Search for WH → Hττ

Maria Teresa Grippo
Giuseppe Bagliesi
Paola Squillacioti

Presentation given by Letizia Lusito at the Pre – Approval , Higgs PAG Meeting

1. Introduction
2. Event Selection
3. Background estimation
4. Systematics
5. Results & Limits

PAS HIG-12-006

CMS PAS HIG-12-006

DRAFT
CMS Physics Analysis Summary

The content of this note is intended for CMS internal use and distribution only

2012/01/31
Head Id: 99477
Archive Id: 99605P
Archive Date: 2012/01/30
Archive Tag: trunk

Search for the Standard Model Higgs Boson
Produced in Association with a W Boson
in Final States with Electrons, Muons, and Taus

The CMS Collaboration

http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=HIG-12-006

AN-11-502

CMS NOTE AN-11-502

The Compact Muon Solenoid Experiment

CMS Draft Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

2012/01/30
Head Id: 97957
Archive Id: 98757:99143M
Archive Date: 2012/01/25
Archive Tag: trunk

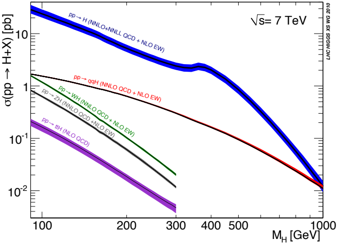
Search for the Standard Model Higgs Boson produced in association with a W boson in final states with electrons, muons, and taus

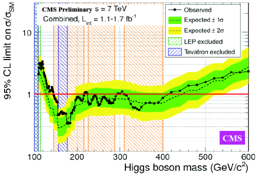
M. Bachtis[5], G. Bagliesi[3], C. Calabria[1], A. Colaleo[1], S. Dasu[5], S. Dutta[4], E. Friis[5], S. Gennai[2], M.T. Grippo[3], L. Lusito[1], L. Perrini[1], R. Radogna[1], I. Ross[5], S. Sarkar[4], A. Savin[5], W. Smith[5], P. Squillacioti[3], J. Swanson[5], and R. Venditti[1]

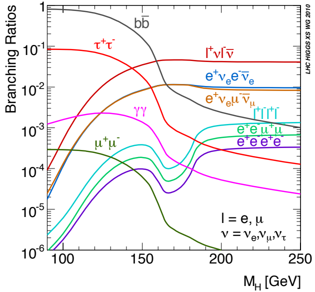
Supporting Analysis Note

Motivations

- Higgs Production in association with W boson:
  - Higher trigger efficiency and smaller QCD contamination thanks to the leptons coming from W
- Decay in $\rightarrow \tau\tau$:
  - in the range [115, 135] H$\rightarrow \tau\tau$ has the 2nd predominant BR, after $b\bar{b}$.







Data and Monte Carlo

- Data: (Total Integrated Luminosity 4.76 fb^{-1})
  - Primary Datasets: DoubleMu, MuEG
  - Prompt Reco V4 and V6 and May10ReReco and 05AugReReco datasets
- Monte Carlo (Fall11)
  - Signal (pythia) $WH + ZH + t\bar{t}H$ with $H \to \tau\tau$, $H \to WW$
  - Backgrounds: Dibosons, DYJets, WJets, TTJets (madgraph), μ enr. QCD (pythia)

Analysis Overview

- $WH \rightarrow \tau\tau$, where W decays in light leptons, one tau decaying leptonically, the other hadronically (τ_h)
- Analysis sensitive to $WH \rightarrow WWW$ since it can produce the same trilepton final state
  (0.092 pb for m_H=120 GeV @ 7 TeV)
- Two final states analyzed: $e\mu\tau_h$ and $\mu\mu\tau_h$
  (indicated simply as $e\mu\tau$ and $\mu\mu\tau$ in the following slides)
- Charge requirement: $\mu^{\pm}\mu^{\pm}\tau^{\mp}$, $e^{\pm}\mu^{\pm}\tau^{\mp}$ to ensure that Z+jets and $t\bar{t}$ that pass the selection have one fake light lepton instead of a fake hadronic tau (which has a much higher fake rate)
- WZ/ZZ (non-fake) background estimation: CMS σ measurement
- Effective cross sections:

$WH \rightarrow \tau\tau$ (m_H=120 GeV @ 7 TeV)	$\sigma \times BR$
$\mu\mu\tau$	7.25 fb
$e\mu\tau$	14.5 fb

Lepton reconstruction, ID and isolation [1]

- **Muons**
  - Global, ≥ 1 good hit in the first two stations of the muon detector
  - Tracker, ≥ 2 matches in the chambers of the muon detector
  - ≥ 10 hits in the tracker system (≥ 1 in the pixel detector only)
  - χ^2/NDF of the global track fit < 10
  - $|\eta| < 2.1$
  - impact parameter in the transverse plane $|d_0| < 0.02$ cm, in the longitudinal plane $|d_z| < 0.2$ cm wrt Primary Vertex
  - Isolation computed in $\Delta R = 0.4$
- **Electrons**
  - Gaussian Sum Filter- track matching
  - Loose MVA preselection (MVA WWID)
  - Boosted decision tree MVA discriminator based on shower shape variables
  - $|d_0| < 0.02$ cm, $|d_z| < 0.1$ cm, Vertexing Conversion Veto, NExp.Hits ≤ 0
  - $|\eta| < 2.5$
  - Isolation computed in $\Delta R = 0.4$

[1] same as in HIG-11-029

Lepton reconstruction, ID and isolation [1]

- **Taus**
  - HPS algorithm
  - “Decay Mode Finding”, “Combined Loose Isolation”
  - Isolation computed in ΔR= 0.5
  - $\Delta\beta$ corrections applied
  - $|\eta| <$2.5
- **Isolation**
  - Particle-Flow based isolation
  - isolation corrected for pile-up effects using the $\Delta\beta$ technique:

$$I_{\mathrm{rel}} = \frac{\Sigma p_T(charged) + max(\Sigma E_T(neutral) + \Sigma E_T(photon) - \Delta\beta, 0)}{p_T(\mu \text{ or } e)}$$

[1] same as in HIG-11-029

e$\mu\tau$ Selection

- Trigger: Mu17_Ele8_CaloId(L/T)_(CaloIsoVL)
- $H\tau\tau$ e-ID and iso, I/p_T <0.3, p_T >10 GeV
- $H\tau\tau$ μ-ID and iso, I/p_T <0.3, p_T >18 GeV
- τ HPS Decay Mode + Combined Loose Iso, p_T >20 GeV
- τ AgainstElectronMedium + MVA, AgainstMuonTight
- sum of the charges of the three leptons equal to 1
- no extra e, μ or *b*-jets in the event

$\mu\mu\tau$ Selection

- Trigger: lowest unprescaled double muon triggers
- $H\tau\tau$ μ-ID and iso, ΔR = 0.4, I/p_T $<$0.3, p_T $>$18, 9 GeV
- τ HPS Decay Mode + Combined Loose Iso, p_T $>$20 GeV
- τ AgainstMuonTight, againstElectronLoose
- sum of the charges of the three leptons equal to 1
- no extra e, μ or *b*-jets in the event

Topological Selection

Two topological selections that are common to the two channels:

- L_T >80 GeV (scalar sum of final state leptons E_T's)
- Common vertex (of the three leptons) χ^2/NDF <10

Background estimation

Two categories:

- Dibosons (*WZ*, *ZZ*)
    - Three real isolated leptons
    - Selection efficiency estimated using MC
    - Normalization taken from 2011 CMS measurement of *WZ* and *ZZ* cross sections, consistent with NNLO predictions
- Backgrounds with at least one quark or gluon jet incorrectly identified as an isolated e, μ
    - Z+jets, $t\bar{t}$, W+jets, QCD
    - Estimated using the fake rate method: measure jet $\rightarrow$ e/μ/τ fake rate $f(p_T)$ in control regions

Fake Rate Method

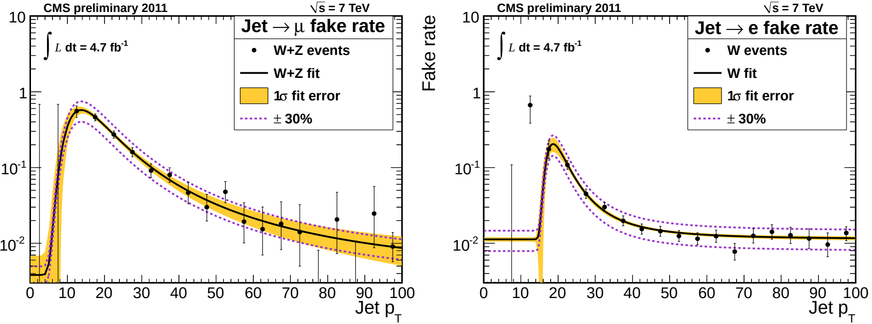
Electron, muon and tau fake rates are measured in selected background enriched control regions with the following requirements:

- be exclusive of the signal region
- be as close as possible to the signal region to minimize biases
- have very low contamination from processes with real isolated leptons

Three different background enriched control regions are used to measure the fake rate:

- $W \rightarrow \mu\nu$+jet
- $Z \rightarrow \mu\mu$+jet
- QCD heavy-flavour (anti-isolated muon +jet)

Fake Rate Method



muon/electron fake rate measurement

(combination of the *W* and *Z* control regions and the corresponding fit)

Yellow bands: error from Minuit (applying error propagation to the fit covariance matrix), not used. The error condidered is simply $\pm$30% from the black lines.

Discrepancy between data/fit in e FR distribution does not affect the analysis because the anti-isolated electrons are generally much higher in p_T

Fake Rate Method

- Fake background events estimated by weighting the anti-isolated events by the corrected fake rate function:
  $\omega(p_T) = f(p_T)/(1 - f(p_T))$
- **Because of the charge requirement, all fake backgrounds with two isolated leptons never have a fake hadronic tau**
- **All fake backgrounds have at least one fake muon, one fake electron or both** :
  Total fake background = μ fake rate + e fake rate
  - $Z \rightarrow \mu + \tau_h$ + fake e (estimated by electron fake rate)
  - $Z \rightarrow e + \tau_h$ + fake μ (estimated by muon fake rate)
  - $W \rightarrow \mu\nu$+ fake τ_h + fake e (estimated by electron fake rate)
  - $W \rightarrow e\nu$+ fake τ_h + fake μ (estimated by muon fake rate)
  - etc.
- Fake rate estimate corrected for the presence of QCD in each region (which generally has a lower fake rate)

Fake Rate Method Corrections

- The contribution of two backgrounds ($W \to \tau_h + 2jets$ and QCD) is counted twice in each of the muon and electron fake rates
- To correct for this, a “double fake rate” correction $\omega_\mu(p_T^\mu)\cdot\omega_e(p_T^e)$is estimated by simultaneously anti-isolating electron and muon and subtracting this from the sum of the single e and μ fake rates
- The fake rate in QCD events is measured to be different than electroweak events
- To correct for this, the QCD fraction in each control region is estimated by anti-isolating all three objects and extrapolating into the e and μ control regions
- Final corrected estimate for a given fake object type is the weighted average of the estimates using EWK ($W \to \mu\nu$+jets, $Z \to \mu\mu$+jets) and QCD fake rates
- MC ZZ/WZ yields are corrected for the expected contribution to the fake rate estimate (3%)

Data and MC corrections

- Pile-Up 3D reweighting (MC)
- Efficiencies for lepton reconstruction, ID, isolation from data
- Efficiency of Double Muon trigger from data
- Correction factors for values extracted from MC determined from data using tag&probe
- Correction factor for MuonEG trigger measured in $Z \rightarrow \tau\tau \rightarrow e\mu$ control region
- Corrections to Jet Energy Scale: *L1FastJet*, *L2Relative*, *L3Absolute* (MC and data), *L2L3Residual* (data)

Systematics: normalization uncertainties

Source	Value
Luminosity [a]	4.5%
σ_{WZ} [b]	16.6%
σ_{ZZ} [b]	40%
σ_H (PDF) [c]	4.5%
MC Eff. χ^2/L_T [d]	5%
Fakes normalization [e]	30%
Tau ID [f]	6%
Muon ID + Iso [g]	1%
Electron ID + Iso [g]	2%

[a] *Measurement of CMS Luminosity*, **CMS-PAS-EWK-10-004**

[b] *Measurement of WW and observation of WZ and ZZ in leptonic modes*, **CMS-PAS-EWK-11-010**

[c] *Handbook of LHC Higgs Cross Section:1. Inclusive Observables*, **CERN-2011-002, arXiv:1101.0593**

[d] *Norm. unc. related to the efficiency of χ^2/L_T cuts on MC H, WZ, ZZ*

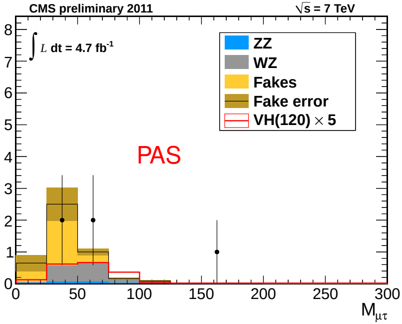
[e] *Errors in fake rate function or estimation of fake composition (QCD and EWK)*

[f] *Performance of tau lepton reconstruction and identification in CMS*, **CMS-TAU-11-001**

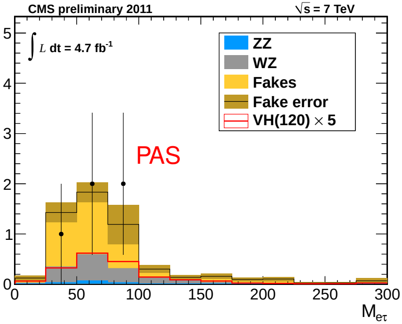
[g] *Unc. on data-MC correction factors measured with tag&probe*

Results

Invariant mass pairs distributions
correlated with Higgs mass, used to extract limits



invariant mass of the sub-leading muon and hadronic tau in the $\mu\mu\tau$ final state



invariant mass of the electron and hadronic tau in the $e\mu\tau$ final state

Results

Observed yelds and backgrounds estimates

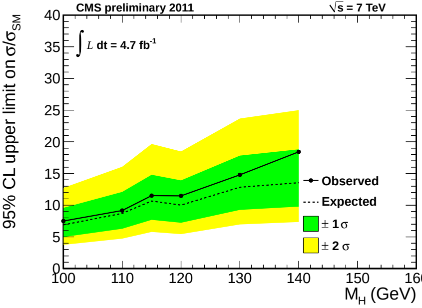
Process	$\mu\mu\tau$	$e\mu\tau$
Fake Background	3.0 ± 0.6	3.9 ± 0.5
WZ	1.3 ± 0.2	1.4 ± 0.2
ZZ	0.1 ± 0.1	0.2 ± 0.1
Σ SM	4.4 ± 0.6	5.5 ± 0.6
$\mathbf{N_{obs}}$	5 ± 2.2	5 ± 2.2
VH (120)	0.4	0.4

Exclusion Limits

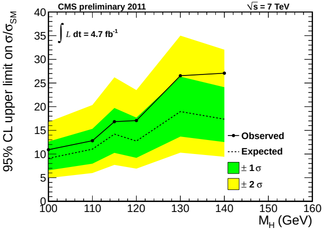
- Observed spectra show no evidence for the presence of a Higgs boson signal
- Set 95% confidence level (CL) upper bounds on the H cross sections in terms of the SM expectation
- Asymptotic CL_s method
- Contribution from *HWW* is only included for $m_H \geq 120$ GeV

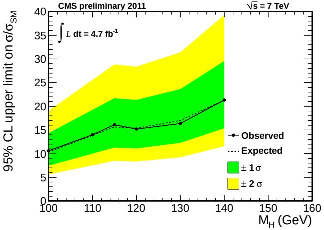
Exclusion Limits

PAS



At m_H = 120 GeV limit is $\approx$ 10 times the expected SM background cross section





Top $\mu\mu\tau$, bottom $e\mu\tau$

Conclusions

- Search for a SM higgs boson in association with *W* boson
- Full 2011 statistics
- Two final state:
  - $e^{\pm}\mu^{\pm}\tau^{\mp}$
  - $\mu^{\pm}\mu^{\pm}\tau^{\mp}$
- 10 events observed, compatible with SM background expectations
- Upper limits on *WH* production cross section at 95% CL
- At m_H = 120 GeV expected exclusion is $\approx$ 10 times the SM background cross section

BACKUP

MC samples

/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/GVJets_7TeV-madgraph/Summer11-PU_S4_START42_V11-v1/AODSIM
/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
/QCD_Pt-30to80_EMEnriched_TuneZ2_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
/QCD_Pt-80to170_EMEnriched_TuneZ2_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
/TTJets_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-100_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-110_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-115_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-120_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-125_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-135_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-140_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-145_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToTauTau_M-160_7TeV-pythia6-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WH_ZH_TTH_HToWW_M-120_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
/WH_ZH_TTH_HToWW_M-130_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
/WH_ZH_TTH_HToWW_M-140_7TeV-pythia6/Summer11-PU_S4_START42_V11-v1/AODSIM
/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM
/WWJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
/WZJetsTo3LNu_TuneZ2_7TeV-madgraph-tauola/Summer11-PU_S4_START42_V11-v1/AODSIM
/ZZJetsTo4L_TuneZ2_7TeV-madgraph-tauola/Fall11-PU_S6_START42_V14B-v1/AODSIM

WH backgrounds

	Backgrounds
$e^+\mu^+\tau^-$	$t\bar{t} \to e^+\tau^-\ b\bar{b}_\mu$ ($b \to \mu$ fake)
	$Z \to \tau^+\tau^- \to e^+\tau^-$ + jet$_\mu$ (jet $\to \mu$ fake)
	$W \to e^+\nu$ + 2 jet fakes
$\mu^+\mu^+\tau^-$	$t\bar{t} \to \mu^+\tau^-\ b\bar{b}_e$ ($b \to e$ fake)
	$Z \to \tau^+\tau^- \to \mu^+\tau^-$ + jet$_e$ (jet $\to e$ fake)
	$W \to \mu^+\nu$ + 2 jet fakes

Both channels have non-fake *ZZ* and *WZ* (irreducible) backgrounds, which are estimated using MC + CMS EWK measurements.

Object reconstruction

- **Jets**
  - from PF candidates, anti-k_T algorithm (AK5PFJets)
  - Track Counting High Efficiency (TCHE) *b*-tag algorithm
  - Reject events if they have a jet with TCHE $>$ 3.3 (*b*-jet)

Trigger

Channel	Run Range	Trigger
$\mu\mu\tau$	160431–163869	HLT_DoubleMu7
	165088–178380	HLT_Mu13_Mu8
	178420–180252	HLT_Mu17_Mu8
e$\mu\tau$	160431–176469	HLT_Mu17_Ele8_CaloIdL
	176545–180252	HLT_Mu17_Ele8_CaloIdT_CaloIsoVL

Triggers used in each channel for the different run ranges

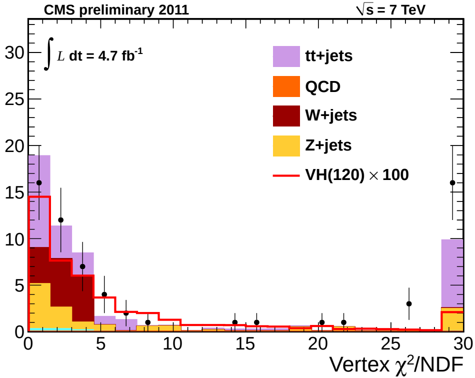
Electron, muons and *b*-jet vetoes

Object	p_T	$\|\eta\|$	Discriminator
Muons	-	-	pat::Muon
Electrons	-	-	pat::Electron VBTF WP95
b–jets	20	2.5	TCHE $>$ 3.3

Selections applied to the veto objects

Vertex χ^2 requirement

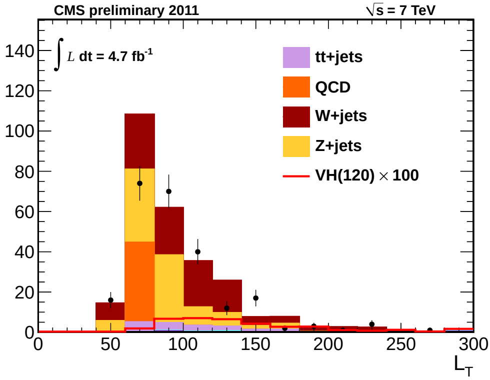
χ^2/NDF of the fit of the vertex built from tracks of all final state leptons



$\mu\mu\tau$ channel after all other cuts except sub-leading muon isolation

$\chi^2/NDF < 10$ GeV to remove *b*-jet events, reduce sensitivity to leptons coming from PU vertices incorrectly associated to the hard interaction

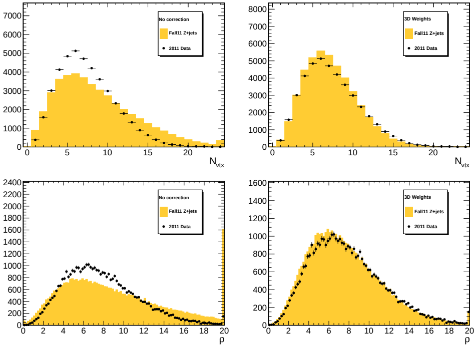
L_T requirement



$\mu\mu\tau$ channel after all cuts except L_T and anti-isolated sub-leading muon

$L_T > 80$ GeV to remove fake background with softer p_T spectrum

Pile Up correction



Number of Reconstructed Primary vertices and ρ fastjet energy density (sensitive to in-time/out-of-time PU events)

More on Fake Rate Method

- For fake backgrounds, require two isolated leptons and anti-isolate fakeable object.
- In $\mu\mu\tau$ “fakeable” object is (subleading) muon.
- In $e\mu\tau$ “fakeable” object is electron.
- Jet $\rightarrow$ e and jet $\rightarrow \mu$ fake rates measured in $Z \rightarrow \mu^+\mu^-$ +jet events.
- Fake rate f(p_T) = N(ID+ISO)/N(reco)
- N (fake, signal) = N (data, anti-iso) x f(p_T)/[1-(p_T)]
- The *ZZ* and *WZ* contribution to N(fake, signal) is corrected using simulation.

More on Fake Rate Method

Fake Rate Recipe:

- Fakeable objects: SS leptons (eμ, $\mu\mu$)
- Estimate QCD contribution in each control region
- Compute corrected signal region estimate for each object
- Take 10% uncertainty on fake rate function
- Sum together object (i.e. e + μ) estimates
- Subtract double fake estimate
- Errors due to control region statistics propagated through calculation
- Error in each bin is uncorrelated
- Fake errors implemented in limit tool by making a shape syst. for each bin

More on Fake Rate Method

- “Triple fake rate” for QCD is calculated since QCD is the only background with three fake objects in the final state
- Then the QCD fraction in the anti-isolated electron region for the e$\mu\tau$ channel is found by anti-isolating the three objects and then applying the weights relative to muon and tau fake rate only: $\omega_{\mu}(p_T^{\mu}) \cdot \omega_{\tau}(p_T^{\tau})$
- Final corrected estimate for a given fake object type is the weighted average of the estimates using EWK ($W \to \mu\nu$+jets, $Z \to \mu\mu$+jets) and QCD fake rates

Background	Final state object e	μ	τ	Estimated by e	μ	$e\mu$	$e\mu\tau$
Two OS isolated leptons (type I)							
Z$\rightarrow \tau\tau(e\tau_h) + \text{jet}_\mu$	real	jet fake	real	no	yes	no	no
Z$\rightarrow \tau\tau(\mu\tau_h) + \text{jet}_e$	jet fake	real	real	yes	no	no	no
$t\bar{t} \rightarrow e\tau_h + \text{jet}_\mu + \text{jet}$	real	jet fake	real	no	yes	no	no
$t\bar{t} \rightarrow \mu\tau_h + \text{jet}_e + \text{jet}$	jet fake	real	real	yes	no	no	no
One isolated leptons (type II)							
W$\rightarrow \mu\nu + 2\text{jets}$	jet fake	real	jet fake	yes	no	no	no
W$\rightarrow e\nu + 2\text{jets}$	real	jet fake	jet fake	no	yes	no	no
W$\rightarrow \tau\nu + 2\text{jets}$	jet fake	jet fake	real	yes	yes	yes	no
No isolated leptons (type III)							
QCD	jet fake	jet fake	jet fake	yes	yes	yes	yes

A subset of the backgrounds in the $e^{\pm}\mu^{\pm}\tau^{\mp}$ channel and the fakeable objects which provide an estimate of them. The center columns describe which of the final state objects are real, and which are fake. The columns on the right indicate which sets of fakeable objects estimate that background.

W+jet control selection

- one isolated (I/$p_T < 0.1$) WW-ID tag muon with $p_T > 20$ GeV and $|\eta| < 2.1$,
- the tag muon and $\not\!\!E_T$ system has $M_T > 40$ GeV,
- the longitudinal impact parameter of the tag muon track with respect to the primary vertex is less 0.2 cm,
- the muon and probe jet have the same sign (to remove Z/γ),
- no loosely isolated (I/$p_T < 0.3$) muons above 5 GeV,
- no loosely isolated (I/$p_T < 0.3$) electrons above 10 GeV,
- no *b*-tagged jets with $p_T > 20$ GeV,
- no hadronic tau candidates passing HPS loose isolation with $p_T > 20$ GeV.

$Z \to \mu\mu$+jet control selection

- two isolated ($I/p_T < 0.1$) WW-ID tag muons with $p_T > 20$, 10 GeV and $|\eta| < 2.1$,
- the invariant mass of the probe system satisfies $85 < M_{\mu\mu} < 95$,
- $\not{E}_T < 20$ GeV,
- the transverse mass of the probe jet and $\not{E}_T$ system is < 20 GeV (to remove *WZ* contamination)
- the longitudinal impact parameter of the tag muon track with respect to the primary vertex is less 0.2 cm,
- no loosely isolated ($I/p_T < 0.3$) muons above 5 GeV,
- no loosely isolated ($I/p_T < 0.3$) electrons above 10 GeV,
- no *b*-tagged jets with $p_T > 20$ GeV,
- and no hadronic tau candidates passing HPS loose isolation with $p_T > 20$ GeV.

QCD control selection

- one anti-isolated ($I/p_T > 0.3$) WW-ID tag muon with $p_T > 20$ GeV and $|\eta| < 2.1$,
- $\not{E}_T < 20$ GeV
- the longitudinal impact parameter of the tag muon track with respect to the primary vertex is less 0.2 cm,
- the tag muon and probe jet have the same sign (to remove Z/γ),
- no loosely isolated ($I/p_T < 0.3$) muons above 5 GeV,
- no loosely isolated ($I/p_T < 0.3$) electrons above 10 GeV,
- no b-tagged jets with $p_T > 20$ GeV,
- and no hadronic tau candidates passing HPS loose isolation with $p_T >$ 20 GeV.

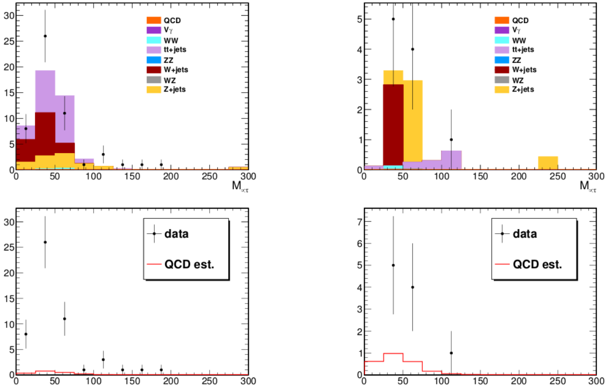
Estimating QCD contribution

- QCD fake rate can be significantly different than W+jet
- Effect concentrated in electron fake rate
- QCD estimate incorrect if only use W+jets FR
- QCD can be masured independently using triple fakes
  - Anti-isolate all three leptons
  - Apply fake rate to two leptons to get QCD yield in third anti-isolated region
- Use weighted average of the two fake rates

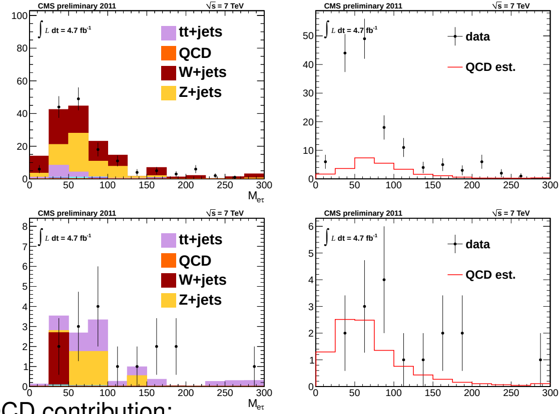
Estimating QCD contribution - $\mu\mu\tau$

Sub μ fake enriched region

Lead μ fake enriched region



Fake Rate



Estimating QCD contribution:

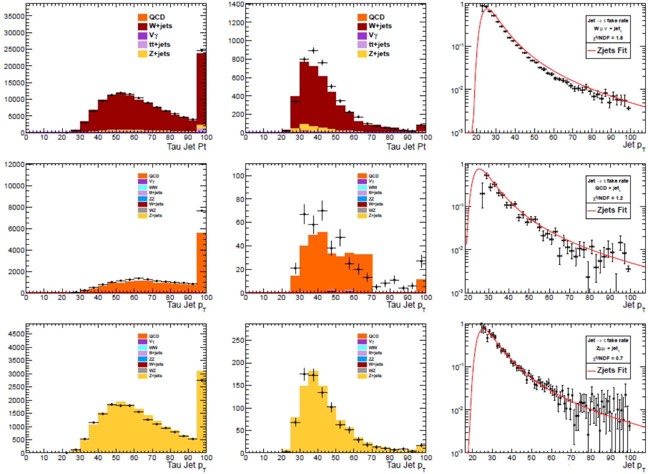
- Anti–isolated control regions for the $e\mu\tau$ channel using the electron (top) and muon (bottom) as the fakeable object.
- Observed yield in the control region is compared to the prediction from simulation (left).
- Data–driven estimate (red-line) of the QCD yield in the respective "single fake" control regions (right).
- The remainder is composed by electroweak backgrounds

Fake Rate measurements (jet $\to \mu$)

W + jets

QCD

$Z \to \mu\mu$

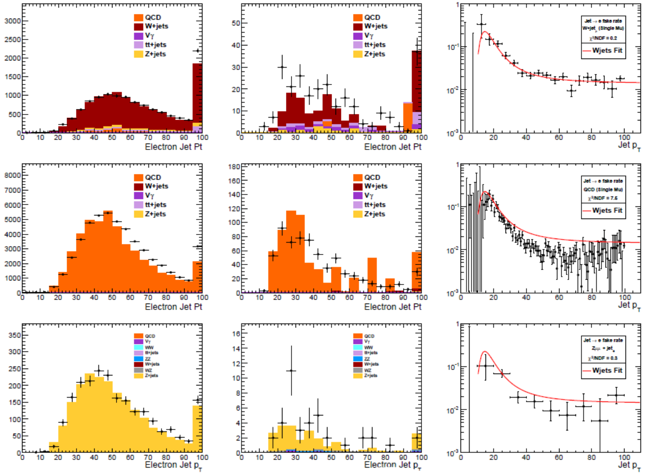


Fake Rate measurements (jet $\to$ e)

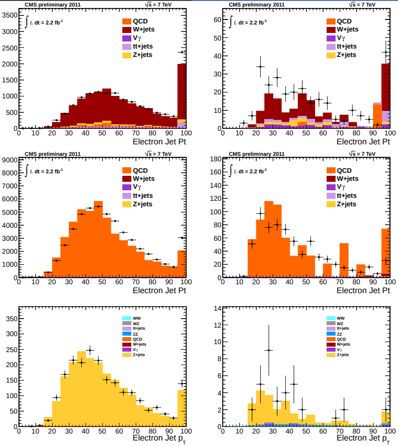
$W + \text{jets}$

QCD

$Z \to \mu\mu$



Fake Rate



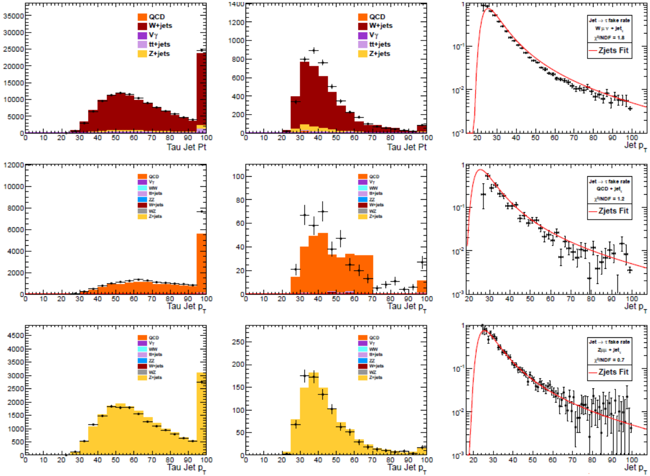
To measure the probability $f(p_T)$ of "loose" jet p_T to pass the tight selection, different control regions have been defined. The selected events in the loose selection versus the electron candidate jet p_T in W + jet (top row), QCD (middle row), and $Z \to \mu\mu$ (bottom row) events are compared to simulation at left, the selected events passing identification and isolation selections are at right. (for muons and taus see backup)

Fake Rate measurements (jet $\to \tau$)

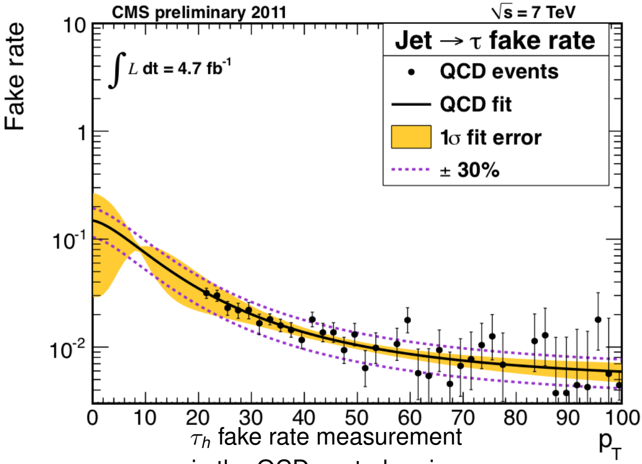
$W + \text{jets}$

QCD

$Z \to \mu\mu$



Fake Rate Method

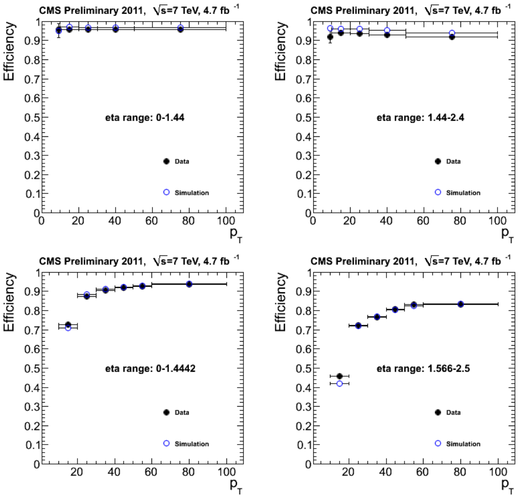


τ_h fake rate measurement
in the QCD control region

Fake Rate Shape

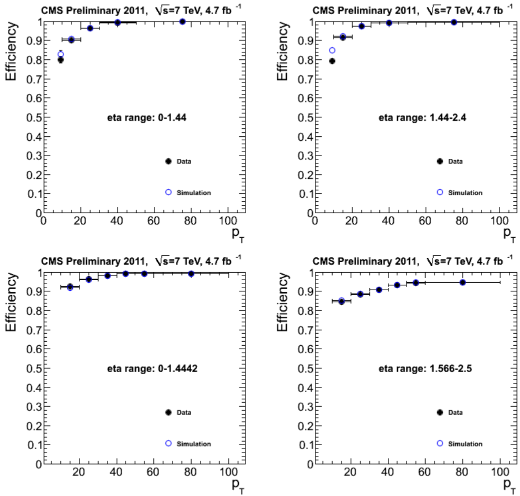
- Statistical + function uncertainty to be uncorrelated between bins in the observable
- Each fake bin has an uncorrelated uncertainty
- Create a shape uncertainty (nuisance + 2 extra histograms) for each bin
- In fit, fake shape can be **ANY** shape inside dark yellow band

Tag&Probe



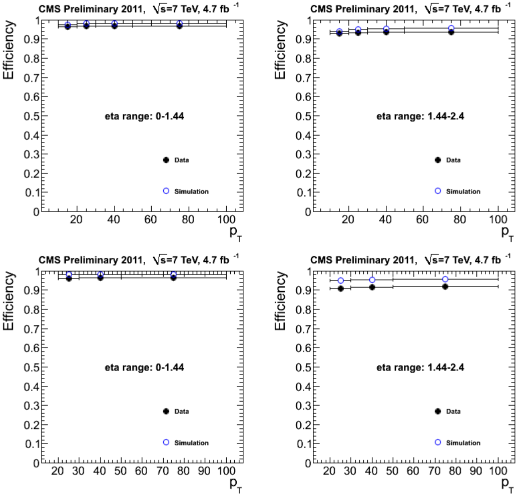
Measured prompt lepton **reconstruction/identification** efficiencies $\epsilon_{T\&P}$ in data and MC. Top plots are for muons, the bottom plots for electrons.

Tag&Probe



Measured prompt lepton **isolation** efficiencies $\epsilon_{T\&P}$ in data and MC. Top plots are for muons, the bottom plots for electrons.

Tag&Probe



Example of measured prompt **muon HLT** efficiencies $\epsilon_{T\&P}$ in data and MC.
Top plots are for HLT_Mu8 trigger, the bottom plots are for HLT_Mu17

Systematics: shape uncertainties

Shape uncertainties on the fake rates estimates

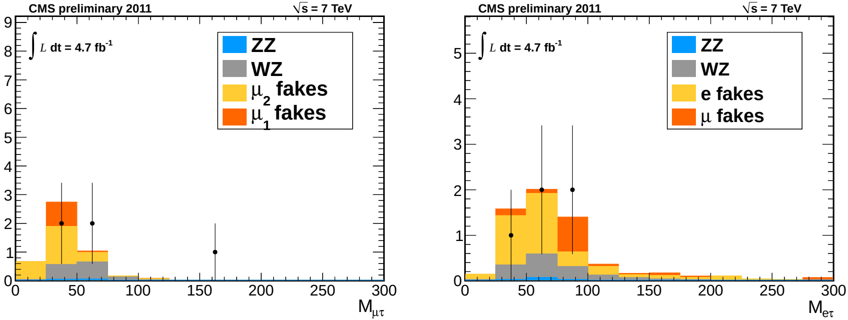
- affect relative yields between bins
- accounts for the statistical uncertainty (Poisson error) in each bin of the anti-isolated region
- No correlation between different bins
- Implemented as a set of shape uncertainties, one for each bin
- The fit can select the fake shape configuration that lies within the statistical fluctuation in every bin
- The corresponding error in the fit is visualized as a dark yellow band in the final distribution of invariant mass (see next slide)

$WH \rightarrow WWW$ contribution

- Increases m_H = 120 GeV yield by 25%
- Increases m_H = 140 GeV yield by 135%
- Extends sensitivity into high mass region

Results

Fake rate estimates - separate contributions

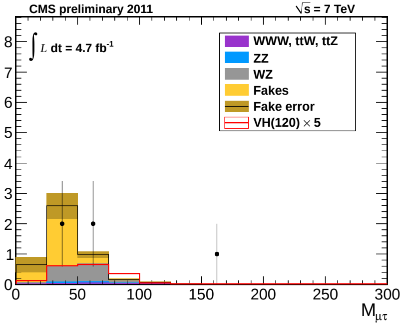


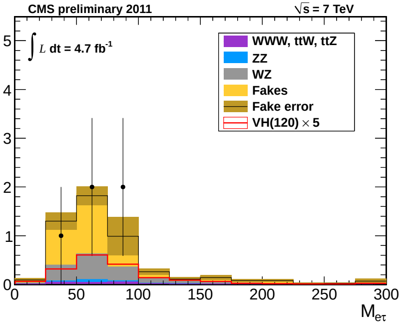
Progress since PAS Freezing

- Limits: fully frequentist CL_s (no significant change in results) and the addition of 150 and 160 GeV mass points.
- Systematics due to Energy Scale (ES) uncertainty (1% for electrons, 3%for taus):
  - The systematics on the yields due to the Electron ES are effectively zero.
  - The systematics on the yields due to Tau ES ranges from 1-2.5%, depending on sample.
- other backgrounds considered: $t\bar{t}W$, $t\bar{t}Z$, and WWW SM processes, which can all produce three isolated leptons in the final state: they contribute at about 1/2 of the expected SM Higgs contribution.
- Estimated using MC (MadGraph) LO cross section. Adding 75% systematic on the cross section in the data card because of these backgrounds makes the limit worse by 3%.

Progress since PAS Freezing

Invariant mass pairs distributions
considering also $t\bar{t}W$, $t\bar{t}Z$, and WWW backgrounds



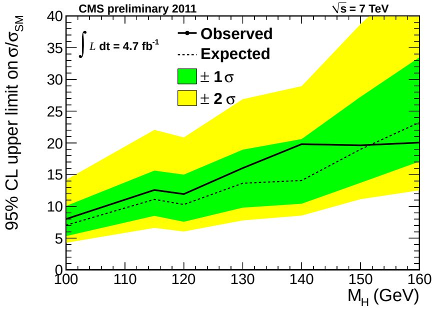


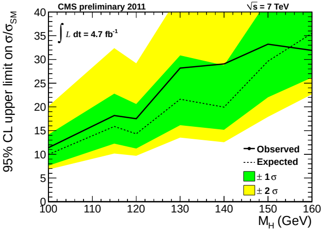
invariant mass of the sub-leading muon and hadronic tau in the $\mu\mu\tau$

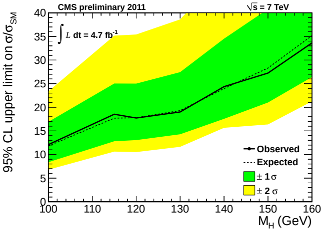
invariant mass of the electron and hadronic tau in the $e\mu\tau$ final state

New Exclusions Limits

Fully frequentist CL_s + new backgrounds + energy scale uncertainty

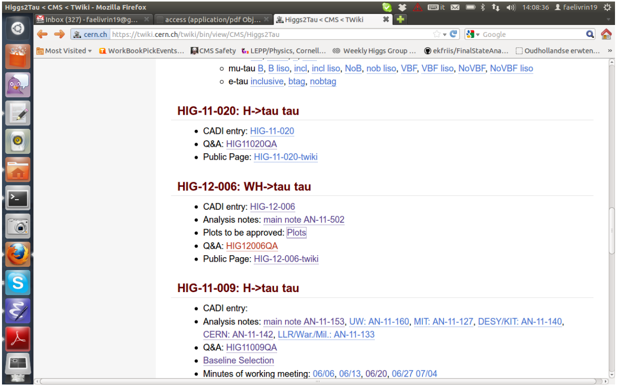






Top $\mu\mu\tau$, bottom $e\mu\tau$

Info



Twiki for the analysis

HyperNews **hn-cms-HIG-12-006@cern.ch**