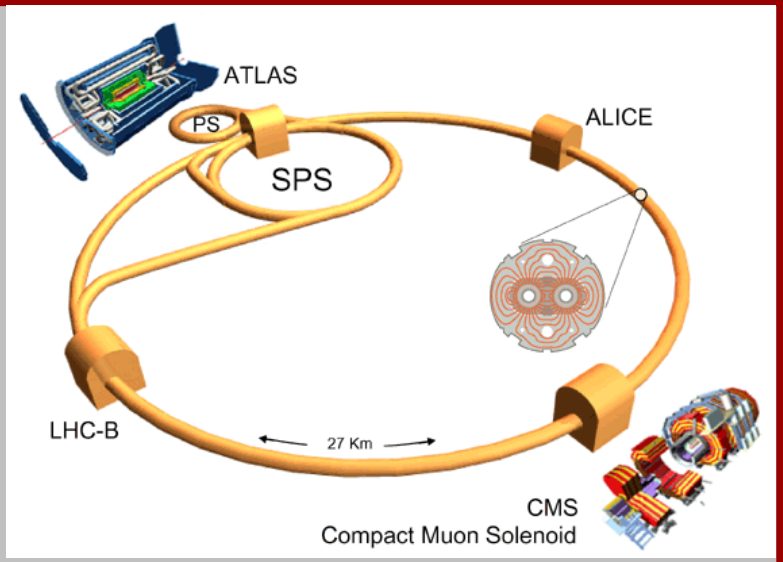
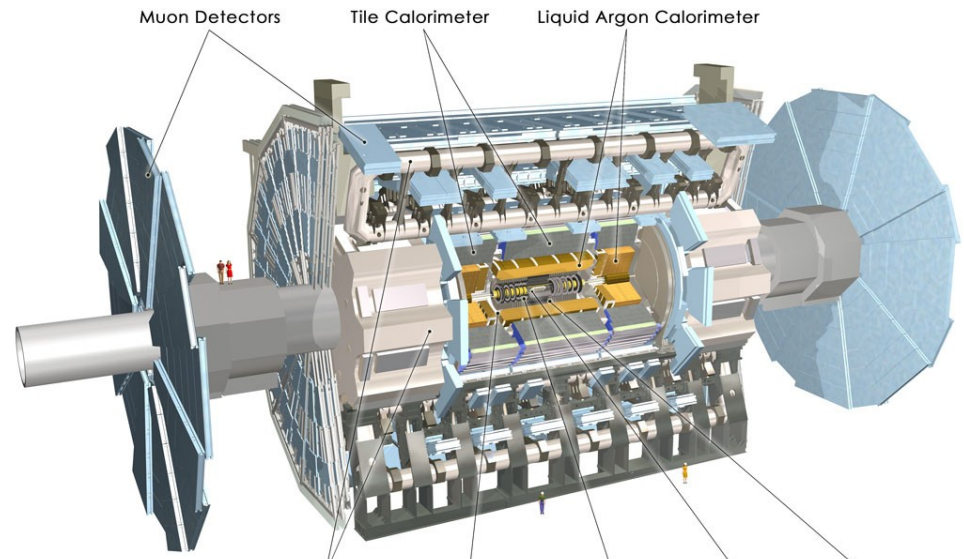
Martin Flechl (Uppsala Universitet)
for the ATLAS and CMS Collaborations

Search for Charged Higgs Bosons at the LHC

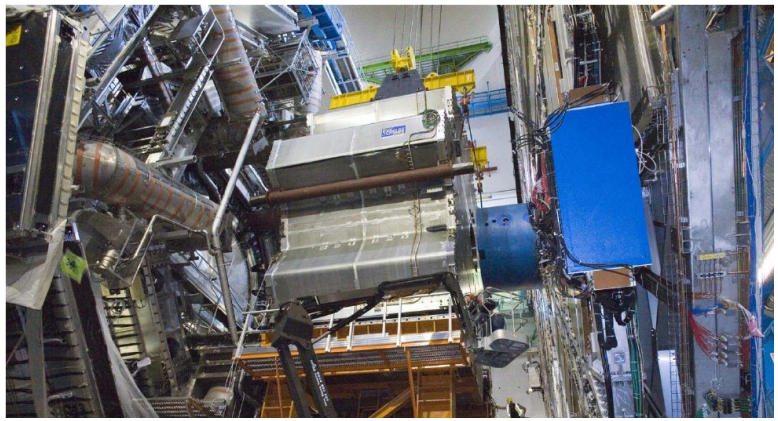
SUSY 2007,
Karlsruhe,
July 28, 2007



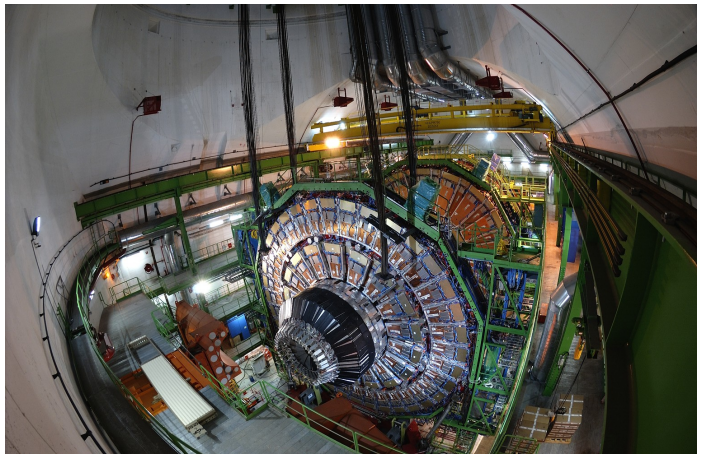
The ATLAS and CMS Detectors



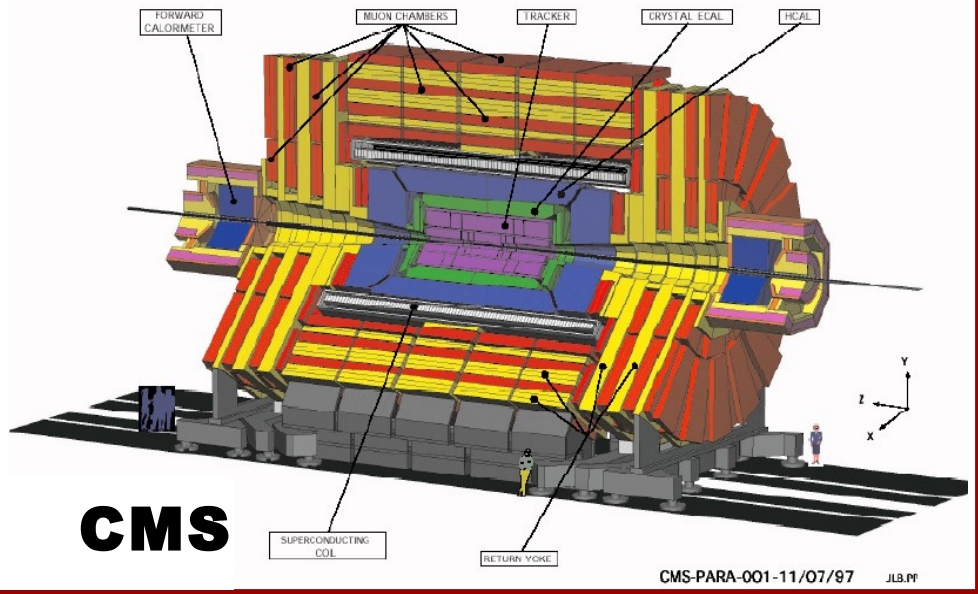
ATLAS



ATLAS, July 2007

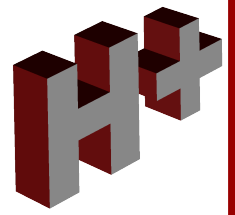


CMS, Jan 2007



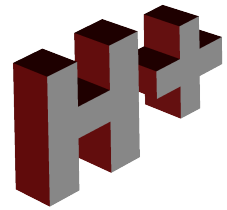
CMS

Outline



- **The Charged Higgs Boson (H^+)**
- **H^+ channels investigated for CMS and/or ATLAS**
  (in detail: publications from 2006/07)
  - H^+ from top quark decays
  - H^+ from gg- and gb-fusion
  - "exotic" channels
- **Discovery reach**

The Charged Higgs Boson



- **Two Higgs Doublet Model (THDM): 5 Higgs Bosons A^0, h^0, H^0, $H^\pm$.**
  - Simple Extension to SM
  - required Higgs Sector of MSSM
  - possible in other SUSY models (fermiophobic models, ...)

  or: H^+ from triplets; several doublets/triplets; Little Higgs; ...

- Charged Higgs searches currently focus on generic THDM (producing cross section limits) and MSSM scenarios
  (unless stated otherwise, the following plots/numbers refer to the m_h-max MSSM scenario)
  - MSSM Higgs sector: at tree-level 2 free parameters, e.g.:

    m_{H+} and **tan β** (Ratio of the Higgs doublet vacuum expectation values)

- The Charged Higgs Boson (**H^+**) is a **heavy[1] charged colorless scalar**

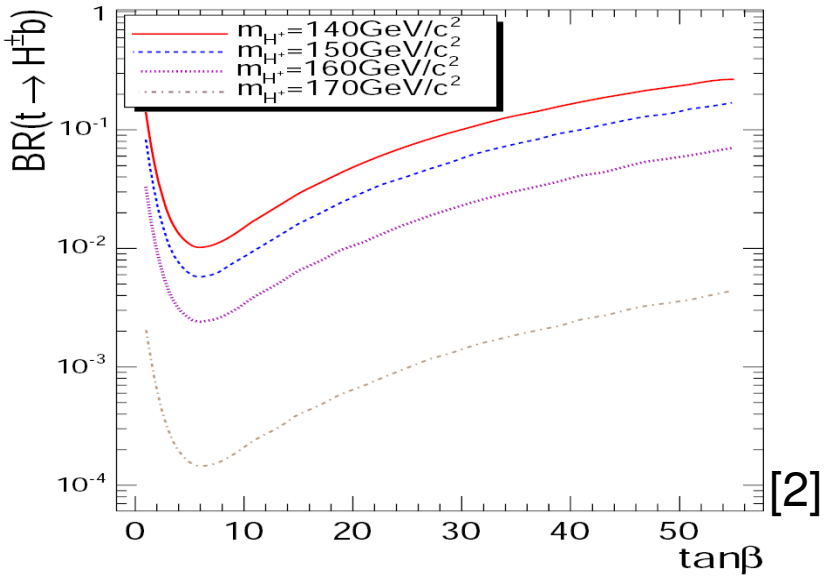
  → **Production** Modes (LHC): $t \to H^+b$ $gg \to tbH^+$ $gb \to tH^+$

  → **Decay** Modes: $H^+ \to tb$ $H^+ \to \tau\nu$ $H^+ \to cs$

[1] e.g. m_h-max MSSM, all tan β: $m_{H+} > 80$ GeV [1]

Overview: $m_{H+} < m_{top}$

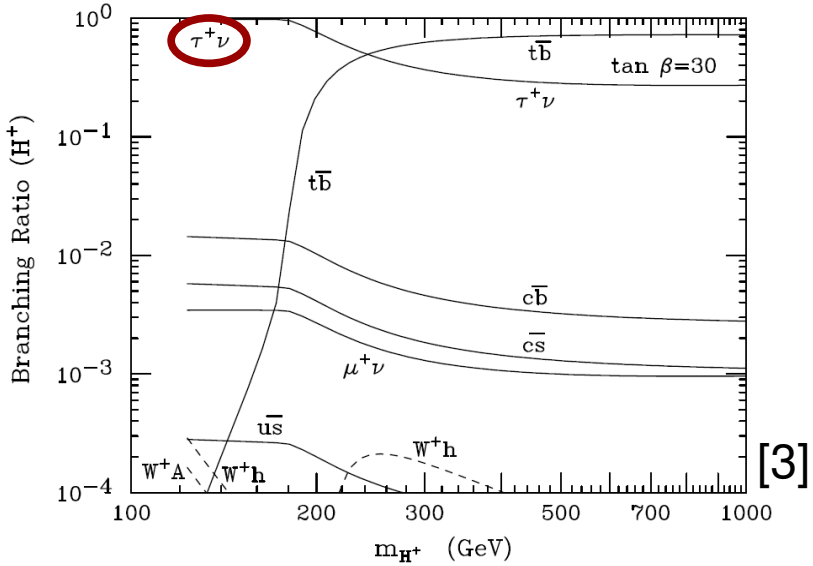
- Production: top quark decays, via
  ttbar→bW⁻ bH⁺
- BR(t → bH⁺) depends on
  m_{H^+} and tan β



[2]

- **BR(H⁺ → τν) ≈ 1**
  → Main channels of interest:

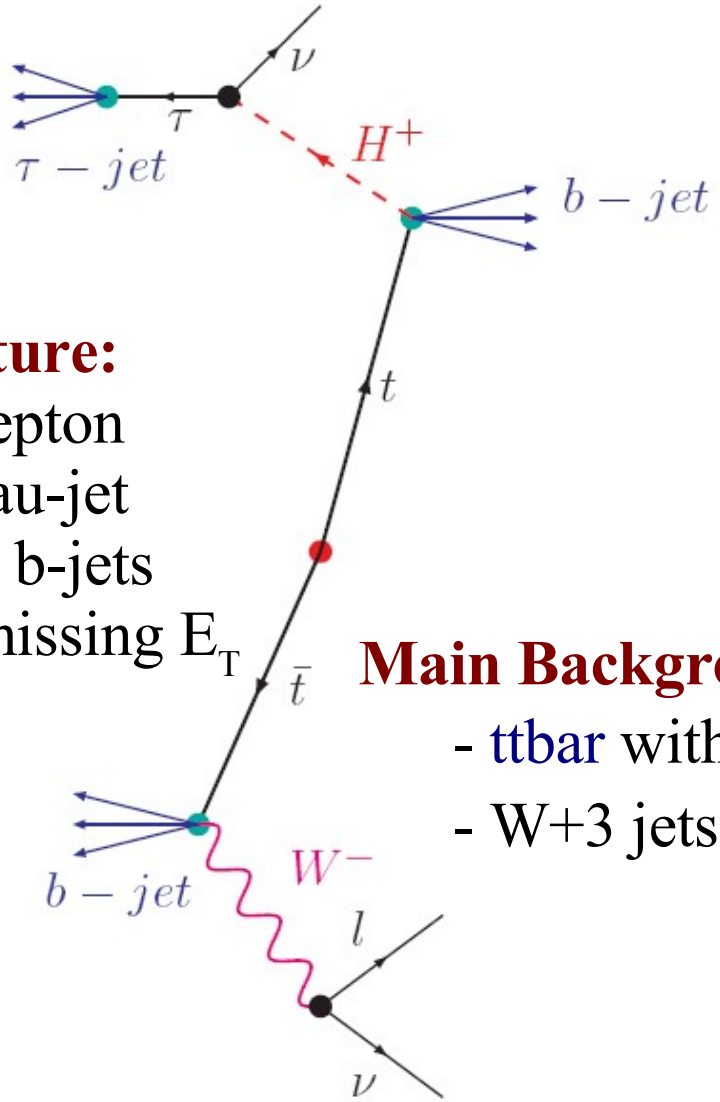
H⁺ Decay	W Decay
τν, τ→had	qq
τν, τ→had	lν
τν, τ→lep	qq



[3]

$tt \rightarrow H^+bWb,\ H^+ \rightarrow \tau_{had}\nu,\ W \rightarrow l\nu$ (1)

CMS NOTE 2006/056, Baarmand/Hashemi/Nikitenko



Signature:

- lepton
- tau-jet
- 2 b-jets
- missing E_T

Main Backgrounds:

- ttbar with one $t \rightarrow bl\nu$
- W+3 jets with $W \rightarrow l\nu$

Exploited difference signal/ttbar:

- $m_{H+} > m_W$: p_T^{τ}, E_T^{miss} larger
- Spin: $H^+ \rightarrow 0$, $W \rightarrow 1$

Event Selection:

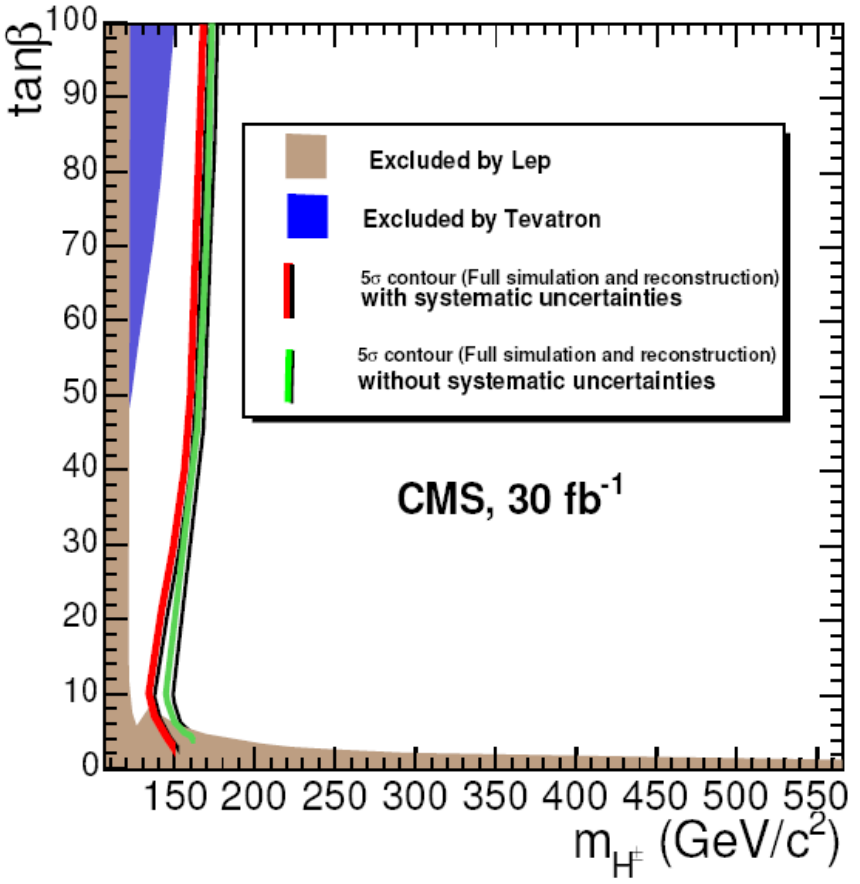
- a triggered lepton
- ≥ 3 jets with $E_T > 40$ GeV
- = 1 of them b-tagged
- $Q(l)+Q(\tau)=0$
- a τ-jet with $E_T > 40$ GeV and $p^{track}/E^{\tau} > 0.8$
- Missing $E_T > 70$ GeV

$tt \rightarrow H^+bWb,\ H^+ \rightarrow \tau_{had}\nu,\ W \rightarrow l\nu$ (2)

CMS NOTE 2006/056, Baarmand/Hashemi/Nikitenko

After all selection cuts (tan β=20):

	σxBR [fb]	Efficiency	Events/10fb^{-1}
m_{H+}=140 GeV	10700	4.8×10^{-3}	510
m_{H+}=150 GeV	5060	5.0×10^{-3}	254
m_{H+}=160 GeV	1830	5.0×10^{-3}	92
$tt \rightarrow l\nu\tau$ bb	2.6×10^{4}	2.0×10^{-3}	516
$tt \rightarrow l\nu l\nu bb$	4.0×10^{4}	7.4×10^{-4}	293
$tt \rightarrow l\nu qqbb$	2.5×10^{5}	1.5×10^{-4}	366
W+3 jets, $W \rightarrow l\nu$	8.4×10^{5}	1.3×10^{-5}	107



Main Systematics Sources:

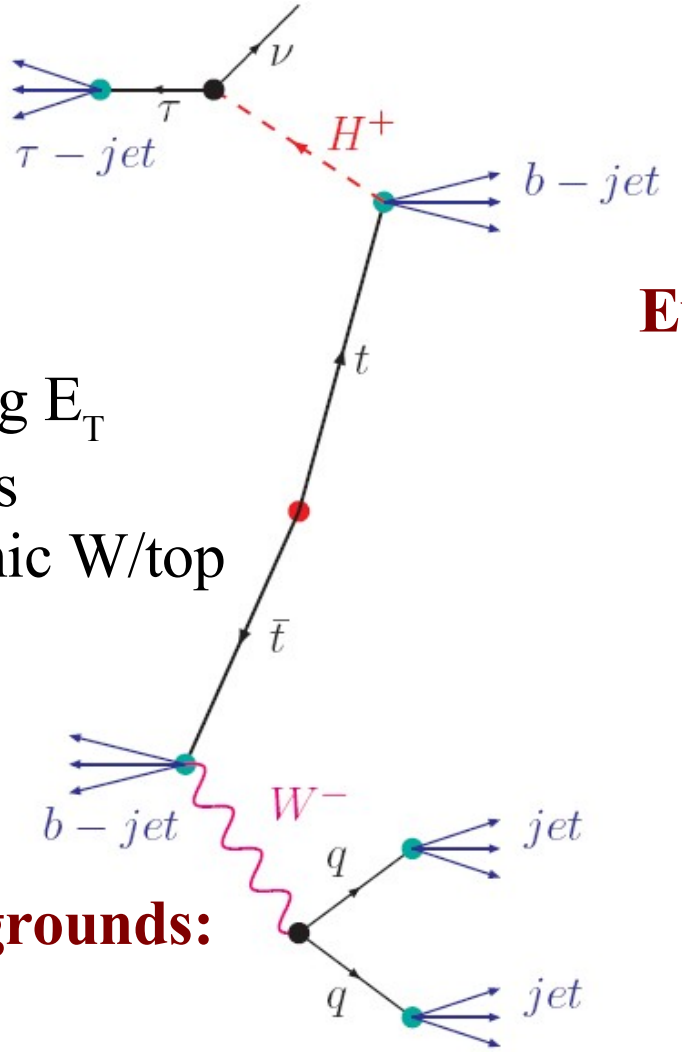
- ttbar cross section
- luminosity measurement
- τ-tagging (efficiency/rejection)
- b-tagging (efficiency/rejection)
- jet energy scale

Discovery Sensitivity:

- tan β>50: up to almost m_{top}
- all tan β: for m_{H+}<130 GeV

$tt \rightarrow H^+bWb,\ H^+ \rightarrow \tau_{had}\nu,\ W \rightarrow qq$ (1)

ATL-PHYS-2003-038, Biscarat/Dosil



Signature:

- tau-jet
- missing E_T
- 2 b-jets
- hadronic W/top

Main Backgrounds:

- ttbar
- QCD

Exploited difference signal/ttbar:

- $m_{H+} > m_W$: p_T^{τ}, E_T^{miss} larger
- Spin: $H^+ \rightarrow 0$, $W \rightarrow 1$

Event Selection:

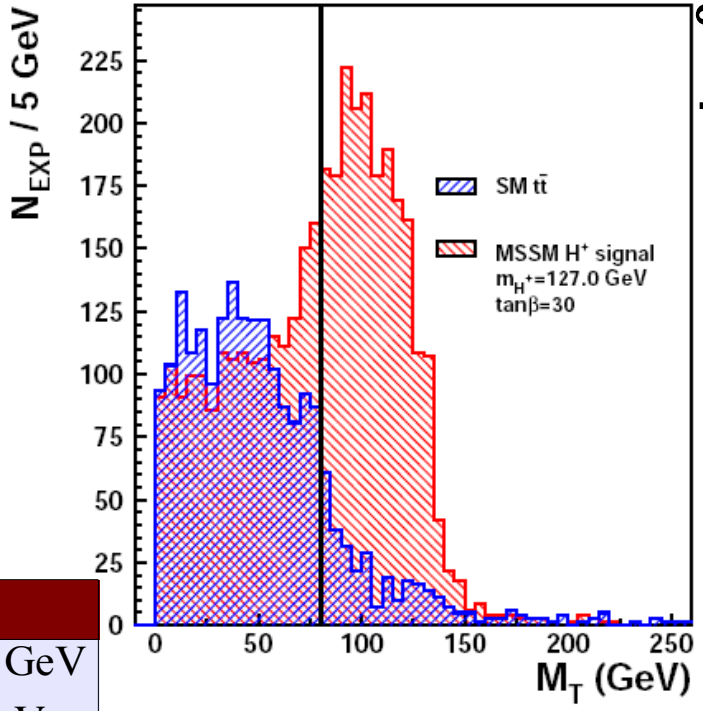
- tau+MET or jet+MET trigger
- = τ-jet, $p_T^{\tau} > 25$ GeV
- =2 b-jets, $p_T^{b1} > 35$ GeV, $p_T^{b2} > 20$ GeV
- ≥2 light jets, $p_T^{j1} > 30$ GeV, $p_T^{j2} > 20$ GeV
- Missing $E_T > 45$ GeV
- W/top Reco (20/40 GeV mass window)
- ttbar pattern (angle/p_T relations of tops)
- Veto on isolated leptons
- $p_T^{\tau} / p_T^{b} > 0.8$ (H^+ side)
- H^+ Transverse Mass

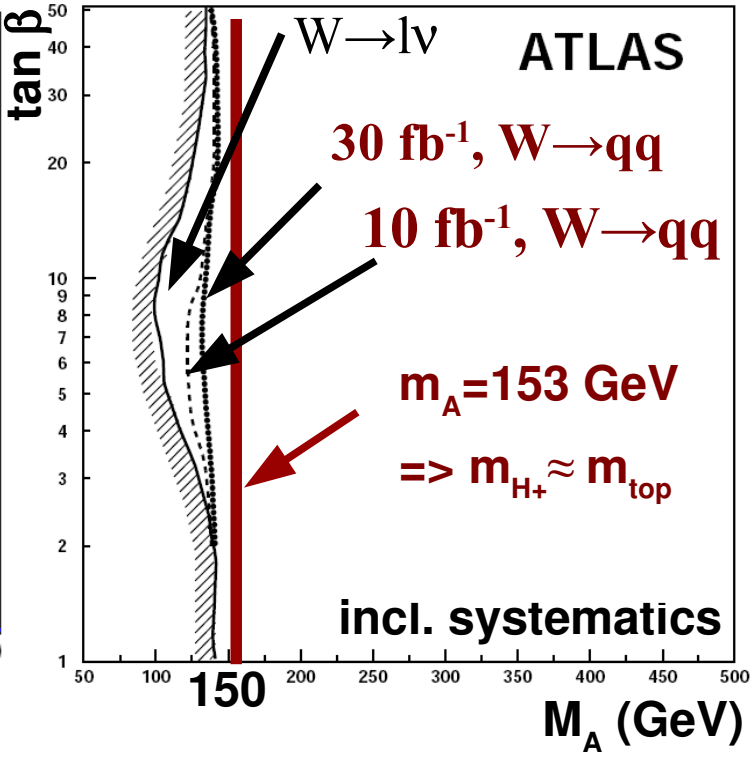
$tt \to H^+bWb,\ H^+ \to \tau_{had}\nu,\ W \to qq$ (2)

ATL-PHYS-2003-038, Biscarat/Dosil

H^+ Transverse Mass

(m_{H+} = 127 GeV, tan β=30)





After all selection cuts (tan β=30):

	Events/10fb^{-1}	
	standard cuts	M_T^{H+}>80 GeV P_t^{τ}>30 GeV
m_{H+}= 85 GeV	5100	-
m_{H+}=127 GeV	4200	2000
m_{H+}=140 GeV	2900	1700
m_{H+}=160 GeV	410	240
ttbar	2300	350
QCD	20	0

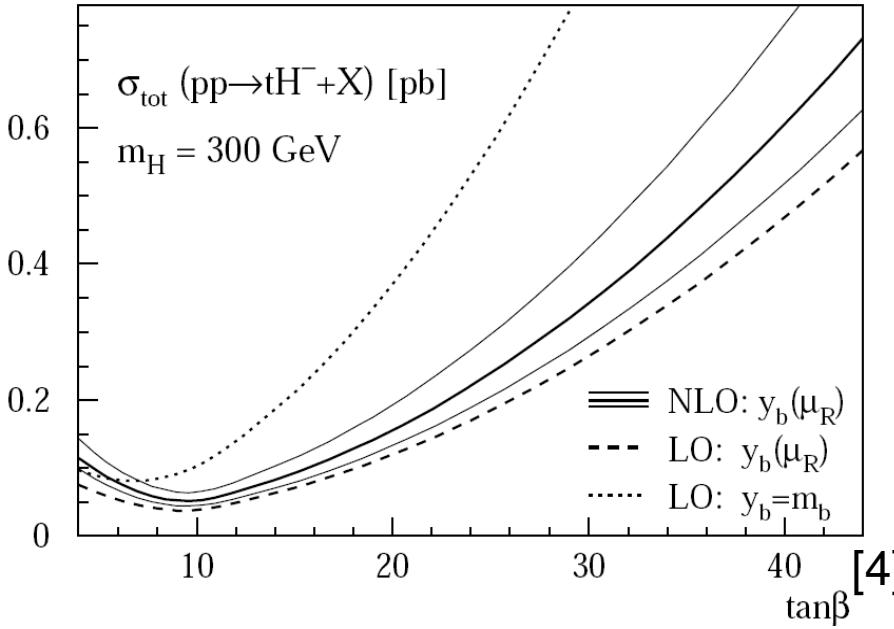
Discovery Sensitivity (30fb^{-1}):

- all tan β: up to almost m_{top}

N.B.: This is Fast Simulation!
... an ATLAS study using a more realistic simulation is on the way.

Overview: $m_{H+} > m_{top}$

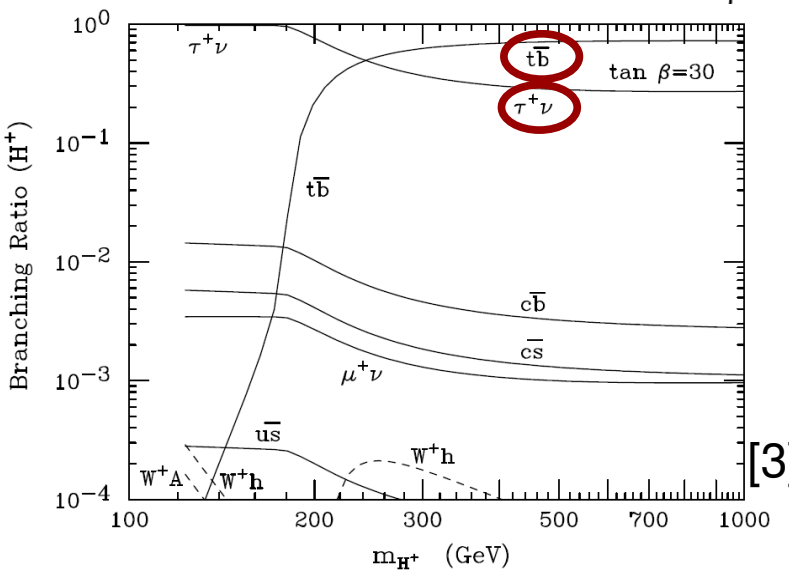
- Production: **gg/gb-fusion**
  gg→tbH$^+$, gb→tH$^+$
  (→double-counting term, resolved by MC Generator "Matchig")



[4]

- **BR(H$^+$ → tb) ≈ 0.8-1**
  → Main channels of interest:

H$^+$ Decay	W Decay
τν, τ→had	qq
tb	lν & qq (2 Ws)



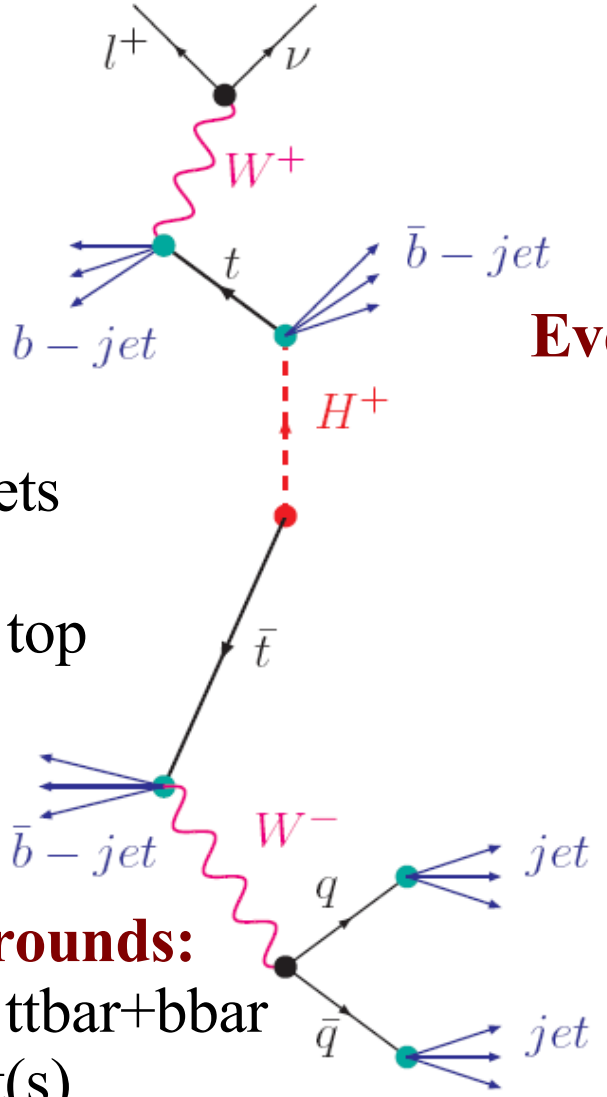
[3]

For each channel, only the most recent CMS or ATLAS study is presented in detail; reference to the study of the other experiment is given in [brackets], differences to the presented publication are briefly discussed and results are given

gg/gb→tH$^+$[b], H$^+$→tb (1)

CMS NOTE 2006/109, Lowette/D'Hondt/Vanlaer

[SN-ATLAS-2004-042, Assamagan/Gollub]



Signature:

- 3-4 b-jets
- lepton
- 2 W, 2 top

Main Backgrounds:

- ttbar+b, ttbar+bbar
- ttbar+jet(s)

Exploited difference signal/ttbar+X:

- m_{H+} invariant mass
- up to 4 b-jets

Event Selection, for 3 *(4)* b-tag-analysis:

- a muon, p_T^{μ}>20 GeV
- at least 5 *(6)* jets, p_T^{μ}>25 GeV
- at least 3 *(4)* b-tags
- kinematic fit imposing mass constraints for both Ws and both top quarks
- LH to suppress combinatorial background
- 3 b-tags: LH to suppress ttbar+X using a) p_T: softest jet from W, b) χ^2 of the fit, c) discriminator: b from H$^+$, d) E_T^{j6}/E_T^{j5}

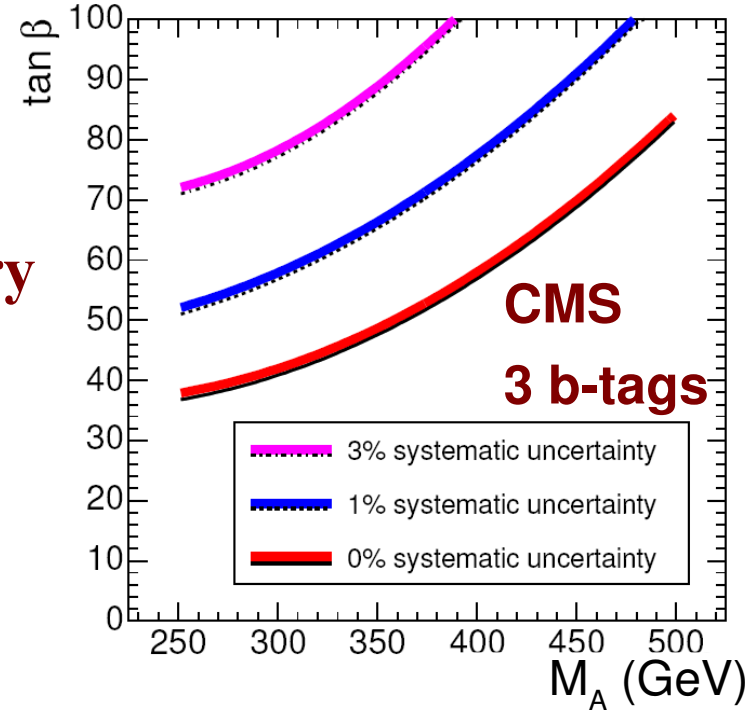
4 b: b-discriminator: b from H$^+$, spectator-b

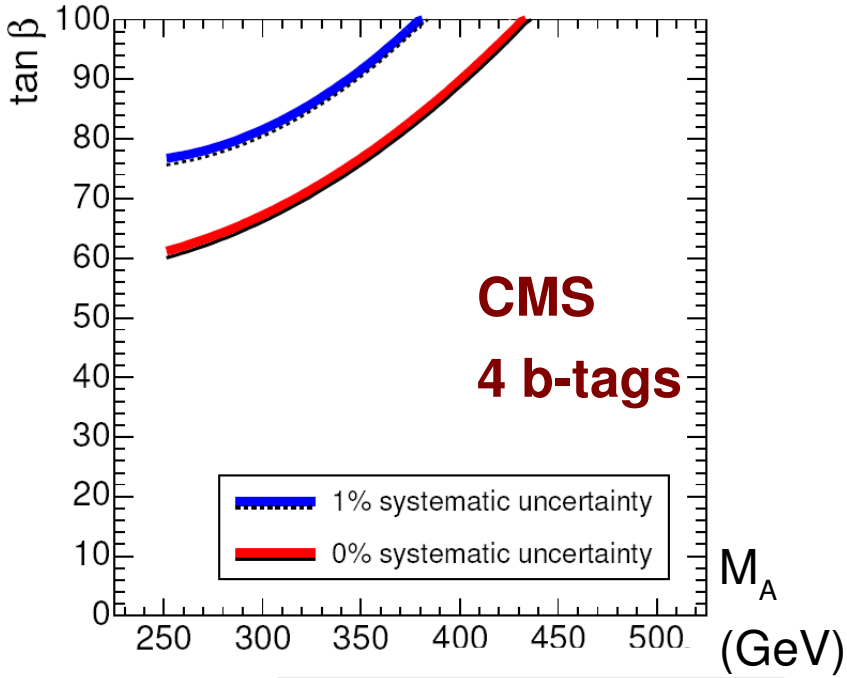
gg/gb→tH$^+$[b], H$^+$→tb (2)

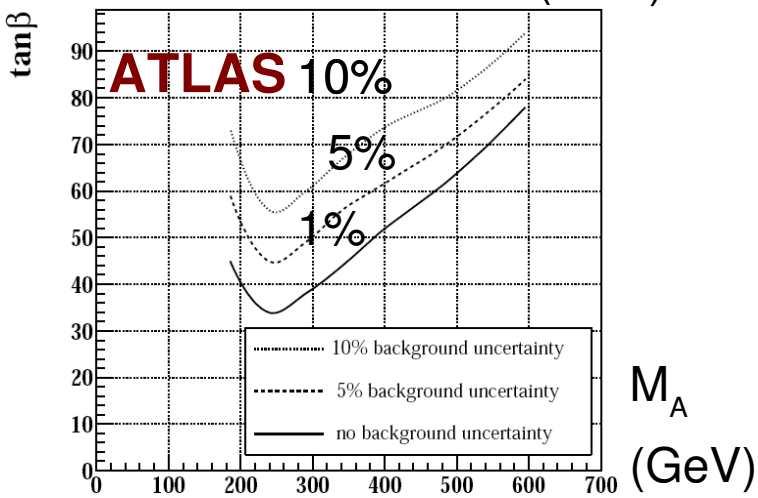
CMS NOTE 2006/109, Lowette/D'Hondt/Vanlaer

[SN-ATLAS-2004-042, Assamagan/Gollub]

MSSM Discovery Contour





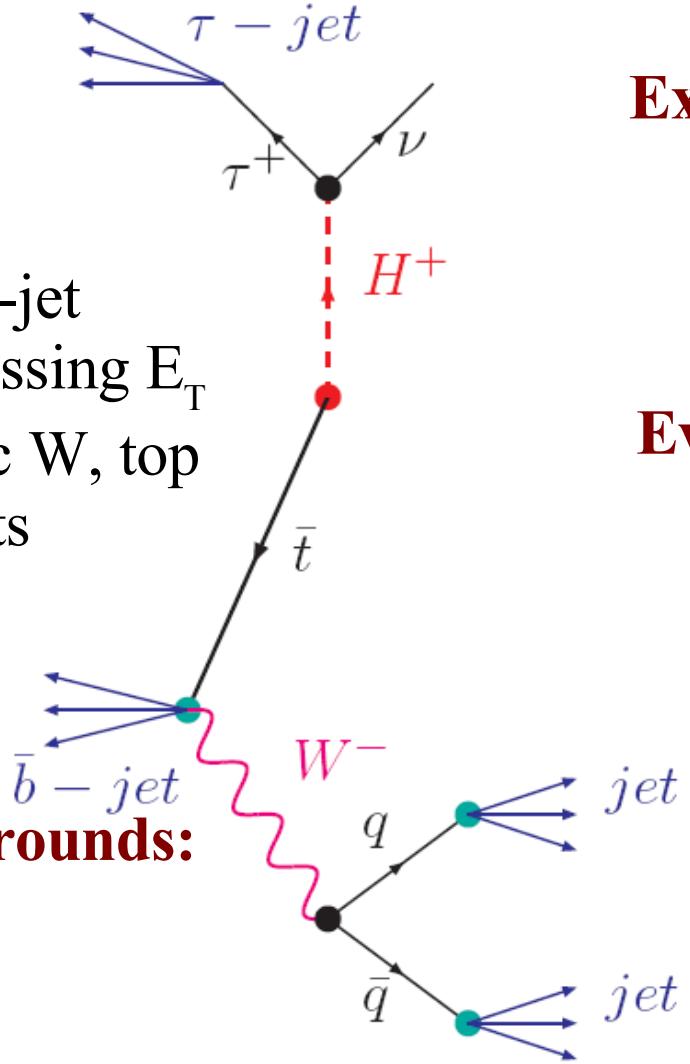


Conclusion: Even assuming very low systematic background uncertainties:
No sensitivity in the MSSM space.
(Similar conclusions for ATLAS from a fast simulation-based study)

gg/gb→tH$^+$[b], H$^+$→τ$_{had}$ν, W→qq (1)

ATL-PHYS-PUB-2007-006, Mohn/Flechl/Alwall

[CMS NOTE 2006/100, Kinnunen, see slide 19]



Signature:

- hard tau-jet
- large missing E_T
- hadronic W, top
- 1-2 b-jets

Main Backgrounds:

- ttbar
- W+jets
- QCD

Exploited difference signal/ttbar:

- m_{H+} invariant mass
- => hard τ-jet, high missing E_T

Event Selection:

(mass range: low/medium/high)

- one hard τ-jet (p_T^{τ}>65/80/100 GeV)
- E_t^{miss} > 120/135/165 GeV
- ≥ 3 more jets (=1 b-tagged)
- Veto on isolated leptons
- W/top-Reco (25 GeV-mass window)
- p_T^{τ} / $p_T^{add.\ Jet}$ > 6.0/5.5/5.0
- azimuthal angle (p_T^{τ} , p_T^{miss}) > 1

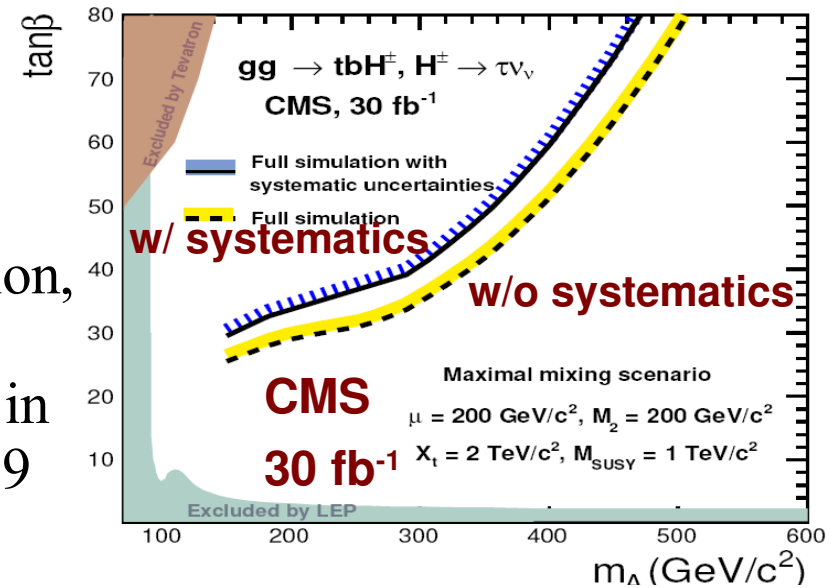
$gg/gb \rightarrow tH^+[b]$, $H^+ \rightarrow \tau_{had}\nu$, $W \rightarrow qq$ (2)

ATL-PHYS-PUB-2007-006, Mohn/Flechl/Alwall

[CMS NOTE 2006/100, Kinnunen]

Event Generator **MATCHIG** allows for the 1st time a matched production gg/gb and thus a **consistent treatment of the transition region $m_{H+} \approx m_{top}$**

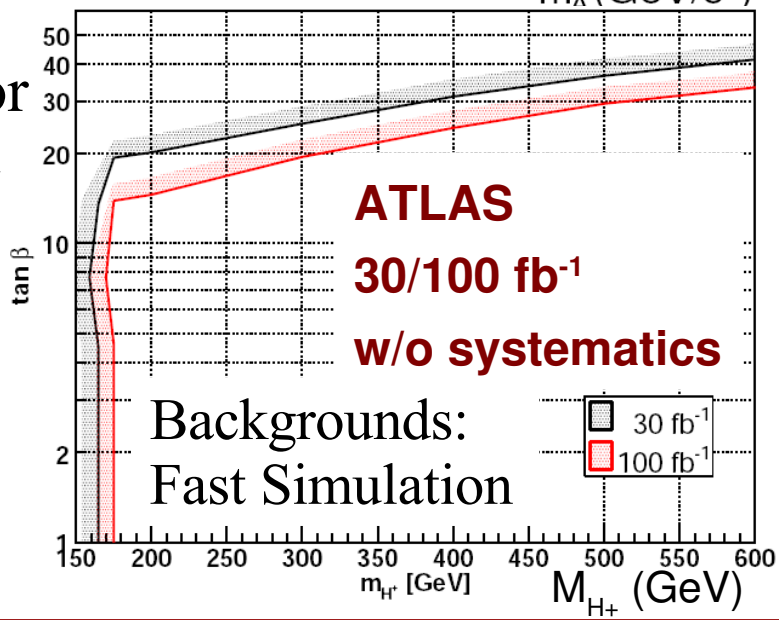
CMS: Fullsim Backgrounds, Trigger Simulation, no MATCHIG, some difference in cuts - see slide 19



After all selection cuts (tan β=35):

	Events/30fb^{-1}	
	Signal	Bkg
m_{H+} = 165 GeV	57	5.4
m_{H+} = 175 GeV	37	5.4
m_{H+} = 300 GeV	11	1.1
m_{H+} = 400 GeV	7	1.1

Discovery Channel for a heavy H^+ at the LHC



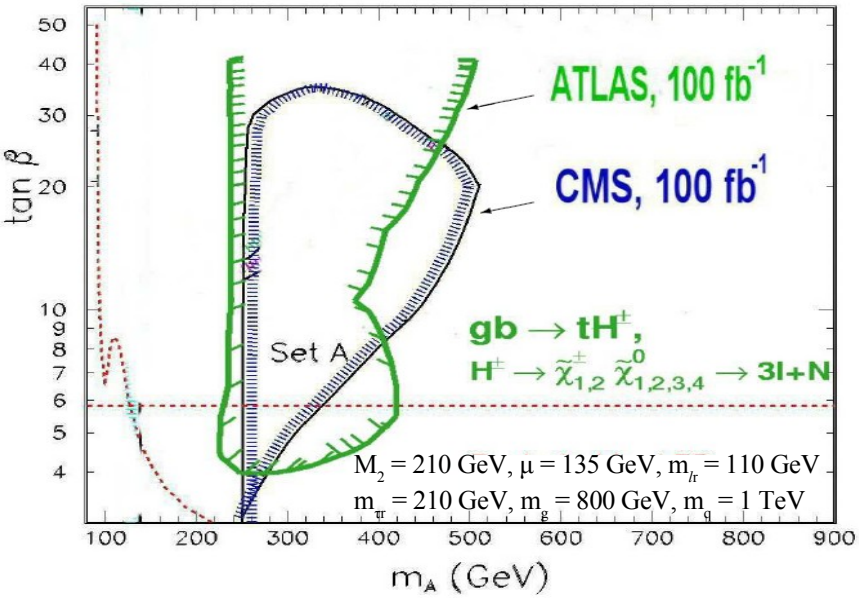
High S/B ratio makes the channel less sensitive to systematics than $H^+ \rightarrow tb$

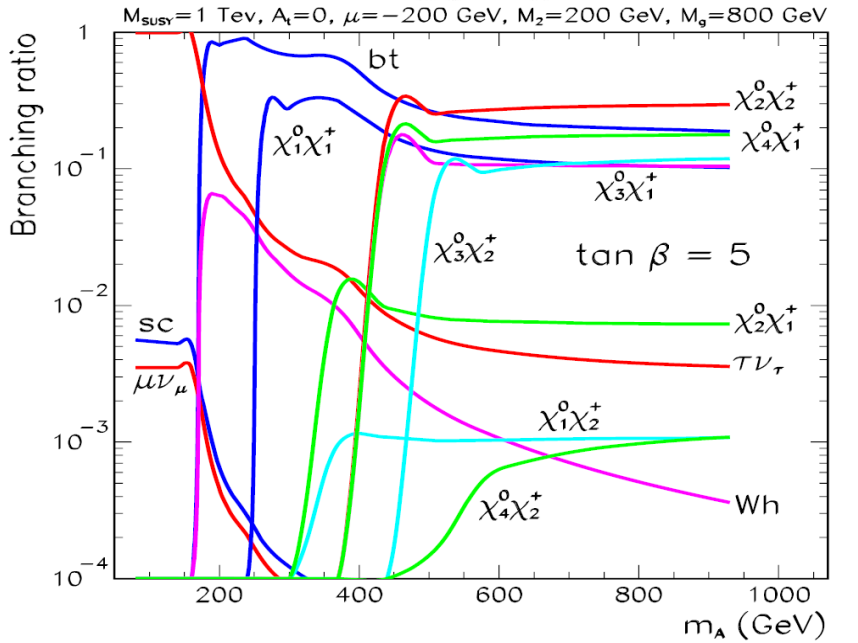
More H^+ channels...

- $H^+ \rightarrow \chi_i^+ \chi_j^0$
  CMS-NOTE-2003-004, SN-ATLAS-2005-050
  sensitive at the uncovered region tan β≈4-20 (of course heavily dependend on the SUSY scenario, and a previous understanding of the SUSY background and parameters)

- $H^+ \rightarrow Wh^0$, $H^+ \rightarrow WH^0$
  ATL-PHYS-99-025, ATL-PHYS-PUB-2005-017
  - significant cross section only for very small tan β.
  - current studies show that even with known m_{h0} and high luminosity, no discovery reach is given

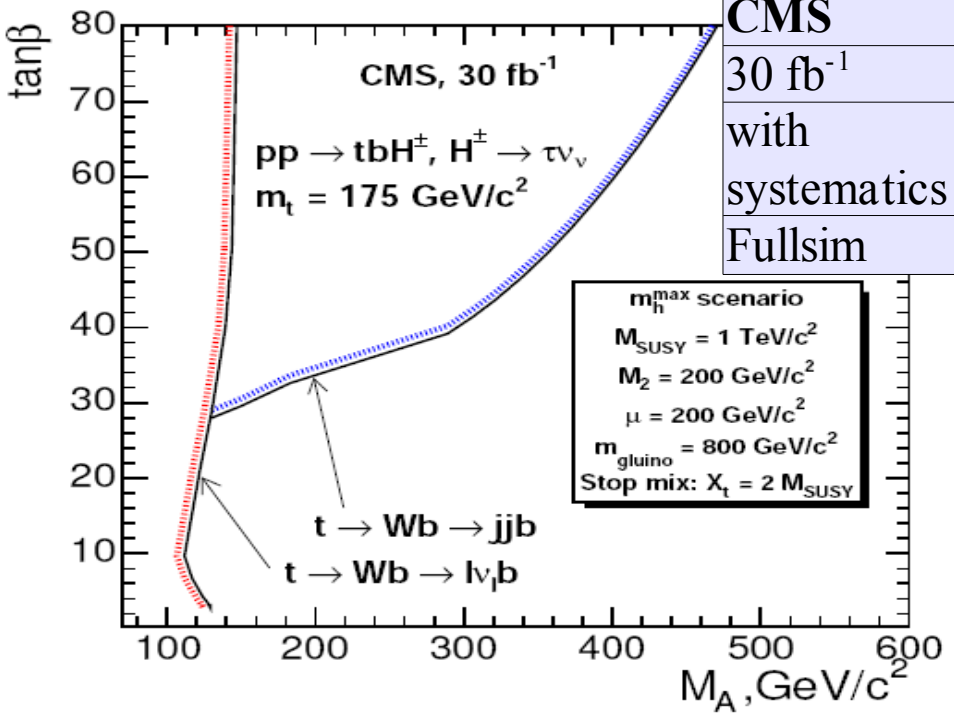
- H^+ sensitivity in ttbar and single top cross section measurements



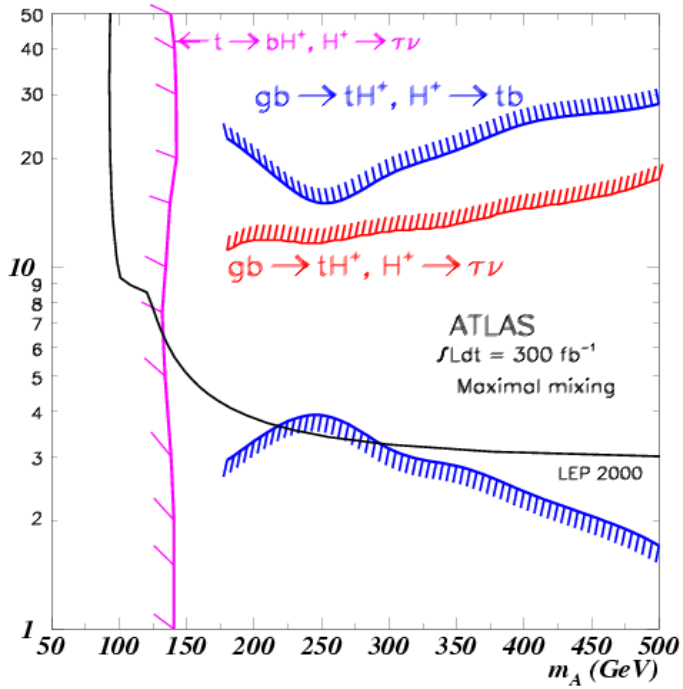


Discovery Reach

CMS and ATLAS Discovery Contours: MSSM, m_h-max scenario



CMS	ATLAS
30 fb^{-1}	300 fb^{-1}
with systematics	without systematics
Fullsim	Fastsim



note: for heavy $H^+ \to \tau\nu$, for consistency, the plot contains results from an ATLFAST study [10] and not the recent fullsim study presented here

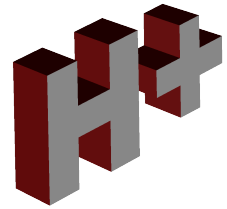
N.B.: The currently approved discovery contours cannot be compared.
ATLAS update expected for end of this year.

The current studies suggest:

$m_{H+} < \approx m_{top}$: will be covered at the LHC
(in worst case at high luminosity)

$m_{H+} > m_{top}$: sensitive only for high tan β

Conclusions and Outlook



- **Implications of current studies:**
  - **$H^+ \to \tau\nu$** is the prime LHC H^+ discovery channel in the MSSM space (and *could be* the first BSM-signal and SUSY-glimpse we see)
  - **$H^+ \to tb$** does not have any MSSM discovery sensitivity
  - **light m_{H+}**: the LHC experiments are sensitive to an MSSM H^+ up to **m_{H+} values close to m_{top}**
  - **heavy H^+**: high luminosity runs are needed. The medium tan β region is not covered (might be accessible after a SUSY discovery)

- **The future:**
  - refine studies, understand systematics, identify control samples / sidebands, improve tools (b/τ-tagging, ...)
  - first studies on **$H^+ \to \tau\nu$ with $\tau \to l\nu\nu$** are arriving
  - all presented channels+some more: currently investigated with Full Simulation for ATLAS, too => results end of this year
  - data!!!

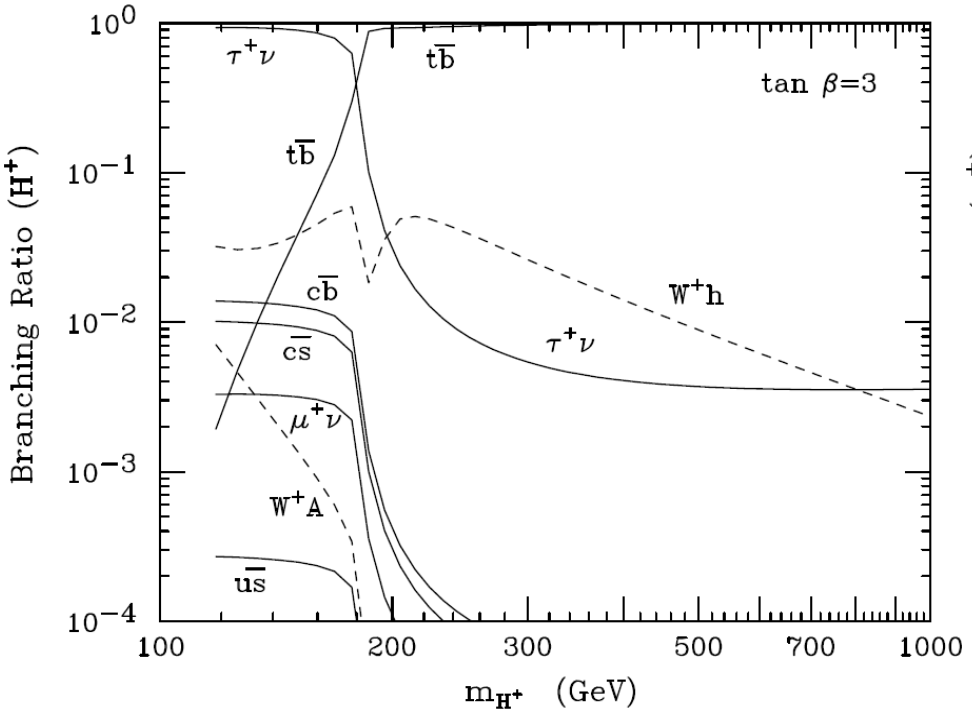
Backup Slides

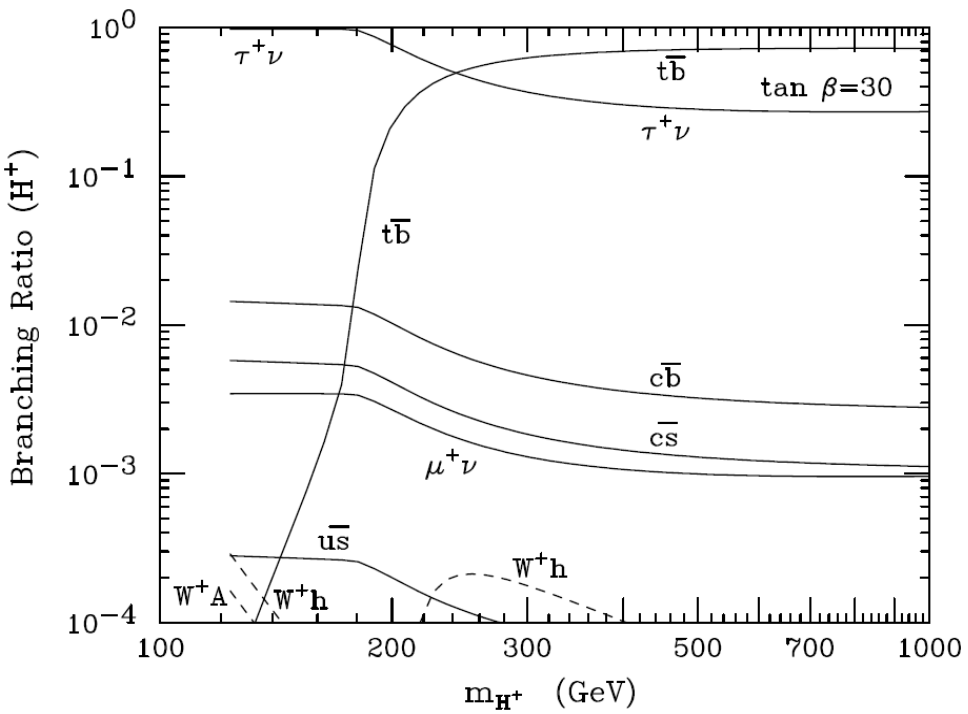
The m_h-max scenario of the MSSM:

$M_2 = 200$ GeV $\mu = 200$ GeV $X_T = 2$ TeV

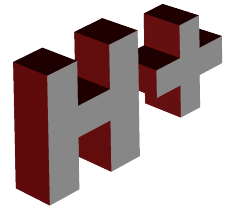
$M_{SUSY} = 1$ TeV $m_{gluino} = 800$ GeV

m_{H+} and tan β are free parameters





Differences between ATLAS and CMS Studies (1)



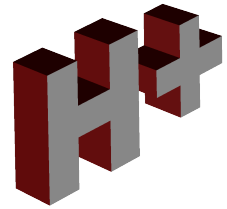
$gg/gb \rightarrow tH^+[b]$, $H^+ \rightarrow tb$

In SN-ATLAS-2004-042, as compared to CMS NOTE 2006/109:

- based on Fast Simulation
- no pile-up
- mass range m_{H+} = 200-800 GeV investigated
- only investigates $gg \rightarrow tbH^+$
- looks at muon *and electron* decays of one of the Ws
- Likelihood to decrease combinatorial background, but no kinematic fit to the particle four-momenta
  uses reconstructed angles, momenta and invariant mass
- different variables for background suppression:

  m_{b0b2} $\cos(b_0,b_2)$ $\cos(b_0 + b_2)$ $\cos(b_0,b_2)$ $\cos(t^{H+},H^+)$

Differences between ATLAS and CMS Studies (2)

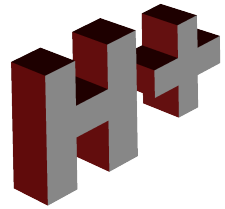


$gg/gb \rightarrow tH^+[b]$, $H^+ \rightarrow \tau_{had}\nu$, $W \rightarrow qq$

In CMS NOTE 2006/100, as compared to ATL-PHYS-PUB-2007-006:

- Full Simulation used for backgrounds
- only $gg \rightarrow tH^+b$ simulated (scaled to $gg/gb \rightarrow tH^+[b]$ cross section)
- Simulation includes pile-up for low luminosity runs
- Poisson significance estimator used
- same optimisation for whole mass range (m_{H+} = 170-600 GeV)
- cut on p (leading track) / E (τ-jet) > 0.8 (exploit τ helicity correlations)
- Veto on additional central jets [instead of cut on p_T(additional jet)/p_T(τ-jet)]
- no cut on the pseudorapidity of the τ-jet
- trigger simulation applied
- differences in τ-jet/b-jet/lepton reconstruction and tagging

References



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