

thFCNC, CMS

The top-charm frontier at the LHC
Workshop

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January 15, 2014



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Multilepton Results for 3 Leptons (4L: see documentation)



| Selection | | E_T^{miss} | $N(\tau_h)=0, N_{b\text{-jets}}=0$ | | $N(\tau_h)=1, N_{b\text{-jets}}=0$ | | $N(\tau_h)=0, N_{b\text{-jets}}\geq 1$ | | $N(\tau_h)=1, N_{b\text{-jets}}\geq 1$ | | |
|------------------|-------------|---------------------|------------------------------------|------|------------------------------------|-----|--|-----|--|-----|--------------|
| 3 Lepton Results | | | obs | exp | obs | exp | obs | exp | obs | exp | |
| OSSF0 | $H_T > 200$ | NA | (100, ∞) | 5 | 3.7 ± 1.6 | 35 | 33 ± 14 | 1 | 5.5 ± 2.2 | 47 | 61 ± 30 |
| OSSF0 | $H_T > 200$ | NA | (50,100) | 3 | 3.5 ± 1.4 | 34 | 36 ± 16 | 8 | 7.7 ± 2.7 | 82 | 91 ± 46 |
| OSSF0 | $H_T > 200$ | NA | (0,50) | 4 | 2.1 ± 0.8 | 25 | 25 ± 9.7 | 1 | 3.6 ± 1.5 | 52 | 59 ± 29 |
| OSSF1 | $H_T > 200$ | above-Z | (100, ∞) | 5 | 3.6 ± 1.2 | 2 | 10 ± 4.8 | 3 | 4.7 ± 1.6 | 19 | 22 ± 11 |
| OSSF1 | $H_T > 200$ | below-Z | (100, ∞) | 7 | 9.7 ± 3.3 | 18 | 14 ± 6.4 | 8 | 9.1 ± 3.4 | 21 | 23 ± 11 |
| OSSF1 | $H_T > 200$ | on-Z | (100, ∞) | 39 | 61 ± 23 | 17 | 15 ± 4.9 | 9 | 14 ± 4.4 | 10 | 12 ± 5.8 |
| OSSF1 | $H_T > 200$ | above-Z | (50,100) | 4 | 5 ± 1.6 | 14 | 11 ± 5.2 | 6 | 6.8 ± 2.4 | 32 | 30 ± 15 |
| OSSF1 | $H_T > 200$ | below-Z | (50,100) | 10 | 11 ± 3.8 | 24 | 19 ± 6.4 | 10 | 9.9 ± 3.7 | 25 | 32 ± 16 |
| OSSF1 | $H_T > 200$ | on-Z | (50,100) | 78 | 80 ± 32 | 70 | 50 ± 11 | 22 | 22 ± 6.3 | 36 | 24 ± 9.8 |
| OSSF1 | $H_T > 200$ | above-Z | (0,50) | 3 | 7.3 ± 2 | 41 | 33 ± 8.7 | 4 | 5.3 ± 1.5 | 15 | 23 ± 11 |
| OSSF1 | $H_T > 200$ | below-Z | (0,50) | 26 | 25 ± 6.8 | 110 | 86 ± 23 | 5 | 10 ± 2.5 | 24 | 26 ± 11 |
| OSSF1 | $H_T > 200$ | on-Z | (0,50) | *135 | 127 ± 41 | 542 | 543 ± 159 | 31 | 32 ± 6.5 | 86 | 75 ± 19 |

| Selection | | E_T^{miss} | $N(\tau_h)=0, N_{b\text{-jets}}=0$ | | $N(\tau_h)=1, N_{b\text{-jets}}=0$ | | $N(\tau_h)=0, N_{b\text{-jets}}\geq 1$ | | $N(\tau_h)=1, N_{b\text{-jets}}\geq 1$ | | |
|------------------|-------------|---------------------|------------------------------------|-------|------------------------------------|--------|--|------|--|-----|---------------|
| 3 Lepton Results | | | obs | exp | obs | exp | obs | exp | obs | exp | |
| OSSF0 | $H_T < 200$ | NA | (100, ∞) | 7 | 11 ± 4.9 | 101 | 111 ± 54 | 13 | 10 ± 5.3 | 87 | 119 ± 61 |
| OSSF0 | $H_T < 200$ | NA | (50,100) | 35 | 38 ± 15 | 406 | 402 ± 152 | 29 | 26 ± 13 | 269 | 298 ± 151 |
| OSSF0 | $H_T < 200$ | NA | (0,50) | 53 | 51 ± 11 | 910 | 1035 ± 255 | 29 | 23 ± 10 | 237 | 240 ± 113 |
| OSSF1 | $H_T < 200$ | above-Z | (100, ∞) | 18 | 13 ± 3.5 | 25 | 38 ± 18 | 10 | 6.5 ± 2.9 | 24 | 35 ± 18 |
| OSSF1 | $H_T < 200$ | below-Z | (100, ∞) | 21 | 24 ± 9 | 41 | 50 ± 25 | 14 | 20 ± 10 | 42 | 54 ± 28 |
| OSSF1 | $H_T < 200$ | on-Z | (100, ∞) | 150 | 152 ± 26 | 39 | 48 ± 13 | 15 | 14 ± 4.8 | 19 | 23 ± 11 |
| OSSF1 | $H_T < 200$ | above-Z | (50,100) | 50 | 46 ± 9.7 | 169 | 139 ± 48 | 20 | 18 ± 8 | 85 | 93 ± 47 |
| OSSF1 | $H_T < 200$ | below-Z | (50,100) | 142 | 125 ± 27 | 353 | 355 ± 92 | 48 | 48 ± 23 | 140 | 133 ± 68 |
| OSSF1 | $H_T < 200$ | on-Z | (50,100) | *773 | 777 ± 116 | 1276 | 1154 ± 306 | 56 | 47 ± 13 | 81 | 75 ± 32 |
| OSSF1 | $H_T < 200$ | above-Z | (0,50) | 178 | 196 ± 35 | 1676 | 1882 ± 540 | 17 | 18 ± 6.7 | 115 | 94 ± 42 |
| OSSF1 | $H_T < 200$ | below-Z | (0,50) | 510 | 547 ± 87 | 9939 | 8980 ± 2660 | 34 | 42 ± 11 | 226 | 228 ± 63 |
| OSSF1 | $H_T < 200$ | on-Z | (0,50) | *3869 | 4105 ± 666 | *50188 | 50162 ± 14984 | *148 | 156 ± 24 | 906 | 925 ± 263 |

t → cH Result

- ▶ For pp → ttbar → (bW)(cH) → multileptons:

| Higgs Decay Mode | obs | exp | 1σ range |
|--|--------|--------|---------------|
| $h \rightarrow WW^*$ (BR = 23.1 %) | 1.58 % | 1.57 % | (1.02–2.22) % |
| $h \rightarrow \tau\tau$ (BR = 6.15 %) | 7.01 % | 4.99 % | (3.53–7.74) % |
| $h \rightarrow ZZ^*$ (BR = 2.89 %) | 5.31 % | 4.11 % | (2.85–6.45) % |
| combined | 1.28 % | 1.17 % | (0.85–1.73) % |

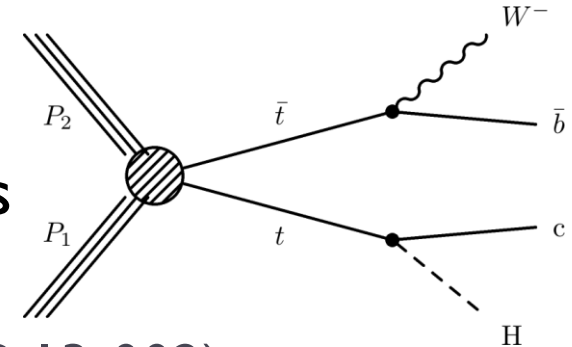
- ▶ $\lambda_{tch} = \sqrt{|\lambda_{tc}^h|^2 + |\lambda_{ct}^h|^2} < 0.21 \quad \sim 2 \text{ sqrt}(\text{BR})$



Summary slides

Introduction

- ▶ $t \rightarrow cH$ is FCNC, negligible in SM
- ▶ Observation would indicate new physics
- ▶ Investigated $pp \rightarrow t\bar{t} \rightarrow (bW)(cH)$
 - ▶ Use CMS inclusive multilepton search (SUS-13-002) to pursue Higgs $\rightarrow WW, ZZ, \tau\tau$ – e.g. $t\bar{t} \rightarrow (bW)(cH) \rightarrow bcWW$
 - ▶ We assume SM Higgs branching ratios
- ▶ References
 - ▶ N. Craig et al., “Searching for $t \rightarrow ch$ with multileptons”, doi:10.1103/PhysRevD.86.075002
 - ▶ K.-F. Chen, W.-S. Hou, C. Kao, and M. Kohda, “When the Higgs meets the Top: Search for $t \rightarrow ch^0$ at the LHC”, arXiv:1304.8037



Event Selection

- ▶ Using 19.5/fb (2012 CMS dataset at 8 TeV)
 - ▶ Dilepton triggers
- ▶ Selections:
 - ▶ e, mu: $p_T > 10 \text{ GeV}$, $|\eta| < 2.4$
 - ▶ tau: visible $p_T > 20 \text{ GeV}$, $|\eta| < 2.3$
 - ▶ jet: $p_T > 30 \text{ GeV}$, $|\eta| < 2.5$
- ▶ Light lepton p_T must pass 20/10/10 GeV threshold (for first, second, third lepton)
- ▶ Combined Secondary Vertex (Medium) b-tag

Event Classification

- ▶ **General idea: use bins instead of cuts, and pick sensitive bins for interpretation (model-dependent)**
 - ▶ Take advantage of the power of cuts (high S/B), but still make use of the rest of the data
- ▶ **Bin in the number of leptons (e/μ vs. τ_{had})**
- ▶ **Bin in whether there is an opposite-sign same-flavor (OSSF) lepton pair or not**
- ▶ **For events with an OSSF pair, bin in dilepton mass (below Z , on Z , above Z ; Z window: 30 GeV)**
- ▶ **Bin in whether there is a b-tag or not**
- ▶ **Bin in MET, with lower edges 0, 50, 100, 150, 200 GeV**
- ▶ **Bin in H_T (below/above 200 GeV)**

Most Sensitive $t \rightarrow cH$ Signal Regions



- ▶ The signal yields are for nominal $\text{BR}(t \rightarrow cH) = 1\%$

| OSSF pair | $N_{\tau_{\text{had}}}$ | E_T^{miss} [GeV] | H_T [GeV] | $N_{b\text{-jets}}$ | data | background | signal |
|-----------|-------------------------|---------------------------|-------------|---------------------|------|---------------|----------------|
| below Z | 0 | 50–100 | 0–200 | ≥ 1 | 48 | 48 ± 23 | 9.5 ± 2.3 |
| n/a | 0 | 50–100 | 0–200 | ≥ 1 | 29 | 26 ± 13 | 5.9 ± 1.3 |
| below Z | 0 | 0–50 | 0–200 | ≥ 1 | 34 | 42 ± 11 | 5.9 ± 1.2 |
| n/a | 0 | 0–50 | 0–200 | ≥ 1 | 29 | 23 ± 10 | 4.3 ± 1.1 |
| below Z | 0 | 50–100 | > 200 | ≥ 1 | 10 | 9.9 ± 3.7 | 3.0 ± 1.1 |
| below Z | 0 | 0–50 | > 200 | ≥ 1 | 5 | 10 ± 2.5 | 2.8 ± 0.8 |
| below Z | 0 | 50–100 | 0–200 | 0 | 142 | 125 ± 27 | 9.7 ± 2.1 |
| n/a | 1 | 0–50 | 0–200 | ≥ 1 | 237 | 240 ± 113 | 13.1 ± 2.6 |
| n/a | 0 | 50–100 | 0–200 | 0 | 35 | 38 ± 15 | 4.3 ± 1.1 |
| above Z | 0 | 0–50 | 0–200 | ≥ 1 | 17 | 18 ± 6.7 | 2.8 ± 0.8 |

- ▶ Example efficiency in the first channel

- ▶ $\text{BR}(H \rightarrow WW) \cdot \text{BR}(W \rightarrow e/\mu + \nu)^3 \cdot \text{eff}_{\text{lep}}^3 \cdot \text{eff}_{\text{btag}} \cdot \text{frac}(\text{OSSF, below Z, MET, HT})$
 $= 23.1\% \cdot (20\%)^3 \cdot (75\%)^3 \cdot 70\% \cdot 2/3 \cdot \text{frac}(\text{below Z, MET, HT})$
 $\approx 10 \cdot 10^{-5} \cdot \text{frac}(\text{below Z, MET, HT})$
 ... where $\text{frac}(\text{below Z, MET, HT}) \approx 0.3$