Prospects for Charged Higgs Discovery at Colliders

Uppsala, 16-19 September 2008

Charged Higgs Prospects with CMS

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Introduction

Studies for H^+ discovery reach in MSSM were complished during 2006
-The m_h(max) scenario with μ=200 GeV/c^2 was used
-Main results based on full simulation studies will be shown in the following

Studies are in progress for analysis methods and data driven background measurements
-Some preliminary results are discussed

Contents:
- Searches for the light charged Higgs bosons with the **$H^\pm$ -> $\tau\nu$** decay channel in the tt events
- Searches for the heavy charged Higgs bosons:
  - with the **$H^\pm$ -> $\tau\nu$** decay channel
  - with the **$H^\pm$ -> tb** decay channel
- Recent studies for methods and background measurements

Search for light charged Higgs bosons

- Search strategy is based on looking for excess of events over SM expectation :

$$\sigma = \frac{N_{obs.}^{MSSM} - N_B^{SM}}{\sqrt{N_B^{SM}}}$$

Signal process **gg -> tt -> $W^{\pm}H^{\pm}$bb->$\ell\nu\tau\nu$bb, ℓ = e or** μ, including off-shell contributions near $m_{H+} = m_{top}$ with the process **gb->t$H^{\pm}$**
Signal generation with PYTHIA, τ decays with TAUOLA

Backgrounds: pp ->tt->W^+W^-bb, $W^+ \to \tau^+\nu$, $W^- \to \ell\nu$, pp ->tt->W^+W^-bb, W^+->jj, $W^- \to \ell\nu$
pp ->tt->W^+W^-bb, $W^+ \to \ell\nu$, $W^- \to \ell'\nu$, W+3 jet production

Event generation:
tt background (with τ+lepton, jet+lepton and lepton+lepton) with **PYTHIA**
W+3jets, $W \to \ell\nu$ and Zbb, $Z \to \ell\ell$ with **MadGraph**
Wt, $W_1 \to \ell\nu$, $W_2 \to \tau\nu$ or qq, tq+tb, t->Wb$\to \ell\nu$b, Wbb, $W \to \ell\nu$, with **TopRex**

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Event selection and τ-jet identification

Event selection

- one lepton passing the Level-1 and HLT triggers
- at least 3 jets with $E_T > 40$ GeV
- exactly one b jet
- one identified τ jet, $E_T > 40$ GeV
- $Q_\ell \times Q_\tau = -1$
- Missing $E_T > 70$ GeV

Identification of the τ jet:

- Tracker isolation with signal cone = 0.07, isolation cone= 0.4, $p_T > 1$ GeV for tracks
- ECAL isolation: ΣE_T^{cell} $(0.13<\Delta R<0.4) < 5.6$ GeV
- Electron supression: E_T(HCAL cell in the jet) > 2 GeV
- $p^{leading\ track} / E^\tau > 0.8$, to exploit the opposite τ helicity correlations in the **H±** -> $\tau\nu$ and **W±** -> $\tau\nu$ decays, leading to harder pions from **H±** -> $\tau\nu$

Efficiencies:

signal 11-15%, tt->WWbb -> bb$\tau^+\nu\ell\nu$ 5%, W+3jets 1%, tt->WWbb -> bb$\ell'\nu'\ell\nu$ 2%

W+jet background

Data driven medhod for the measurement of W+jet background

Event selection to obtain a sample in a signal-free ”area” :

- one lepton (Level-1 and HLT)
- **3 non-b jets**
- **no τ jets**
- including pixel isolation for an electron to avoid QCD background
- substraction of the tt contribution
- propagation to ”signal area” through:

$$N_S^{W+3\,jets} = \in_{W+3\,jets}^{S} \frac{N_B^{obs.} - N_B^{t\bar{t}}}{\in_{W+3\,jets}^{B}}$$

where N^B_{tt} is the tt contamination, ε^S and ε^B efficiencies for signal and background selections

Systematic uncertainty can be estimated as

$$\Delta_{sys.}^{W+3j} = \Delta_{stat.} \oplus \frac{\Delta N_B^{t\bar{t}}}{N_B^{W+3j}} \oplus \Delta_{3non-b-jet} \oplus \Delta_{1b-jet\ mistag} \oplus \Delta_{1tau\ mistag}$$

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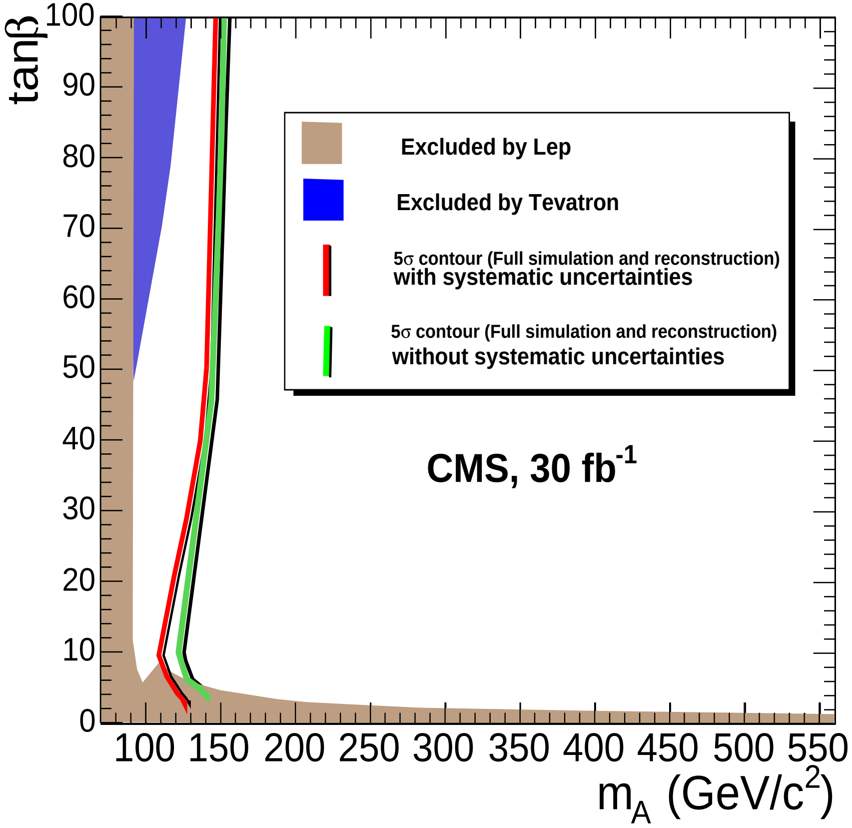
Expected $H^{\pm}$ discovery reach for gg -> tt -> $W^{\pm}H^{\pm}$bb->$\ell\nu\tau\nu$bb

in m_h^{max} scenario with μ = 200 GeV



Systematic uncertanties from
jet energy scale (3%),
missing E_T scale (10%),
b tagging (5%), τ tagging(4%),
lepton identificatio (2%),
b mis-tagging (5%),
τ-mis-tagging (2%), luminosity (3%)
estimates for 30 fb^{-1}
tt cross section (5.6%)

Systematic uncertainties added quadratically to the statistical uncertainty

Heavy Charged Higgs bosons with $H^{\pm} \to \tau\nu$

Published results based on CMS full simulation

Event genaration with the **$gg \to tbH^{\pm}$** process
- allows predictions close to the tt threshold

Signal generation with PYTHIA, Normalization to the NLO cross sections

Background generation:
- tt with PYTHIA
- Wtb with Toprex
- W+3jets with Madgraph
- QCD multi-jet with PYTHIA

τ decays with TAUOLA in signal and backgrounds

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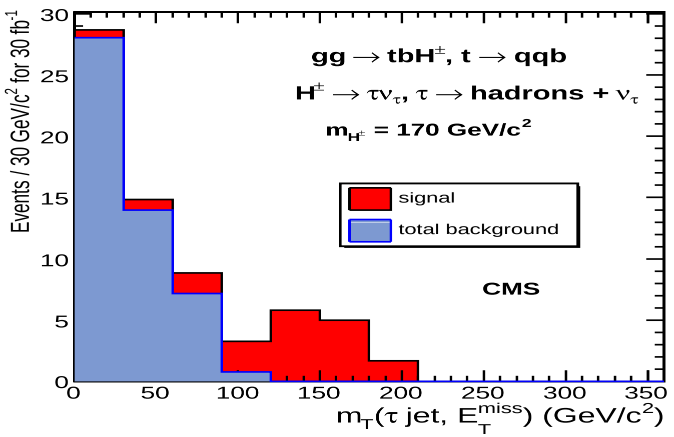
Event selection for published results

Trigger: Level-1: τ jet, **E_T > 93 GeV,** HLT: **Missing E_T > 67 GeV**,
p_T > 25 GeV for the leading track, **isolation** in a cone around the leading track

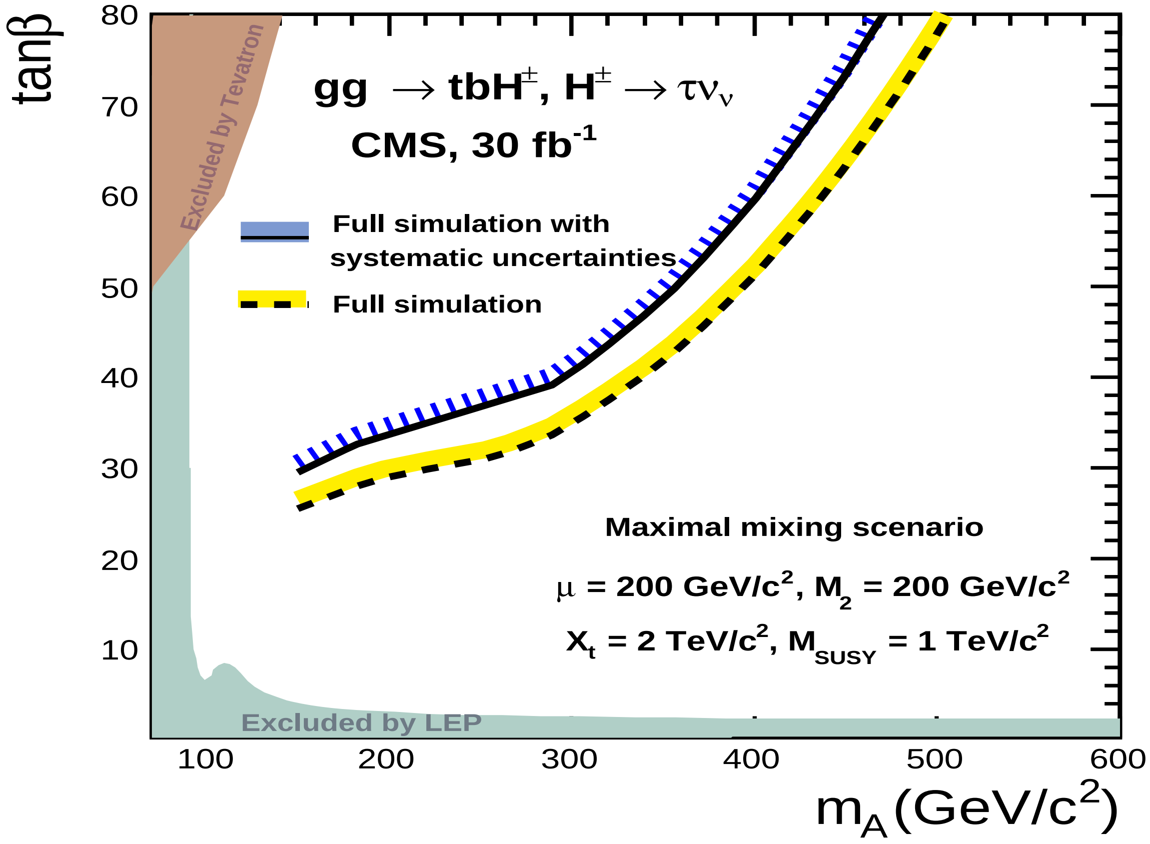
Offline analysis:

- Veto on isolated leptons from W->$\ell\nu$ to ensure missing E_T from $H^{\pm}$ -> $\tau\nu$
- Identification of one hadronic τ jet
  - cone algorithm, track and ECAL isolation, helicity cut: $p^{\text{leading track}}/E^{\text{t jet}} > 0.8$
  - signal efficiency 4-9%, hadronic jet rejection ~10^4
- Missing E_T > 100 GeV
- W and top mass reconstruction, b tagging
- veto on addional central jets with E_T > 25 GeV
- transverse mass reconstruction from the τ jet and Missing E_T

Transverse mass distributions for the signal and background with all selection cuts



Discovery potential



Total background in the signal area $m_T > 100$ GeV:

1.7 ± 1.0 events

including systematic uncertainties, main source jet and E_T^{miss} scales

SUSY corrections not taken into account in the production

H^+ discovery reach and parameter dependence

M. Hashemi, S. Heinemeyer, R. Kinnunen, A. Nikitenko and G. Weiglein, DCPT-08-38, IPPP-08-19, Apr 2008

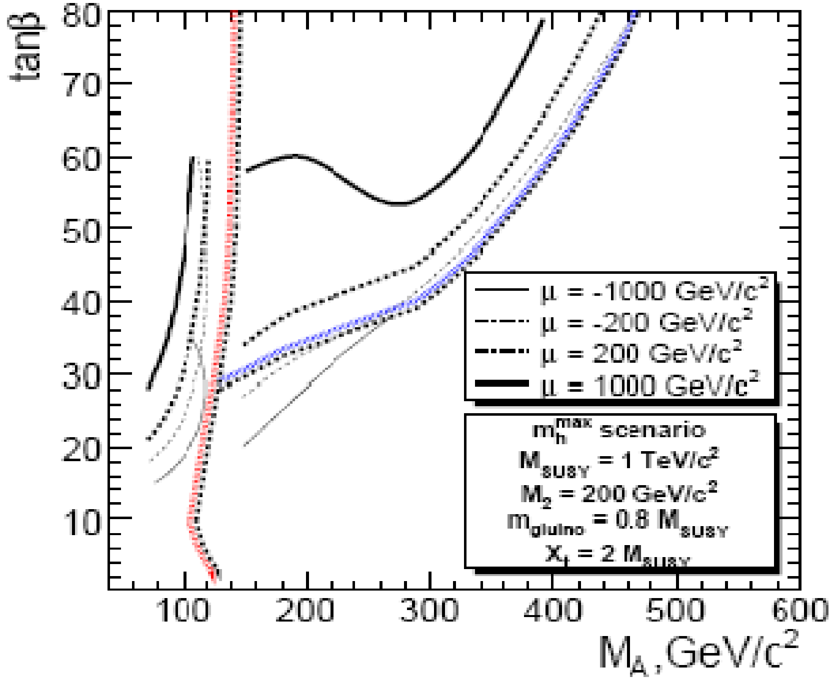


Figure 3: Discovery reach for the charged Higgs boson of CMS with 30 fb^{-1} in the M_A–$\tan\beta$ plane for the m_h^{max} scenario for $\mu = \pm 200, \pm 1000$ GeV in comparison with the results from the CMS PTDR (thickened dotted (red and blue) lines), obtained for $\mu = +200$ GeV and neglecting the Δ_b effects.

Variation smaller in the no-mixing scenario

Search for charged Higgs bosons with $H^{\pm}$ -> tb

- final state: bbbqq'lν
  - isolated lepton to trigger on
  - charged Higgs mass can be reconstructed
  - only final state with muon investigated

Search strategies for $H^{\pm} \rightarrow tb$

- resolving 3 b-jets: inclusive mode
  - → LO production through $gb \rightarrow tH^{\pm}$
  - → large background from $t\bar{t}$ + jets
  - → high combinatorics
- resolving 4 b-jets: exclusive mode
  - → LO production through $gg \rightarrow tH^{\pm}b$
  - → smaller background (from $t\bar{t}b\bar{b}$ and $t\bar{t}jj$ + 2 mistags)
  - → even higher combinatorics

Event generation and selections

Signal generation with **PYTHIA**, **gb -> $tH^\pm$** for 3b selection
and **gg -> $tbH^\pm$** for 4b selection
Background generation:
ttjj with **MadGraph/MadEvent** for 3b selection
ttbb and ttjj with **CompHEP** for 4b selection

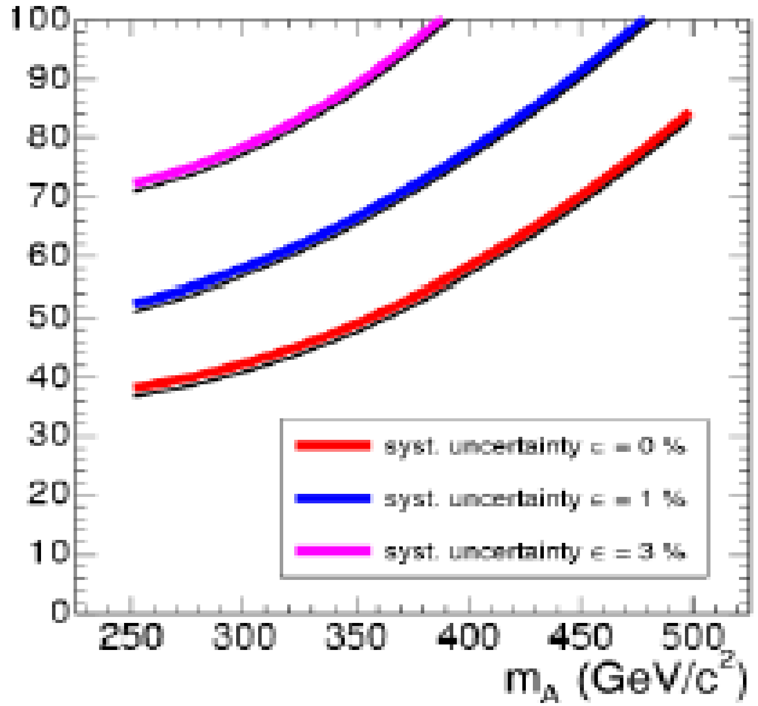
Event selection and background suppression:

- one isolated lepton
- at least 5 (6) jets for the 3(4)b selection with E_T > 25 GeV
- at least 3 (4) b-tagged jets for the 3(4)b selection with E_T > 25 GeV
- Kinematic fit for H^+ mass reconstruction
- Combined Likelihood ratio method for
  - selecting best possible jet association
  - suppression of backgrounds

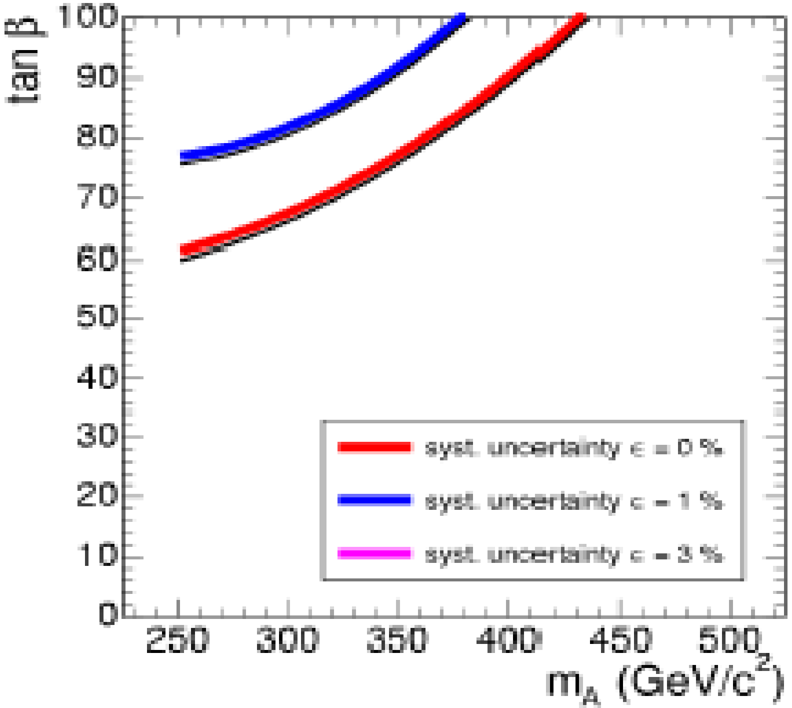
with several varibles (p_t^{bjet}, η^{bjet}, b-discriminator, χ^2 probability of the kinematic fit..)

$H^{\pm}$ Observability in the $H^{\pm}$ ->tb decay

3 b-tag channel



4 b-tag channel



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Ongoing study on selection methods and background measurements

New features in background generation

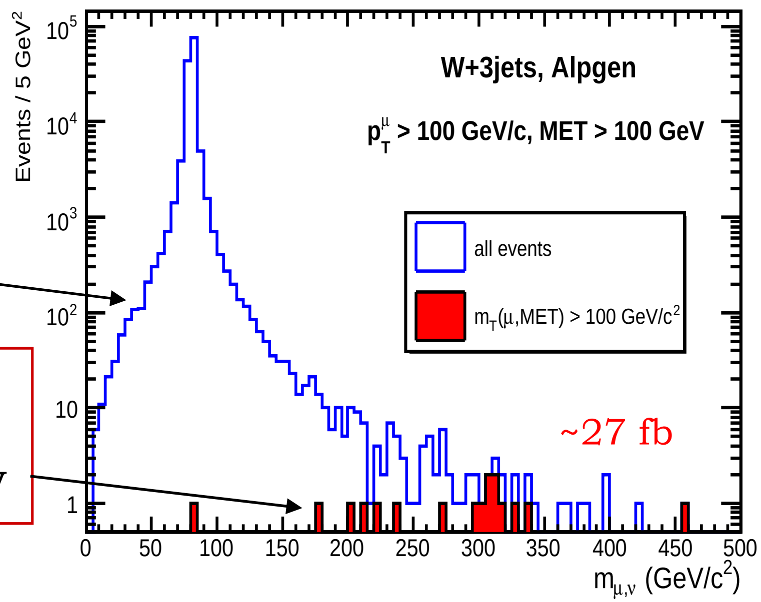
- Generation of tt and W+3/4jet backgrounds with **ALPGEN+TAUOLA**
- tt with with tt+0jet (74%) and tt+1jet (21%) production
- **W+3/4 jet generation in 2 W-mass bins, 0-150 GeV, 150-500 GeV** to obtain good statistics in the important large mass tail (courtesy of M. Mangano)

CMS Very Preliminary

W+3/4jet events become signal-like in the BW-tail of W

Full W+3jet sample

Events selected in a background study with muons, main cuts: $p_T^{\mu} > 100$ GeV, missing $E_T > 100$ GeV, $m_T(\mu, E_T^{miss}) > 100$ GeV



Trigger for gg->tbH$^{\pm}$, H$^{\pm}$ ->$\tau\nu$

New features: lowered E_T thresholds, ECAL isolation, tracker selection on two levels

Level 1: Single tau, E_T > 80 GeV

Level 2: Missing E_T > 65 GeV, ECAL isolation of tau candidates

- Sum of ECAL transverse deposits in $0.13 < \Delta R < 0.4$ smaller than 5 GeV

Level 2.5 : Signal vertex from pixel reconstruction
Regional track reconstruction with maximum 7 hits
Reconstruction region in $\eta-\phi$: 0.1x0.1
Isolation in $0.065 < \Delta R < 0.4$, $p_T^{\text{leading track}} > 20$ GeV,
isolation tracks p_T >5 GeV

Level 3: As for Level2.5 but with wider reconstruction region in $\eta-\phi$:
0.5x0.5 and isolation tracks $p_T > 1$ GeV

Off-line selection and methods

1. Selection of hadronic events to ensure missing E_T from $H^{\pm} \rightarrow \tau\nu$:
   - **Veto on isolated electrons** with $p_T > 8$ GeV/c
   - **Veto on all reconstructed muons** with $p_T > 4$ GeV/c

2. **Identification of one energetic hadronic τ jet**, $E_T > 100$ GeV,
New ⟶ **devided to 1- and 3-prong selections**
   - Kinematic cuts, isolation and other τ identification cuts
   - τ helicity-correlation cuts

New ⟶ ~~3.~~ **Veto on additional τ jets** (from the associated top)
   - Identification of soft τ jets
4. **Missing E_T** > 100 GeV
5. **B tagging**
6. **W and top mass reconstruction**
7. transverse mass reconstruction from the τ jet and Missing E_T

New ⟶ **No veto on addional central jets**

Identification of the τ jet from $H^{\pm} \to \tau\nu$

Goal is to obtain:
~10^5 supression for hadronic jets to keep under control the QCD multi-jet backgroud
(further suppression mainly from Missing E_T cut)

~100-1000 suppression of genuine τ jets from the tt and W+3/4jet backgrounds

~10% signal efficiencies for 1-prong τ jets

Identification based on calorimeter τ jets

- Some improvements can be expected from **Particle Flow method** or **a method correcting τ-jet with tracks**: replace the calorimeter τ jet with tracks whenever possible, correcting for π^0's

Algorithm of reconstructing large E_T one-prong τ's, "HardTauAlgorithm"

for **good geometrical ECAL-HCAL-track matching** :

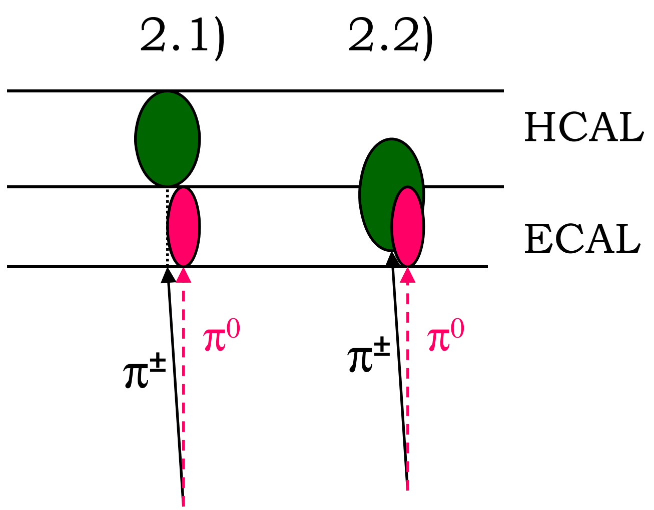
1. If $|E_T^{HCAL+ECAL} - p_T^{track}| < 2\,\sigma_{CALO}$: use **τ ~ track p**, corresponds to $\tau \to \pi^{\pm} + \nu$

2. If $E_T^{HCAL+ECAL} - p_T^{track} > 2\,\sigma_{CALO}$
   - 2.1 if $|E_T^{HCAL} - p_T^{track}| < 2\,\sigma_{HCAL}$: use **τ ~ track p + ECAL cluster**, corresponds to $\tau \to \pi^{\pm} + n\pi^0 + \nu$ with charged pion not interacting in ECAL
   - 2.2 if $p_T^{track} - E_T^{HCAL} > 2\,\sigma_{HCAL}$, $\pi^{\pm}$ interaction in ECAL, take the **calo jet**
   - 2.3 if $E_T^{HCAL} - p_T^{track} > 2\,\sigma_{HCAL}$, hadronic jet, **reject**

3. If $E_T^{HCAL+ECAL} - p_T^{track} < 2\,\sigma_{CALO}$: track reconstruction problem, **reject**

Optimization was performed for:
- the cones for energy collection in ECAL and HCAL
- the regions for the categories

Performance of the method:
Resolution and efficiency for τ jets with E_T>100 GeV very similar to the one obtained from the PF method



New τ selection

- Kinematical selections
  - $E_T^{jet} > 100$ GeV, smaller η range, **$|\eta^{jet}| < 2.0$,** helps to reduce QCD and W+3/4jet backgrounds
- Tight isolation with charged tracks
  - consider good tracks with **$p_T > 0.5$ GeV,** significant improvement of isolation power against QCD
  - signal cone 0.04, isolation cone 0.45
- Electromagnetic isolation, rejection of neutral hadrons and electrons with track/HCAL matching

One-prong selection

- Track quality cuts for leading track, Helicity correlation cut

Three-prong selection

- Selection of $\tau \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\pm}$ decay modes (~10% of τ decays)
- Helicity correlation cut for 3-prongs
- Invariant mass cut, efficient due to charged content of the τ jet
- Cut on flight path significance

Helicity correlation cut

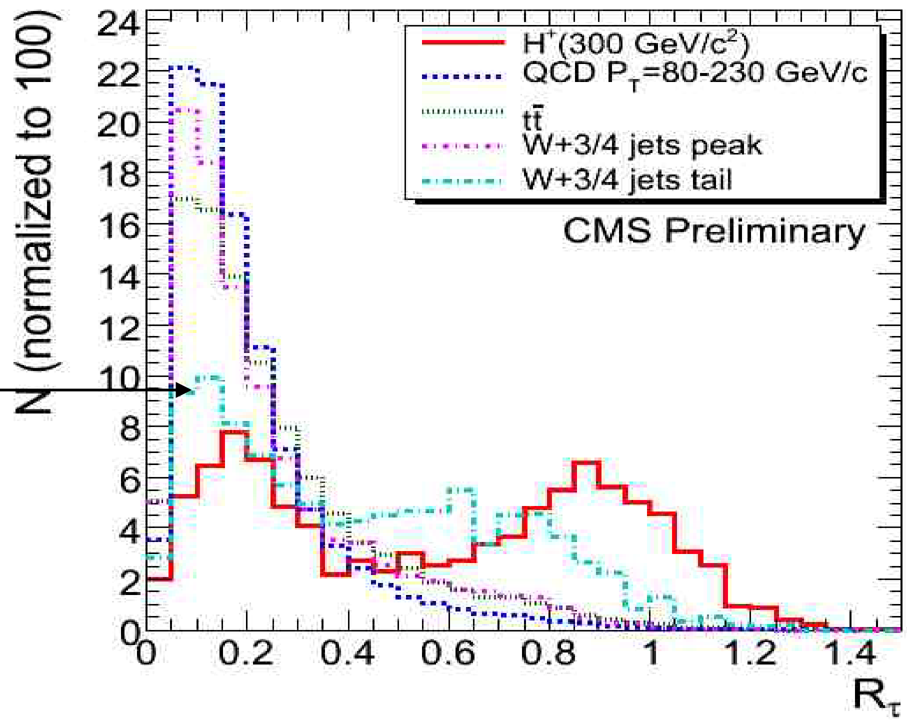
•Helicity correlations: fraction of visible energy is larger for τ jets coming from $H^{\pm}$ decay than for τ jets coming from W decay in tt and W+3/4jet events

Define R_{τ} and cut value:

$R_{\tau} = p^{ldg\ trk} / E^{jet} > 0.8$ for 1-prong τ jets

W+3/4jet events in the large W mass tail become signal-like, due to the large boost from mass

R_{τ} for 1-prong final state with kinematical cuts



Large improvement in R_{τ} shape with PF method or with HardTauAlgorithm

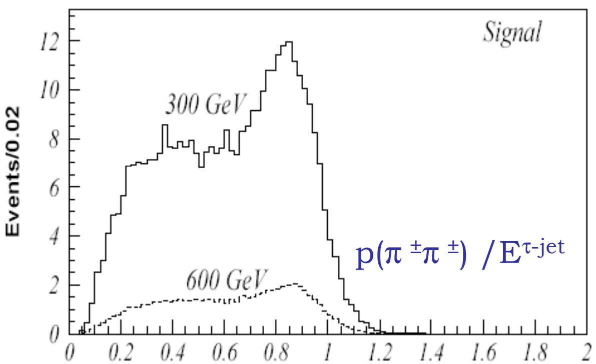
Features of the 3-prong selection

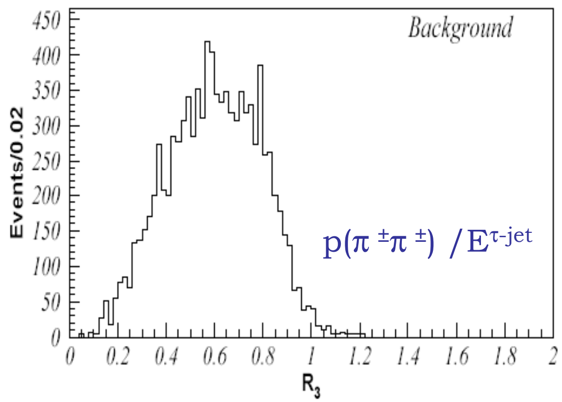
Select the $\tau \rightarrow a_1^{\pm} \nu$, $a_1^{\pm} \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\pm}$ **decay modes only**
(2/3 of all $\tau \rightarrow 3\pi^{\pm}\nu + X$ decays) to suppress the hadronic QCD jets
Selection with calorimeter/track matching variable:
$|\Sigma p^{tracks} / E^{jet} - 1| < 0.3$

Helicity correlation cut: $p(\pi^{\pm}\pi^{\pm}) / E^{\tau\text{-jet}} > 0.75$, selects a_{1L} decays where charged pions carry very little or most of the τ jet energy

M. Guchait, R. Kinnunen, D.P. Roy, hep-ph/0608324, $p(\pi^{\pm}\pi^{\pm}) / E^{\tau\text{-jet}} > 0.8$ or $p(\pi^{\pm}\pi^{\pm}) / E^{\tau\text{-jet}} < 0.3$ was proposed, but QCD background too large for $p(\pi^{\pm}\pi^{\pm}) / E^{\tau\text{-jet}} < 0.3$

Fast simulation





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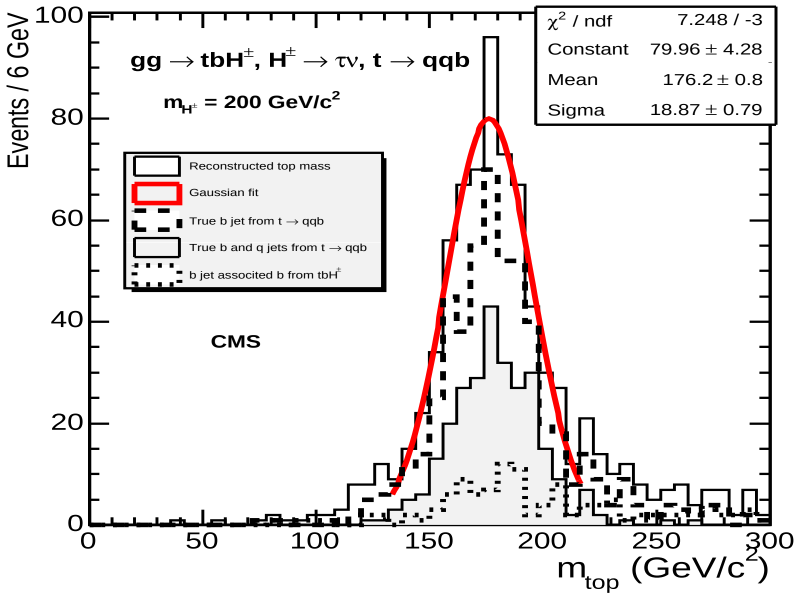
Hadronic top and W mass reconstruction

Published results:

Simple fit with $\chi^2 = ((m_{jj} - m_W)/\sigma_W)^2 + ((m_{jjj} - m_{top})/\sigma_{top})^2$

- One jet in m_{jjj} the best tagged b jet

– σ_w and σ_{top} from a fit with MC matching



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Hadronic top and W mass in the new study

Kinematic fit:

Minimization of $\chi^2 = ((m_{jj} - m_W)/\sigma_w)^2 + ((m_{jjj} - m_{top})/\sigma_{top})^2 + \Sigma((E_i^m - E_i)/\sigma_i)^2$

with respect to jet energies E_i , one jet (p_3) b tagged
with the constraints, $m_{jj}^2 - (p_1 + p_2)^2 = 0$, $m_{jjj}^2 - (p_1 + p_2 + p_3)^2 = 0$

- b jet chosen as the one with maximum b-discriminator value, $E_T > 30$ GeV
- Minimization was done using Lagrange Multipliers and Partitioned Matrix Method.
- σ_i are the estimated jet uncertainties in the CMS detector
- $\chi^2 < 9.2$ required

- Large improvement in the W and top mass resolutions

- W and top peaks appear in the (W+jets, QCD) backgrounds also, but improvement of S/B ratios is obtained with mass window cuts

Background analysis with muons

Data driven method to measure the tt and W+3/4jet backgrounds due to missing E_T mis-measurement
-Exploits the precise muon momentum measurement in W->μν decays

Data sample used: **muonic multi-jet events**

Preliminary study was performed with
- separating the tt and W+jet components with b jets and W/top mass
- propagating the result to ”signal-selection” scaling with efficiencies in signal selection and in muon selection

\- drawback: **complicated estimation of systematic uncertainties**

Plan for optimized study

\- replacing the muon with τ with the same energy and decaying the τ with correct polarization state
\- running the standard signal selection
\- no separation of tt and and W+jet backgrounds

Event selection used in the preliminary study

Off-line selection cuts for events from single muon trigger:

- One isolated muon with $p_T^{\mu} > 100$ GeV
- Lepton veto, τ-jet veto
- $E_T^{miss} > 100$ GeV
- 3 jets, $E_T > 20$ GeV

tt selection:

- **2 b jets**, suppression of W+jets
- W and top reconstruction, suppression of W+jets and recidual τ jets
- $m_T(\mu, E_T^{miss})$ reconstruction

W+3/4jet selection:

- **no b jets**, suppression of tt
- top and W mass veto, suppression of tt, **no τ-jet suppression**
- $m_T(\mu, E_T^{miss})$ reconstruction

Propagation of the selected tt events to "signal selection" with

$N^{tt}_{signal\text{-}sel} = (N^{tt}_{ttsel} - N^{W3/4j}_{ttsel}) * (\varepsilon^{\tau}/\varepsilon^{\mu})$, subtracting the W+3/4jet contamination

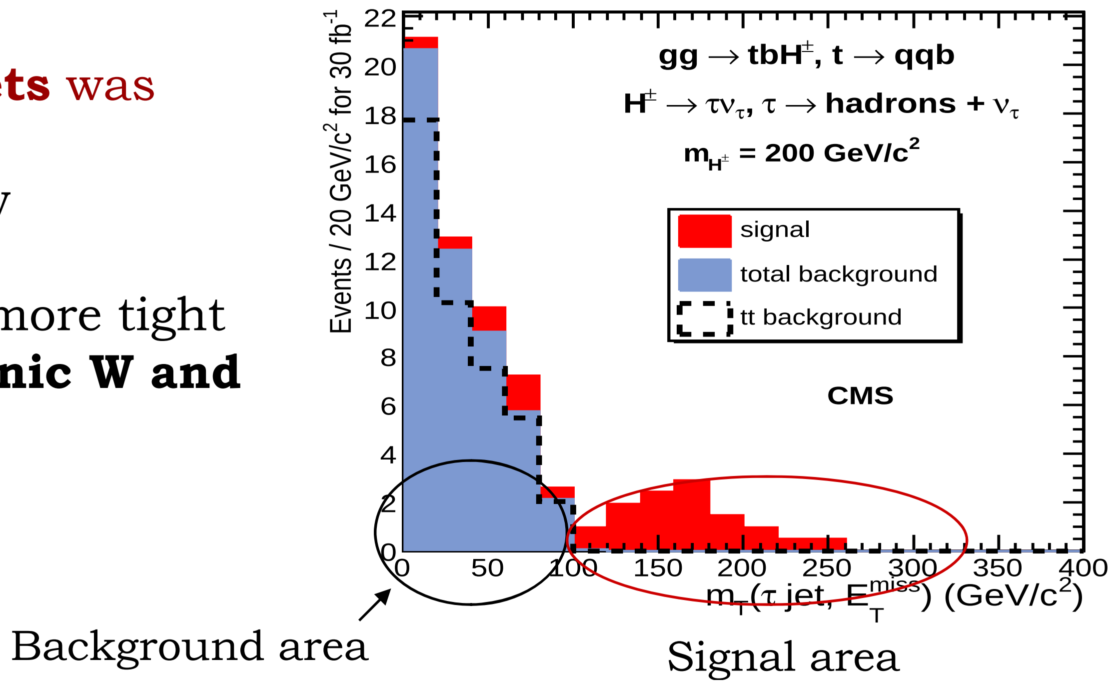
Further drawback observed: **difficult to suppress the tt contamination for the W+3/4jet selection**

Importance of hadronic purity

Result learned from the preliminary background study with muons

W->τν->hadrons+νν decays from the associated top were found as an important background source in tt events
-Addional neutrinos alter the direction and magnitude of E_T^{miss} and the background event can fall to the signal area, large $m_T(\tau\,jet, E_T^{miss})$

Veto on addionnal τ jets was introduced,
- challenging due to low E_T scale of the τ jets
- maybe replaced with more tight requirements on **hadronic W and top masses**



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QCD multi-jet background

Method to measure the background with hadronic multi-jet data

Event selection:

- tau + MET trigger
- At least one jet with $p_T^{jet} > 100$ GeV
- One of the jets with $p_T^{jet} > 100$ GeV taken randomly as τ candidate
- 3 jets, $E_T > 20$ GeV
- one ”b” jet
- top and W mass reconstruction
- $E_T^{miss} > 100$ GeV
- $m_T(\tau$ candidate,MET) reconstruction

Events in the ”signal area” can be obtained with the normalization:

$N^{QCD}(\tau\text{-sel}) = N^{QCD}(\text{QCD-sel}) * \varepsilon(\tau\text{–miss-id})$

$\varepsilon(\tau\text{–miss-id})$ can be measured from γ+jet events or from QCD di-jet events

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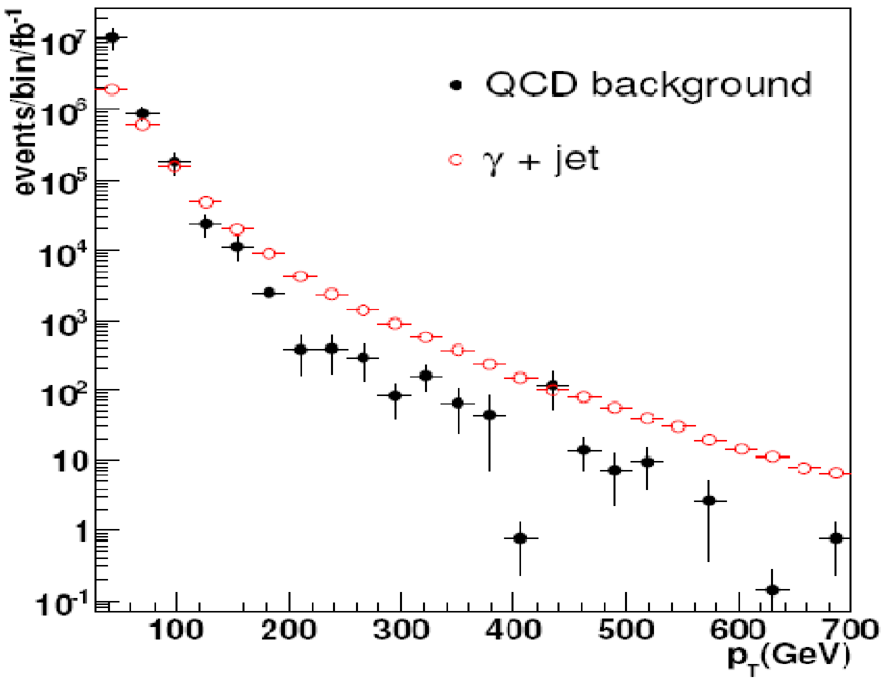
Fake τ probability from γ+jet events

Expected rate for isolated photons and QCD background

QCD background suppression has been done with isolation and cluster shape cuts for photons
Photon-jet balance cut also applied

Good S/B can be achieved at large p_T



Luminosities of **~10 fb^{-1}** may be needed for a precisions better than ~30% for jets with E_T > 100 GeV, assuming a hadronic jet rejection of ~10^5

Other possibility: use the **QCD di-jet events from pre-scaled jet triggers**
Advantage: ~1000 times larger rate and gluonic jets

Conclusions

The $H^{\pm}$ -> $\tau\nu$ decay channel in the tt production and in the associated gg -> $tbH^{\pm}$ production are the discovery channels for H^{+} with large parameter space reach, results from with full simulation and reconstruction of the CMS detector response

Large sensitivity was observed to μ parameter with a more recent study

Recent studies concentrate on analysis methods and background measurements

- Significantly more efficient **τ identification method** has been developped and was discussed
- **Data driven background methods** were discussed:
  - Preliminary method to measure the tt and W+3/4jet with muonic multi-jet events: τ jets from the associated top in tt events are a significant background source
  - Method to measure the QCD multi-jet background with the hadronic multi-jet events, determining the the fake rate probability with the γ+jet events or QCD di-jet events

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Back-up slides

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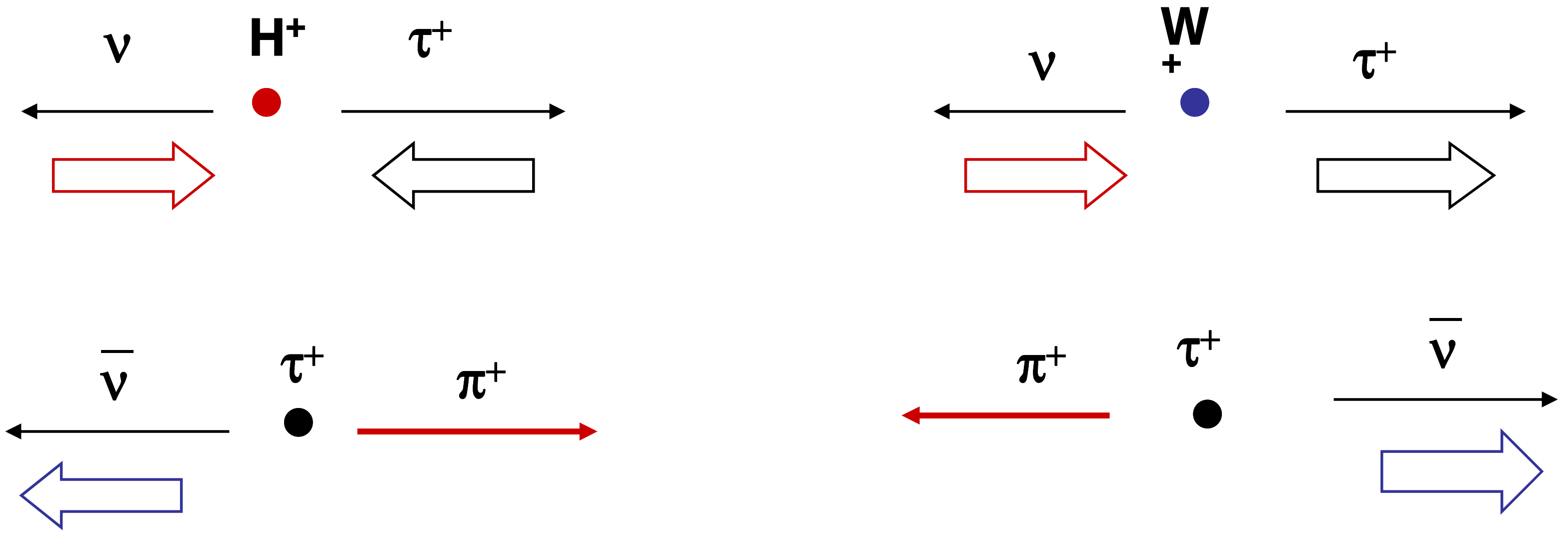
Helicity correlations

Illustration with simple spin arguments for $\tau^+ \to \pi^+\nu$ form $H^+ \to \tau^+\nu$ and $W^+ \to \tau^+\nu$:



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