Search for $H^{\pm} \to \tau^{\pm} \nu_{\tau}$ with fully hadronic final state in CMS

Alexandros Attikis
for the CMS Collaboration

University of Cyprus

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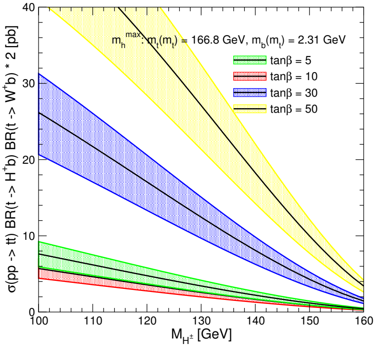
Strong evidence of Higgs-like particle with $m_{h^0} = 125\,\mathrm{GeV}/c^2$:

- Allowed MSSM parameter range still remains very large
- Difficult to set stringent bounds on MSSM just by measuring h^0
- $H^{\pm}$ discovery = unequivocal proof of BSM

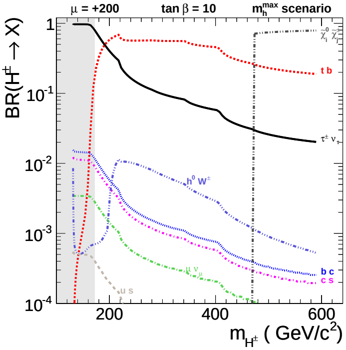
Common to distinguish between "Light" and "Heavy" $H^{\pm}$:

- $m_{H^{\pm}} \lesssim m_t - m_b$

$pp \to t\bar{t} \to bH^{\pm}bW^{\mp}$ with $\sigma_{t\bar{t}} = 164.57\,\mathrm{pb}$



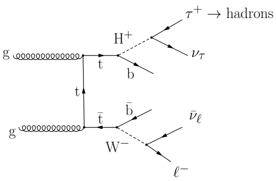
$\mathrm{BR}\left(H^{\pm} \to X\right)$ for $\tan\beta = 10$



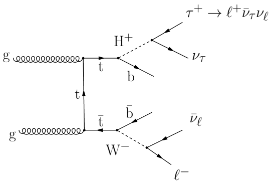
Four main final states for dominant $t\bar{t} \rightarrow bH^{\pm}bW^{\mp}$ [1]:

1. Semi-leptonic; $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau} \rightarrow \text{hadrons}\,\nu_{\tau}\nu_{\tau}$, $W^{\pm} \rightarrow \ell^{\pm}\nu_{\ell}$
2. Another semi-leptonic; $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau} \rightarrow \ell^{\pm}\nu_{\ell}\nu_{\tau}\nu_{\tau}$, $W^{\pm} \rightarrow q\bar{q}'$
3. Di-lepton; $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau} \rightarrow \ell^{\pm}\nu_{\ell}\nu_{\tau}\nu_{\tau}$, $W^{\pm} \rightarrow \ell^{\pm}\nu_{\ell}$
4. Fully hadronic; $H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau} \rightarrow \text{hadrons}\,\nu_{\tau}\nu_{\tau}$, $W^{\pm} \rightarrow q\bar{q}'$
    - One τ jet ($H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau}$)
    - At least two hadronic jets ($W^{\pm} \rightarrow q\bar{q}'$)
    - Two b-jets ($t \rightarrow bH^{\pm}$, $\bar{t} \rightarrow \bar{b}W^{\pm}$)
    - Large $E_{\mathrm{T}}^{\mathrm{miss}}$ ($H^{\pm} \rightarrow \tau^{\pm}\nu_{\tau}$, $\tau^{\pm} \rightarrow \text{hadrons}\,\nu_{\tau}$)
    - Reconstruct m_{T} (and $m_{H^{\pm}}$ for light $H^{\pm}$) (more sensitive than leptonic channels)

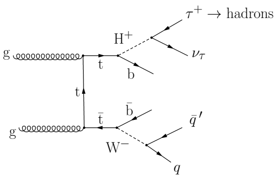
semi-leptonic



di-lepton



fully-hadronic



Three types:

1. QCD multi-jet background:
   - Dominant reducible background
   - Fake E_T^{miss} and jets mimicking τ jets/ b-jets
   - Suppressed with tight τ-jet ID, large E_T^{miss}, $\Delta\phi\left(\tau \text{ jet}, E_T^{miss}\right)$
   - Measured from data (more from Matti)

2. EWK+$t\bar{t}$ genuine τ background:
   - Events with ≥ 1 τ-lepton within acceptance
   - Largely irreducible background
   - W + jets, SM $t\bar{t}$, $Z^0/\gamma^* \rightarrow \ell^+\ell^-$, single-top, di-boson (WW, WZ, ZZ)
   - Partly suppressed with b-tagging, R_τ variable
   - Measured from data (more from Matti)

3. EWK+$t\bar{t}$ fake τ background:
   - Events with no τ-lepton in final state OR outside acceptance
   - Minor background ($\sim 5\%$ to Event yield)
   - Pass selections due to $e^\pm/\mu^\pm$/jet mis-identified as τ jets
   - Measured by use of simulations

The Particle Flow (PF) algorithm:

- Aims to reconstruct a particle-based description of the full event
- Combines sub-detector information (Tracker, ECAL, HCAL, Muon systems)
  - Iterative tracking (charged particles)
  - Calorimeter clustering (neutral particles)
  - Link algorithm (tracks ⇆ clusters)
  - All final-state particles reconstructed ($e^{\pm}$, $\mu^{\pm}$, γ, charged/neutral hadrons)
- PF particles → higher-level objects ($E_{\mathrm{T}}^{\mathrm{miss}}$, τ jets, b-jets)

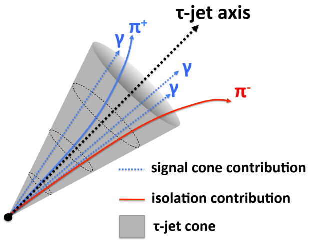
Object reconstruction:

- Muons: Global fit to hits in tracker and muon systems
- Electrons: Energy clusters in ECAL matched to tracker hits
- Jets: Using PF particles and anti-k_{T} algorithm with $R = 0.5$
- τ jets: PF jets as input to Hadron plus Strips (HPS) algo
- b-jets: PF jets as input to Track Counting High Efficiency (TCHE) algo
- PF $E_{\mathrm{T}}^{\mathrm{miss}} = -\sum_{i}^{\text{PF particles}} \vec{E}_{T,\,i}$

τ jets identified with Hadron plus Strips (HPS) algo [2]:

- Addresses photon conversions in tracker ($\gamma \to e^+e^-$)
- Combines PF EM particles (γ, $e^{\pm}$) in "strips" (broadening of calo deposit)
- "Strips" ($\equiv \pi^0$'s) are combined with PF charged hadrons
- Individual decay modes reconstructed (kinematic fits to $\rho^{\pm}$, $\alpha_1^{\pm}$)
- If multiple decay modes, hypothesis with highest $p_T^{\tau\ \mathrm{jet}}$ chosen
- Adjustable isolation cone $\Delta R_i = 0.5$ criteria (threshold for particles considered)
- Improved bkg rejection + τ jet energy (no signal cone ⇒ immune to spillages)

HPS τ jet algorithm



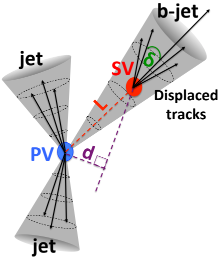
HPS decay modes

Process	$\Gamma_i/\Gamma_{total}(\%)$	$\sum_i \Gamma_i/\Gamma_{total}(\%)$
hadronic 1-prong	–	48.4
$\tau^- \to h^-\nu_\tau$	11.6	–
$\tau^- \to \rho^-\nu_\tau \to h^-\pi^0\nu_\tau$	26.0	–
$\tau^- \to \alpha_1^-\nu_\tau \to h^-\pi^0\pi^0\nu_\tau$	10.8	–
hadronic 3-prong	–	14.6
$\tau^- \to \alpha_1^-\nu_\tau \to h^-h^+h^-\nu_\tau$	9.8	–
$\tau^- \to h^-h^+h^-\pi^0\nu_\tau$	4.8	–
Total	–	63.0
Other hadronic modes	–	1.7

b-tagging with Track Counting High Efficiency (TCHE) algo [3]:

- Maximises efficiency of finding b-jets
- Relies on tracks with large impact parameter
  - $d^{track} = L \sin\delta = \beta\gamma c\tau \sin\delta$
- Tracks ordered in decreasing d^{track} significance:
  - $S_{IP} = \frac{d^{track}}{\sigma_{d^{track}}}$
- Jet b-tagged if $S_{IP}^{2^{nd}\,\mathrm{Trk.}} > 1.7$
- For $p_T = 50 - 80\,\mathrm{GeV}/c$ tagging rate $\simeq 76\%$ (mis-tagging rate $\simeq 13\%$)
- Preferred due to small systematic uncertainties (compared to other options)

Typical b-jet



Official CMS MC production of simulated samples used:

- Centre-of-mass energy set to 7 TeV
- Detector response with GEANT package
- Samples normalised by their cross-section to $2.3\,\mathrm{fb}^{-1}$
- TAUOLA [4] package used to simulate τ-leptons decays ($H^{\pm}$, $W^{\pm}$)
- Simulated events weighted according to true pile-up
  - Flat distribution up to **10**, and Poisson with a mean of **20** interactions
  - Re-weight by true pile-up with **3*D*** matrix method (±1 out-of-time BC)
- JEC applied to account for UE, pile-up
- UE activity addressed by employing PYTHIA Tune Z2 [5]
- Difference in b-tagging efficiency accounted (tagging & mis-tagging scale factors)
- Difference in trigger efficiency accounted with scale factors (more later)

Best available option the single τ jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger:

- Low thresholds ⇒ gain efficiency
- QCD multi-jet suppression ($E_{\mathrm{T}}^{\mathrm{miss}}$ & τ jet isolation)
- Three different run ranges
- Total integrated luminosity of 2.3 fb^{-1} (Run 2011A)
- Efficiency measured separately for τ-part and $E_{\mathrm{T}}^{\mathrm{miss}}$- part (more later)

L1 seed	HLT path	Lumi ($\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$)
L1_SingleTauJet52 OR L1_SingleJet68	HLT_IsoPFTau35_Trk20_MET45	1×10^{33}
L1_SingleTauJet52 OR L1_SingleJet68	HLT_IsoPFTau35_Trk20_MET60	2×10^{33}
L1_Jet52_Central_ETM30	HLT_IsoPFTau35_Trk20_MET60†	2×10^{33}
L1_Jet52_Central_ETM30	HLT_MediumIsoPFTau35_Trk20_MET60†	3×10^{33}

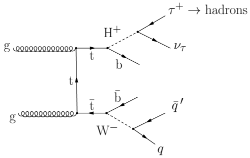
† HF included in HLT $E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction

- IsoPFtau ≡ Tight isolation
- MediumIsoPFtau ≡ ECAL isolation dropped (affected by pile-up)

Summary of event selection requirements:

1. Primary vertex selection
2. τ-jet identification:
   - $p_T > 40$ GeV/c , $|\eta| < 2.1$, $p_T^{\text{Ldg. Trk.}} > 20$ GeV/c
   - 1-prong decays
   - Tight isolation
   - $R_\tau = \frac{p^{\text{Ldg. Trk.}}}{p^{\tau\ \text{jet}}} > 0.7$ (τ polarisation)
3. Isolated $e^\pm/\mu^\pm$ veto:
   - $p_T > 15$ GeV/c , $|\eta| < 2.5$
4. ≥ 3 PF jets:
   - $p_T > 30$ GeV/c , $|\eta| < 2.4$
5. PF $E_T^{\text{miss}} > 50$ GeV
6. ≥ 1 b-tagged jets:
   - TCHE algorithm (high efficiency, low purity)
7. $\Delta\phi\left(\tau \text{ jet}, E_T^{\text{miss}}\right) < 160°$
8. Reconstruct $H^\pm$ transverse mass m_T (τ jet, E_T^{miss})

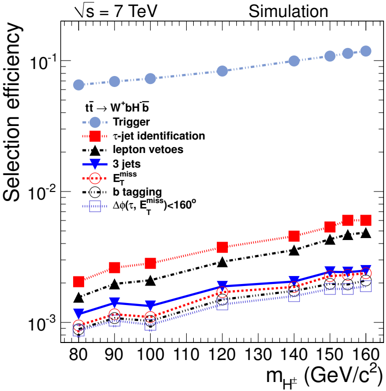
fully-hadronic final state



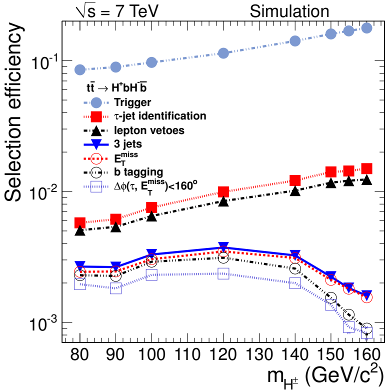
Cumulative signal selection efficiencies:

- $(0.9 - 2) \times 10^{-3}$ for *WH*; $(2 - 0.9) \times 10^{-3}$ for *HH*
- Trigger efficiency larger for *HH*:
  - Two τ-leptons in *HH* $\Rightarrow$ double probability to pass trigger
  - τ-jet isolation tight $\Rightarrow$ rare that 2 τ jets found (no veto)
- Sharp fall for *HH* at jet selection (b-jet phase-space)

$t\bar{t} \rightarrow bW^{\pm}bH^{\mp}$



$t\bar{t} \rightarrow bH^{\pm}bH^{\mp}$



τ-part of trigger efficiency:

- Measured separately for 3 run periods
- From $Z^0/\gamma^* \rightarrow \tau^\pm\tau^\mp$ events with Tag-and-Probe technique
  - single isolated μ trigger used
  - One $\tau^\pm \rightarrow \mu^\pm$ (tag)
  - Other $\tau^\pm \rightarrow$ hadrons (probe)
  - Z^0 mass constraint

Offline selections applied:

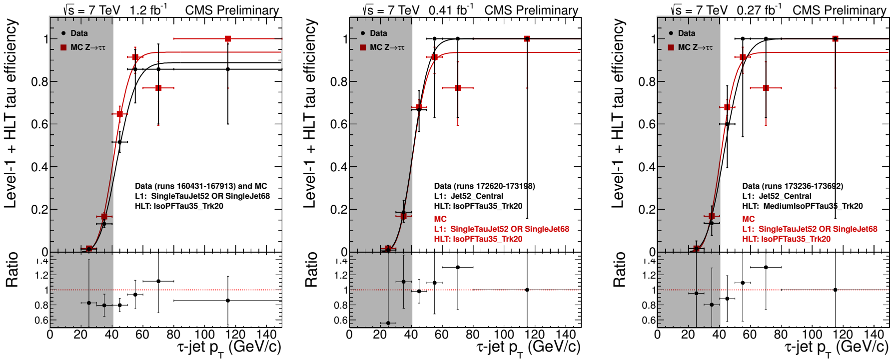
- Exactly 1 good muon
- Exactly 1 tightly isolated τ jet
- $m_\text{T}\left(\mu, E_\text{T}^\text{miss}\right) < 40\,\text{GeV}/c^2$ (Reject W + jets)
- $m_\text{vis}\left(\mu, \tau \text{ jet}\right) < 80\,\text{GeV}/c^2$ (Reject $Z^0/\gamma^* \rightarrow \mu^\pm\mu^\mp$)

Trigger scale factors used for:

- signal samples
- EWK+$t\bar{t}$ fake τ background measurement
- Largest backgrounds measured from data (little MC reliance)

Overall L1+HLT efficiency:

- $\varepsilon_{\mathrm{L1+HLT}} = \dfrac{N^{\mathrm{pass}}_{\mathrm{probes}}}{N^{\mathrm{pass}}_{\mathrm{probes}} + N^{\mathrm{fail}}_{\mathrm{probes}}}$



- Plateau around $p_{\mathrm{T}} \sim 60$ GeV/c
- Data/MC ratio used as MC scale factor (in bins of τ jet p_{T})
- Data weighted by luminosity
- Stat. uncertainty taken as trigger uncertainty (signal, EWK+$t\bar{t}$ fake τ)

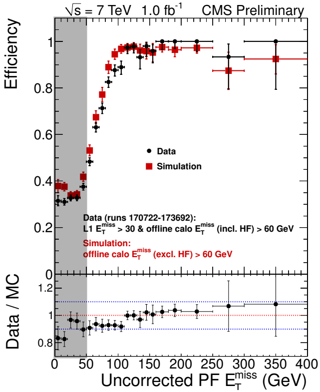
E_T^{miss}- part of trigger efficiency:

- Measured using calo E_T^{miss} ($\simeq$ HLT E_T^{miss})
- From single μ trigger data-sample

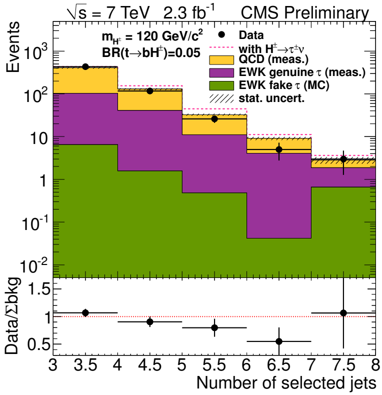
Offline selections applied:

- Signal-like topology
- Exactly 1 τ jet-like muon
- Veto on isolated $e^{\pm}/\mu^{\pm}$
- $\geq$ 3 jets ($\geq$ 1b-jets)

- Data-MC within 10% (no scale factor)
- 10% systematic uncertainty added

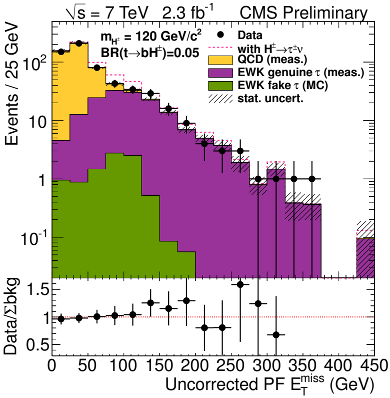


After τ-jet ID, lepton veto, ≥ 3 jets



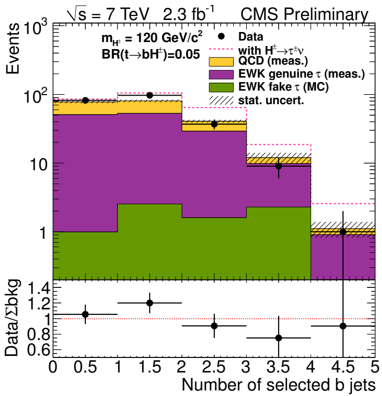
- First 2 bins dominant
- Dominant bins within uncertainty

After τ-jet ID, lepton veto, ≥ 3 jets

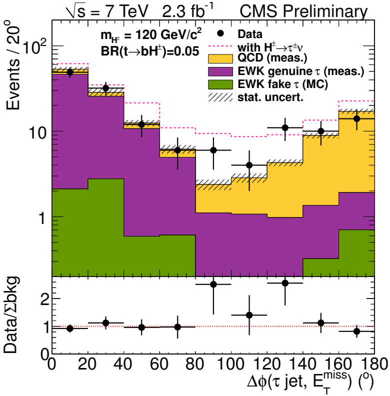


- Transitional region around 90 GeV
- Major backgrounds described well
- $E_T^{miss} > 50$ GeV suppresses QCD

After τ-jet ID, lepton veto, ≥ 3 jets, $E_{\mathrm{T}}^{\mathrm{miss}}$



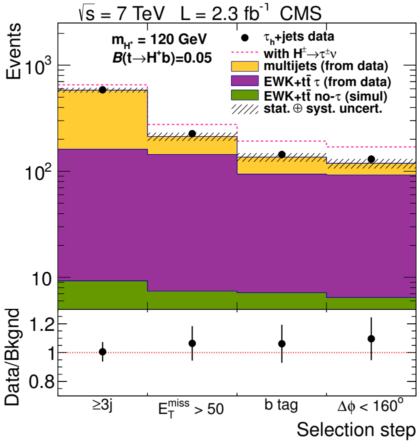
After all selections



- Small excess for 1 b-tagged jet
- Good agreement overall

- b-tagging excess carried over
- QCD "prefers" back-to-back
- Use as QCD-cleaning cut

After each selection step



Event yield after all selections

Process	Events	Stat.	Syst.
$H^{\pm}H^{\mp} + H^{\pm}W^{\mp}$	51	± 4	± 8
QCD multi-jet	26	± 2	± 1
EWK+$t\bar{t}$ genuine τ	78	± 3	± 11
$Z^0/\gamma^* \rightarrow \tau^{\pm}\tau^{\mp}$	7.0	± 2.0	± 2.1
$W^{\pm}W^{\mp} \rightarrow \tau^{\pm}\nu_{\tau}\tau^{\mp}\nu_{\tau}$	0.35	± 0.23	± 0.09
EWK+$t\bar{t}$ fake τ	6.0	± 3.0	± 1.2
Expected from SM	119	± 5	± 12
Observed in data	130		

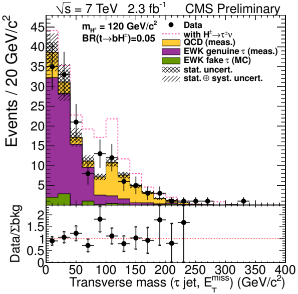
- QCD multi-jet largely suppressed
- EWK+$t\bar{t}$ τ largely irreducible
- EWK+$t\bar{t}$ no-τ negligible

- $m_{H^{\pm}} = 120\,\mathrm{GeV}/c^2$
- $\mathrm{BR}(t \rightarrow bH^{\pm}) = 0.05$
- Event yields within uncertainty

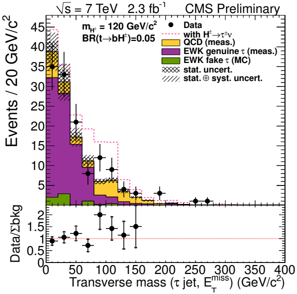
Source	$H^{\pm}H^{\mp}$	$W^{\mp}H^{\pm}$	QCD multi-jet	EWK+$t\bar{t}$ genuine τ			EWK+$t\bar{t}$ fake τ		
				Emb. data	$Z^0/\gamma^* \to \tau^{\pm}\tau^{\mp}$	$W^{\pm}W^{\mp} \to \tau^{\pm}\nu_{\tau}\tau^{\mp}\nu_{\tau}$	$t\bar{t}$	tW	W+jets
single τ jet + E_T^{miss} trigger	12–13	13	–	11	12	11	12	11	14
τ-jet id (excl. R_{τ})	6.0	6.0	–	6.0	6.0	6.0	–	–	–
jet, $\ell \to \tau$ mis-id	–	–	–	–	–	–	15	15	15
JES+E_T^{miss} +R_{τ}	4.7–14	9.0–18	–	6.6	26	23	8.1	2.4	$<$10
isolated lepton veto	0.3–0.5	0.5–0.7	–	–	0.9	1.2	0.9	0.6	0.3
b-tagging	1.1–2.1	1.0–1.7	–	–	–	–	1.4	1.6	–
jet$\to$b mis-id	–	–	–	–	2.0	2.6	–	–	4.8
QCD statistical	–	–	6.5	–	–	–	–	–	–
QCD systematic	–	–	3.8	–	–	–	–	–	–
EWK+$t\bar{t}$ τ statistical	–	–	–	3.4	–	–	–	–	–
f_{QCD}	–	–	–	0.3	–	–	–	–	–
$f_{W^{\pm}\to\tau^{\pm}\nu_{\tau}\to\mu^{\pm}\nu_{\mu}\nu_{\tau}\nu_{\tau}}$	–	–	–	0.7	0.1	0.1	–	–	–
muon selections, ϵ_{sel}^{μ}	–	–	–	0.5	0.1	0.1	–	–	–
pile-up	0.3–4.2	0.6–5.2	–	–	7.6	3.9	7.1	15	10
MC stat	6.2–11	7.0–10	–	–	29	66	28	49	71
cross-section	$^{+7.0}_{-9.6}$	$^{+7.0}_{-9.6}$	–	–	–	–	$^{+7.0}_{-9.6}$	8.0	5.0
luminosity	2.2	2.2	–	–	2.2	2.2	2.2	2.2	2.2

m_T distributions

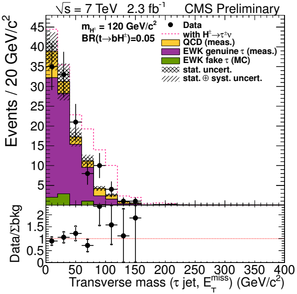
without $\Delta\phi$ cut



$\Delta\phi < 160°$



$\Delta\phi < 130°$

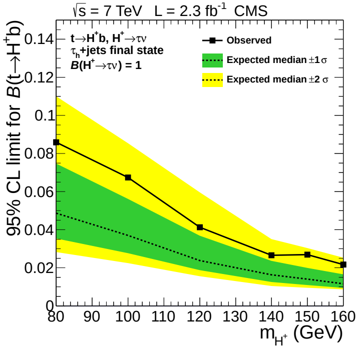


- EWK+$t\bar{t}$ genuine τ background is separable (largely irreducible)
- QCD multi-jet "sits" in signal region (reducible & controlled with $\Delta\phi$)
- EWK+$t\bar{t}$ fake τ is negligible
- Small excess around $80 < m_T < 100\,\mathrm{GeV}/c^2$
- Remaining bins within uncertainty
- $\Delta\phi < 160°$ option chosen (measurable QCD, smaller uncertainties)
- Used in a CLs binned maximum likelihood ratio fit to extract limits

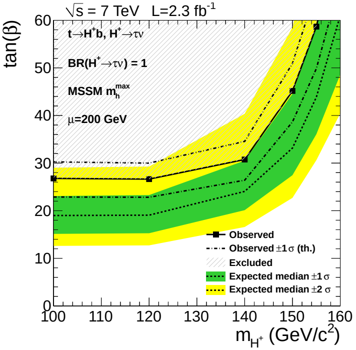
Limits obtained for mass range $80\,\text{GeV}/c^2 \leq m_{H^\pm} \leq 160\,\text{GeV}/c^2$:

- Modified frequentist method with profile likelihood ratio test-statistic
- Upper limits on $\text{BR}(t \to bH^\pm)$ assuming $\text{BR}(H^\pm \to \tau^\pm \nu_\tau) = 1$:
  - expected: $1.5 - 5.2\%$ (sensitivity)
  - observed: $2.2 - 7.3\%$
- Excluded significant region in $(\tan\beta, m_{H^\pm})$ plane of MSSM m_h^{max} scenario

Model-Independent



$(\tan\beta, m_{H^\pm})$ plane



Searched for light $H^{\pm}$ in $t \to bH^{\pm}$ decays:

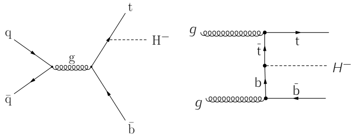
- $H^{\pm} \to \tau^{\pm}\nu_{\tau}$ and $\tau^{\pm} \to$ hadrons ν_{τ} decays
- Analysed $2.3\,\text{fb}^{-1}$ CMS-recorded data (Run 2011A)
- Major backgrounds measured from data
- m_{T} employed in CLs binned maximum likelihood ratio fit
- Upper limits $\text{BR}(t \to bH^{\pm})$
- Excluded significant region in $(\tan\beta, m_{H^{\pm}})$

Outlook for light $H^{\pm}$:

- Current analysis not entirely systematics-limited
- Re-commission bkg measurements & improve
- Clean further signal region
- Improve systematics (Trigger & JES better with full 2011)
- Aim for Moriond 2013 (2011 + 2012 data)

First results for heavy $H^{\pm}$ ($H^{\pm} \to \tau^{\pm}\nu_{\tau}$):

- Final state identical to light $H^{\pm}$
- Main backgrounds the same
- Aim for Moriond 2013 (2011 + 2012 data)



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[6] M. E. Cabrera, J. A. Casas, and A. Delgado, "Upper Bounds on Superpartner Masses from Upper Bounds on the Higgs Boson Mass", *Phys. Rev. Lett.* **108** (Jan, 2012) 021802. doi:10.1103/PhysRevLett.108.021802.

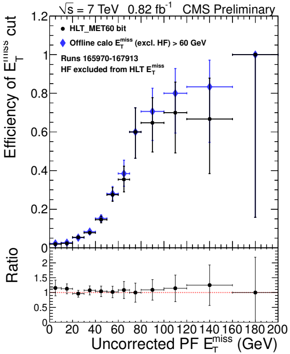
[7] S. Heinemeyer, O. Stal, and G. Weiglein, "Interpreting the LHC Higgs Search Results in the MSSM", *Phys.Lett.* **B710** (2012) 201–206, arXiv:1112.3026. doi:10.1016/j.physletb.2012.02.084.

- Calo $E_{\mathrm{T}}^{\mathrm{miss}} \simeq$ HLT $E_{\mathrm{T}}^{\mathrm{miss}}$
- Implications of SM Higgs with $m_{h^0} = 125\,\mathrm{GeV}/c^2$
- R_τ variable

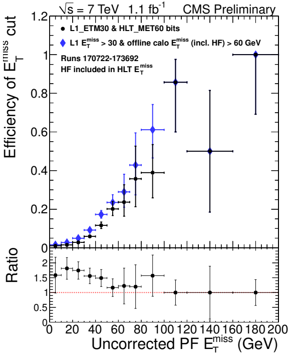
Establish that Calo $E_T^{miss} \simeq$ HLT E_T^{miss}:

- Select datasets using single τ jet trigger (τ-part of signal)
- Apply signal-like selection requirements:
  - ≥ 3 jets, ≥ 1b-jets, isolated e/μ veto
- Apply HLT E_T^{miss} (require events to pass single τ jet + E_T^{miss} trigger)
- Efficiencies measured as a function of uncorrected PF E_T^{miss}
- Good agreement between calo and HLT E_T^{miss} objects (PF $E_T^{miss} > 50$ GeV)

HF excluded



HF included



At tree-level, Higgs-related parameters determined by:

- $\tan\beta$ and m_{A^0}

At loop-level:

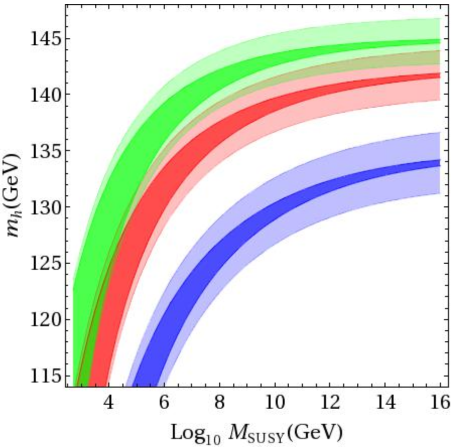
- Soft SUSY-breaking 3rd generation squark mass M_{SUSY}
- Stop mixing parameter X_t

Can get $m_{h^0} \simeq 125\,\mathrm{GeV}/c^2$ for all scenarios with some degree of mixing

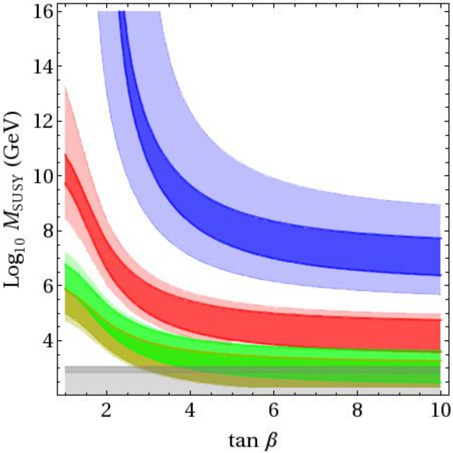
Parameter	no-mixing $m_{\mathrm{h}}^{\mathrm{no-mix}}$	maximal-mixing $m_{\mathrm{h}}^{\mathrm{max}}$
M_{SUSY}	2 TeV	1 TeV
X_t	0	$2M_{\mathrm{SUSY}}$
μ	+200 GeV	+200 GeV
$m_{\tilde{g}}$	1.6 TeV	$0.8M_{\mathrm{SUSY}}$
M_2	200 GeV	+200 GeV

Upper bounds on Superpartner masses from upper bounds on m_{h^0} [6]

$\tan\beta = 10$, 3 , 1

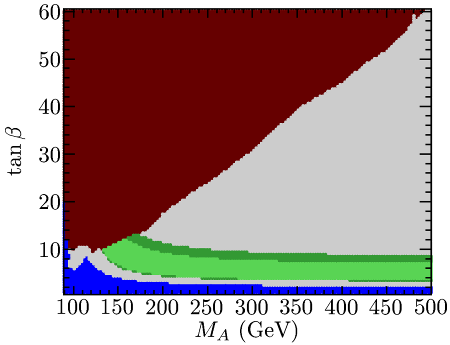


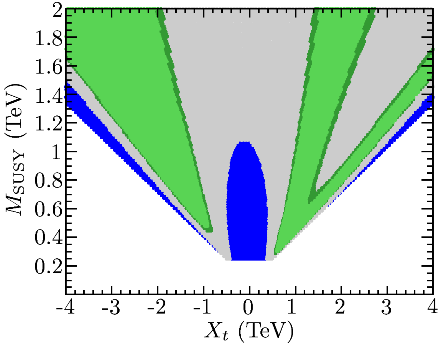
$m_{h^0} = 115$, 120 , 130 , 140



Interpreting the LHC Higgs Search Results in the MSSM [7]

LEP , Tevatron , prior to LHC resuts , m_{h^0}-compatible



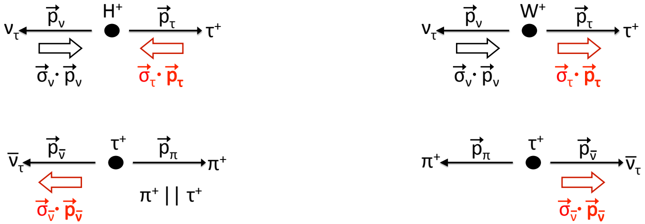


$\mathrm{BR}(\tau^{\pm} \rightarrow \text{hadrons } \nu_\tau) \sim 64\%$:

Process	$\Gamma_i/\Gamma_{\text{total}}(\%)$	$\sum_i \Gamma_i/\Gamma_{\text{total}}(\%)$
hadronic 1-prong (excl. K^0's)	–	48.1
$\tau^- \rightarrow h^- \nu_\tau$	11.6	–
$\tau^- \rightarrow \rho^- \nu_\tau \rightarrow h^- \pi^0 \nu_\tau$	26.0	–
$\tau^- \rightarrow \alpha_1^- \nu_\tau \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	9.3	–
$\tau \rightarrow h^- \nu_\tau + \geq 3\pi^0$	1.3	–
hadronic 3-prong (excl. K^0's)	–	14.6

τ helicity correlations:

- $H^{\pm}$ scalar with $J_{H^{\pm}} = 0$ ($W^{\pm}$ vector with $J_{W^{\pm}} = 1$)
- Neutrino (anti-neutrino) is left-handed (right-handed)
- τ-lepton in $H^+ \rightarrow \tau^+ \nu_\tau$ ($W^+ \rightarrow \tau^+ \nu_\tau$) left-handed (right-handed)
- More energetic Ldg. Ch. particle in $H^+ \rightarrow \tau^+ \nu_\tau$ decay



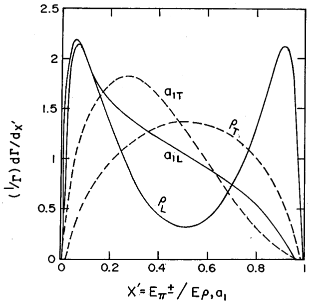
Differential decay width of τ-leptons decaying to $\pi^\pm$ or $v = \rho^\pm, \alpha_1^\pm$:

$$\frac{1}{\Gamma_\pi}\frac{d\Gamma_\pi}{d\cos\theta} = \frac{1}{2}(1 + P_\tau \cos\theta)$$

$$\frac{1}{\Gamma_v}\frac{d\Gamma_{v,\ L}}{d\cos\theta} = \frac{\frac{1}{2}m_\tau^2}{m_\tau^2 + 2m_v^2}(1 + P_\tau \cos\theta)$$

$$\frac{1}{\Gamma_v}\frac{d\Gamma_{v,\ T}}{d\cos\theta} = \frac{\frac{1}{2}m_v^2}{m_\tau^2 + 2m_v^2}(1 - P_\tau \cos\theta)$$

$$P_\tau^{H^\pm} = +1 \quad , \quad P_\tau^{W^\pm} = -1$$



- θ is angle between π and τ-lepton (τ-lepton's rest frame)
- L-polarisation states: Harder τ jets in $H^\pm$ decays
- T-polarisation states: Harder τ jets in $W^\pm$ decays (dilution of effect)

Define $R_\tau = \frac{p^{\text{Ldg. Trk.}}}{p^{\tau\ \text{jet}}}$:

- $R_\tau \gtrsim 0.8$ and $R_\tau \lesssim 0.2$ retain $\sim 50\%$ of the $\rho_L^\pm$ and $\pi^\pm$, but little of $\rho_T^\pm$
- $\Rightarrow$ Enhance $H^\pm \to \tau^\pm \nu_\tau$ decays