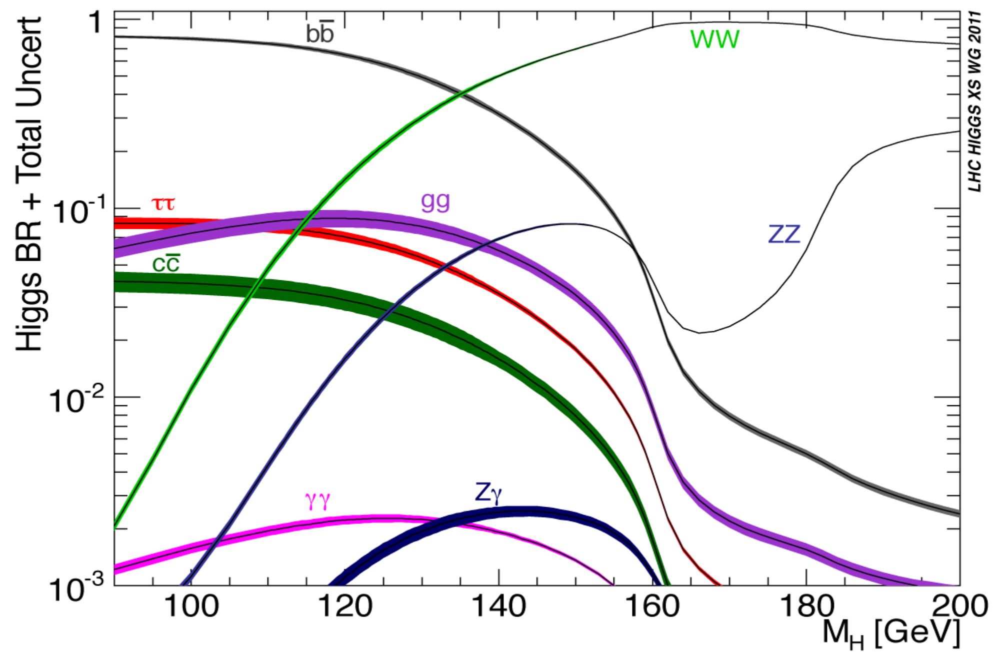
Outline

- Motivations
- Analysis Strategy
- τ reconstruction with CMS
- WH fully hadronic Analysis
- Combined Limits
- Conclusions

Motivations

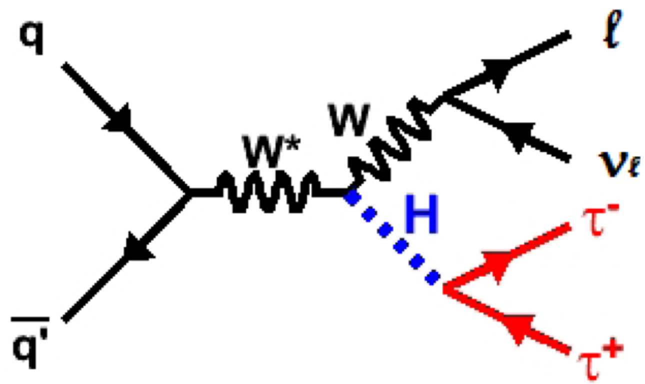
- Cross section for the Associated Production is an order of magnitude lower than that of the gluon-gluon fusion mechanism
- In the light mass region the Higgs boson decaying into τ-leptons pairs has the second BR.
- Additional lepton coming from the W provides additional handle to suppress the background.
- Importance of probing Higgs coupling with leptons.
- The Fully Hadronic channel has the highest BR between all the tau decay mode but also suffer of huge background.



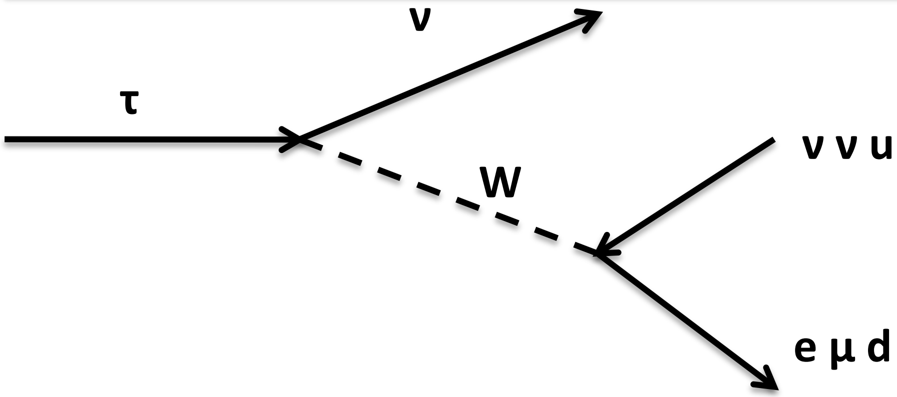


Analysis Strategy

- Whole statistics recorded by CMS in the last two years
  - 2011: L=5 fb^{-1} @ 7TeV 2012: L=19.5 fb^{-1}@ 8TeV
- Two final states
  - $e\tau_{had}\tau_{had}$
  - $\mu\tau_{had}\tau_{had}$
- Cut based analysis to select the final state
  - Object identification
  - Topological cuts
- Background estimation
  - Main Bkg: W+jets, Z+jet, WW, WZ, ZZ, QCD, ttbar
  - Irreducible bkg relies on MC estimate
  - Reducible bkg via fake rate method
- The asymptotic CLs method is used to set exclusion limits

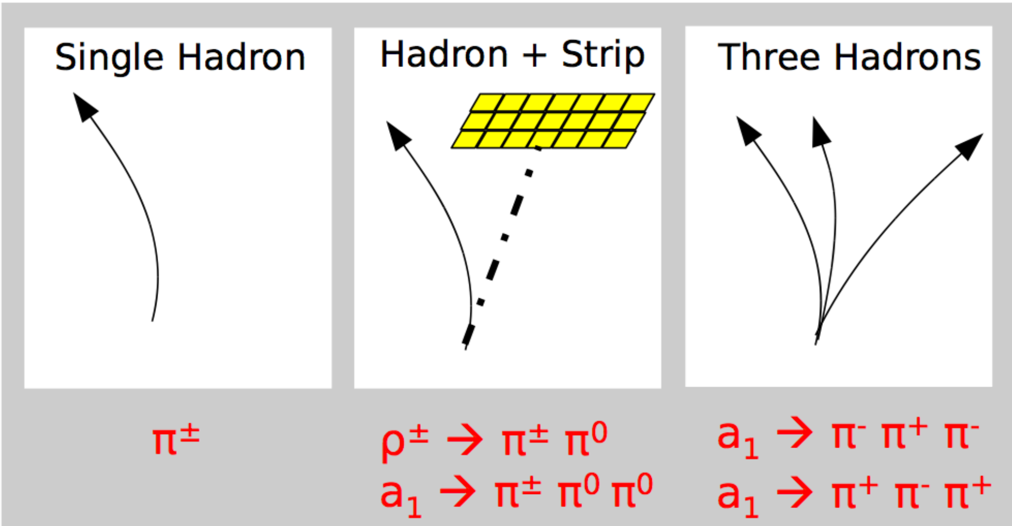


τ reconstruction with CMS : HPS



Decay Mode	Resonance	BR
$\tau \to e\nu\nu$		18%
$\tau \to \mu\nu\nu$		17%
$\tau \to h\nu$		12%
$\tau \to hh^0\nu$	$\rho(770)$	37%
$\tau \to hhh\nu$	a1 (1200)	15%

HPS reconstructs hadronic tau decay mode



Check compatibility on intermediate particle mass

- **Isolation**

Energy deposits in $\Delta R = 0.5$ cone

- **Discriminator against electron**

based on shower shape info and E/p

- **Discriminator against muon**

Based on compatibility between tau leading and muon track

Selections

- Trigger applied on data and MC
- μ/electron
  - at least one well-identified and isolated (Pile Up corrections applied)
  - pt>24 GeV
- Taus
  - reconstructed with HPS Algorithm
  - τ1: pt>45 GeV, Tight Isolation, Tight Muon Rejection, Loose(Tight) electron rejection
  - τ2: pt>30 GeV, Medium Isolation, Tight Muon Rejection, Medium electron rejection
- Q(τ1) + Q(τ2) = 0
- E_T^{miss} > 20 GeV
- No b-tagged jet with pT > 20 GeV

Topological (μ channel)

- $Z \rightarrow \mu\mu$ veto
  - No additional muon
- $Z \rightarrow \tau\tau$ veto
  - $p_t(\tau_1, \tau_2) > 50$ GeV or $M_t(\mu, \tau_{OS}) > 80$ GeV
- Anti-Overlap with $H \rightarrow \tau_\mu \tau_{had}$
  - $M_t(\mu, E_T^{miss}) > 20$ GeV

Topological (e channel)

- $Z \rightarrow \tau\tau$ veto
  - $M_t(e, E_T^{miss}) > 50$ GeV
- $Z \rightarrow ee$ veto
  - No 2 OS electrons with $|m_Z - m_{ee}| < 25$
  - No $|mZ - m(e, \tau_{OS})| < 6$ GeV

Background Estimation

- **Irreducible** : **ZZ**, **WZ** estimated with MC
- **Reducible:** events where **quark or gluon jets** are uncorrectly reconstructed as τ_{had}.
- Data driven estimation by **fake rate techinque.**
  - Processes:
    - **Z (→ττ→lτ_{had})+1jet**
    - **Z (→ee) +1jet**
    - **W(→ lν) +2jets**

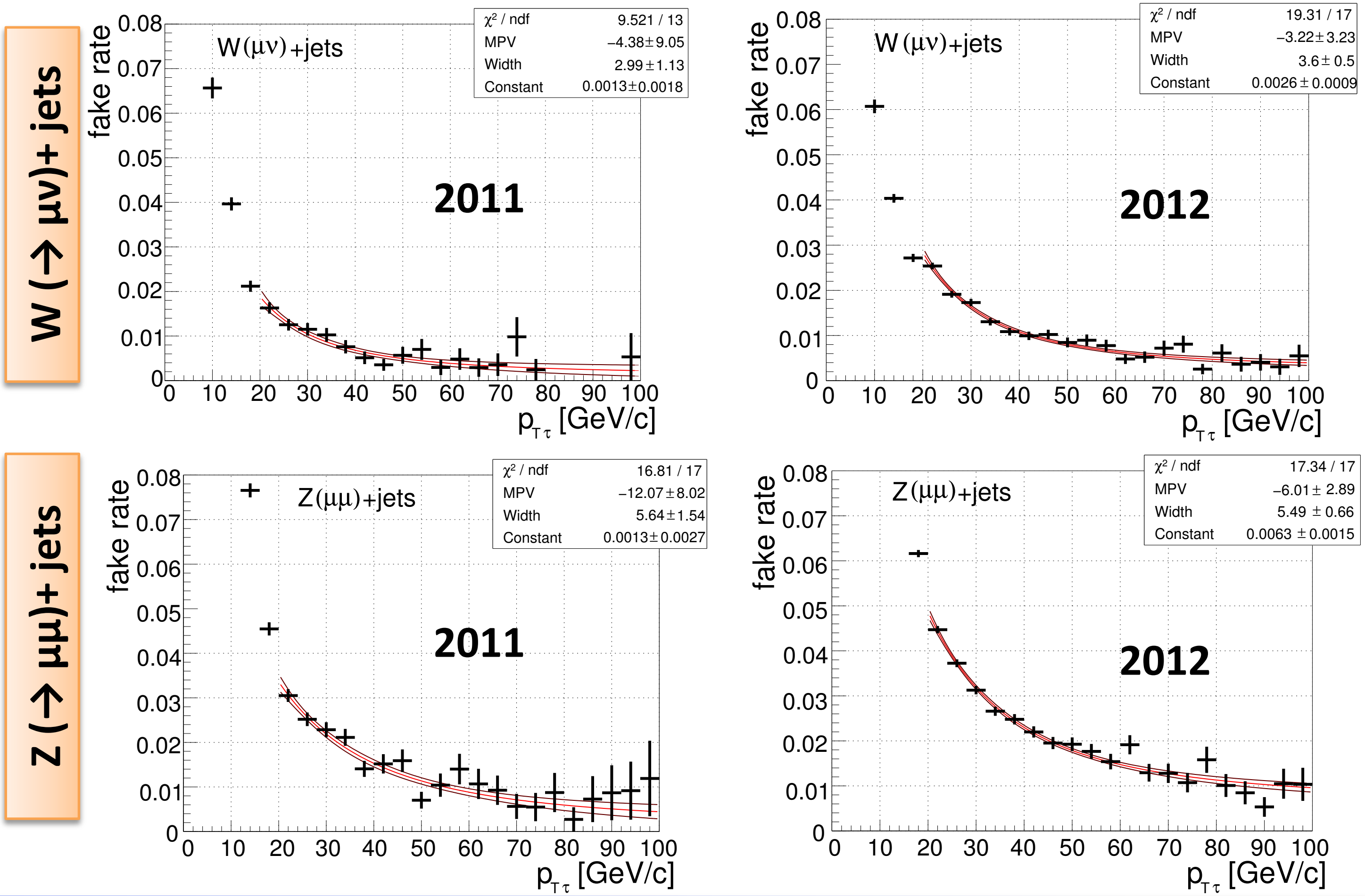
fakeable object is τ-candidate SS to light lepton

  - Measure probability (as a function of **tau pt**) that a jet passes the tau isolation in **background enriched region**:
    - **Z→μμ +jets**
    - **W → μν + jets**

  chosen such that **signal events are excluded.**

jet → τ_{had} Fake rate functions

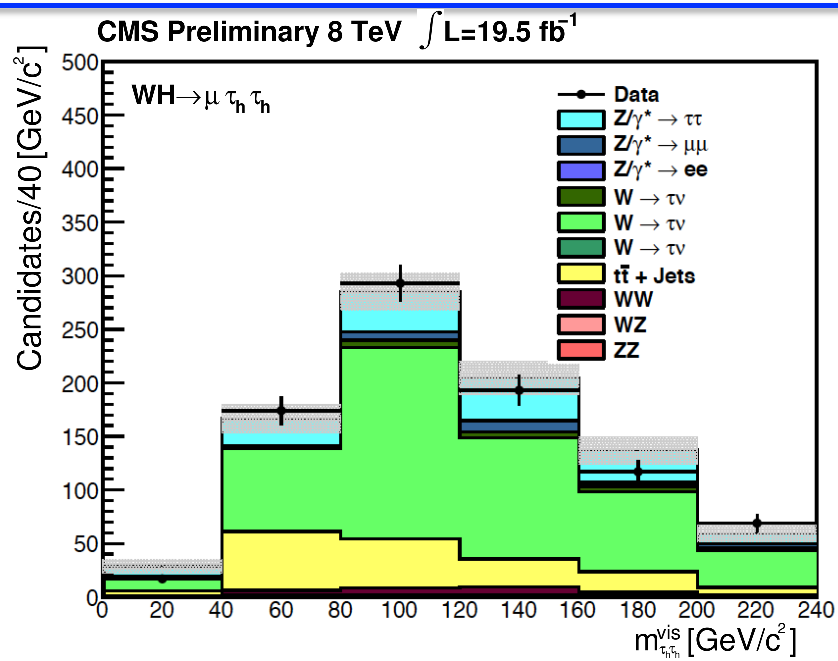
- Different Fake Rate in the two regions due to different fraction of quark and gluon jets → Systematic Effect
- Fit with Landau plus constant → Uncertainty on fit function
- Same function used for both channels → Full Correlation between channels



Fake Background Estimation

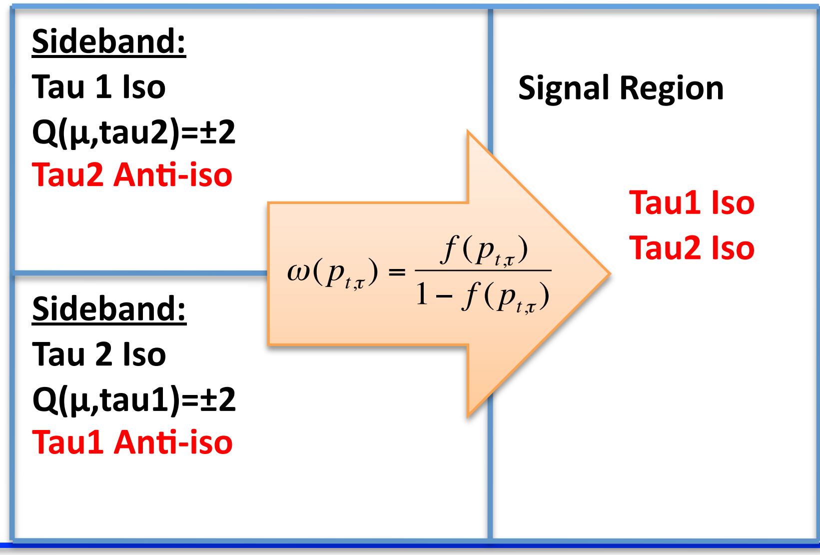
- **From MC studies:**
  - **2/3 bkg: W (→ μν) + 2 jets**
  - **1/3 bkg: Z+1 jet**
- **Total function is a weighted average**

$$f(p_t) = \frac{2 f_{Wjets}(p_t) + f_{Zjets}(p_t)}{3}$$



✓ **Invert isolation of fakeable object**

✓ **Apply a weight to each event according to fake candidate pt.**

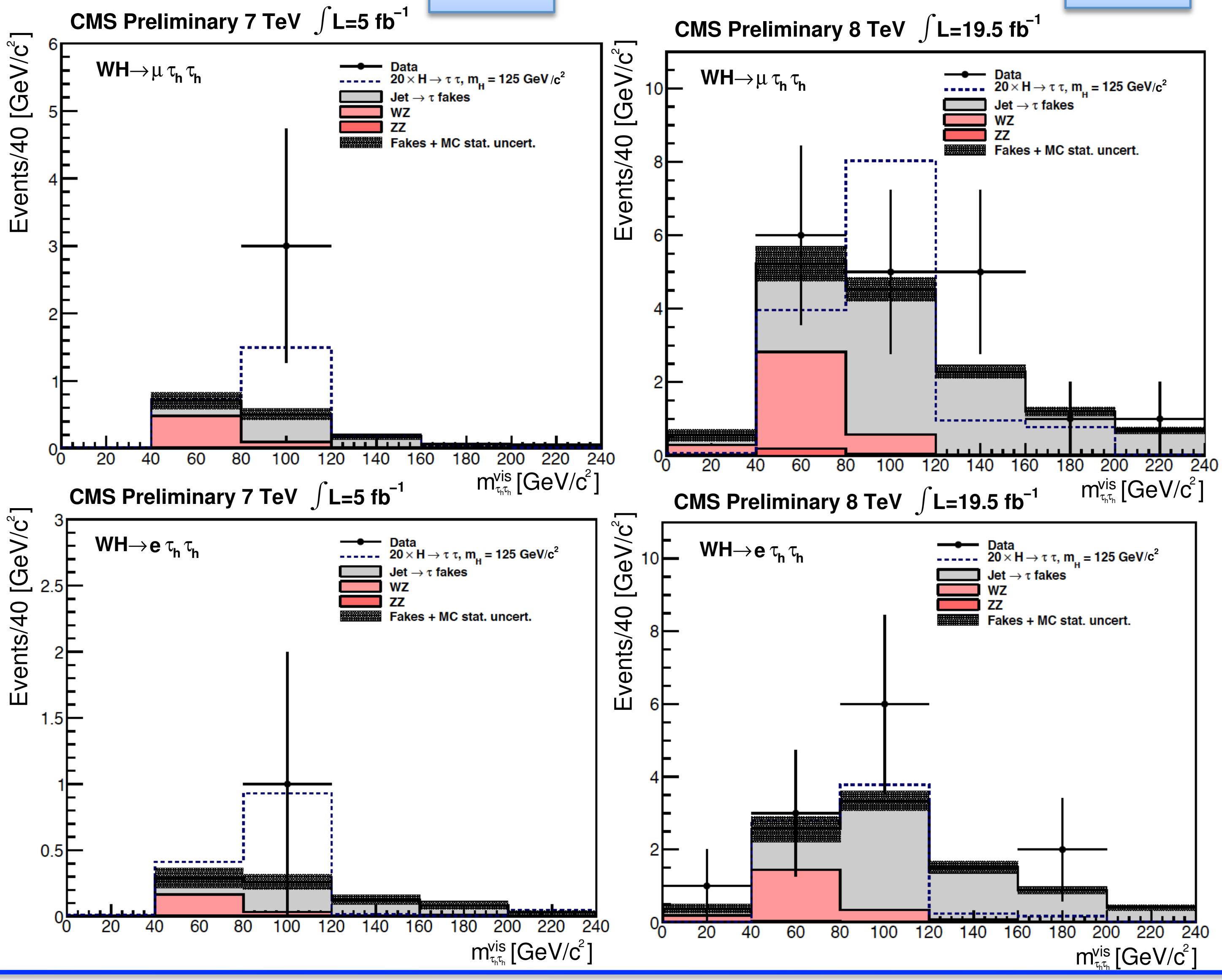


Signal region

2011 | 2012

Muon channel

Electron channel



Search for the SM Higgs boson in the WH production with the eττ and μττ final states

Systematics

Normalization (%)	
Luminosity 2011(2012)	2.2(4.4)
VV MC	4.3 (pdf) + stat.
Trigger Efficiency	3.5
Fake Rate Normalization	20+stat.
Electron ID	2.9
Muon ID	1.4
Tau ID	12
Tau Energy Scale	3
Jet Energy Scale	1
MET	3.7
Electron Veto	3.8
Muon Veto	0.7
Shape Uncertainty	
WH,WZ,ZZ, Fakes	± 1 sigma

- Uncertainties are considered as fully correlated over the 2 channels and data taking periods.
- 20% obtained considering:
  - 10% Fake Rate differences in W+Jets and Z+Jets
  - 10% mismodelling of background composition
  - 10% for fit statistical uncertainty

Recommended value (Electron ID, Muon ID, Tau ID)

Propagate the recommended value to the final yield (Tau Energy Scale, Jet Energy Scale, MET, Electron Veto, Muon Veto)

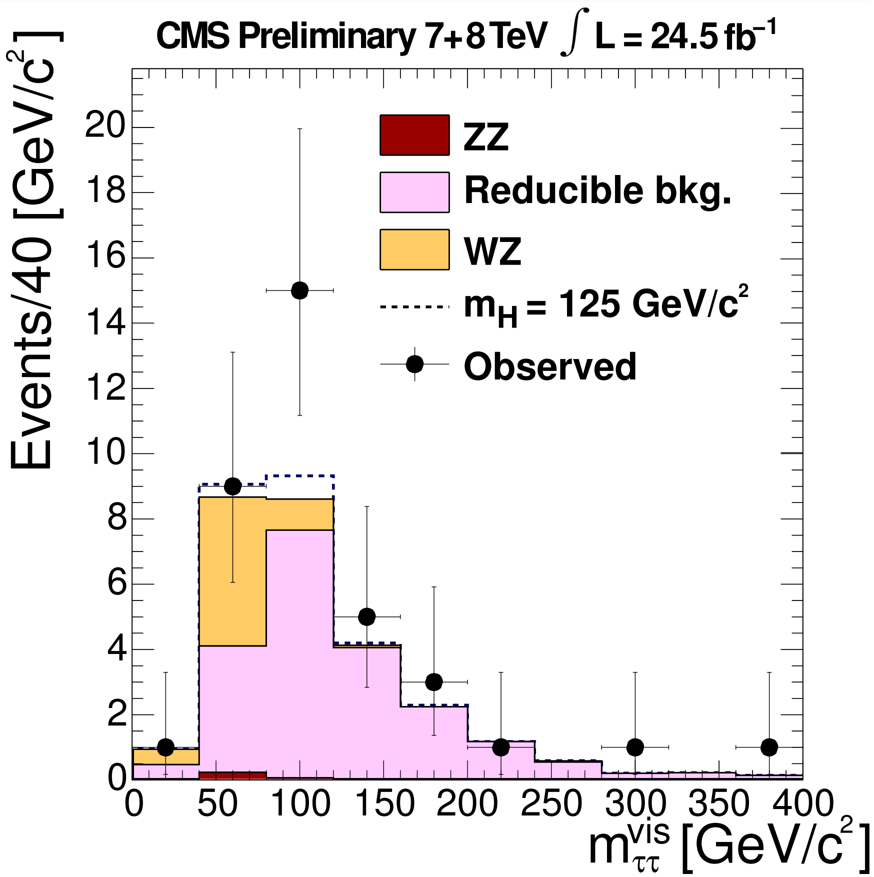
Final Events

Process	lττ
Fakes	20.4 ± 4.3
WZ	6.2 ± 1
ZZ	0.38 ± 0.06
Total Bkg	27.1 ± 4.5
VH→Vττ (mH=125 GeV)	1.2 ± 0.2
Observed	36

Observed events are compatible within the error with what we expect from fake estimation and irreducible background contribution

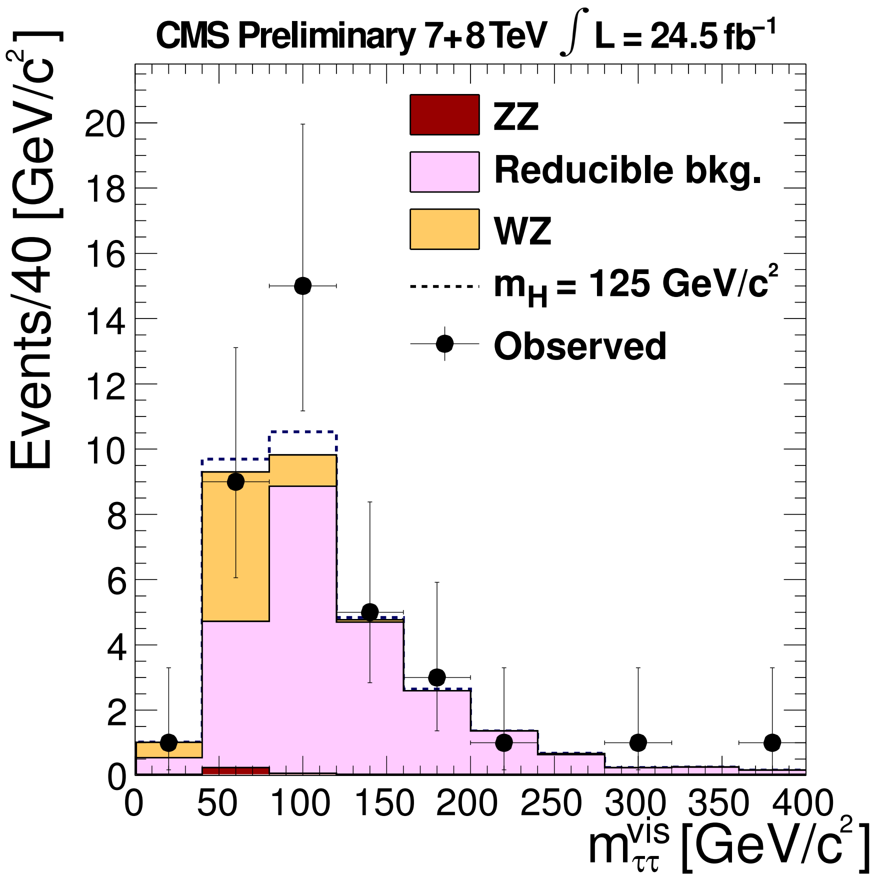
Visible Mass

Pre-fit



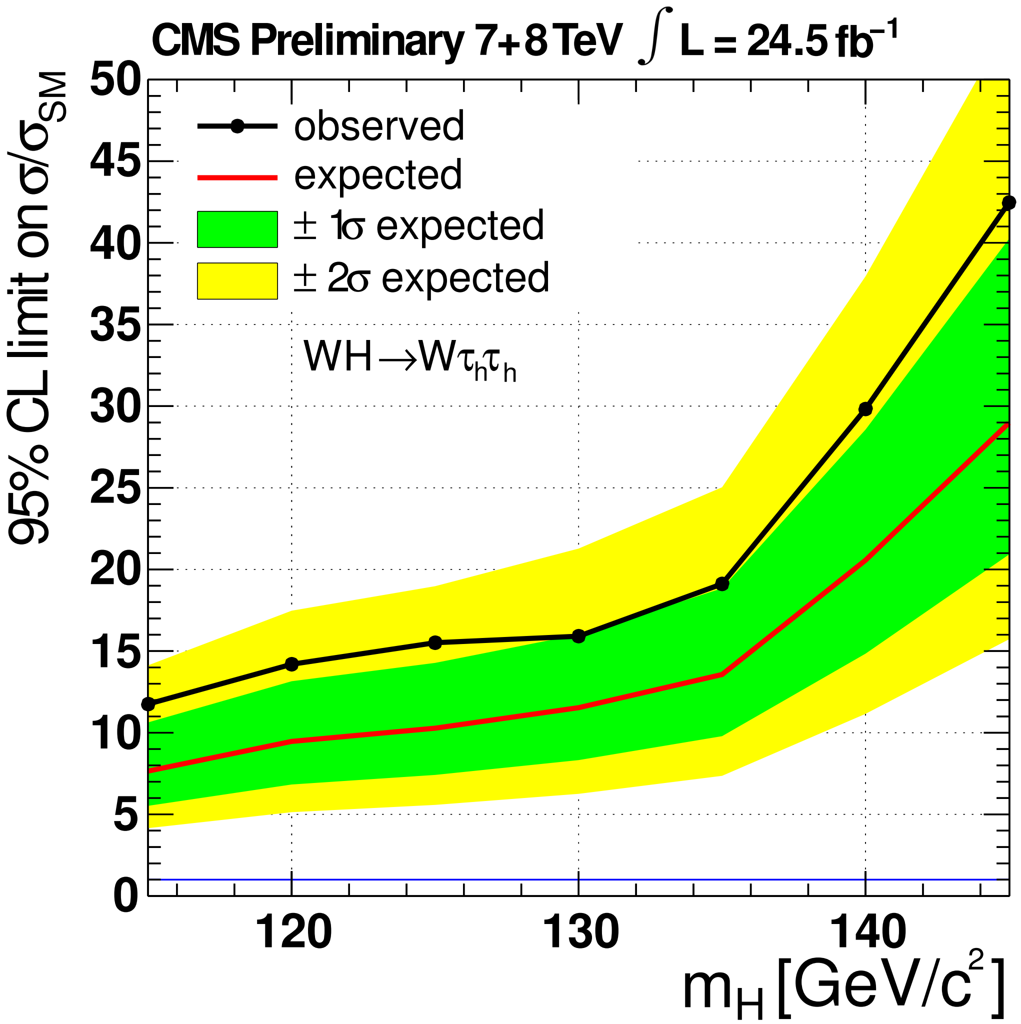
Final distribution of observed and expected events

Post-fit



Best fit to data using the Maximum likelihood method

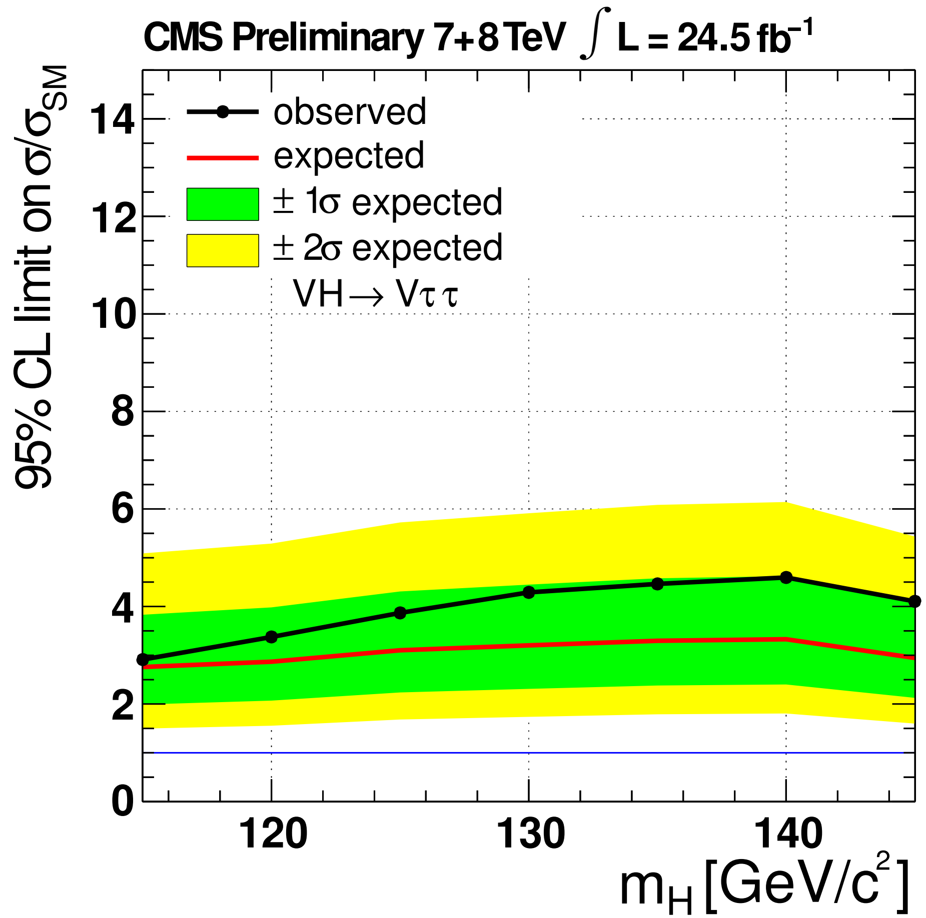
$W(\to l\nu_l)\ H(\to \tau_h\tau_h)$ Limits

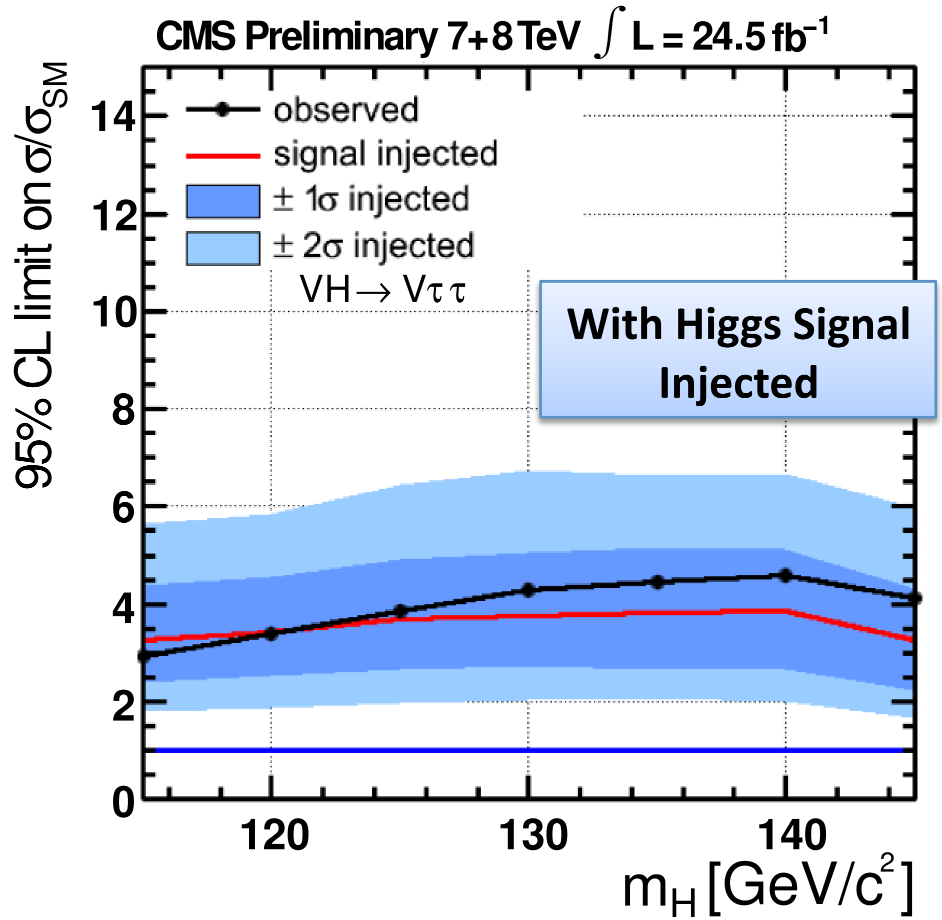


- The **counting experiment** is used to set 2011 limits in mu/e channel (lacking of statistics)
- A **shape analysis** is performed using the di-tau visible mass in 2012 mu/e channel

VH Combined Limits

- **Results have been combined with the other VH channels:**
  - **WH: $\mu\mu\tau_{had}$, $e\mu\tau_{had}$**
  - **ZH: $(\mu\mu, ee) \otimes (\mu\tau_{had}, e\tau_{had}, e\mu, \tau_{had}\tau_{had})$**





Conclusions

- **The search of SM Higgs boson in association with W and in fully hadronic final state has been performed at CMS with full statistics.**
- **Analysis strategy:**
  - **Cut based analysis** to select the final state
  - Background estimation : irreducible bkg via **MC**, reducible bkg via **fake rate method**
- **Limit is measured with counting experiment in 2011 and by fitting the Higgs visible mass for 2012.**
- **Observation is consistent both with the presence and the absence of a SM Higgs boson**
- **This analysis, together with other channels of VH process, will be included in the H→ττ global combination.**

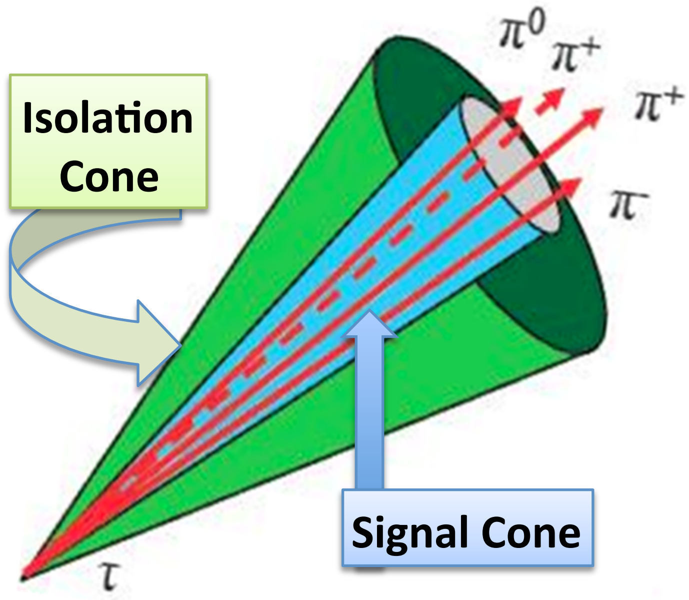
Back-up

Cut-Based Tau Isolation

- Sum p_T of charged and gamma PF candidates not belonging to tau within cone of $\Delta R = 0.5$.
- $\Delta\beta$ Correction to take into account pile-up effects:
  - Neutral pileup contribution estimated from pile-up tracks entering isolation cone.
  - Sum p_T of pile-up tracks multiplied by neutral-to-charged ratio
  - Neutral-to-Charged ratio tuned to obtain flat efficiency vs. pile-up.
  - Estimated neutral pileup contribution subtracted from isolation .

$$I_{PF}^{(\Delta\beta)} = \sum P_t^{charged} + \max(E_t^{\gamma} + E_t^{neutral} - 0.0729 \times E_t^{PU}, 0.0)$$

- Cut Based Isolation Working Points:
  - **VeryLoose**: $I_{PF}^{(\Delta\beta)} < 3\text{GeV}$;
  - **Loose**: $I_{PF}^{(\Delta\beta)} < 2\text{ GeV}$;
  - **Medium**: $I_{PF}^{(\Delta\beta)} < 1\text{GeV}$;
  - **Tight**: $I_{PF}^{(\Delta\beta)} < 0.8\text{GeV}$.



Dataset and Triggers

- $\mu\tau_h\tau_h$: Single Muon Trigger
- $e\tau_h\tau_h$: Electron + Tau Trigger
- Trigger applied on MC and data
- Pile up Reweighting applied

Topological Selections

Additional (both channels)

ΔR between all selected objects

Δz(l, PV)

$Q(\tau 1) * Q(\tau 2) < 0$

$E_T^{miss} > 20$ GeV

No b-tagged jet with pT > 20 GeV **(b-jet veto)**

Additional (μ channel):

- No additional global + PF muon with $p_t > 15$ GeV **(Z → μμ veto)**
- No MVA electron with pT > 10 GeV
- $p_t(\tau_1, \tau_2) > 50$ GeV or $M_t(\mu, \tau_{OS}) > 80$ GeV **(Z → ττ veto)**
- $M_t(\mu, E_T^{miss}) > 20$ GeV **(Overlap removal)**

Additional (e channel):

- $M_t(e, E_T^{miss}) > 50$ GeV **(Z → ττ veto)**
- No 2 OS electrons with $|m_Z - m_{ee}| < 25$ GeV **(Z → ee veto)**
- No $|mZ - m(e, \tau_{OS})| < 6$ GeV **(Z →ee veto)**

Fake Rate Method

- Main reducible backgrounds have at least one **fake lepton** due to a misidentified quark or gluon jet which passes the lepton identification
- Data-driven estimation.
- Measure **misidentification probabilities** for the fake lepton candidates to pass the final isolation criteria in background enriched regions (**control regions**):
  - $W \rightarrow \mu\nu$ + jets
  - $Z \rightarrow \mu\mu$ + jets

  as a function of lepton pt ($f(p_t)$)
- The control regions are chosen such that **signal events are excluded**.
- Define **sideband**: invert isolation on fake lepton candidate.
- Extrapolate reducible background contribution in signal region by weighting each event in sideband with:

$$\omega(p_t) = \frac{f(p_t)}{1 - f(p_t)}$$

Fake Rate Measurement

Denominator

- **<u>W (→μν)+ jets</u>**
- Muon pT > 24 GeV, |η| < 2.1
- PF-based relative isolation < 0.1
  No electron (pT > 15 GeV, loose MVA ID)
- No b-tagged jets (loose CSV WP)
  MT(Muon, MET) > 40 GeV
- 2 SS τ_h

Consider all reconstructed **taus** which are part of a **SS** tau pair and which are SS to the **muon** from the W decay

- **<u>Z+ jets</u>**
- 2 OS muons
- μ1 pT >24GeV, μ2 pT >10GeV, |η|<2.1
- PF-based relative isolation < 0.1
- No electron
- No b-jet
- 80GeV ≤ M(μ1, μ2) ≤ 100 GeV

Consider **all reconstructed taus** in the event

Denominator

Numerator: All Taus passing **Isolation** Requirement