Searching for a charged Higgs bosons in *pp* collisions with the CMS detector

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Seminários do LIP

Outline

Theoretical setup and search strategy

Accelerator and detector

Reconstruction of objects

Searching for a charged Higgs
- Light charged Higgs - $tan\beta < 1$
- Light charged Higgs - $tan\beta > 1$

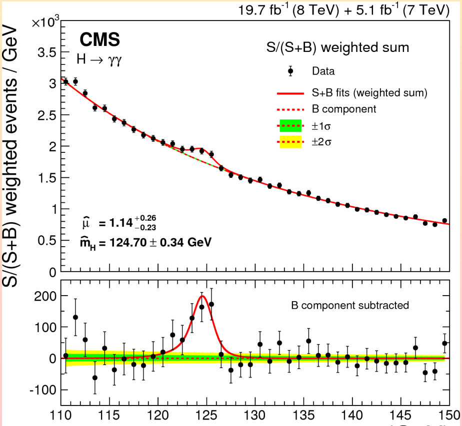
Heavy charged Higgs

Conclusions and outlook

References

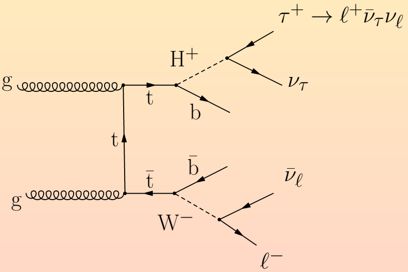
Theoretical setup
and search strategy

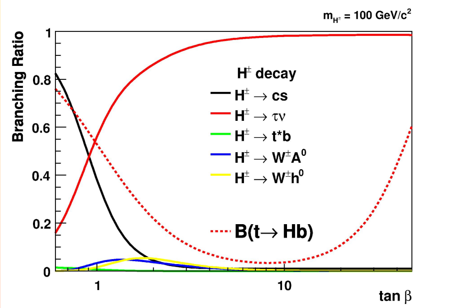
- An Higgs boson compatible with the SM one has been found at the LHC
  it might not be the only one!
- Multi-Higgs models might explain experimental observations
  - **Baryon asymmetry:** explicit and spontaneous CP violation.
  - **Dark matter:** dark matter candidates from doublets w/out a VEV
  - **Neutrino oscillations:** masses generated at $\geq$ 1 loop
- MSSM is the minimal extension: h, H, A, H^+, H^-
  - One characteristic parameter: $tan\beta$ (ratio of VeVs of neutral Higgses)
  - After $h(125)$, Higgs sector can be described using only $m_{H^\pm}$ and $tan\beta$
  - No prediction $\rightarrow$ need to scan full parameter phase space



Searching for charged Higgs using top quarks - I

- $H^{\pm}$ can be produced after top quark decays if $M_{H^{\pm}} < M_t - M_b$
- $t\bar{t}$cross section $\sim$ 165 pb at 7 TeV
- Tau or charmed final states expected depending on $tan\beta$



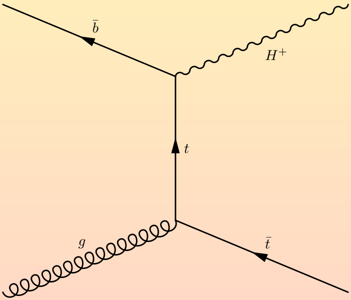


(from `D0 Note 5715-CONF`)

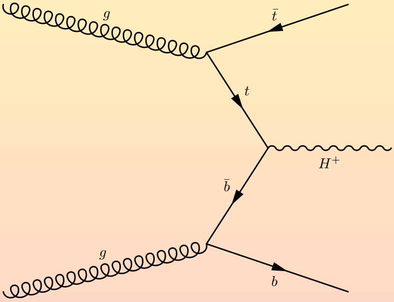
Searching for charged Higgs using top quarks - II

- $H^{\pm}$ can be produced in association with top quarks if $M_{H^{\pm}} > M_t - M_b$

4FS similar to ttH production

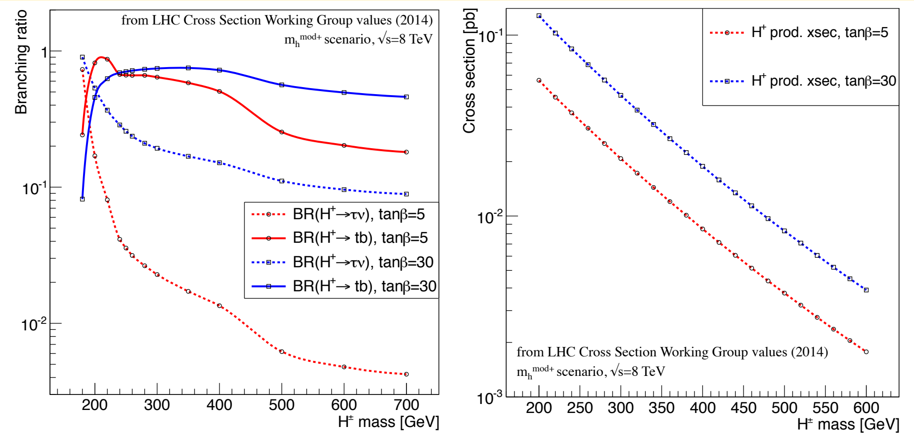


5FS dominates (similar to tW production)



Searching for charged Higgs using top quarks - III

- m_h^{mod+} used as a reference scenario
- $\mathcal{B}$ and σ values from LHC XS Working Group
  - Santander Matching is used to combine 4(5) flavour schemes



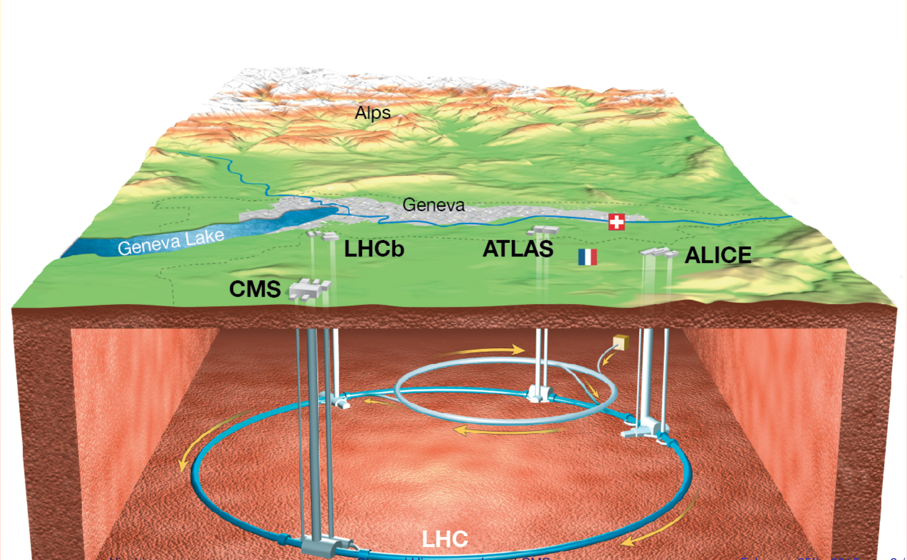
(Plots from [3])

General strategy for searching for $H^{\pm}$ at the LHC

<table>
<tr><th>$M_{H^{\pm}} < M_t - M_b$</th><th>$M_{H^{\pm}} > M_t - M_b$</th></tr>
<tr><td>Assume $\mathcal{B}(H^{\pm} \to \tau\nu_{\tau}) = 1$</td><td>$\mathcal{B}(H^{\pm} \to tb)$ dominant in MSSM
$\mathcal{B}(H^{\pm} \to \tau\nu_{\tau})$ still explorable</td></tr>
<tr><td>Contributions from:
$pp \to HbHb$
$pp \to HbWb$</td><td>Associated production:
$X \to H^{\pm}t$
$X \to H^{\pm}tb$</td></tr>
<tr><td colspan="2">Leptonic tau decays ⇒ dilepton ($e\mu$) final state
Hadronic tau decays ⇒ $\ell\tau_h$, all-hadronic final states</td></tr>
<tr><td>7 TeV, 8 TeV:
CMS-PAS-HIG-12-052 [2]</td><td>8 TeV:
CMS-PAS-HIG-13-026 [3]</td></tr>
<tr><td colspan="2">CMS-PAS-HIG-14-020 [4]</td></tr>
<tr><td>$c\bar{s}$: CMS-PAS-HIG-13-035 [5]</td><td></td></tr>
</table>

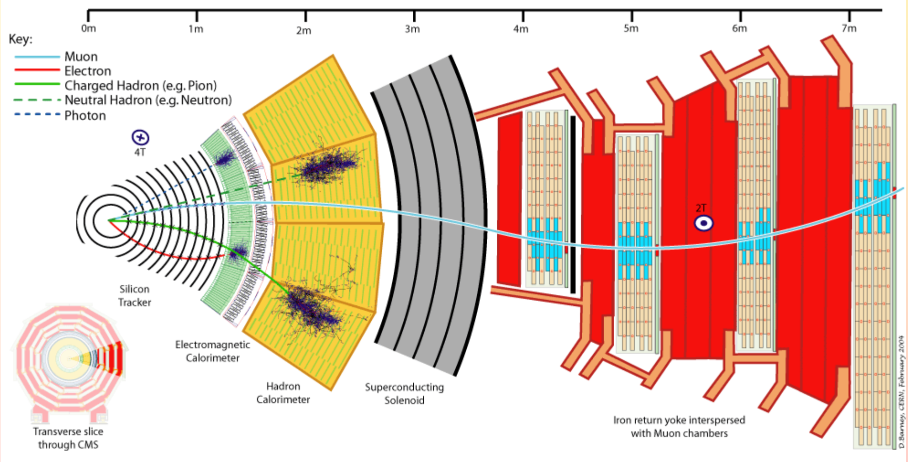
LHC - Large Hardon Collider

- Design center-of-mass energy: 14 TeV
- 5 fb^{-1} at 7 TeV (2011) and 20 fb^{-1} at 8 TeV(2012). Run at 13 TeV about to start



CMS - Compact Muon Solenoid

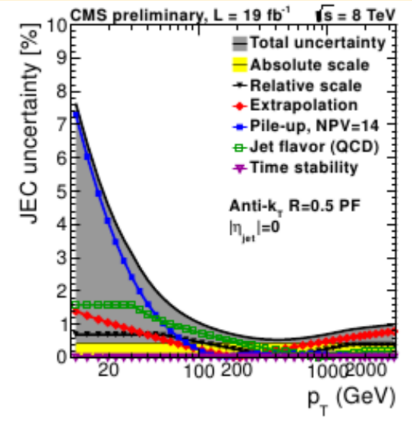
- General purpose detector
- 3.8 Tesla magnet enables excellent track momentum measurements
- 21.5 m long, 15 m diameter, lots of metal

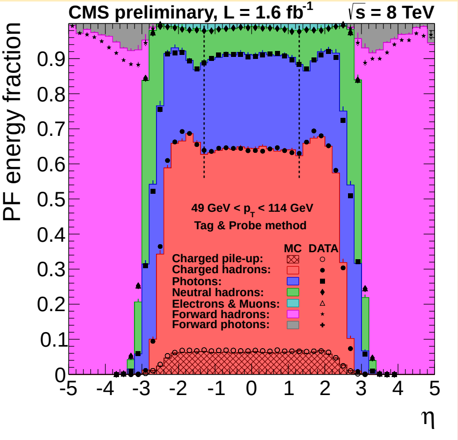


Reconstruction of physics objects at CMS

Reconstruction of physics objects / I

- **Particle flow:** makes the best use of the detector
- Link calorimeter energy clusters with tracks
- Identify PF candidates as e, γ, μ, charged/neutral hadrons
- Simulation describes accurately observed composition
- Gain in jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ energy resolution
- Optimal for tau reconstruction (next slide)

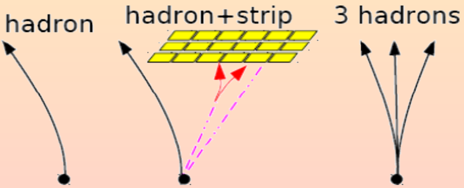


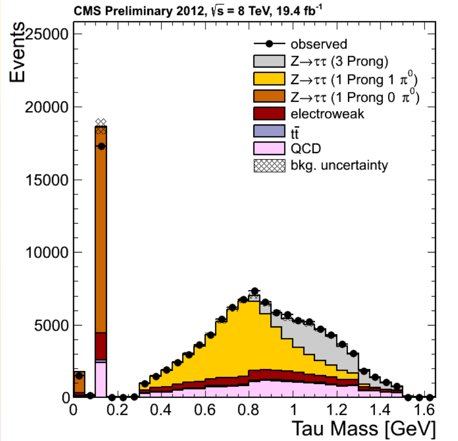


(Plots from [12] and [11])

Reconstruction of physics objects: hadronic τ

- **Tau decay:**
  - to light leptons (e,μ) and 2 neutrinos: $Br \sim 35\%$
  - to hadrons and one neutrino: $Br \sim 65\%$.
- Identification algorithm: `Hadron+Strips (HPS)`
- Decay mode finding discriminator (mass constraints on constituents)
- Many isolation working points for the cuts on particles in isolation code
- $e(\mu)$ rejection: low compatibility of leading $had^{\pm}$ with $e(\mu)$ hypothesis

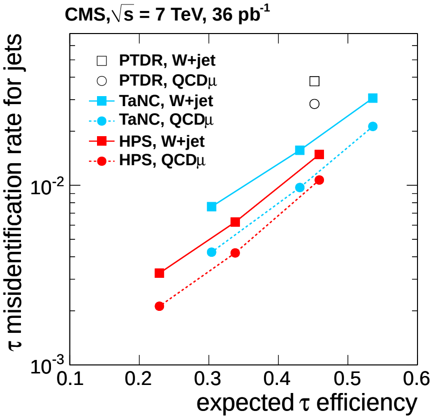


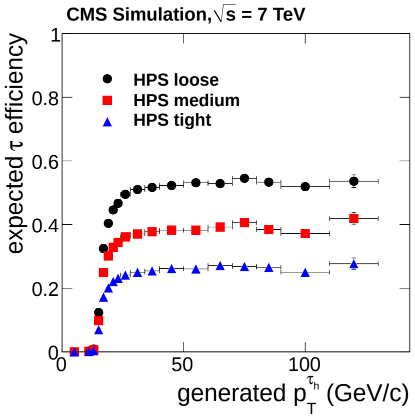


(Plots from [13])

Hadronic τ identification performance

- Taus can be faked from:
  - Jets: measure in data from multijet events (gluon enriched), W/Z+jets and $b\bar{b}$ (quark enriched)
  - Charged leptons: measure in data from $Z \to \ell\ell$ events
- Efficiency can be measured in situ from $Z \to \tau\tau \to \mu\tau_h$ events

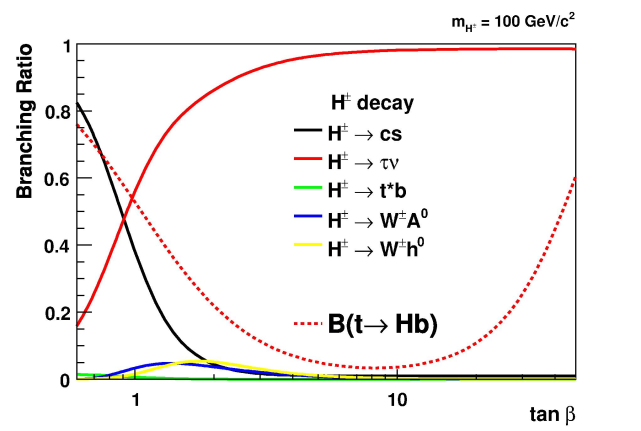




From JINST, 7 (2012) P01001 [8]

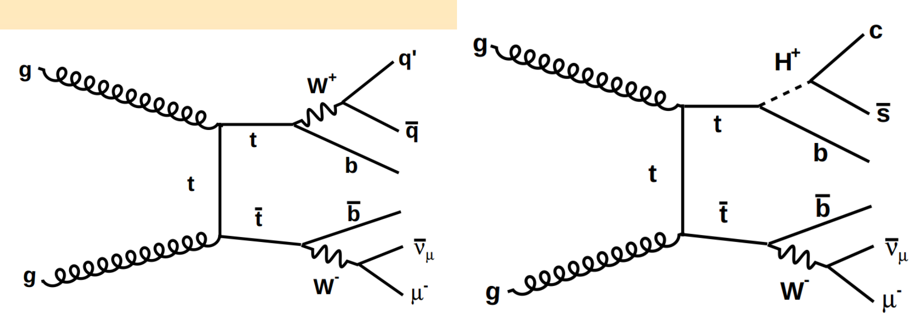
Searching for a light $H^{\pm}$

$tan\beta < 1$: search with $c\bar{s}$ final states
$tan\beta > 1$: search with $\tau\nu_{\tau}$ final states



(from D0 Note 5715-CONF)

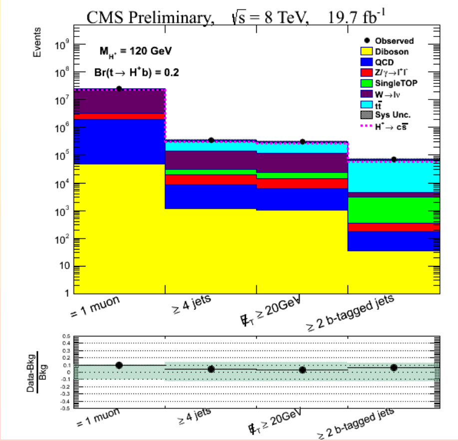
Searching for a light $H^{\pm}$ when $tan\beta < 1$



(Plots from [5])

Lepton + jets channel selection

- **Trigger: single muon trigger**
  - Muon $p_T > 24$ GeV, $|\eta| < 2.1$
  - Integrated luminosity: $19.7 \pm 0.5\ fb^{-1}$
- Dominant backgrounds: $t\bar{t}$production.
- **Selection:** $\geq 1 muon$, **veto leptons,** ≥ 4 **jets,** $E_{\mathrm{T}}^{\mathbf{miss}}$, ≥ 2 **b-tagged jets**

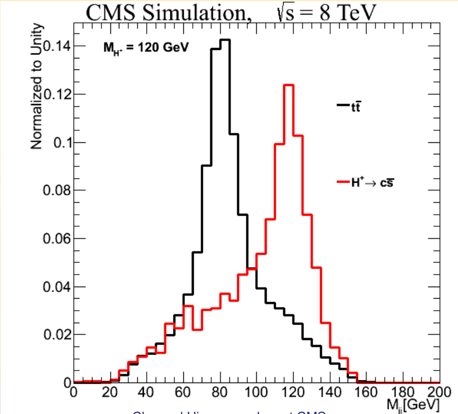


(Plots from [5])

W/H mass reconstruction

- Fully reconstruct $t\bar{t}$ events from the final state
  - Improved mass resolution of the hadronically decaying boson
- Constraining hypothesis:
  - Two top quarks, each decaying into a W boson and a b
  - One W boson decays into $\mu\nu_\mu$
  - One W/H decays into quark-antiquark' pair
  - Top mass constrained to 172.5 GeV (fit is for boson mass)

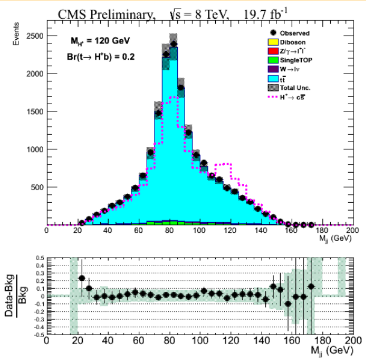
Dijet mass reconstruction (from [5])

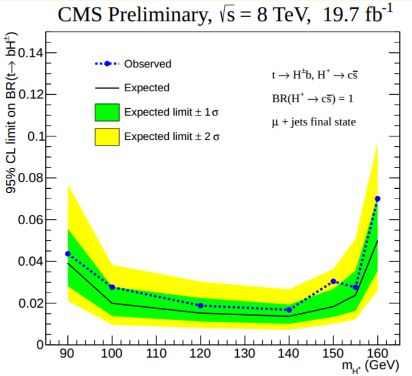


Limits computation

- Dijet mass distribution at final selections step is used for limit computation

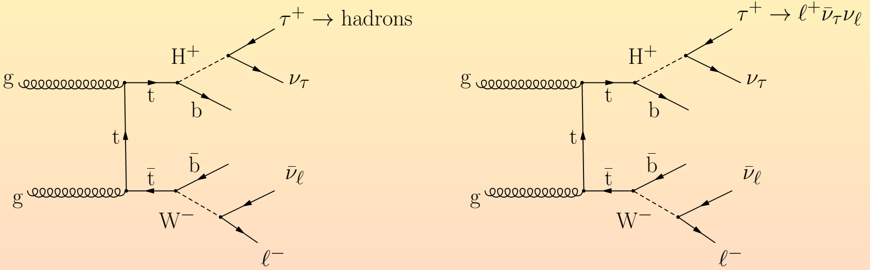
Source	$N_{events} \pm$ Uncertainty
HW, $M_H = 120\ GeV$, $\mathcal{B}(t \to bH^+) = 0.2$	3670 ± 503
SM $t\bar{t}$	16911 ± 2163
W+Jets	242 ± 52
Z+Jets	29 ± 5
SingleTop	463 ± 50
Dibosons	5 ± 1
Total Bkg	17651 ± 2164
Data	17759





(Plots from [5])

Searching for a light $H^{\pm}$ when $tan\beta > 1$

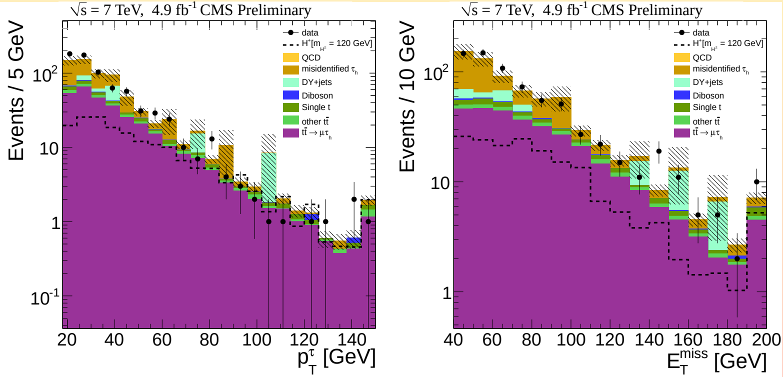


- Representative diagrams for the $\ell\tau_h$ and $e\mu$ final states
- SM expectations: assume theoretical prediction $\sigma(t\bar{t}) = 165^{+4}_{-9}(scale)^{+7}_{-7}(PDF)\ pb$
- Fully hadronic final state discussed onwards

Tau dilepton channel selection

- Data collected at a c.m. energy of 7 *TeV*
- **Trigger: single lepton trigger**, $p_T > 17 - 27\ GeV$ depending on flavour
- Integrated luminosity: $1.99 \pm 0.05\ fb^{-1}$ **($e\tau_h$)**, $4.9 \pm 0.05\ fb^{-1}$ **($\mu\tau_h$)**
- **Offline selection: 1 isolated lepton,** ≥ 2 **jets,** E_T^{miss}**,** ≥ 1 **b-tags,** $1\tau_h$**, opposite sign**

τ_h p_T — E_T^{miss}



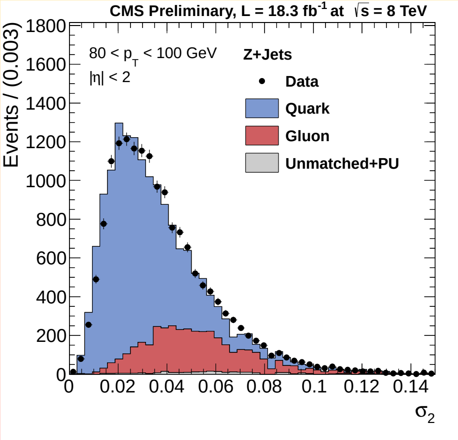
Final selection stage

Signal ($m_{H^\pm} = 120$ GeV) normalized to $\mathcal{B}(t \to H^+ b) = 0.05$

(Plots from [2])

Background estimate

- Irreducible $t\bar{t} \to W^+ b W^- \bar{b} \to \ell \nu b \tau_h \nu \bar{b}$ use simulation
- Fake τ_h
  - Dominant contributions:
    - $W + jets$
    - $t\bar{t} \to W^+ b W^- \bar{b} \to \ell \nu b q q' \bar{b}$
  - Use jet width to take into account differences in tau fake rate for gluons and jets

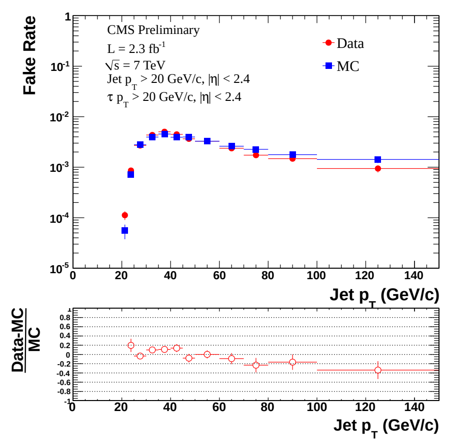


(Plots from [14])

Jet $\to \tau_h$ probability

- **k-Nearest-Neighbours algorithm:**
  - Phase space: $(p_T^{jet}, |\eta|^{jet}, R^{jet})$
  - Training set of jets from dedicated real-τ_h-free samples
  - Classify jets near to a reconstructed τ_h as fakes
  - Obtain probability of faking a $\tau_h \propto$ number of fakes in the nearest 20 jets
  - Extract a weights matrix $P(p_T^{jet}, |\eta|^{jet}, R_{jet})$
  - Estimate in g/q-jets dominated samples and average the resulting probability

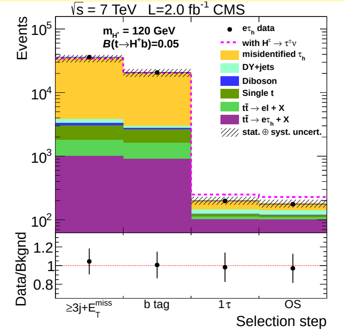
- Apply jet$\to \tau_h$ probability to inclusive jet distributions
- Obtain number of fake events as ratio between reweighted/unweighted jet distributions



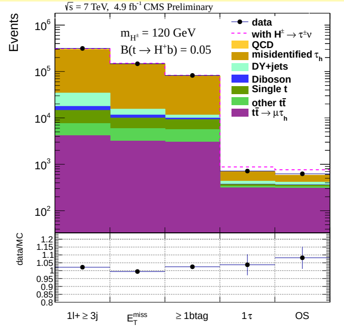
(Plots from [2])

Cutflow and yields

- $e\tau_h$



- $\mu\tau_h$



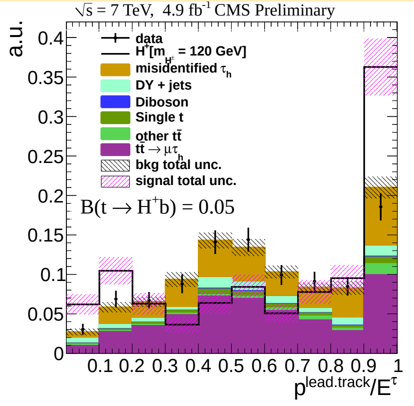
Source	$N_{ev}^{e\tau_h} \pm$ stat. $\pm$ syst.	$N_{ev}^{\mu\tau_h} \pm$ stat. $\pm$ syst.
HH+HW, $m_{H^+} = 120\,GeV$, $\mathcal{B}(t \to H^+b) = 0.05$	$51 \pm 3 \pm 8$	$179.3 \pm 8.7 \pm 22.1$
misidentified τ (from data)	$54 \pm 6 \pm 8$	222.0 ± 11.4
$t\bar{t} \to WbW\bar{b} \to \ell\nu b\ \tau\nu\bar{b}$	$100 \pm 3 \pm 14$	$304.7 \pm 2.8 \pm 25.9$
$t\bar{t} \to WbW\bar{b} \to \ell\nu b\ \ell\nu\bar{b}$	$9.0 \pm 0.9 \pm 1.8$	$21.4 \pm 0.7 \pm 6.9$
$Z/\gamma^* \to ee, \mu\mu$	$4.8 \pm 1.8 \pm 1.3$	$0.4 \pm 0.4 \pm 0.1$
$Z/\gamma^* \to \tau\tau$	$17.0 \pm 3.3 \pm 3.0$	$50.6 \pm 17.6 \pm 20.7$
single top quark	$7.9 \pm 0.4 \pm 1.1$	$26.6 \pm 1.2 \pm 3.3$
diboson	$1.3 \pm 0.1 \pm 0.2$	$4.4 \pm 0.5 \pm 0.7$
Total expected background	$194 \pm 8 \pm 20$	$630.1 \pm 17.9 \pm 46.9$
Data	176	620

(Plots from [2])

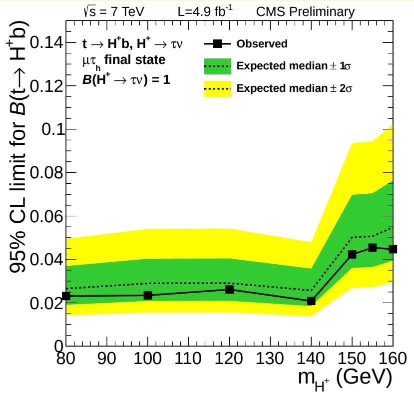
Limits, $\mu\tau_h$ final states

- Good agreement data/predictions $\rightarrow$ set limits
- Perform a shape analysis of $R := \frac{p^{leadtrack}}{E^{\tau}}$ [10]
  - taus from the W are softer (left polarized)
  - taus from $H^{\pm}$ are harder (right polarization)
- Exclude $\mathcal{B}(t \rightarrow H^{\pm}b)$ for most masses (syst limited)

R^{τ_h} variable ($\mu\tau_h$ final state)



$\mu\tau_h$ limit



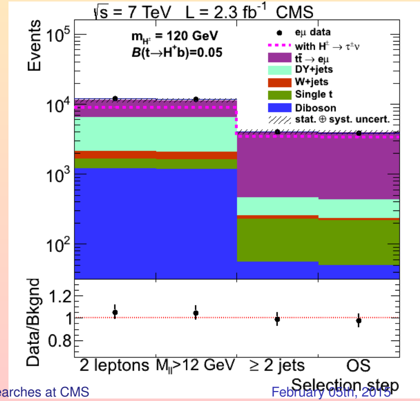
(Plots from [2])

$e\mu$ channel (from [2])

- $e\mu$ channel can be used as normalization channel for SM $t\bar{t}$
  - Improve on systematics of irreducible background
- **Trigger: electron-muon trigger**
  - $p_T^{\ell} > 8$ GeV and $pT^{\ell'} > 17$ GeV
  - Integrated luminosity: 2.27 ± 0.05 fb^{-1}
- **Selection: 1$e\mu$ pair, ≥ 2 jets, veto low $e\mu$ masses, opposite sign**
- Clean signature ($\geq 90\%$ purity after selection

- Expected deficit w.r.t. SM
  - Selection efficiency: $\epsilon(H^+ \rightarrow \ell\nu_\ell) < \epsilon(W^+ \rightarrow \ell\nu_\ell)$
  - H^+ case: softer lepton p_T spectrum
- Irreducible SM $t\bar{t}$ bkg dominating

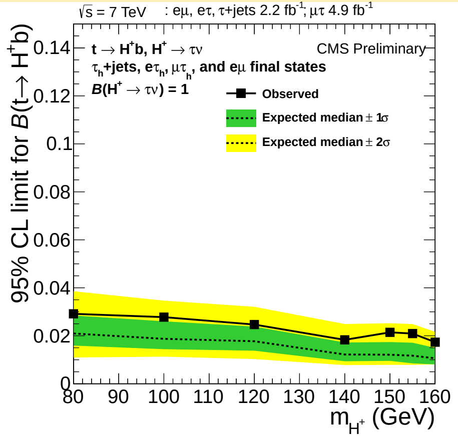
Source	$N_{ev}^{e\mu} \pm$ stat. $\pm$ syst.
HH+WH, $m_{H^+} = 120\,$GeV, $\mathcal{B}(t \rightarrow H^+b) = 0.05$	$125 \pm 9 \pm 13$
$t\bar{t}$ dileptons	$3423 \pm 35 \pm 405$
other $t\bar{t}$	$23 \pm 3 \pm 3$
$Z/\gamma^* \rightarrow \ell\ell$	$192 \pm 12 \pm 19$
W+jets	$14 \pm 6 \pm 2$
single top quark	$166 \pm 3 \pm 18$
diboson	$48 \pm 2 \pm 5$
Total expected background	$3866 \pm 38 \pm 406$
Data	3875

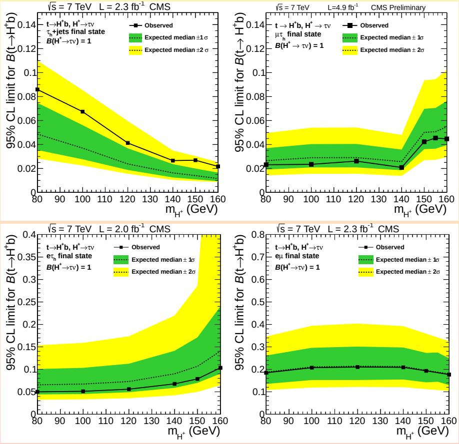


Model-independent combined limit

- Combined limit calculated for all final states, $\ell\tau_h$, $e\mu$, $\tau_h + jets$ [2]
- Slight excess after combination
  - Driven by tau+jets final state

Combined limit

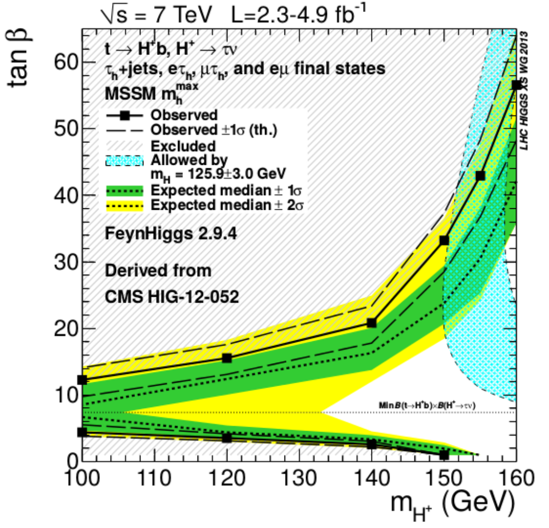




(Plots from [2])

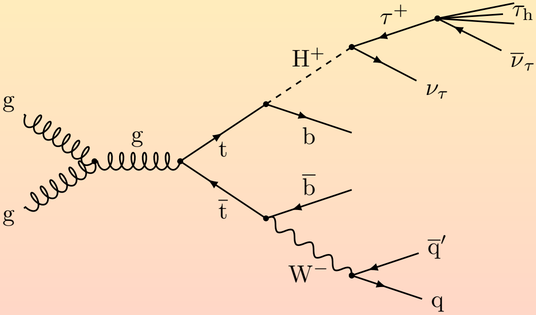
Model-dependent exclusion region

- Exclusion region in the MSSM plane
- $M^{squarkmass}_{SUSY-breaking} = 1\ TeV$, $\mu_{higgsino} = +200\ GeV$
- Other parameters in backup



(Plots from [2])

Searching for a light $H^{\pm}$ when $tan\beta > 1$, τ_h+jets final state



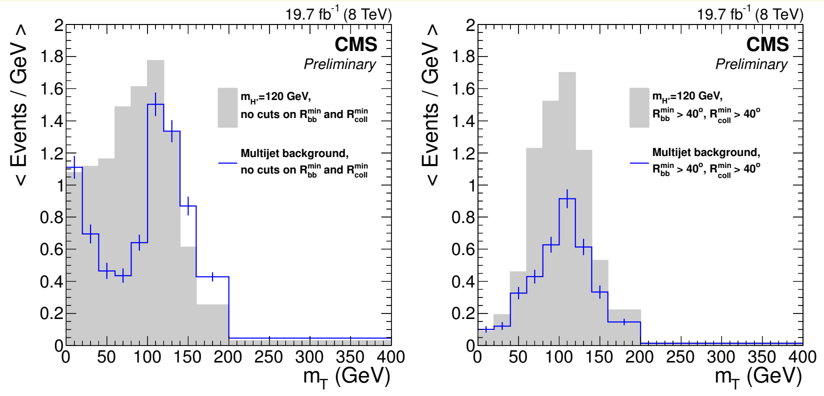
- τ_h+jets has been updated for 8 TeV data
- Gain from increased luminosity and improved background estimation

(Plots from [4])

τ_h+jets channel selection

- **Trigger: τ_h-$E_{\mathrm{T}}^{\mathbf{miss}}$ trigger**
  - $E_{\mathrm{T}}^{\mathrm{miss}} > 70$ GeV, τ_h w/ $p_T > 35$ GeV
  - Integrated luminosity: $19.7 \pm 0.5\ fb^{-1}$
- Dominant backgrounds: multijet production and EWK processes.
- **Selection: 1 τ_h, ≥ 3 jets, veto leptons, $E_{\mathrm{T}}^{\mathbf{miss}}$**
- Exploit angular variables to suppress multijet background

No angular variables cut — After angular variables cut

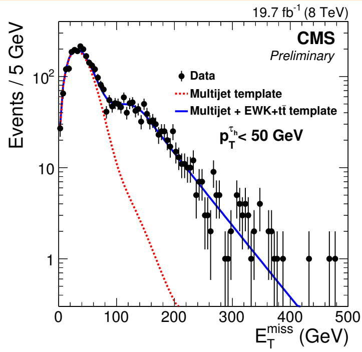


(Plots from [4])

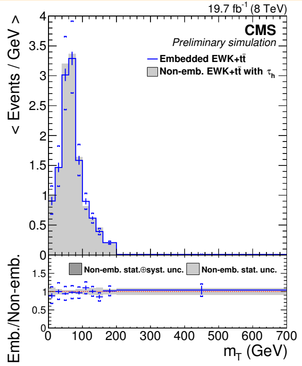
τ_h+jets background estimation (from [4])

- Multijet background: use tau fakes method
  - Likelihood fit of E_T^{miss} distribution gives N(multijet, EWK+ttbar)
  - Multijet templates from data, EWK+ttbar from MC
  - Apply the obtained fake probability to data-driven template in signal region
- EWK+$t\bar{t}$with taus
  - "tau embedding": substitute muons with taus in $\mu +$ *jets* events and pass them though full selection
  - Differences w.r.t. the nominal MC distribution taken as source of systematic uncertainty

Templates in signal region



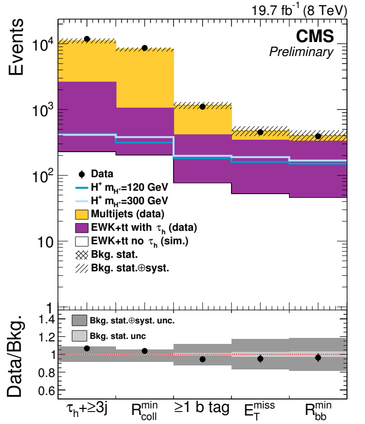
Embedding closure test

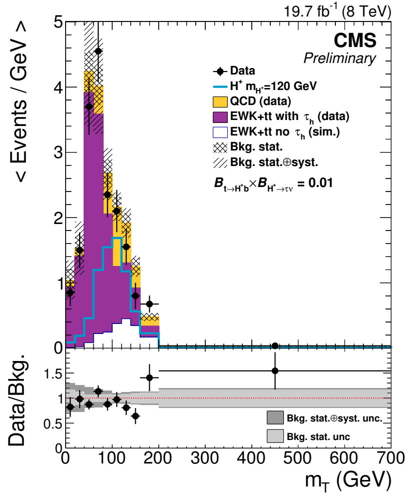


τ_h+jets final selection (from [4])

- Transverse mass at final selections step is used for limit computation

	N_{events} ± stat. ± syst.
Signal, $m_{H^\pm} = 120 GeV$	$151 \pm 4 \ ^{+17}_{-18}$
Signal, $m_{H^\pm} = 300 GeV$	$168 \pm 2 \pm 16$
Multijet background (data)	$78 \pm 3 \pm 17$
EWK+$t\bar{t}$with τ_h(data)	$283 \pm 12 \ ^{+55}_{-54}$
EWK+$t\bar{t}$no τ_h(sim.)	$47 \pm 2 \ ^{+11}_{-10}$
Total expected from the SM	$407 \pm 12 \ ^{+59}_{-58}$
Observed:	392

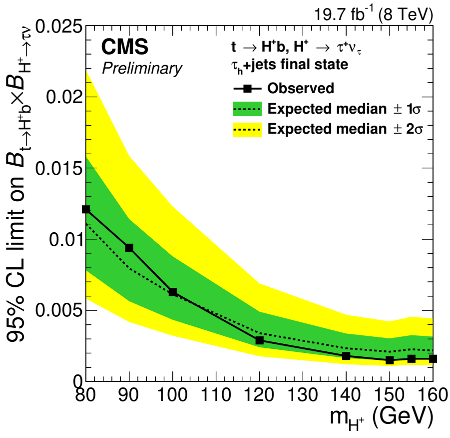




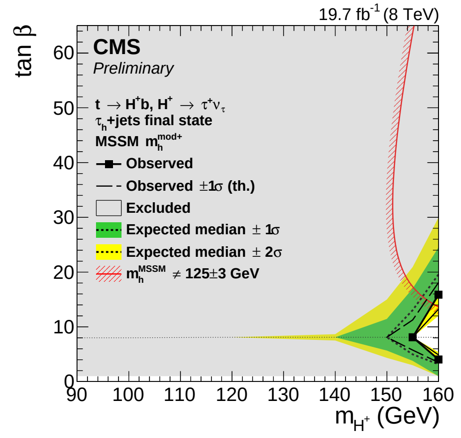
Results

- Model-independent upper limits are computed for $\mathcal{B}(t \to H^{\pm} b \times \mathcal{B}(H^{\pm} \to \tau\nu)$
- Limits are then interpreted as exclusion region in $(m_{H^{\pm}} - tan\beta)$ plane for the m_h^{mod+} scenario
- Not much space left available in the parameter space!

Model-independent upper limits



Exclusion region (m_h^{mod+} scenario)



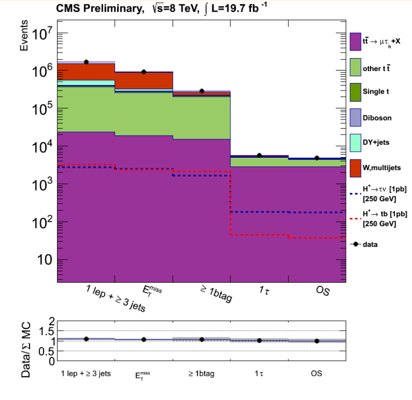
(Plots from [4])

Searching for a heavy $H^{\pm}$

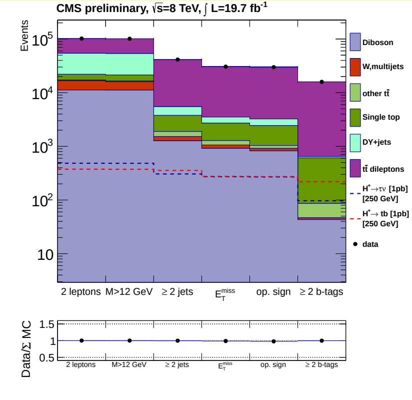
Event yields

- Same final states can be used
- Explore sensitivity to $H^{\pm}$ in production of $t\bar{b}$
  - Change in $t\bar{t}$kinematics and acceptance
  - Extra b-jet multiplicity
- Use full 8 TeV dataset

$\mu\tau$



$e\mu$



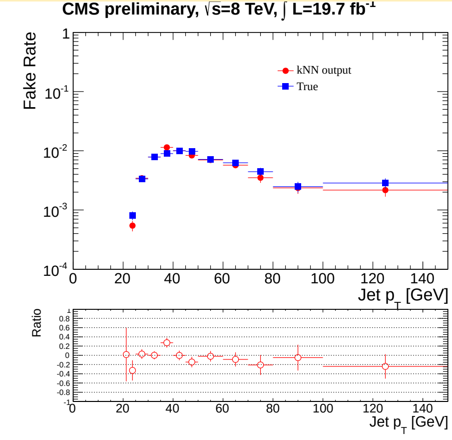
Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$

(Plots from [3])

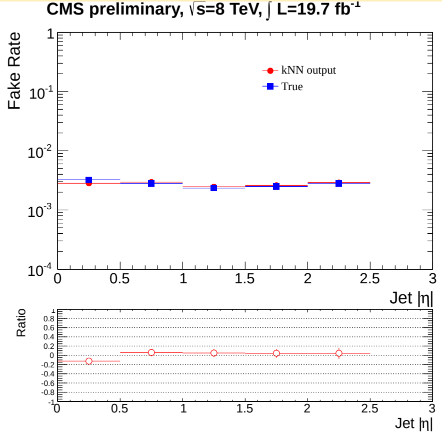
Fake rate estimate

- Improved estimation of the tau fake rate
  - Use dedicated samples for data-driven estimate
  - Full account of quark/gluon composition in the sample
  - Improved median for fake rate estimation

Fake rate (p_T) [mainly quark jets]



Fake rate (η) [mainly quark jets]



(Plots from [3])

Final selection - $\mu\tau$ and dilepton final states

- Accounting for charge conjugate production

$\mu\tau_h$ final state	N_{events} ($\pm$ stat. $\pm$ syst.)
$H^+ \rightarrow \tau_h\nu$, $M_{H^+} = 250$ GeV	$176 \pm 6 \pm 13$
$H^+ \rightarrow tb$, $M_{H^+} = 250$ GeV	$37 \pm 2 \pm 3$
$t\bar{t} \rightarrow \mu\tau_h + X$	$2836 \pm 42 \pm 237$
τ fakes	1544 ± 175
$t\bar{t}$ dileptons	$96 \pm 7 \pm 13$
$Z/\gamma \rightarrow ee, \mu\mu$	$12 \pm 5 \pm 4$
$Z/\gamma \rightarrow \tau\tau$	$162 \pm 20 \pm 14$
single top	$150 \pm 8 \pm 18$
dibosons	$20 \pm 1 \pm 2$
total SM backgrounds	$4821 \pm 48 \pm 296$
data	4839

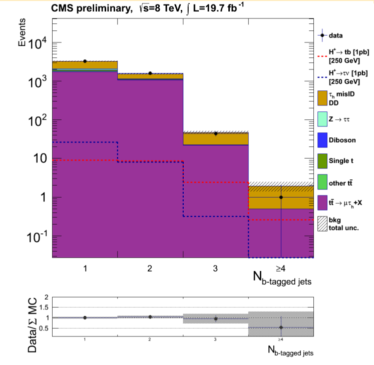
Dilepton final states	ee	$e\mu$	$\mu\mu$
$H^+ \rightarrow \tau\nu$, $M_{H^+} = 250$ GeV	$39 \pm 3 \pm 3$	$97 \pm 4 \pm 5$	$40 \pm 3 \pm 3$
$H^+ \rightarrow tb$, $M_{H^+} = 250$ GeV	$85 \pm 3 \pm 2$	$219 \pm 5 \pm 5$	$90 \pm 3 \pm 2$
$t\bar{t}$ dileptons	$5693 \pm 17 \pm 140$	$15295 \pm 28 \pm 376$	$6333 \pm 18 \pm 156$
other $t\bar{t}$	$22 \pm 4 \pm 1$	$40 \pm 5 \pm 1$	$16 \pm 3 \pm 0$
Drell-Yan	$96 \pm 8 \pm 2$	$38 \pm 3 \pm 1$	$138 \pm 10 \pm 4$
W+jets, multi-jets	$6 \pm 2 \pm 0$	$4 \pm 1 \pm 0$	$0 \pm 1 \pm 0$
single top	$198 \pm 6 \pm 5$	$522 \pm 16 \pm 13$	$228 \pm 10 \pm 6$
dibosons	$15 \pm 1 \pm 0$	$43 \pm 2 \pm 1$	$20 \pm 1 \pm 1$
total SM backgrounds	$6030 \pm 20 \pm 140$	$15942 \pm 33 \pm 376$	$6735 \pm 23 \pm 156$
data	6162	15902	6955

Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$

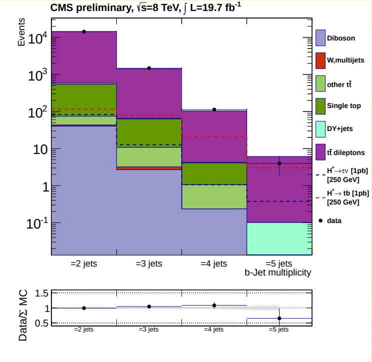
Limit computation

- Approaches chosen for dealing with the two different decay channels
  1. Use benchmark model: m_h^{mod+}
  2. Assume separately $Br = 100\%$ for each channel while setting to zero the other
- Leptonic analyses: exploit the expected higher b-jets multiplicity in the signal w.r.t. SM
- b-tagged jets multiplicity shape used for the limits setting procedure

$\mu\tau$



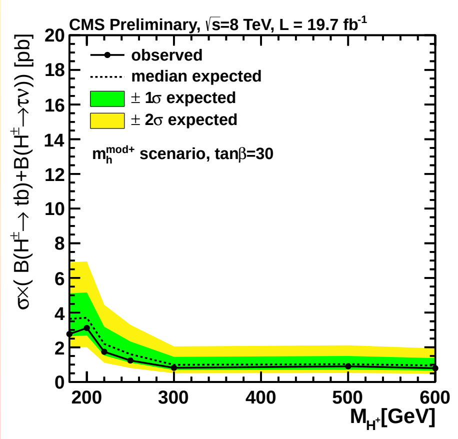
$e\mu$



Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$
(Plots from [3])

Result in the m_h^{mod+} reference scenario: $\mu\tau + e\mu + ee + \mu\mu$

- Signals weighted according to m_h^{mod+} predictions
- Chosen reference $tan\beta = 30$
- Limits are always higher than the m_h^{mod+} prediction
- No enough sensibility to exclude portions of parameter space in the chosen scenario

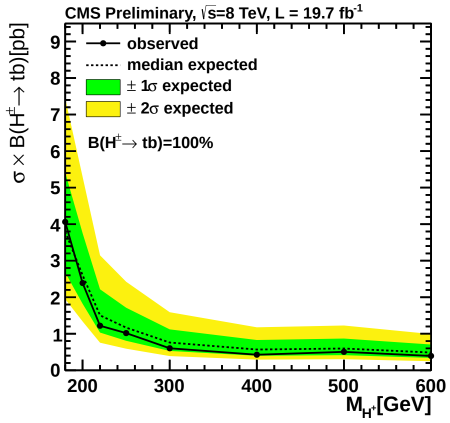


(Plots from [3])

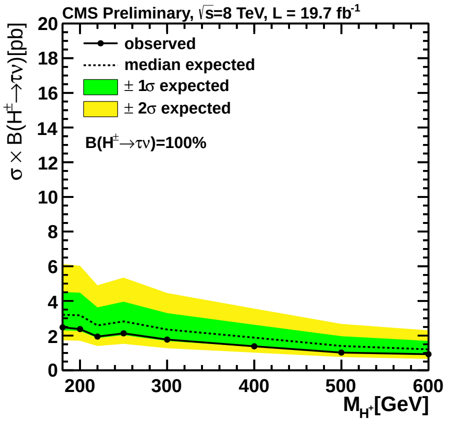
Single-contributing channel approach: $\mu\tau + e\mu + ee + \mu\mu$

- Each channel is allowed to contribute exclusively
- Assume that one of them has $\mathcal{B} = 1$ and the other has $\mathcal{B} = 0$

$\mathcal{B}(H^{\pm} \to tb) = 1$



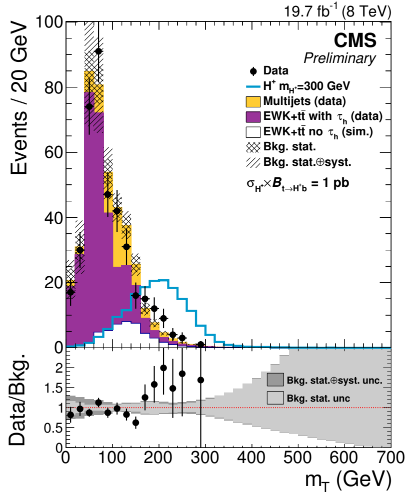
$\mathcal{B}(H^{\pm} \to \tau\nu) = 1$



(Plots from [3])

Limit computation in τ_h+jets

- Complement search with τ_h+jets final state
- Transverse mass at final selections step is used for limit computation
- In the heavy charged Higgs mass case, better discrimination than in the light mass case

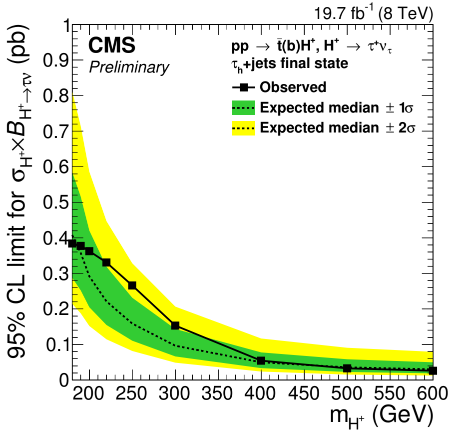


(Plots from [4])

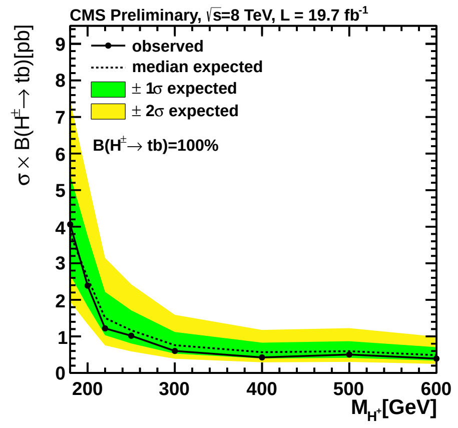
Summary: heavy charged Higgs

- Best results for the two decay modes:
  - Fully hadronic final state for $H^{\pm} \to \tau\nu$ decays
  - Leptonic (dilepton) final states for $H^{\pm} \to tb$ decays (the only result!)

$\mathcal{B}(H^{\pm} \to \tau\nu) = 1$



$\mathcal{B}(H^{\pm} \to tb) = 1$



(Plots from [3] and [4])

Conclusions

Summary

- We have searched for a charged Higgs boson with the CMS detector using the full dataset
- Combine different final states to fully scan the mass versus *tan*β plane
  - Results interpreted in the context of the `MSSM` model
- Unfortunately, data is consistent with background predictions
  - Stringent limits are set from our direct searches
- These preliminary results are now being combined into a paper and into my thesis

THANKS FOR THE ATTENTION!

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Search for a light charged Higgs boson in top quark decays in *pp* collisions at $\sqrt{s} = 7\ TeV$
Journal of High Energy Physics, 07 (2012) 143.

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Updated search for a light charged Higgs boson in top quark decays in *pp* collisions at $\sqrt{s} = 7\ TeV$
CMS-PAS-HIG-12-052, [CDS:1502246]

CMS Collaboration
Search for a heavy charged Higgs boson in proton-proton collisions at $\sqrt{s} = 8\ TeV$ with the CMS detector
CMS-PAS-HIG-13-026, [CDS:1755203]

CMS Collaboration
Search for charged Higgs bosons with the H+ to tau nu decay channel in the fully hadronic final state at $\sqrt{s} = 8\ TeV$
CMS-PAS-HIG-14-020, [CDS:1950346]

References II

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  Search for $H^{\pm}$ to cs-bar decay
  CMS-PAS-HIG-13-035, [CDS:1728343]
- CMS Collaboration
  Particle-Flow Event Reconstruction in CMS and Performance for Jets, Taus, and E_T^{miss}
  CMS-PAS-PFT-09-001, [CDS:1194487]
- CMS Collaboration
  Performance of muon identification in *pp* collisions at $\sqrt{s} = 7$ *TeV*
  CMS-PAS-MUO-10-002, [CDS:1279140]
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  JINST, 7, P01001 (2012)
- CMS Collaboration
  Performance of the b-jet identification in CMS
  CMS-PAS-BTV-11-001, [CDS:1366061]

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Looking for the charged Higgs boson
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CMS-DP-2013-033, [CDS:1627305]

CMS Collaboration
Jet Energy Corrections and Uncertainties. Detector Performance Plots for 2012.
CMS-DP-2012-012, [CDS:1460989]

CMS Collaboration
CMS Particle Flow and Tau Identification Results
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsPFT

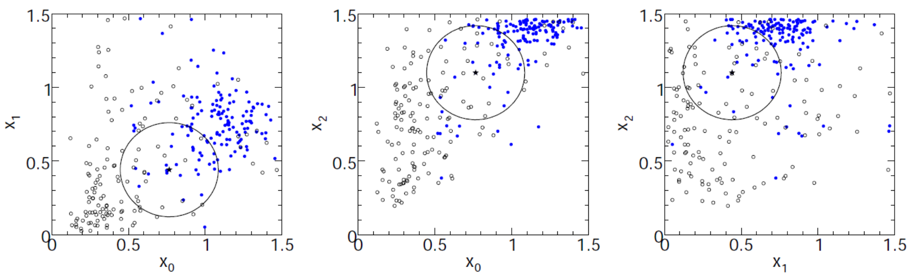
References IV

CMS Collaboration
Performance of quark/gluon discrimination in 8 TeV pp data
CMS-PAS-JME-13-002, [CDS:1599732]

BACKUP SLIDES

kNN method for jet $\to \tau_h$ probability

- `k-Nearest-Neighbours` **algorithm:**
  - Phase space: $(p_T^{jet}, |\eta|^{jet}, R^{jet})$
  - Training set of jets from dedicated real-τ_h-free samples
  - Classify jets near a reconstructed τ_h as fakes
  - Obtain probability of faking a $\tau_h \propto$ number of fakes in the nearest 20 jets
  - Extract a weights matrix $P(p_T^{jet}, |\eta|^{jet}, R_{jet})$
  - Estimate in g/q-jets dominated samples and average the resulting probability



(from TMVA Users Guide)

- TAUOLA package used to simulate tau decays
- Full detector simulation based on GEANT4

Process	σ (pb)	Generator
MSSM signal		PYTHIA
$t\bar{t}$	165	MADGRAPH + PYTHIA
Single top	7.87 (7.87) tW channel	POWHEG
	42.6 (22.0) t channel	POWHEG
	2.7 (1.5) s channel	POWHEG
W+Jets	31314	MADGRAPH + PYTHIA
$DY \rightarrow \ell\ell$	3048	MADGRAPH + PYTHIA
QCD (μ enriched)	84679	PYTHIA
WW	43	PYTHIA
WZ	18.2	PYTHIA
ZZ	5.9	PYTHIA

HIG-12-052: Sources of systematic uncertainty

$\mu\tau_h$ channel

	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	τ fakes	Single top	VV	DY(ee,$\mu\mu$)	DY($\tau\tau$)
τ-jet id	6	6	6			6	6		6
jet, $\ell \to \tau$ mis-id				30				30	
JES+JER+MET	6	4	5	4		6	11	100	21
b-jet tagging	6	5	5	5		7			
jet$\to$b mis-id							9	9	9
pile up	4	2	2	8		2	3	25	4
lepton selection	2	2	2	2		2	2	2	2
τ fakes					5				
cross-section	$^{+7}_{-10}$					8	4	4	
MC stats	4	5	1	3		4	11	100	35
luminosity	2.2					2.2			

$e\tau_h$ channel

	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	τ fakes	Single top	VV	DY($\mu\mu$)	DY($\tau\tau$)
τ-jet id	6.0	6.0	6.0			6.0	6.0		6.0
jet, $\ell \to \tau$ mis-id				15.0				15.0	
JES+JER+MET	6.0	5.0	5.0	4.0		6.0	11.0	100.0	22.0
b-jet tagging	6.0	5.0	5.0	5.0		7.0			
jet$\to$b mis-id							8.0	8.0	9.0
pileup modelling	4.0	2.0	2.0	8.0		2.0	3.0	25.0	4.0
lepton selections	2.0	2.0	2.0	2.0		2.0	2.0	2.0	2.0
τ fakes (stat)					10.0				
τ fakes (syst)					12.0				
cross-section	$^{+7.0}_{-10}$					8.0	4.0	4.0	
MC stats	5.0	4.0	2.0	9.0		4.0	9.0	100.0	16.0
luminosity	4.5					4.5			

- Same methods as in $\ell\tau_h$ channels

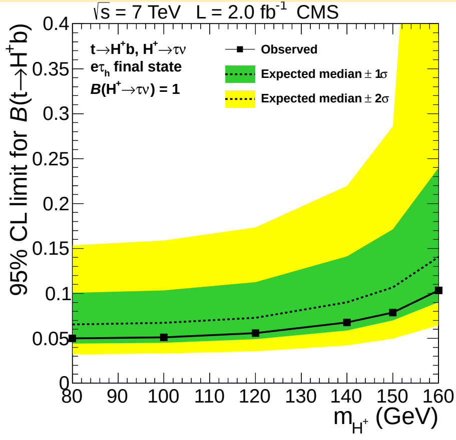
	HH	*WH*	$t\bar{t}$	DY($\ell\ell$)	W+jets	Single top	diboson
JES+JER+E_T^{miss}	2.1	2.0	2.0	6.0	10.8	4.0	6.5
cross section		$^{+7}_{-10}$		4.3	5.0	7.4	4.0
pileup modeling	4.5	4.5	5.0	5.5	4.0	5.5	5.5
MC stat	5.3	7.9	1.0	6.5	42.9	1.9	4.3
luminosity				2.2			
dilepton selection				2.5			

Limits, $e\tau_h$, $\mu\tau_h$ final states

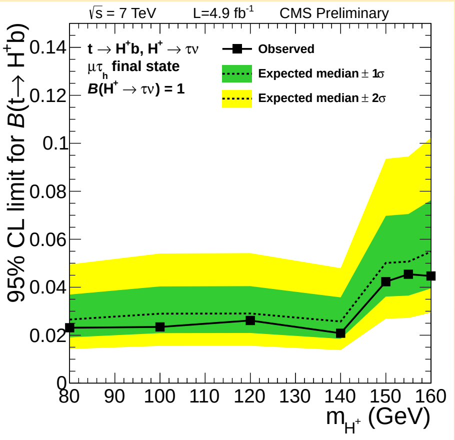
- Expectations from simulation compared with observed data yields
- Assumption: any excess/deficit w.r.t expected SM yield is due to $t \rightarrow H^+ b$

  - Limits improved in $\mu\tau_h$ final state (from $\sim$ 5% in the paper)
  - Systematics drive the estimation

$e\tau_h$ limit



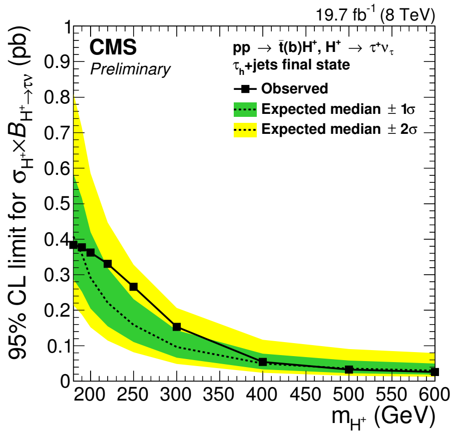
$\mu\tau_h$ limit



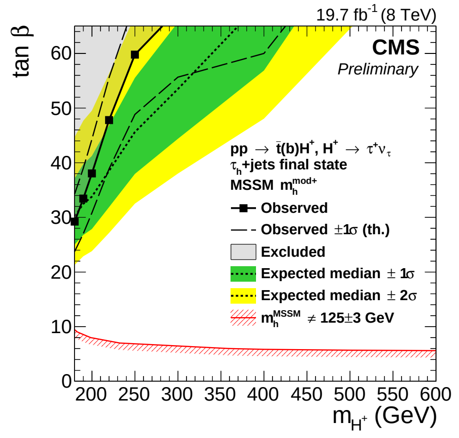
Results in the fully hadronic final state

- Results are available only for $\mathcal{B}(H^{\pm} \to \tau_h \nu$
- Tighter limits than the leptonic analyses
- No result for $H^{\pm} \to tb$: if there, it is included in the data driven estimation of EWK+ttbar with $\tau_h$background

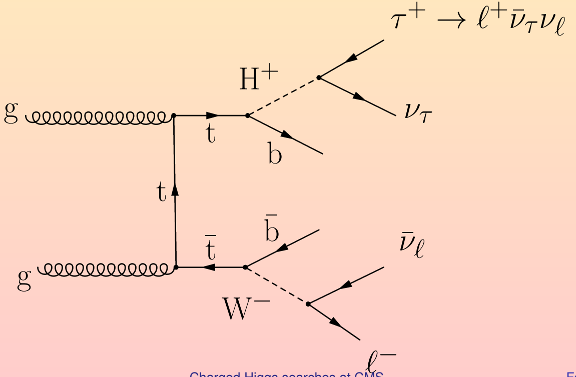
$\mathcal{B}(H^{\pm} \to \tau\nu) = 1$



Exclusion region in m_h^{mod+} scenario

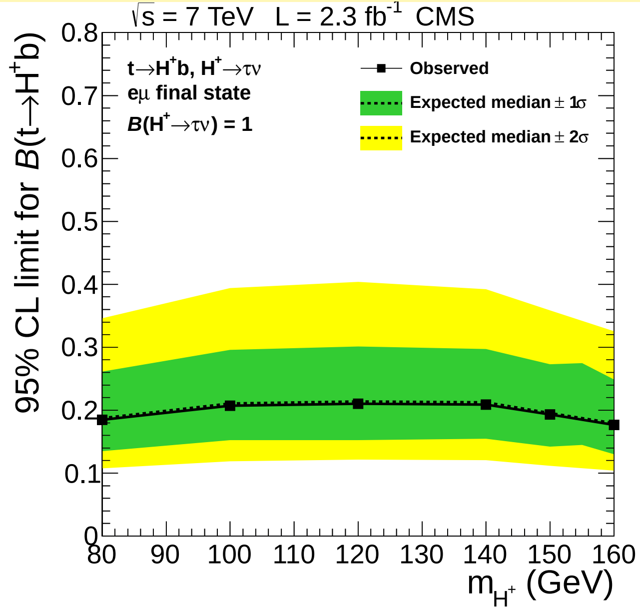


$e\mu$ final state
Event selection
Yields and limit computation



Cutflow, yields and results

- Analysis to be improved at 13 TeV



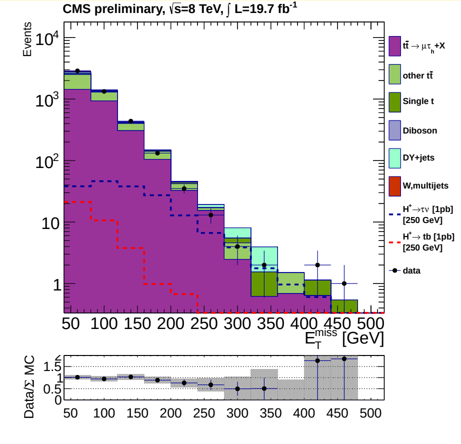
- Search for light MSSM $H^{\pm}$ boson in $\ell\tau_h$, $e\mu$ and fully-hadronic final states at $\sqrt{s} = 7\ TeV$
- No deviations from expected limit with luminosities of 2.3 to 4.9 fb^{-1}

- TAUOLA package used to simulate tau decays
- Full detector simulation based on GEANT4

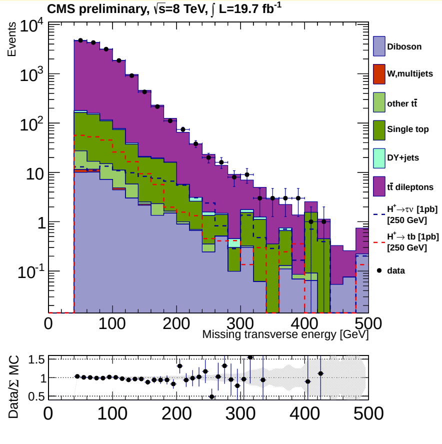
Process	σ (pb)	Generator
MSSM signal		PYTHIA
$t\bar{t}$	245.8	MADGRAPH + PYTHIA
Single top	11.1 (11.1) tW channel	POWHEG
	56.4 (30.7) t channel	POWHEG
	3.8 (1.8) s channel	POWHEG
W+Jets	37509	MADGRAPH + PYTHIA
$DY \rightarrow \ell\ell$	3504+861	MADGRAPH + PYTHIA
QCD (μ enriched)	134680	PYTHIA
WW	54.8	PYTHIA
WZ	33.7	PYTHIA
ZZ	17.6	PYTHIA

HIG-13-026: E_T^{miss} at final selection /1

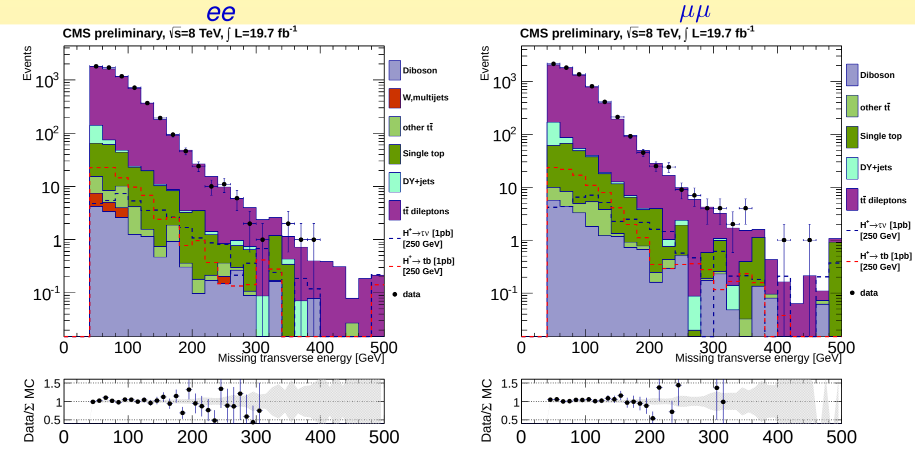
$\mu\tau$



$e\mu$



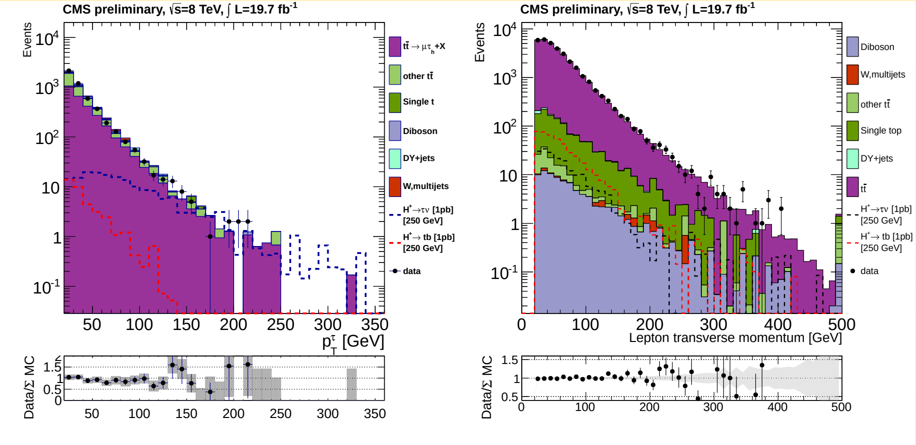
Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$



Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$

- τ pt ($\mu\tau$ final state)
- Inclusive leptons pt (dilepton final states)

$\mu\tau$ $\quad$ $e\mu$

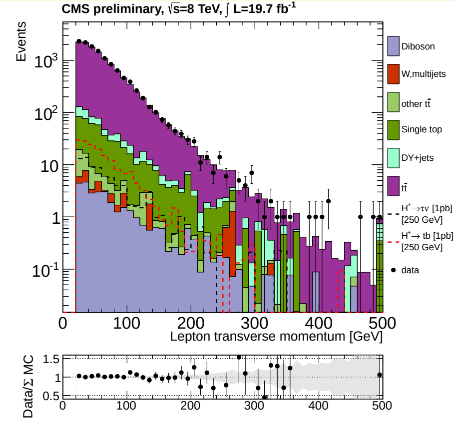


Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$

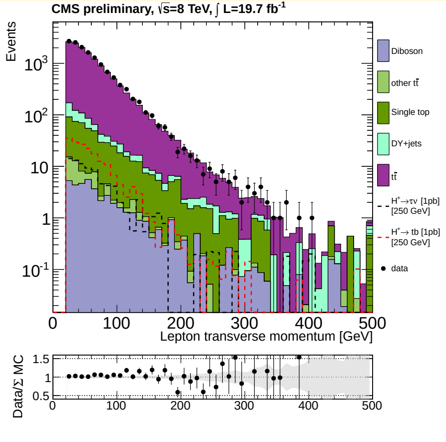
HIG−13−026: Lepton transverse momentum multiplicity at final selection /2

- Inclusive leptons pt

ee



$\mu\mu$



Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$

HIG–13–026: Systematic components

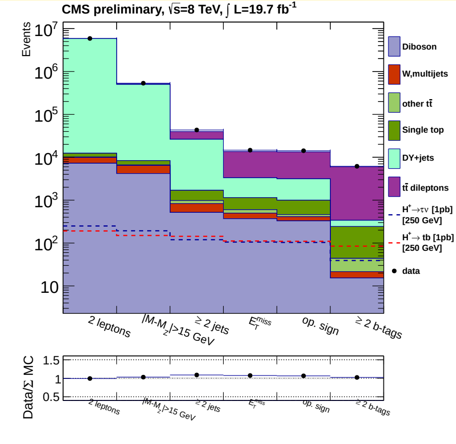
$\mu\tau_h$ channel

	Signal	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	τ fakes	Single top	VV	DY(ee,$\mu\mu$)	DY($\tau\tau$)
τ-jet id	6	6			6	6		6
jet, $\ell \to \tau$ mis-id			30				30	
JES+JER+E_T^{miss} +TES	6	5	4		6	11	100	21
b-jet tagging	6	5	5		7			
jet$\to$b mis-id						9	9	9
pile up	4	2	8		2	3	25	4
lepton selection	2	2	2		2	2	2	2
τ fakes				11				
cross section	30	3	3		8	4	4	
top quark p_T scale		shape	shape					
τ embedding								shape
matching scale		1	1					
PDF	1	5	5					
Q^2 scale		3	3					
MC statistics	3	1	3		4	11	100	35
luminosity	3							

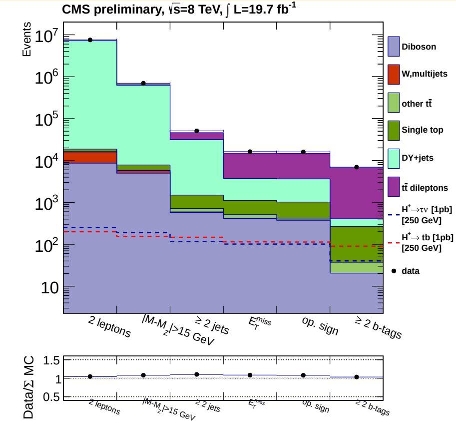
$e\mu$ channel (ee,$\mu\mu$ are similar)

	Signal	$t\bar{t}$	DY	W+jets	Single top	VV
Energy scales (JES+JER+E_T^{miss})	2	2	6	11	4	7
b-jet tagging	3	4	9	10	4	9
jet$\to$b mis-id	3	4	10	11	4	9
pile up	5	5	6	4	6	6
dilepton selection	3	3	3	3	3	3
cross section	30	3	4	5	7	4
DY E_T^{miss} modeling			30			
top quark p_T scale		shape				
matching scale		1				
PDF	1	5				
Q^2 scale		3				
MC statistics	1	1	7	43	2	4
luminosity	3					

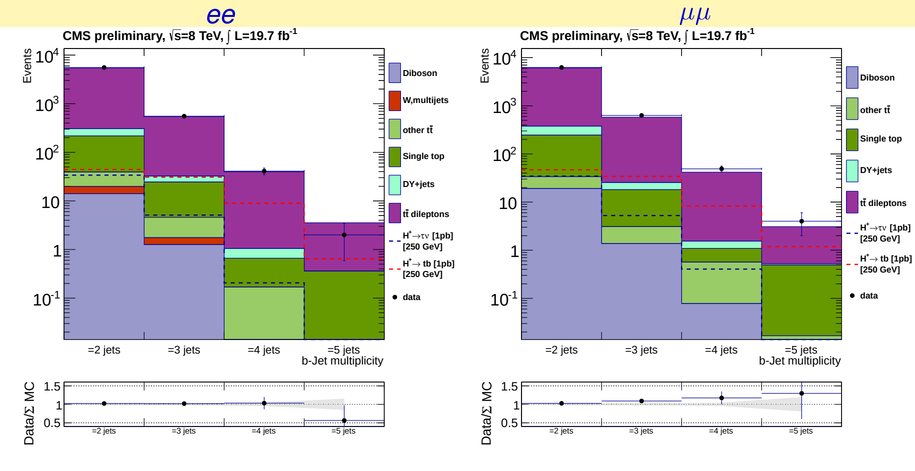
ee



$\mu\mu$



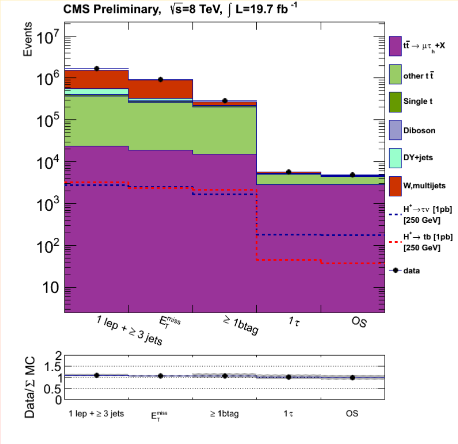
Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$



Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$

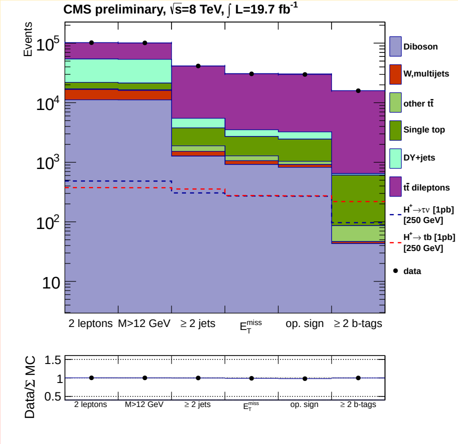
Event selection $\mu\tau$ final state

- Data collected at a c.m. energy of 8 TeV
- **Trigger: single muon trigger.**
  - $\mu\tau_h$: single muon trigger ($p_T^{\mu} > 24$ GeV)
  - Integrated luminosity: 19.7 ± 0.5 fb^{-1}
- **Selection: 1 muon, ≥ 2 jets, E_T^{miss}, ≥ 1 b-tags, $1\tau_h$, opposite sign**



Event selection - dilepton final states

- **Trigger: dilepton (e, μ) trigger**
  - One lepton with $p_T > 8$ GeV and another with $pT > 17$ GeV
  - Integrated luminosity: $19. \pm 0.5$ fb^{-1}
- **Selection: 1$\ell\ell'$ pair, ≥ 2 jets, veto low dilepton masses, Z mass veto, opposite sign**



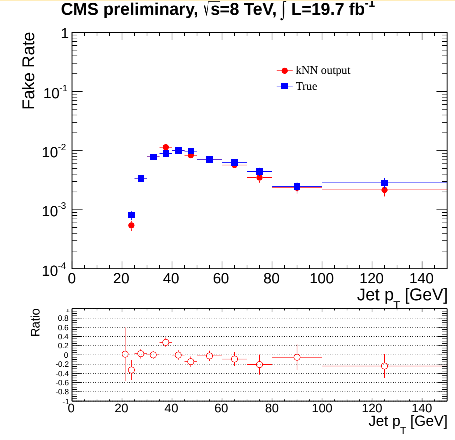
Background estimation: $\mu\tau$ channel: *jet* $\rightarrow \tau$ fakes

- $\mu\tau$ channel: *DY* $\rightarrow \tau\tau$ from embedded data
- $\ell\ell'$ channels: additional Drell-Yan normalization uncertainty
- All the others taken from MC

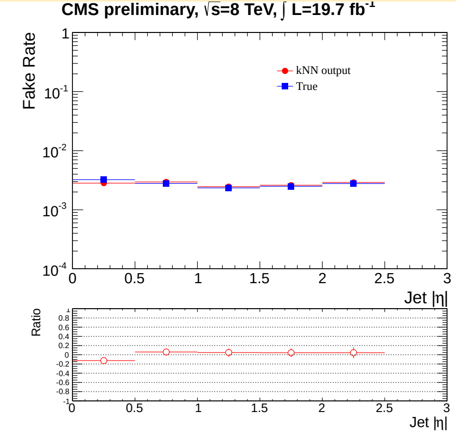
Fake rate estimate

- Use dedicated samples to perform the data-driven estimation
- Recompute fake rates for 8 *TeV* using `kNN` algorithm
- Account for the quark/gluon jets compositions of the samples from MC
- Improved median for the estimate of the fake events (see Matti's talk)

Fake rate (p_T) [mainly quark jets]

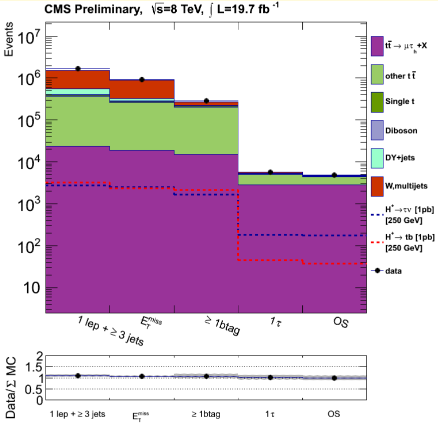


Fake rate (η) [mainly quark jets]

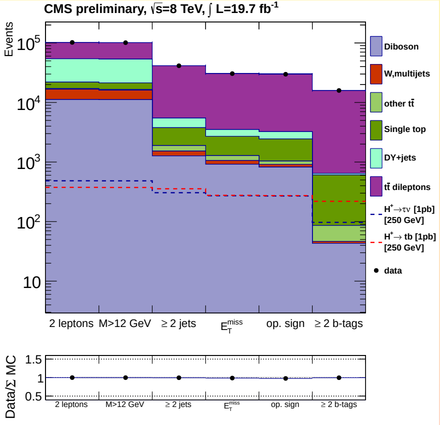


Event yields

$\mu\tau$



$e\mu$



Signal normalized to $\sigma = 1$ pb, $\mathcal{B} = 100\%$