

# Search for MSSM $H^+ \rightarrow \tau \nu$ with $\ell + \tau(\rightarrow had)$ and $\ell\ell$ final states in CMS

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On behalf of the CMS collaboration

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cH<sup>±</sup>argued 2012, Uppsala

## Outline

### Theoretical summary and final state choice

### Reconstruction of objects

#### $\ell\tau_h$ , $\ell = e, \mu$ final states

- Event selection

- Background estimation

- Yields and systematics

- Limits on  $Br(t \rightarrow H^+ b)$

#### $e\mu$ final state

- Event selection

- Yields and systematics

- Limits on  $Br(t \rightarrow H^+ b)$

### Combined limits on $Br(t \rightarrow H^+ b)$

### Summary

### References

## Charged Higgs in top quark physics

- Low mass region ( $M_{H^+} < M_t - M_b$ ):  
 $H^+$  can be produced in top decays  $t \rightarrow H^+ b$
- High mass region ( $M_{H^+} > M_t - M_b$ ):  
 $H^+$  can be produced in association with top:  $pp \rightarrow tbH^+ (tH^+)$
- For  $\tan(\beta) > 5$ , preferential charged Higgs decay is  $H^+ \rightarrow \tau \nu_\tau$
- $H^+$  decay modes alter  $\tau$  yields in  $t\bar{t}$  production w.r.t. SM

- Search assumptions:

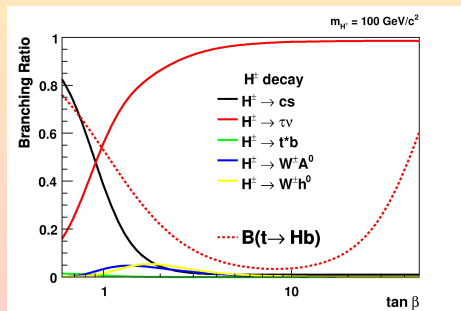
- $M_{H^+} < M_t - M_b$
- $Br(H^+ \rightarrow \tau \nu_\tau) = 1$

- Contributions from:

- $pp \rightarrow HbHb$
- $pp \rightarrow HbWb$

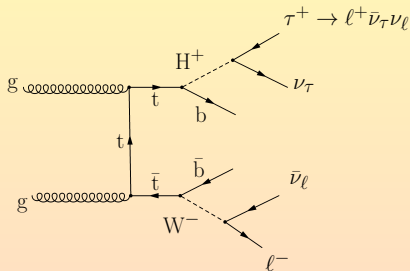
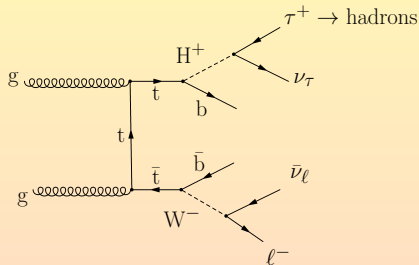
- CMS Collaboration:

JHEP07 (2012) 143 [1]



(from D0 Note 5715-CONF)

## Final states considered

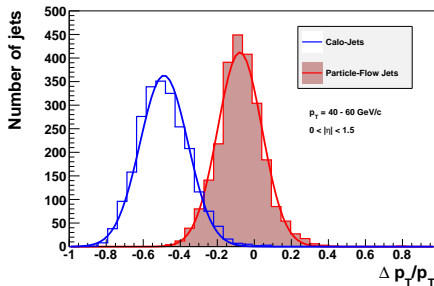


- Representative diagrams for the  $\ell\tau_h$  and  $e\mu$  final states
- SM expectations: assume theoretical prediction  
 $\sigma(t\bar{t}) = 165_{-9}^{+4}(\text{scale})_{-7}^{+7}(\text{PDF}) \text{ pb}$

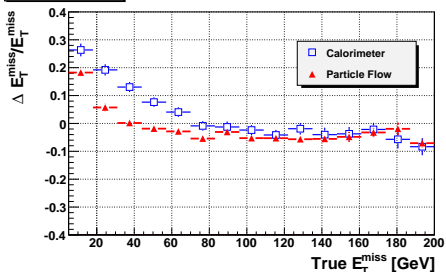
## Reconstruction of physics objects / I

- **Particle flow:** full reconstruction of the particles in the event [2]
- **Muons:** simultaneous global track fit (tracker and muon chambers) [3]
- **Electrons:** tracker hits matched to EM calorimeter energy deposits
- **Jets:** anti-kt clustering algorithm with radius 0.5
- **Missing  $E_T$ :**  $\Sigma \vec{p}_T$  of all reco objects in the volume of the detector
- $\tau \rightarrow$  **hadrons:** hadron-plus-strips algorithm
- More details in Arun's talk

CMS Preliminary



CMS Preliminary

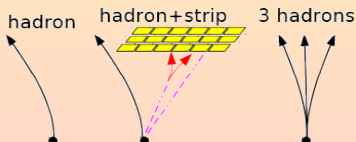


## Reconstruction of physics objects: hadronic $\tau$

### • Tau decay:

- to light leptons ( $e, \mu$ ) 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

### Dominant hadronic decay modes



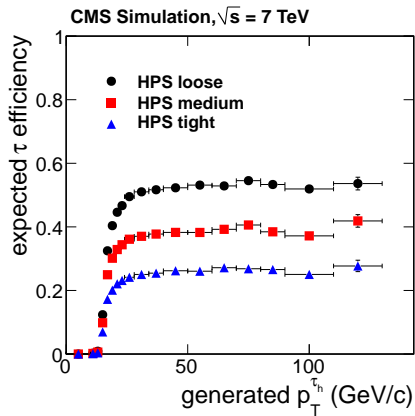
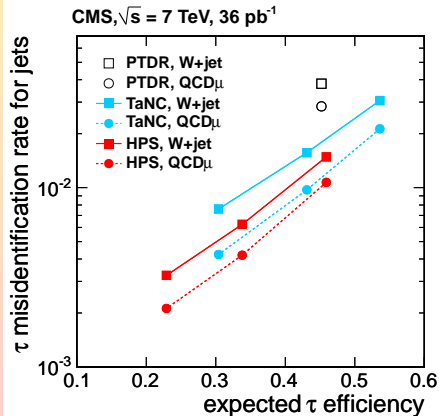
Decay mode	Res.	Branching frac. (%)
$\tau^- \rightarrow h^- \nu_\tau$		11.6%
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	$\rho^-$	26.0%
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a_1^-$	9.5%
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a_1^-$	9.8%
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$		4.8%

From JINST, 7 (2012) P01001 [4]



## Hadronic $\tau$ identification performance

- Fake rates for jets commissioned in data and simulation
  - qcd-type (gluon-enriched) from di-jet events
  - Z- and W- type (quark-enriched) from W+jets and  $\mu$ -enriched QCD sample
- Fake rates for electrons/muons: tag and probe in  $Z \rightarrow \ell\ell$  events
- Reconstruction efficiency:  $Z \rightarrow \tau\tau \rightarrow \mu\tau_h$  events (tag and probe + fit)



From JINST, 7 (2012) P01001 [4]

Results based on JHEP07 (2012) 143

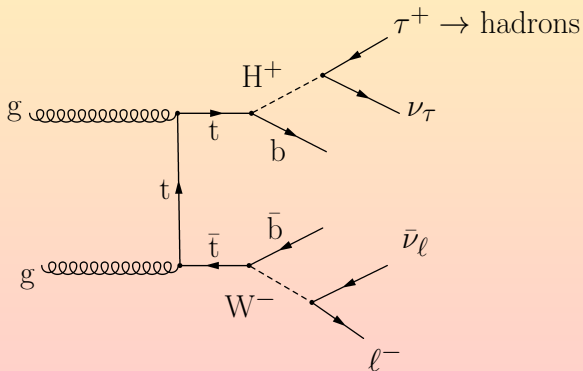


## Simulation of the physics processes

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

Process	$\sigma$ (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 ( $\mu$ enriched)	84679	PYTHIA
WW	43	PYTHIA
WZ	18.2	PYTHIA
ZZ	5.9	PYTHIA

$\ell\tau_h, \ell = e, \mu$  final states





## Event selection

- **Trigger: single lepton trigger.**

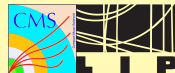
- $e\tau_h$ : e+jets trigger (more aggressive on backgrounds)  
 $p_T^e > 17 - 27 \frac{\text{GeV}}{c}, \geq 2 \text{ jets w/ } p_T > 30(25) \frac{\text{GeV}}{c}, H_T^{\text{miss}} > 15 - 20 \frac{\text{GeV}}{c}$   
 $(H_T^{\text{miss}} := |\Sigma p_T^{\text{jet}}|)$
- $\mu\tau_h$ : single muon trigger ( $p_T^\mu > 17 - 24 \frac{\text{GeV}}{c}$ )
- Integrated luminosity:  $1.99 \pm 0.05 \text{ fb}^{-1} (e\tau_h), 2.22 \pm 0.05 \text{ fb}^{-1} (\mu\tau_h)$

- **Selection: 1 lepton,  $\geq 2$  jets,  $E_T^{\text{miss}}, \geq 1$  b-tags,  $1\tau_h$ , opposite sign**

- One isolated electron(muon) with  $p_T > 35 (30) \frac{\text{GeV}}{c}, |\eta| < 2.5 (2.1)$
- $\geq 2$  jets with  $p_T > 35 (30) \frac{\text{GeV}}{c}, |\eta| < 2.4$
- $E_T^{\text{miss}} > 45 (40) \text{ GeV}$  for  $e\tau_h (\mu\tau_h)$
- $\geq 1$  b-tagged jet (track counting based algorithm)
- One  $\tau_h$  with  $p_T > 20 \frac{\text{GeV}}{c}, |\eta| < 2.4$
- Opposite charges between  $\tau$  and  $e(\mu)$

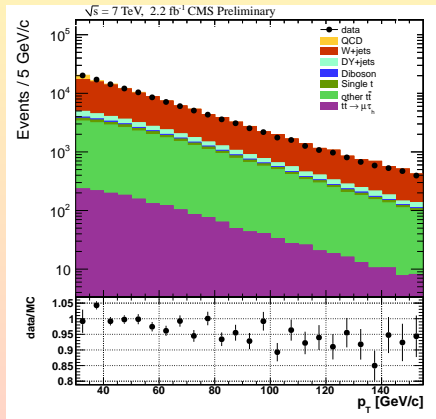
- **Lepton isolation: relative w.r.t. lepton  $p_T$**

- Isolation of a lepton candidate:  $I = \Sigma p_T$  reconstructed particles within  $\Delta R < 0.3$  around lepton direction
- Isolation cut:  $rellso = \frac{I}{p_T^e(\mu)} < 0.1 (0.2)$
- Separation from any other selected jet in  $\Delta R > 0.3$
- Vetoed events with additional isolated leptons



# Control distributions - I

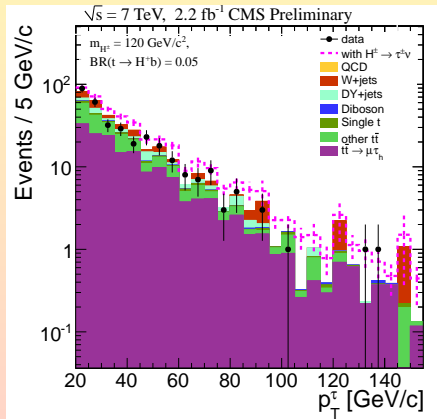
## • Muon $p_T$



- Shown at selection step:  
1 lepton + 3 jets
- Signal negligible at this level

## Control distributions - II

### • Tau $p_T$



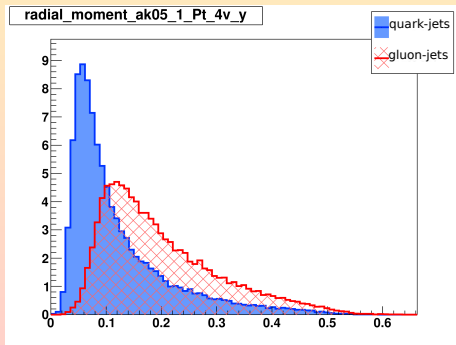
- Shown at selection step:  
 $1 \text{ l} + 3 \text{ jets}, e_t^{\text{miss}}, 1 \text{ b-tag}$
- Only irreducible backgrounds
- Harder  $p_T$  spectrum for  $H^+$



## Main backgrounds

- Irreducible  $t\bar{t} \rightarrow W^+ b W^- \bar{b} \rightarrow \ell \nu b \tau_h \nu \bar{b}$
- Misidentified  $\tau_h$ 
  - Dominant contributions:
    - $W + jets$
    - $t\bar{t} \rightarrow W^+ b W^- \bar{b} \rightarrow \ell \nu b q q' \bar{b}$
  - Fake probability changes for quark and gluon jets modeled by

$$R^{jet} = \sqrt{\sigma_{\eta\eta}^2 + \sigma_{\phi\phi}^2}$$



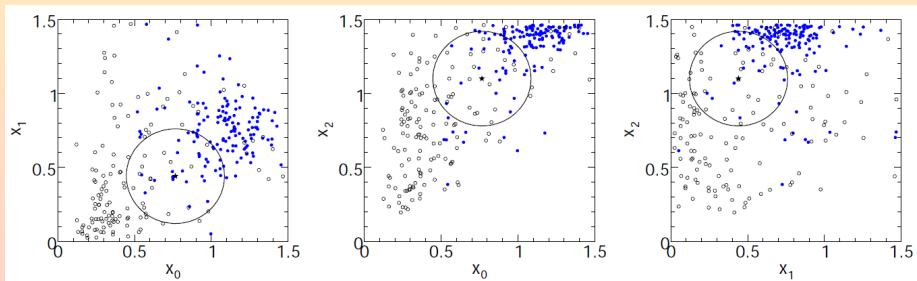
(from arXiv:1106:3076)



## Jet $\rightarrow \tau_h$ probability

### • k-Nearest-Neighbours algorithm:

- Phase space:  $(p_T^{jet}, |\eta|^{jet}, R^{jet})$
- Training set of jets from dedicated real- $\tau_h$ -free samples
- Classify jets near a reconstructed  $\tau_h$  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

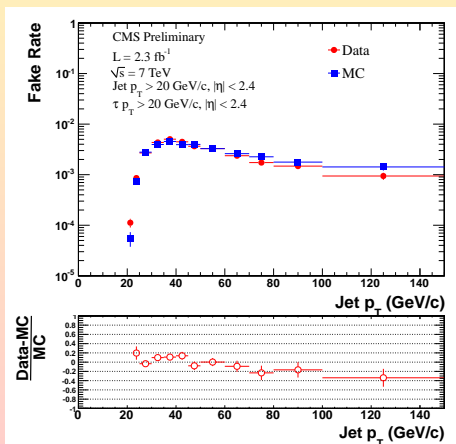


(from TMVA Users Guide)

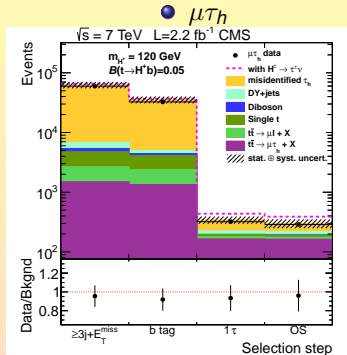
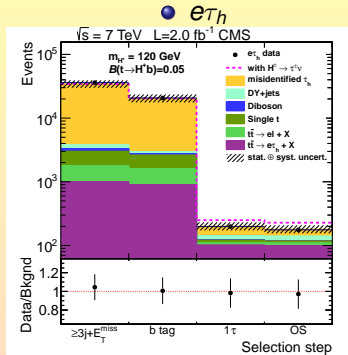


## Data driven background estimation

- Apply  $\text{jet} \rightarrow \tau_h$  probability to inclusive jet distributions
- Obtain number of fake events as ratio between reweighted/unweighted jet distributions
- See Matti's talk for details



# Cutflow and yields



Source	$N_{\text{ev}}^{e\tau_h} \pm \text{stat.} \pm \text{syst.}$	$N_{\text{ev}}^{\mu\tau_h} \pm \text{stat.} \pm \text{syst.}$
HH+HW, $m_H = 120 \text{ GeV}$ , $B(t \rightarrow H^+ b) = 0.05$	$51 \pm 3 \pm 8$	$89 \pm 4 \pm 13$
misidentified $\tau$ (from data)	$54 \pm 6 \pm 8$	$89 \pm 9 \pm 11$
$t\bar{t} \rightarrow WbW\bar{b} \rightarrow \ell\nu b \tau\nu\bar{b}$	$100 \pm 3 \pm 14$	$162 \pm 4 \pm 23$
$t\bar{t} \rightarrow WbW\bar{b} \rightarrow \ell\nu b \ell\nu\bar{b}$	$9.0 \pm 0.9 \pm 1.8$	$13.0 \pm 1.2 \pm 2.5$
$Z/\gamma^* \rightarrow ee, \mu\mu$	$4.8 \pm 1.8 \pm 1.3$	$0.7 \pm 0.7 \pm 0.7$
$Z/\gamma^* \rightarrow \tau\tau$	$17.0 \pm 3.3 \pm 3.0$	$26.0 \pm 4.3 \pm 6.1$
single top quark	$7.9 \pm 0.4 \pm 1.1$	$13.5 \pm 0.5 \pm 1.9$
diboson	$1.3 \pm 0.1 \pm 0.2$	$2.0 \pm 0.2 \pm 0.3$
Total expected background	$194 \pm 8 \pm 20$	$306 \pm 11 \pm 32$
Data	176	288



## Sources of systematic uncertainty ( $\mu\tau_h$ channel) - I

- $\tau$ -fake events from data driven method
- $\tau$  jet ID and jet,  $\ell \rightarrow \tau$  misidentification rate: from tag and probe [4]
- Pileup modeling due to the reweighting of simulated events according to measured vertexes

	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	misident. $\tau$	Single top	diboson	DY( $\mu\mu$ )	DY( $\tau\tau$ )
JES+JER+ $E_T^{\text{miss}}$	6.0	5.0	5.0	4.0		6.0	11.0	100.0	22.0
cross section	$+7.0$ $-10$					8.0	4.0	4.0	
pileup modeling	4.0	2.0	2.0	8.0		2.0	3.0	25.0	4.0
MC stat	5.0	4.0	2.0	9.0		4.0	9.0	100.0	16.0
luminosity	2.2					2.2			
$\tau$ -jet id	6.0	6.0	6.0			6.0	6.0		6.0
jet, $\ell \rightarrow \tau$ misident.				15.0				15.0	
b-jet tagging	6.0	5.0	5.0	5.0		7.0			
jet $\rightarrow$ b misident.							8.0	8.0	9.0
misident. $\tau$ (stat.)					10.0				
misident. $\tau$ (syst.)					12.0				
lepton selections	2.0					2.0			

$e\tau_h$  channel table found in backup



## Sources of systematic uncertainty ( $\mu\tau_h$ channel) - II

- Jet energy/resolution and  $E_T^{\text{miss}}$  scale: from  $p_T$  balance in dijet and  $\gamma$ -jet events
- b-tagging efficiency and misidentification rate: from b-jets properties [5]
- Lepton veto application: from uncertainty in lepton reconstruction, identification and isolation efficiencies

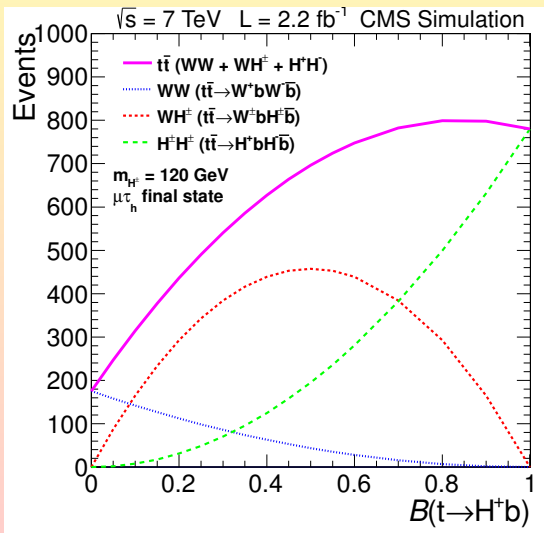
	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	misident. $\tau$	Single top	diboson	DY( $\mu\mu$ )	DY( $\tau\tau$ )
JES+JER+ $E_T^{\text{miss}}$	6.0	5.0	5.0	4.0		6.0	11.0	100.0	22.0
cross section	$+7.0$ $-10$					8.0	4.0	4.0	
pileup modeling	4.0	2.0	2.0	8.0		2.0	3.0	25.0	4.0
MC stat	5.0	4.0	2.0	9.0		4.0	9.0	100.0	16.0
luminosity	2.2					2.2			
$\tau$ -jet id	6.0	6.0	6.0			6.0	6.0		6.0
jet, $\ell \rightarrow \tau$ misident.				15.0				15.0	
b-jet tagging	6.0	5.0	5.0	5.0		7.0			
jet $\rightarrow$ b misident.							8.0	8.0	9.0
misident. $\tau$ (stat.)					10.0				
misident. $\tau$ (syst.)					12.0				
lepton selections	2.0					2.0			

$e\tau_h$  channel table found in backup



## Method for computing the limits

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

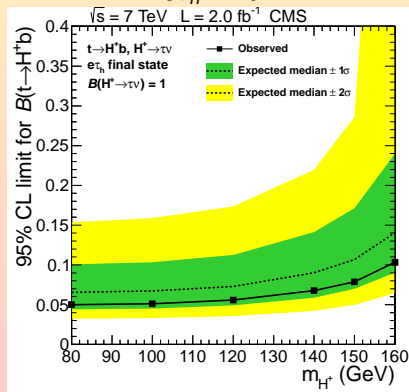




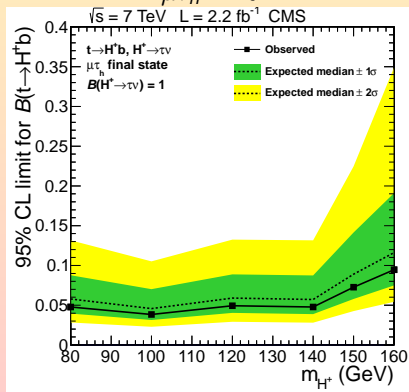
## Limits, $e\tau_h, \mu\tau_h$ final states

- $e\tau_h, \mu\tau_h$  limits
  - Reach 5%
  - Systematics drive the estimation
  - Large bands at high masses
  - More statistics needed
  - Benefit from analysis improvement

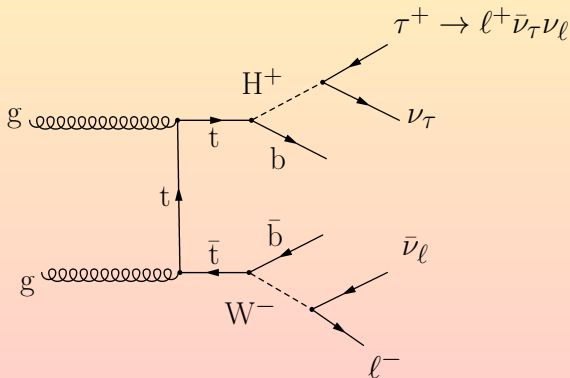
### • $e\tau_h$ limit



### • $\mu\tau_h$ limit



# $e\mu$ final state





## Event selection

- **Trigger: electron-muon trigger**

- One electron with  $p_T > 8 \frac{\text{GeV}}{c}$  and a muon with  $p_T > 17 \frac{\text{GeV}}{c}$   
**OR**  
 one electron with  $p_T > 17 \frac{\text{GeV}}{c}$  and a muon with  $p_T > 8 \frac{\text{GeV}}{c}$
- Integrated luminosity:  $2.27 \pm 0.05 \text{ fb}^{-1}$

- **Selection: 1  $e\mu$  pair,  $\geq 2$  jets, veto low  $e\mu$  masses, opposite sign**

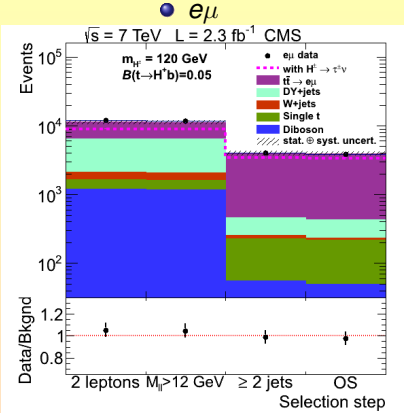
- $\geq 1$  isolated electron and  $\geq 1$  isolated muon with  $p_T > 20 \frac{\text{GeV}}{c}$ ,  
 $|\eta| < 2.5$  (2.4) for  $e(\mu)$
- Two or more jets with  $p_T > 30 \frac{\text{GeV}}{c}$ ,  $|\eta| < 2.4$
- $e\mu$  invariant mass  $M_{e\mu} > 12 \frac{\text{GeV}}{c^2}$
- Electron and muon required to have opposite electric charges

- **Lepton isolation: relative w.r.t. lepton  $p_T$**

- Isolation cut:  $relIso = \frac{I}{p_T^e(\mu)} < 0.15$
- Separation from any other selected jet in  $\Delta R > 0.4$

# Cutflow and yields

- 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



Source	$N_{ev}^{e\mu} \pm \text{stat.} \pm \text{syst.}$
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



## Sources of systematic uncertainty

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

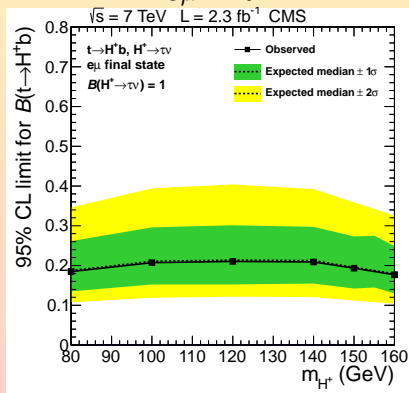
	$HH$	$WH$	$t\bar{t}$	$DY(\ell\ell)$	W+jets	Single top	diboson
JES+JER+ $E_T^{miss}$	2.1	2.0	2.0	6.0	10.8	4.0	6.5
cross section		$+7$ $-10$		4.3	5.0	7.4	4.0
pileup modeling	4.5	4.5	5.0	5.5	4.0	5.5	5.5
MC stat	5.3	7.9	1.0	6.5	42.9	1.9	4.3
luminosity	2.2						
dilepton selection	2.5						



## Limits, $e\mu$ final state

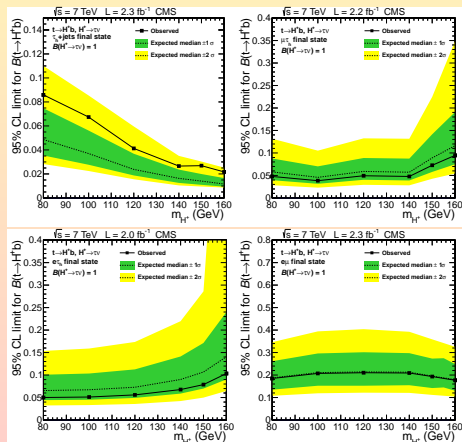
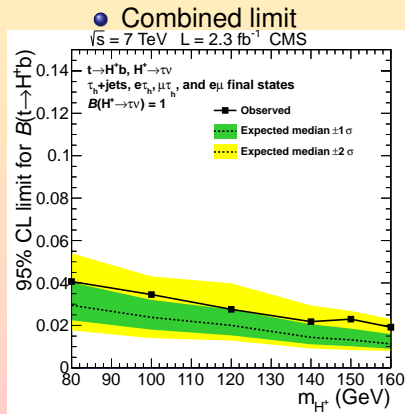
- $e\mu$  channel limit  $\sim 20\%$ 
  - Irreducible SM  $t\bar{t}$  background dominating
  - Would benefit from improved analysis techniques

### $e\mu$ limit



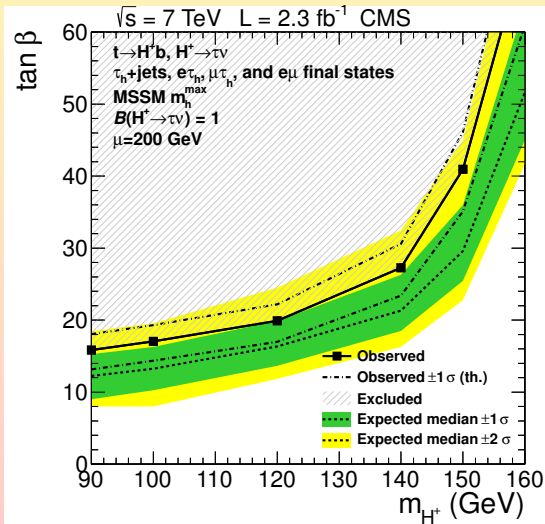
## Model-independent combined limit

- Combined limit calculated for all final states,  $\ell\tau_h$ ,  $e\mu$ ,  $\tau_h + jets$
- Details on fully hadronic final state can be found in Alexandros' talk
- Combined limit is driven by systematics



## Model-dependent exclusion region

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



# Summary



- Search for light MSSM  $H^\pm$  boson in  $\ell\tau_h$  and  $e\mu$  final states at  $\sqrt{s} = 7\text{ TeV}$
- No deviations from expected limit with luminosities of 1 to 2  $fb^{-1}$



## References I



### CMS Collaboration.

Search for a light charged Higgs boson in top quark decays in  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$

[Journal of High Energy Physics, 07 \(2012\) 143.](#)



### 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  $\sqrt{s} = 7 \text{ TeV}$

[CMS-PAS-MUO-10-002, \[CDS:1279140\]](#)



### CMS Collaboration

Performance of  $\tau$ -lepton reconstruction and identification in CMS

[JINST, 7, P01001 \(2012\)](#)



## References II



CMS Collaboration

Performance of the b-jet identification in CMS

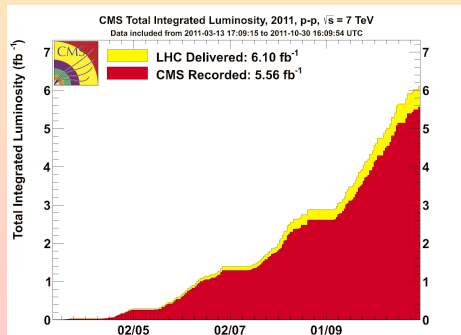
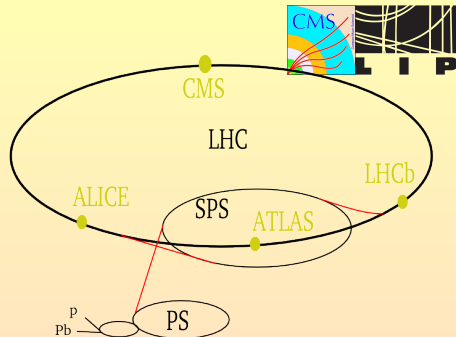
[CMS-PAS-BTV-11-001](#), [CDS:1366061]



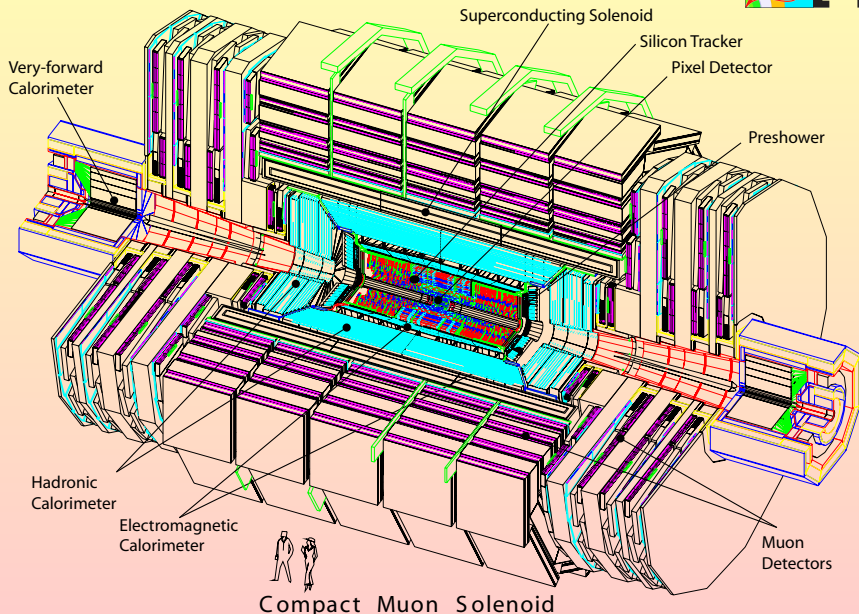
# BACKUP SLIDES

# BACKUP: The Large Hadron Collider

- 26.7 km pp collider located at CERN
- Superconducting magnets
- $T \sim 1.8\text{ K}$ ,  $p \sim 10^{13}\text{ atm}$
- Designed for  $\sqrt{s} = 14\text{ TeV}$ 
  - Operated at  $7\text{ TeV}$  (2011)
  - Operated at  $8\text{ TeV}$  (2012)
- Current  $L^{inst} \sim 8 \times 10^{33}\text{ cm}^{-2}\text{ s}^{-1}$
- Delivered:  $6.10\text{ fb}^{-1}$  (2011)
- Results presented here [1]:
  - Data recorded by CMS detector
  - $L^{inst} \sim 3 \times 10^{33}\text{ cm}^{-2}\text{ s}^{-1}$
  - $\sqrt{s} = 7\text{ TeV}$
  - $L^{int} = 1 - 2\text{ fb}^{-1}$



# BACKUP: The Compact Muon Solenoid

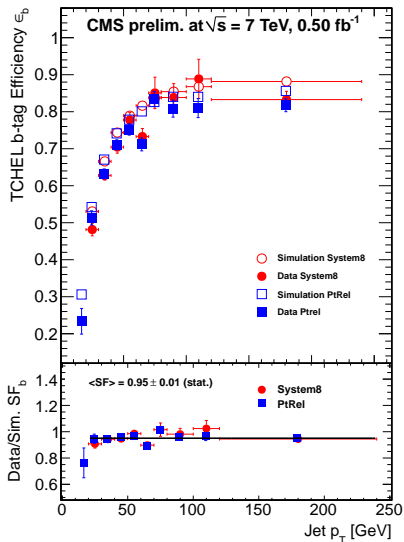


Compact Muon Solenoid

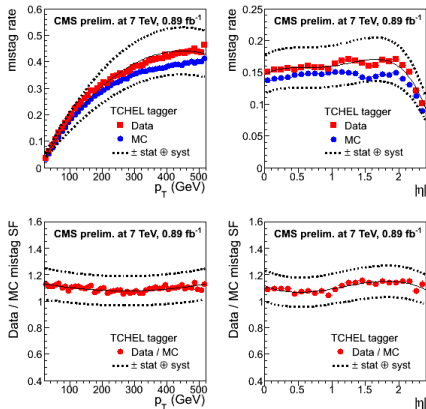


# BACKUP: b-jet tagging

## ● Eff. from $\mu$ -jet events



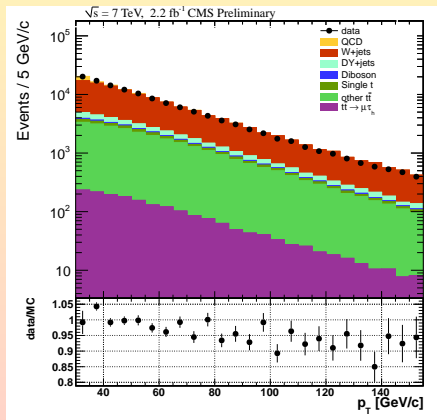
## ● Mistag rate



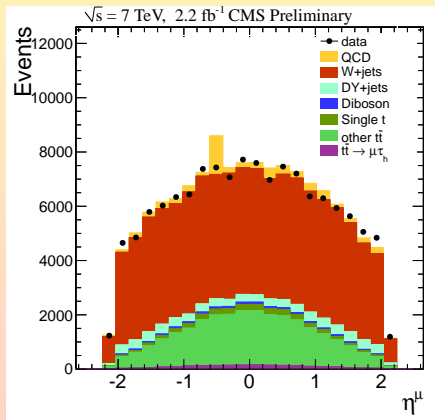


# BACKUP: Control distributions at ( $1\mu$ , 3 jets) step

## • Muon $p_T$ ( $1\mu$ , 3 jets) step



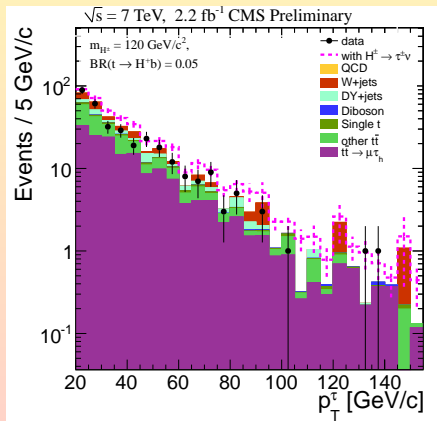
## • Muon $\eta$ ( $1\mu$ , 3 jets) step



# BACKUP: Control distributions at $(1\mu, 3 \text{ jets}, E_T^{miss}, 1 \text{ b-jet})$ step

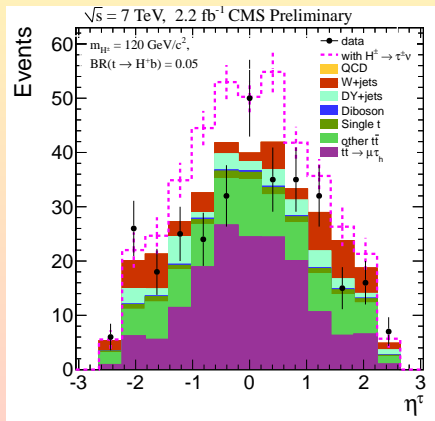
## • Tau $p_T$

$(1\mu, 3 \text{ jets}, E_T^{miss}, 1 \text{ b-jet})$  step



## • Tau $\eta$

$(1\mu, 3 \text{ jets}, E_T^{miss}, 1 \text{ b-jet})$  step

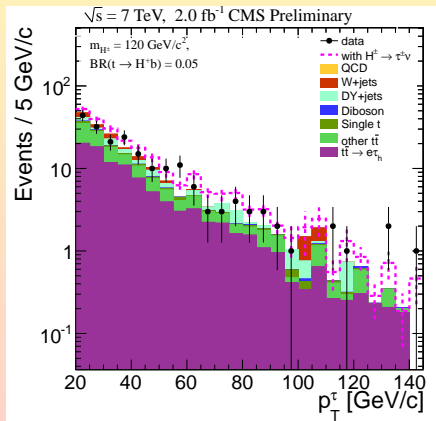




# BACKUP: Control distributions at (1e, 3 jets, $E_T^{miss}$ , 1 b-jet) step

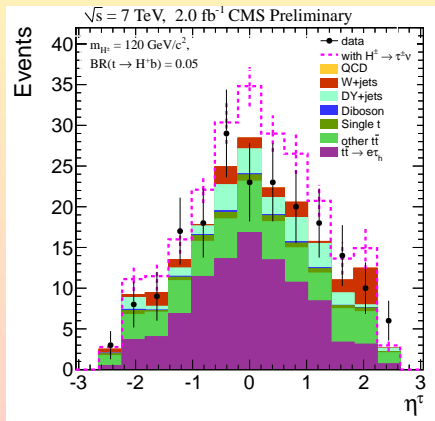
## • Tau $p_T$

(1e, 3 jets,  $E_T^{miss}$ , 1 b-jet) step



## • Tau $\eta$

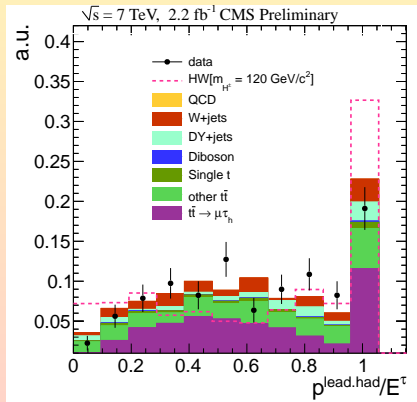
(1e, 3 jets,  $E_T^{miss}$ , 1 b-jet) step



# BACKUP: Control distributions at $(1\mu, 3 \text{ jets}, E_T^{\text{miss}}, 1 \text{ b-jet})$ step



## • Tau $p_T$ ( $1\mu, 3 \text{ jets}, E_T^{\text{miss}}, 1 \text{ b-jet}$ ) step





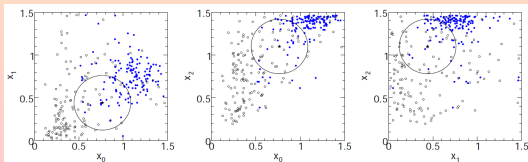
## BACKUP: Fake rate estimation strategy

- Calculate probability  $w(jet \rightarrow \tau)$ 
  - Operate at selection step (1 lep)+(MET)+(≥ 3 jets)+(≥ 1 b-tagged jet)
  - $\ell + \geq 3jets$  event, with one jet faking  $\tau$ 
    - From multi-jet data sample (“W-Jets”, mainly g-jets  $\rightarrow$  overestimation)
    - From photon+jet data sample (“QCD-Jets”, mainly q-jets  $\rightarrow$  overestimation)
  - Build phase space:  $(p_T^{jet}, |\eta^{jet}|, R^{jet} = \sqrt{\sigma_{\eta\eta}^2 + \sigma_{\phi\phi}^2})$
  - Divide inclusive distributions into two categories:
    - **Jets that fake taus (cat. F):** jet with the nearest  $\tau$  within  $\Delta R < 0.3$
    - **Jets that don't fake taus (cat. NF):** all the others
  - Apply to the two subsets k-nearest-neighbours algorithm in the phase space
  - Obtain weight for each jet describing the probability of faking a  $\tau$
  - Ratio between the weighted and unweighted distribution is  $w(jet \rightarrow \tau)$
- Apply the fake rate probability to the data sample at the  $1\tau$  selection step
- Obtain an estimate of the number of the background events faking taus



## BACKUP: $w(jet \rightarrow \tau)$ estimate - kNN algorithm details

- Weights parametrized in the phase space and determined by a multivariate method
- Each jet is compared with the nearest jets which populate the phase space
- Count  $N(\text{nearest jets in } \mathbf{F})$  and  $N(\text{nearest jets in } \mathbf{NF})$
- Estimator: number of the nearest jets that are in the  $\mathbf{F}$  category
- Usually, training performed in a fixed volume in the phase space (PDE-RS algorithm)
- Nearest-Neighbour algorithm: training within a fixed number of jets, instead of in a fixed volume
  - Volume is resized as a function of the local data density
  - Finer description of local features of high-density regions
- Final per-jet weight is proportional to  $\frac{N_{\text{jets faking taus}}}{20}$
- Fake probability as a function of each variable from ratio  $\frac{\text{incl weighted distribution}}{\text{incl unweighted distribution}}$





# BACKUP: Fake tau backgrounds using data driven method, after 1st step

## • $\mu\tau_h$ channels

Sample	MC expectation	Estimated from MC	Estimated from data	Residual from MC
QCD multi-jet	$120.1 \pm 8.9$	105.1	113.0	34.4
W+jets		147.3	144.5	44.3
Average		$126.2 \pm 21.1$	$128.8 \pm 15.8$	$39.4 \pm 4.9$

## • $e\tau_h$ channels

Sample	MC expectation	Estimated from MC	Estimated from data	Residual from MC
QCD multi-jet	$57.9 \pm 5.1$	54.9	64.1	19.6
W+jets		78.9	86.7	27.4
Average		$66.9 \pm 12.0$	$75.4 \pm 11.3$	$23.5 \pm 3.9$

- **MC expectation:** yields from simulation ( $W + jets, t\bar{t} \rightarrow \ell\nu b\ell\nu\bar{b}$ )
- **Estimated from MC:** apply data driven method to simulation events
- **Estimated from data:** apply data driven method to data. After res. subtraction
- **Residual from MC:** apply data driven method to other MC and remove from data



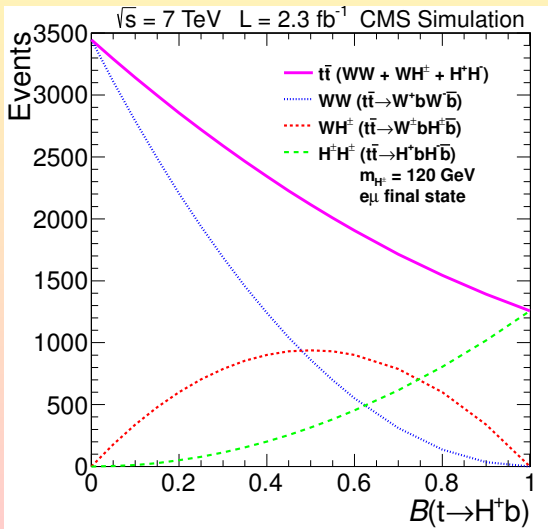
# BACKUP: sources of systematic uncertainty ( $e\tau_h$ channel)

	HH	WH	$t\bar{t}_{\ell\tau}$	$t\bar{t}_{\ell\ell}$	misident. $\tau$	Single top	diboson	DY( $\mu\mu$ )	DY( $\tau\tau$ )
JES+JER+ $E_T^{\text{miss}}$	8	6	4	5		6	9	21	14
cross section	$+7.0$ $-10$					8.0	4.0	4.0	
pileup modeling	3	4	2	3		3	5	17	3
MC stat	6	5	3	10		5	7	37	20
luminosity	2.2					2.2			
$\tau$ -jet id	6.0	6.0	6.0			6.0	6.0		6.0
jet, $\ell \rightarrow \tau$ misident.				15.0				15.0	
b-jet tagging	6	6	5	5		7			
jet $\rightarrow$ b misident.							8	7	8
misident. $\tau$ (stat.)					12				
misident. $\tau$ (syst.)					15				
lepton selections	3.0					3.0			
trigger	1.0					1.0			



## BACKUP: Method for computing the limits

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





# BACKUP: 95% CL upper limits for $Br(t \rightarrow H^+ b)$

95% CL upper limit on  $\mathcal{B}(t \rightarrow H^+ b)$

$m_{H^+}$ (GeV)	Expected limit					Observed limit
	$-2\sigma$	$-1\sigma$	median	$+1\sigma$	$+2\sigma$	
80	0.018	0.022	0.029	0.040	0.054	0.041
100	0.014	0.018	0.024	0.032	0.043	0.035
120	0.013	0.015	0.028	0.027	0.040	0.028
140	0.009	0.011	0.014	0.021	0.030	0.022
150	0.008	0.010	0.013	0.019	0.027	0.023
160	0.008	0.009	0.011	0.016	0.023	0.019



## BACKUP: MSSM $m_h^{max}$ scenario for $\tan(\beta)$ exclusion

- $M_{SUSY} = 1 \text{ TeV}$  (common soft-SUSY-breaking squark mass of the third generation)
- $\mu = +200 \text{ GeV}$  (Higgsino mass parameter)
- $M_2 = 200 \text{ GeV}$  (SU(2)-gaugino mass parameter)
- $m_{\tilde{g}} = 0.8 \times M_{SUSY}$  (gluino mass)
- $X_t = 2 \times M_{SUSY}$  ( $A_t - \frac{\mu}{\tan(\beta)}$  stop mixing parameter)
- $A_b = A_t$  (trilinear stop and sbottom couplings)
- $M_1$  fixed via unification relation  $M_1 = \frac{5}{3} M_2 \sin(\theta_W) \cos(\theta_W)$

# BACKUP: Exclusion region in the $M_A, \tan(\beta)$ space for combined analysis

## ● Exclusion region (all channels)

