Charged Higgs Search in CMS in $H^{\pm} \rightarrow t\,b$

Outline

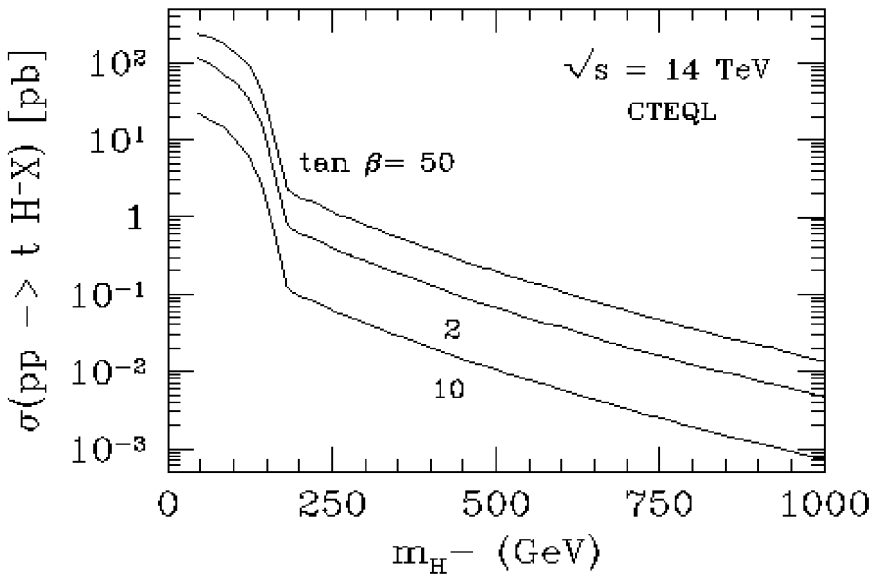
- charged Higgs production and decay
- the $gb \rightarrow tH^{\pm} \rightarrow ttb$ channel
  - signal and background
  - fast simulation, triggers and event selection
  - Higgs mass reconstruction
  - new idea
- improvements and problems
- conclusions

Charged Higgs Production

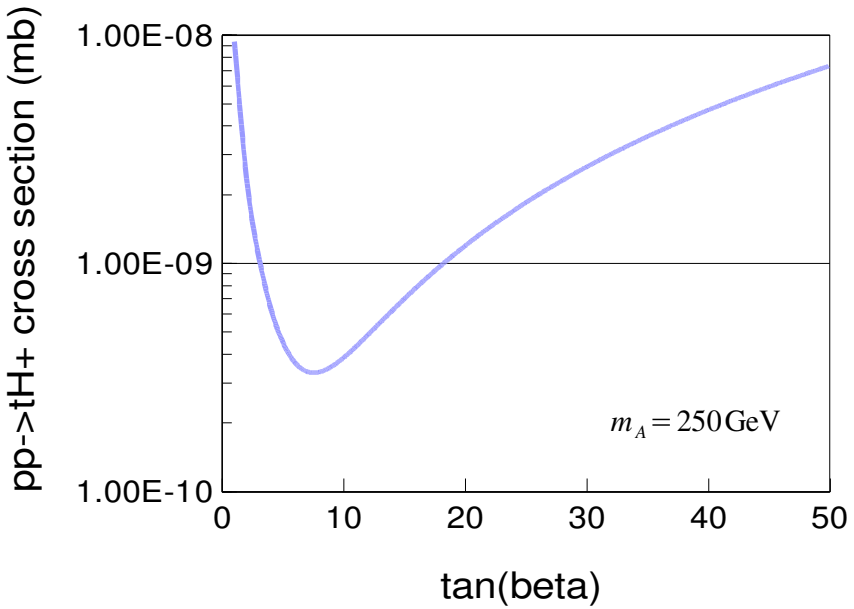
Production channel: $gb \to tH^{\pm}$

- considered in the MSSM
- cross section depends on 2 parameters (1st order):

$m_A = \sqrt{m_{H^{\pm}}^2 - m_W^2}$ dependence



$\tan\beta$ dependence



Charged Higgs Decay

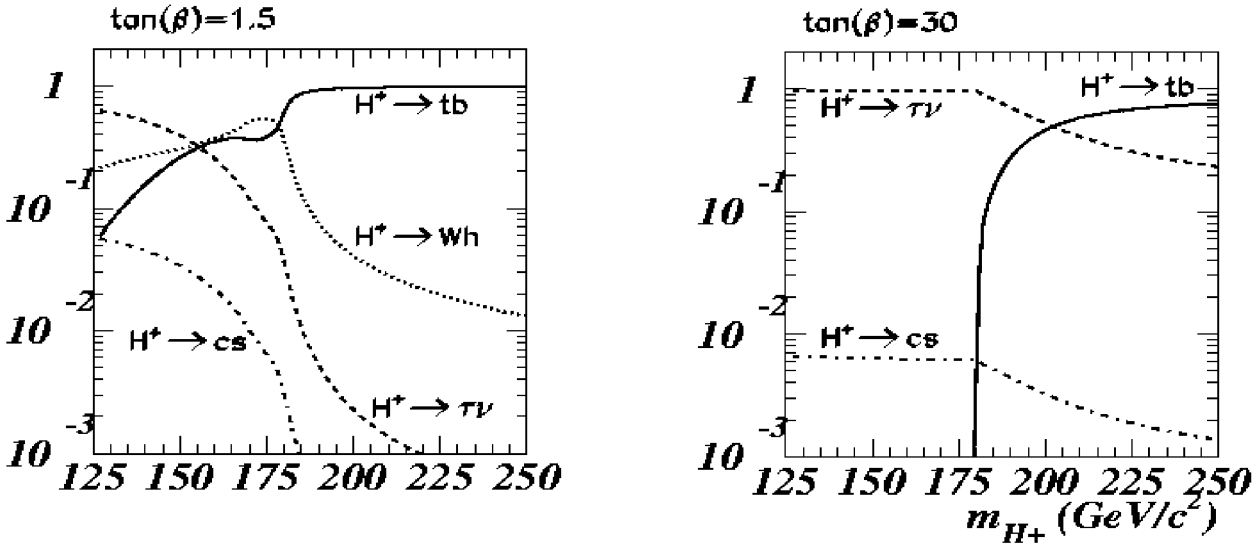
Decay channels

- most important decay channels:

  $H^{\pm} \to \tau \nu$ in the complete mass range

  $H^{\pm} \to t b$ if $m_{H^{\pm}} > m_t$

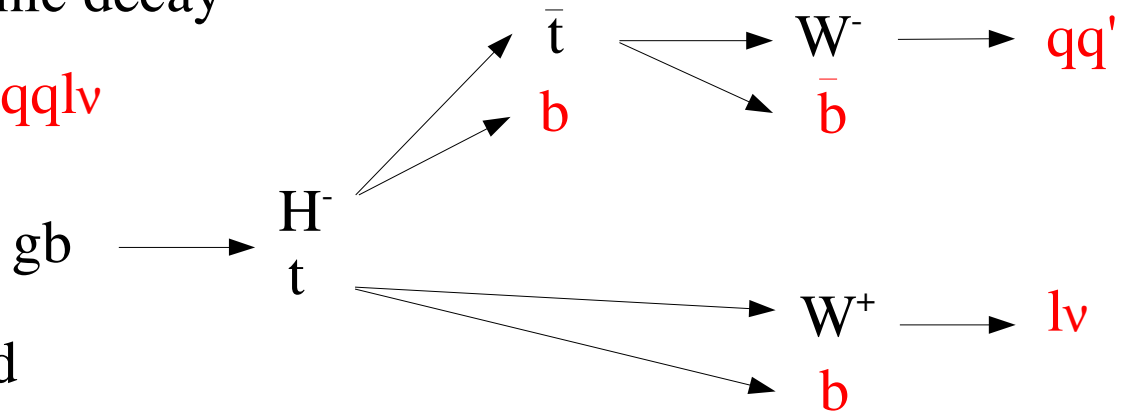
- low dependence on m_A and $\tan\beta$ for the $t b$ decay channel



$gb \to tH^{\pm} \to ttb$: Signal and Background

Signal characteristics

- studied in the semileptonic decay
- complex final state: bbbqqlν



- full hadronic also started

Backgrounds

- SM ttb(b), ttj(j) + b-mistag

  → kinematically very similar to signal!

- SUSY backgrounds neglected

$gb \to tH^{\pm} \to ttb$: Generation and Selection

Simulation

- fast simulation with PYTHIA 6.125, HDECAY 3.0, CMSJET 4.801
  - background from ttbar
  - signal samples for $m_A = (250, 300, 350, 400, 450, 500)\,\text{GeV}$

Triggers and selection

- application of CMS high level trigger cuts at low luminosity
- demands for event reconstruction
  - 1L: at least 1 isolated lepton $\quad p_T > 10\,\text{GeV}, \;\; |\eta| < 2.4$
  - 3B: at least 3 jets tagged as b-jet
  - 5J: at least 5 jets in total

$\Big\}\; p_T > 20\,\text{GeV}, \;\; |\eta| < 2.4$

Mass reconstruction

- find all solutions for which:

$$|m_{qq} - m_W| < 20\,\text{GeV} \quad ; \quad p_{z,\nu} \text{ such that } m_{l\nu} = m_W$$

$$|m_{qqb} - m_t| < 40\,\text{GeV} \quad ; \quad |m_{l\nu b} - m_t| < 40\,\text{GeV}$$

- choose best solution

$$(m_{qqb} - m_t)^2 + (m_{l\nu b} - m_t)^2 \text{ is minimized}$$

energy of b-jet from $H^{\pm}$ decay is maximized

- always 2 solutions:

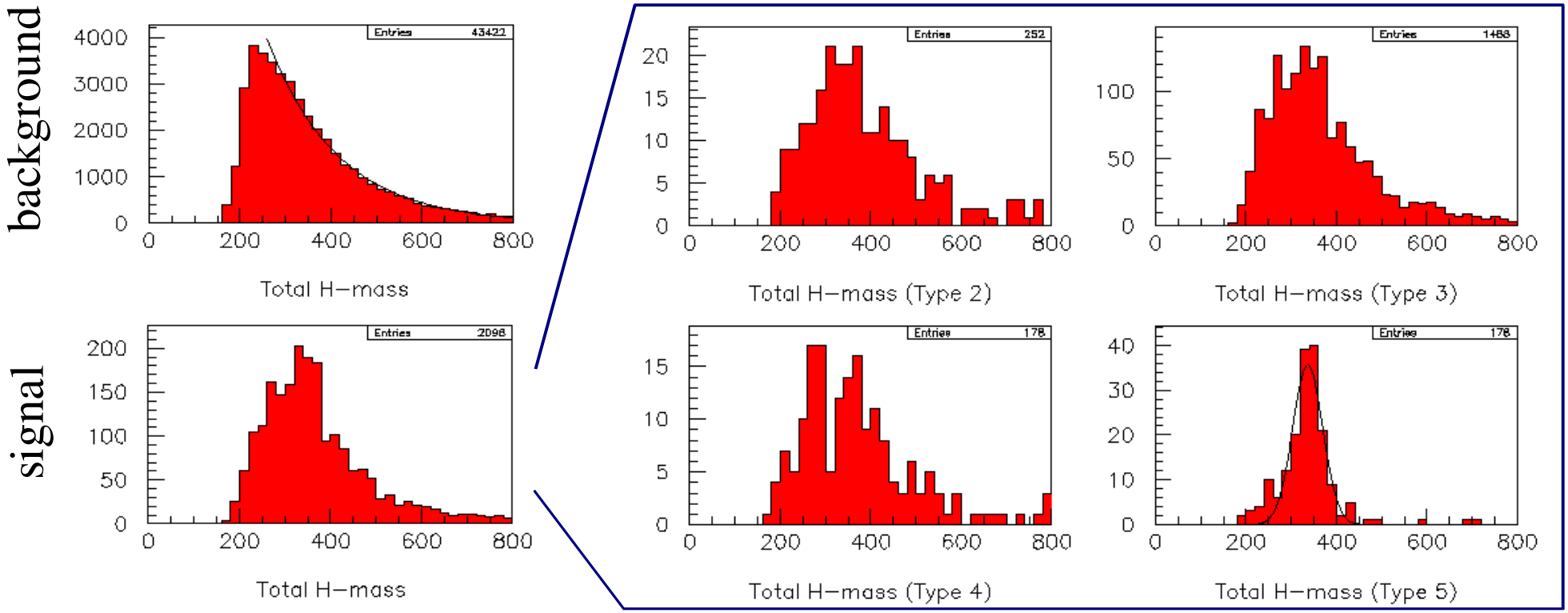
$$m_{H^{\pm}} = m_{qqbb} \text{ (hadronic) and } m_{H^{\pm}} = m_{l\nu bb} \text{ (leptonic)}$$

$gb \to tH^{\pm} \to ttb$: Higgs Mass Reconstruction (2)

Reconstructed Higgs mass distributions

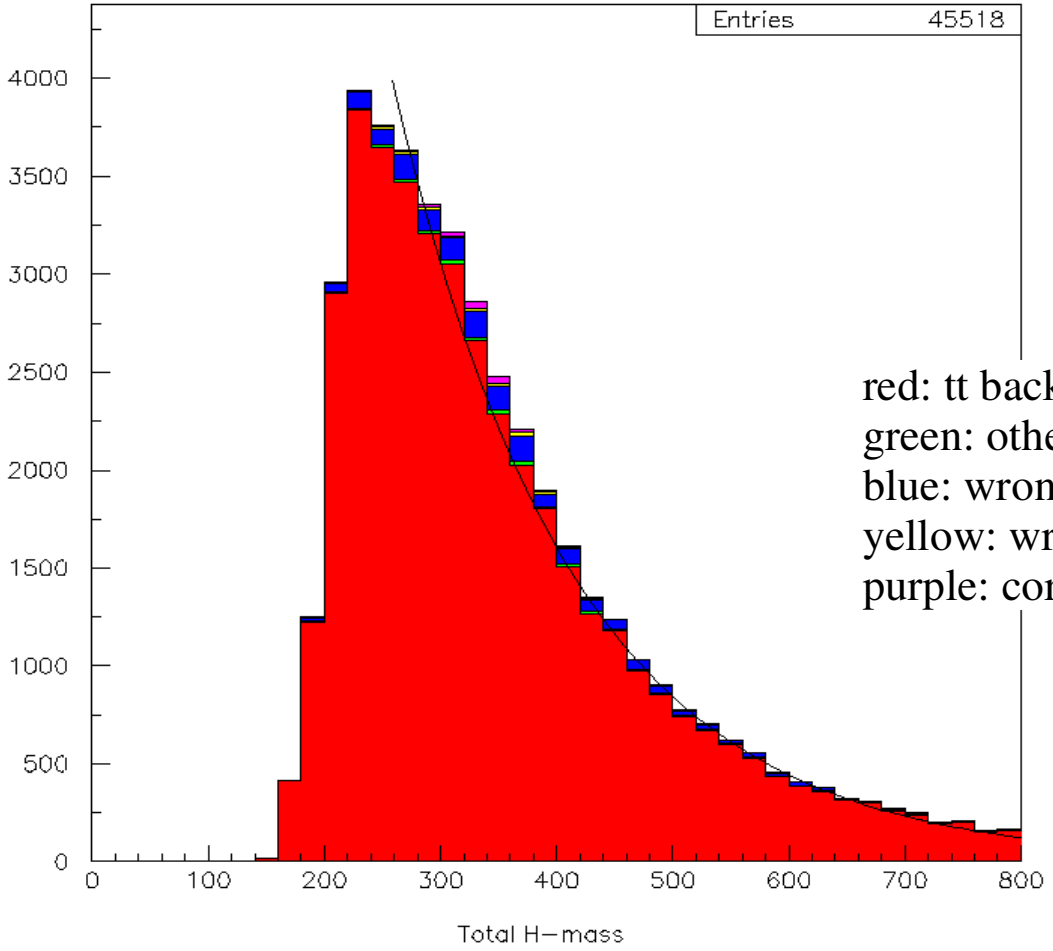
- characteristics: 30 fb^{-1}, $m_A = 350$, $\tan\beta = 50$

Type 2: other final state
Type 3: wrong jet pairing
Type 4: wrong mass solution
Type 5: correct mass solution



$gb \to tH^{\pm} \to ttb$: Higgs Mass Reconstruction (3)

Total mass distribution (30 fb^{-1}, $m_A = 350$, $\tan\beta = 50$)



red: tt back
green: other final state
blue: wrong jet pairing
yellow: wrong mass solution
purple: correct mass solution

$gb \to tH^{\pm} \to ttb$: New Idea (1)

New idea

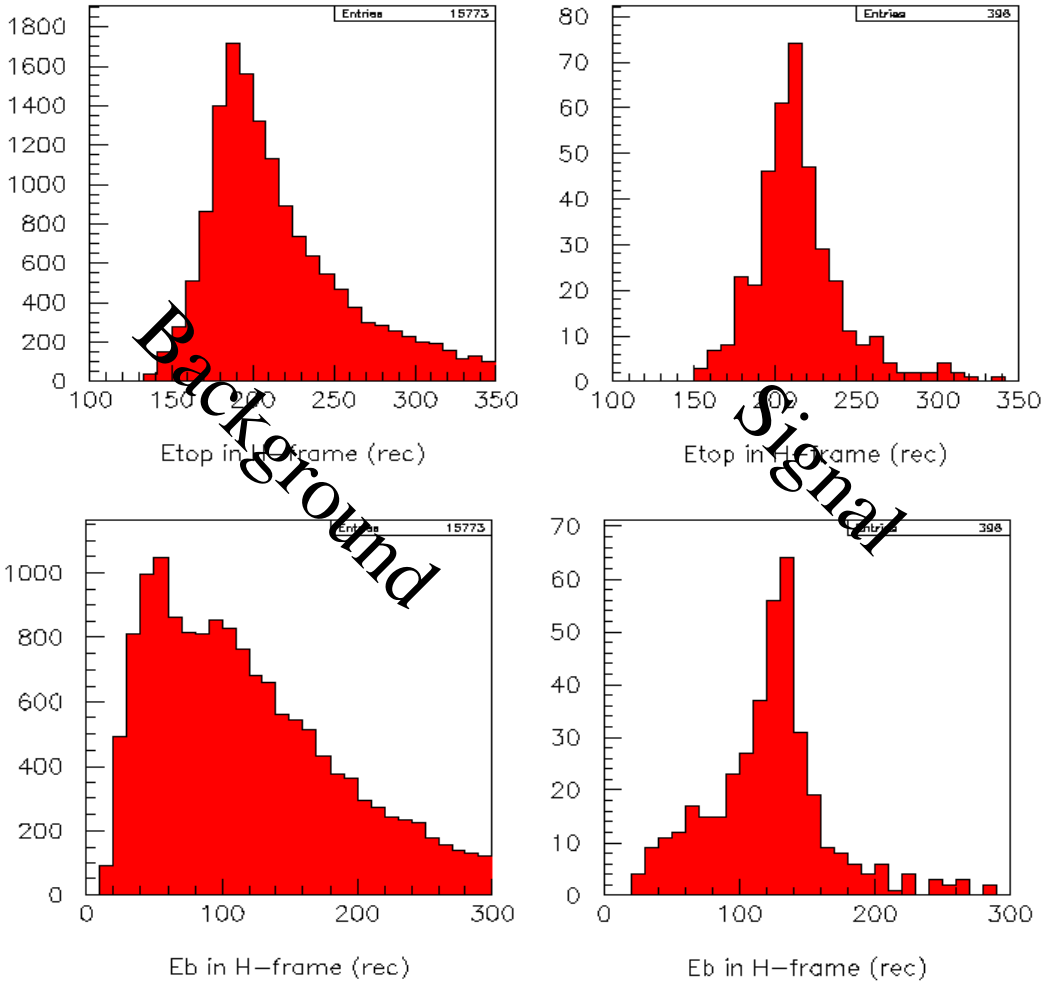
- suppose we know $m_{H^{\pm}}$
- in restframe Higgs:

$$E_t = \frac{1}{2\,m_{H^{\pm}}}\left(m_{H^{\pm}}^2 + m_t^2 - m_b^2\right)$$

$$E_b = \frac{1}{2\,m_{H^{\pm}}}\left(m_{H^{\pm}}^2 - m_t^2 + m_b^2\right)$$

- advantages:
  - way to reject bad t-b pairing
  - S/N improves drastically
  - significant reduction of combinatorial background

$m_A = 350\,\text{GeV}$

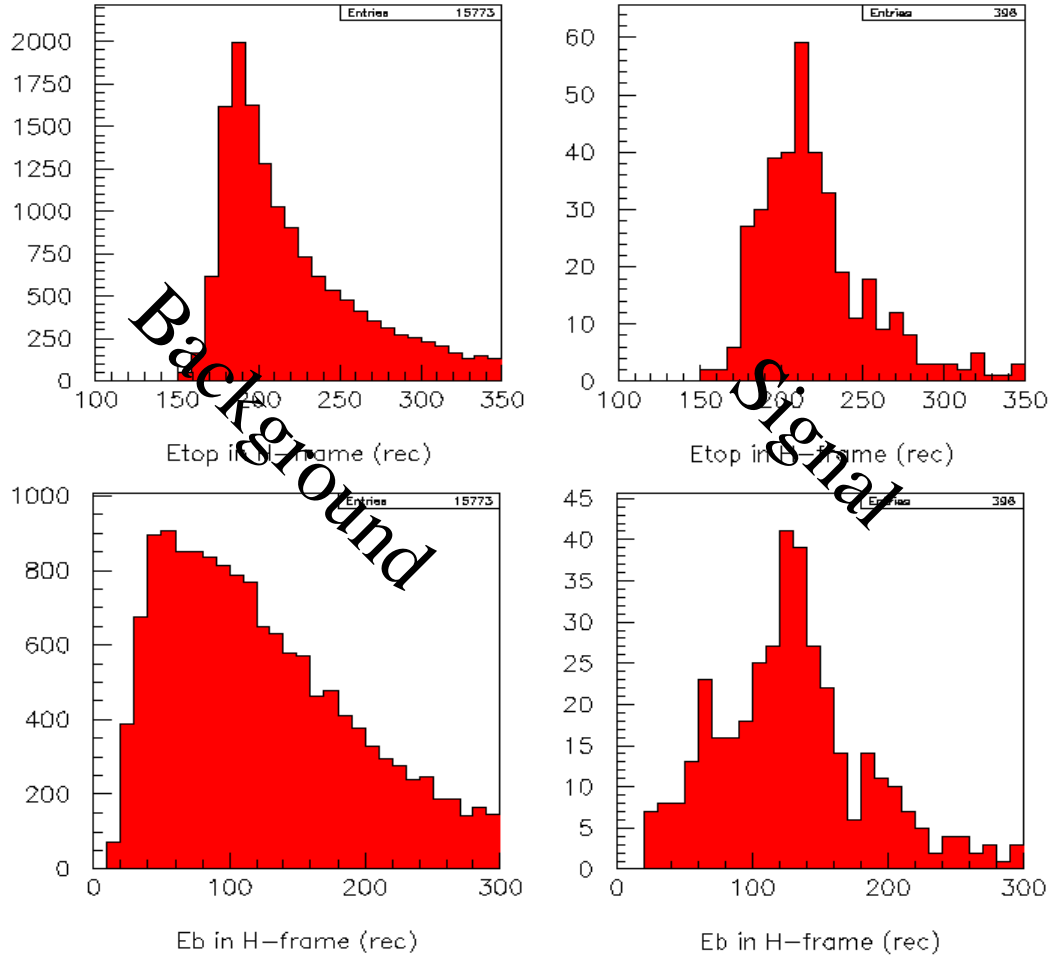


$gb \to tH^{\pm} \to ttb$: New Idea (2)

But we don't know the Higgs mass!

$m_A = 350\,\text{GeV}$

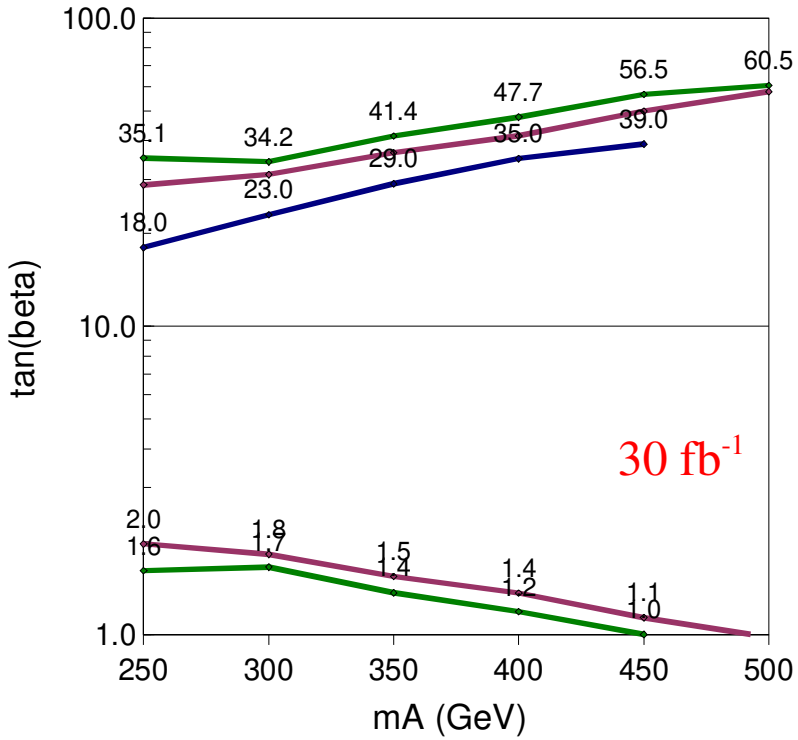
- solution 1: scan a mass range
  - problematic: for wrong mass hypothesis, you pick up all bad solutions again
- solution 2: use reconstructed $m_{H^{\pm}}$ for each event instead
  - cuts on E_t and E_b less efficient
  - info on good t-b pairing lost
- other ideas?

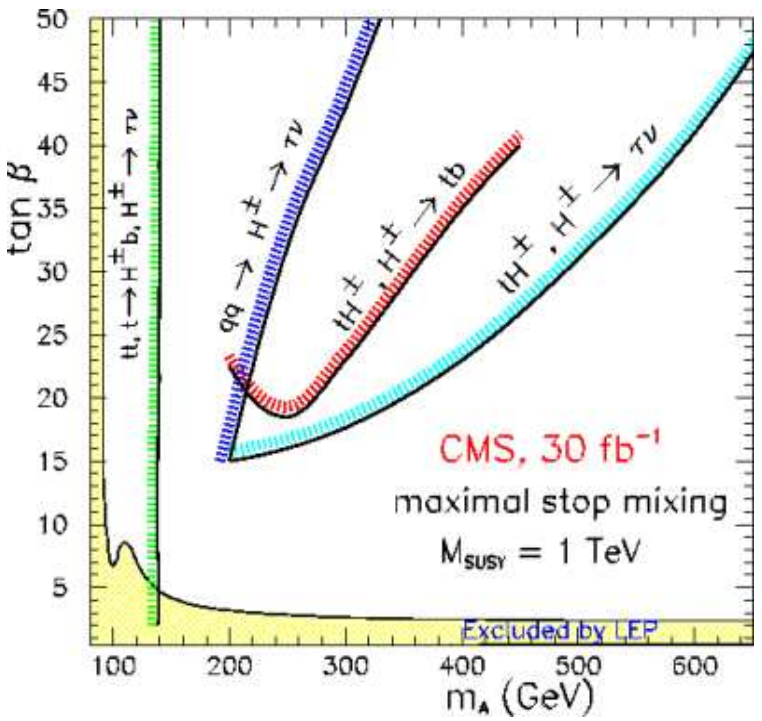


$gb \to tH^{\pm} \to ttb$: Discovery Contours

Discovery contours

- contour for which statistical significance $\sigma = S/\sqrt{B} > 5$





P. Salmi, R. Kinnunen, N. Stepanov:
CMS NOTE 2002/024

- the intermediate tanβ region is very difficult!

Improvements (1)

Expected improvements for $gb \to tH^{\pm} \to ttb$

- improved b-tagging
- exploitation of kinematical differences in Higgs rest frame
- discrimination between good and bad solution?
- further reduction of combinatorial background

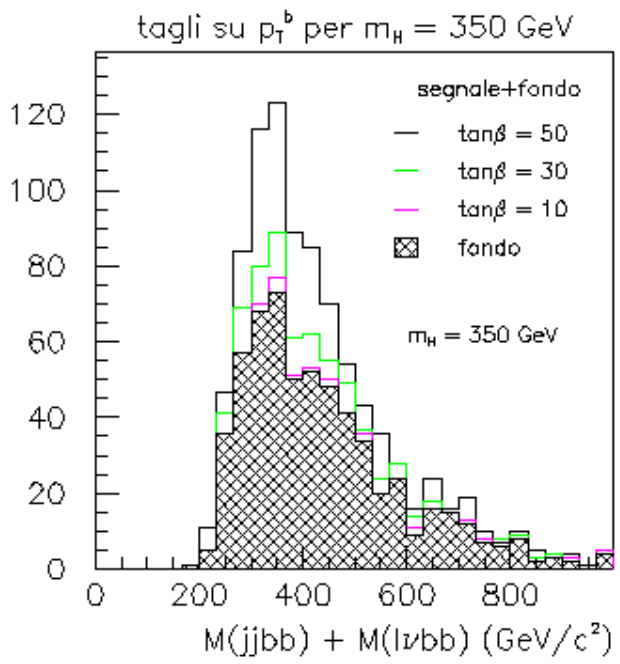
  → event weights instead of hard cuts
- inclusion of fully hadronic qqqqbbb final state

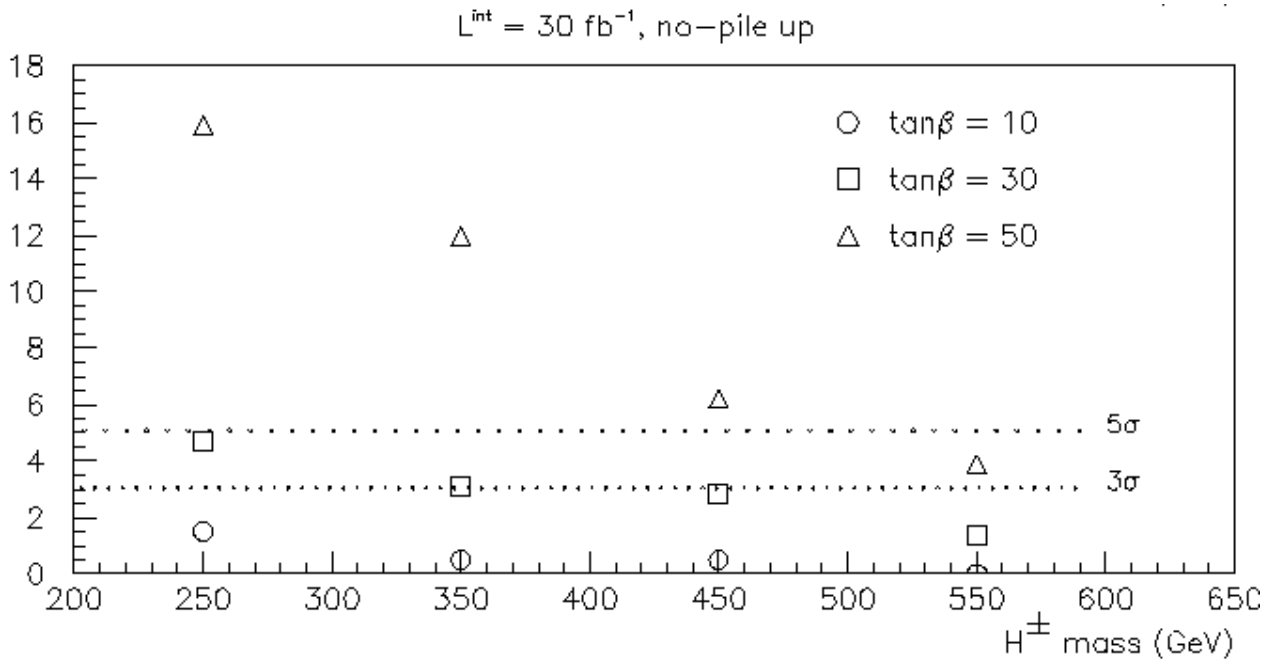
  → event rate doubles but no lepton in final state (need b-trigger)
- ...?

Improvements (2)

Use of $gg \to tbH^{\pm} \to ttbb$

- lower cross section
- better SM background suppression because of extra b





A. Tricomi & student

Problems (1)

Expected problems: signal generation

- inclusive $pp \to tH^{\pm} + X$ NLO cross section calculation available

  (T. Plehn: hep-ph/0206121)

  → use of bottom parton description

  → running bottom Yukawa coupling suppresses cross section

- Pythia only has $gb \to tH^{\pm}$ implemented

  → larger cross section than inclusive case

- what K-factor to use?

- what about $gg \to tbH^{\pm}$ cross section?

Problems (2)

Expected problems: background

- other monte carlo needed, because:
  - Pythia underestimates cross section of tt + n jets (n > 1)
  - single- and non-resonant contributions possibly important
    → ATLAS approach (tt + tWb) is overestimation of ~25%
  - no top off-shell effects in Narrow Width Approximation (NWA)
- new parton-level program available (N. Kauer: hep-ph/0212091)
  → to be interfaced with e.g. Pythia
- how to estimate NLO correction on background: use signal K-factor?
- kinematics?

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Conclusions

- $H^{\pm} \to t\,b$ channel is under study...
  - SM background too high, but much room for improvement (Higgs rest frame observables, $gg \to tbH^{\pm}$,...)
  - intermediate $\tan\beta$ region is very difficult
- ... but some crucial theoretical questions to be answered
  - signal: cross sections
  - background: generation, cross section and kinematics

Thank you!

$gb \to tH^{\pm} \to ttb$: Analysis Strategy Details (1)

Simulation

- generated with PYTHIA 6.125
  - background from ttbar (~760 pb)
  - signal samples for $m_A = (250, 300, 350, 400, 450, 500)\,\text{GeV}$
- HDECAY 3.0 for branching ratios
- CMS fast simulation with CMSJET 4.801
- b-tagging from FATSIM

$gb \to tH^{\pm} \to ttb$: Analysis Strategy Details (2)

Triggers

- application of trigger cuts at low lumi (values from DAQ TDR)

Selection criteria

- 1L: at least 1 isolated lepton:
  - $p_T > 10\,\mathrm{GeV}$, $|\eta| < 2.4$
- 3B: at least 3 jets tagged as b-jet:
  - roughly: 2 tracks with IP significance > b-tag cut
- 5J: at least 5 jets in total:
  - $p_T > 20\,\mathrm{GeV}$, $|\eta| < 2.4$

$gb \to tH^{\pm} \to ttb$: Analysis Strategy Details (3)

Efficiencies

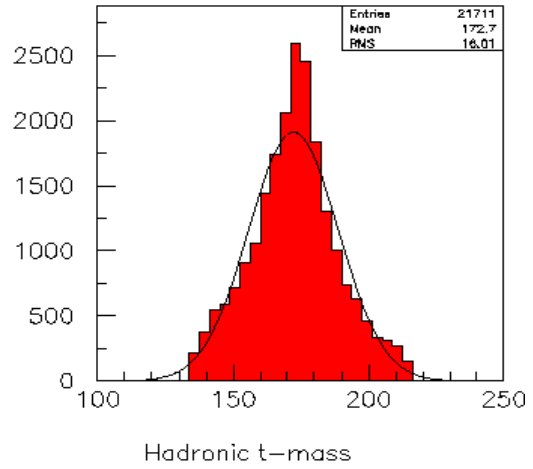
tanβ = 30	For 30 fb^{-1}	HLT (%)	1L (%)	3B (%)	5J (%)	TotEff (%)	Left
tt back	22800000	69	64	1.3	48	0.17	37653
$tH^{\pm}$; m_A = 250	44960	69	54	11.6	69	2.01	904
$tH^{\pm}$; m_A = 300	30788	66	51	14.5	71	2.58	794
$tH^{\pm}$; m_A = 350	20350	64	49	16.0	72	2.92	595
$tH^{\pm}$; m_A = 400	14235	64	47	18.1	73	3.37	480
$tH^{\pm}$; m_A = 450	9790	64	45	18.1	74	3.46	339
$tH^{\pm}$; m_A = 500	7021	65	43	19.3	75	3.74	262

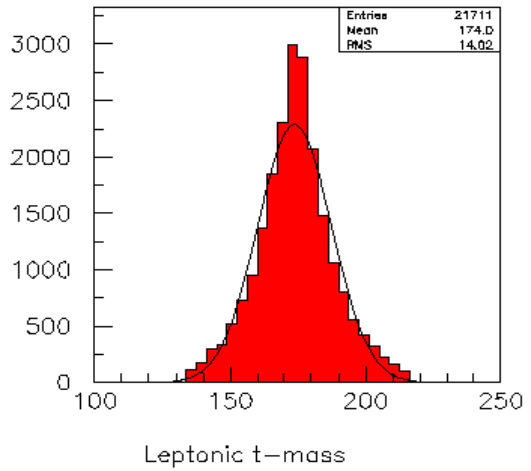
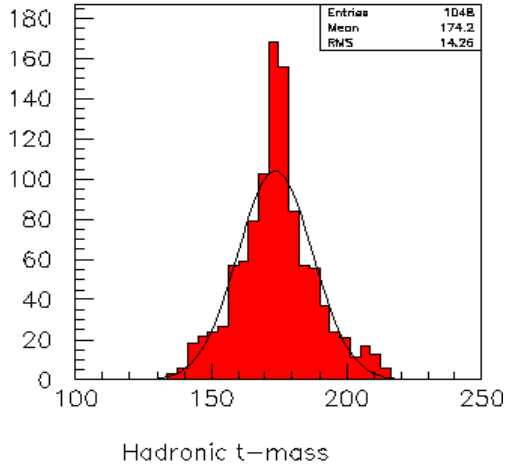
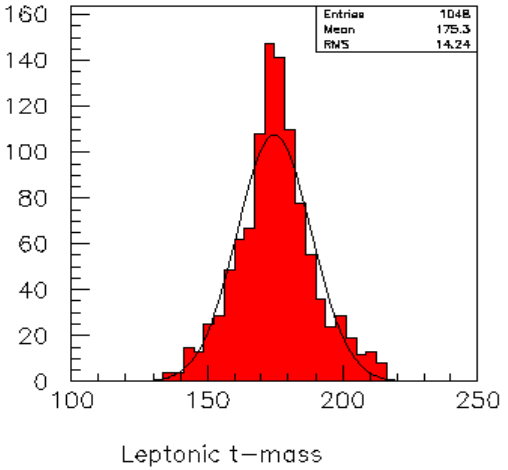
- importance of excellent off-line b-tagging

$gb \to tH^{\pm} \to ttb$: Top Mass Distributions

Reconstructed top mass distributions

background





signal