$H^\pm W^\mp$ production in the MSSM at the LHC

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based on

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Outline

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- Cuts for background suppression
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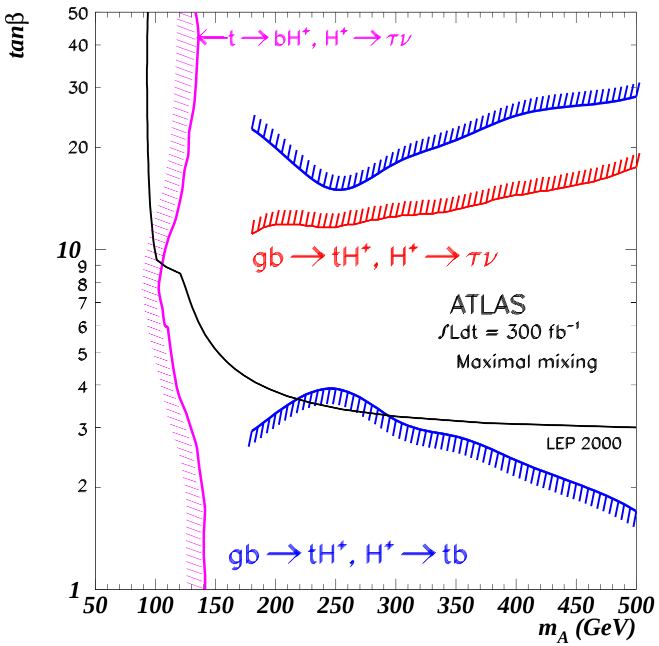
Introduction

- Discovery of charged Higgs ($H^\pm$) $\Rightarrow$ new physics
- Search for $H^\pm$ at LHC

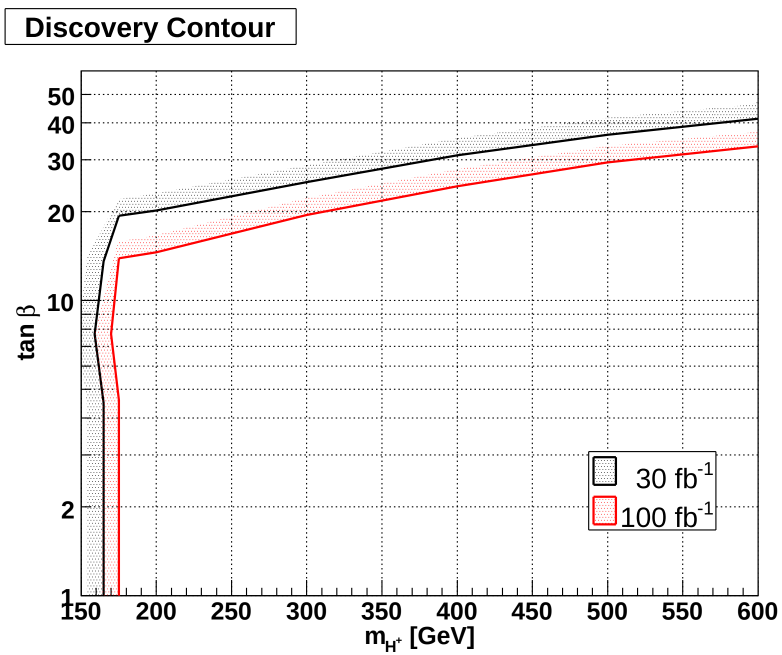
$\longrightarrow$ main search channels: $gb \to H^- t$ and $gg \to H^- t\bar{b}$

e.g. studies from ATLAS

[Assamagan, Coadou, Deandrea '02]



[Mohn, Flechl, Alwall '07]



$\longrightarrow$ gap for $m_{H^\pm} \gtrsim m_t$ and intermediate $\tan\beta$

Introduction

- $H^{\pm}W^{\mp}$ production: large cross section

  [Barrientos Bendezú, Kniehl, '98; Brein, '02; Asakawa, Brein, Kanemura '05]

- Higher order corrections [Yang, Li, Jin, Zhu, '00; Hollik, Zhu, '01; Zhao, Li, Li, '05]

  $\longrightarrow$ typically $\mathcal{O}$ (5–10%)

- $H^{\pm} \to tb$ decay: large irreducible background from $t\bar{t}$ production

  [Moretti, Odagiri, '98]

- Here: $H^{\pm}W^{\mp}$ production and $H^{\pm} \to \tau^{\pm}\nu$ decay
  - Suppression of background by appropriate cuts
  - In MSSM with real and complex parameters

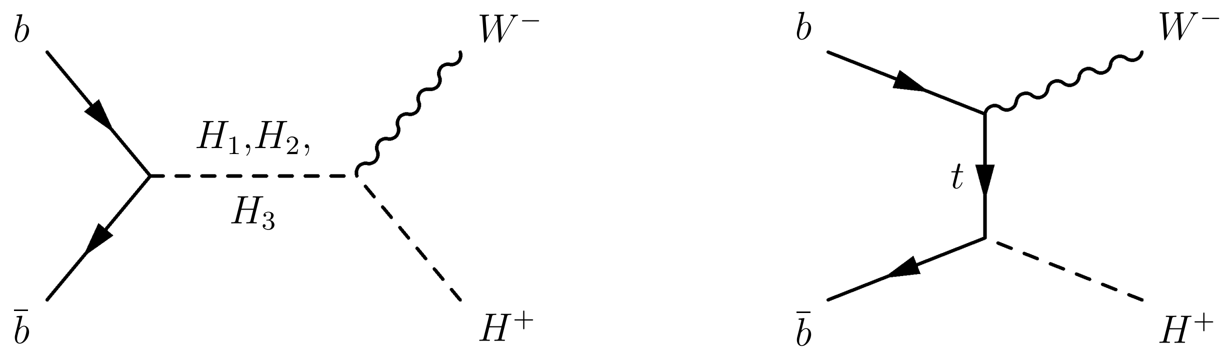
    $\longrightarrow$ Resonance enhancement possible

    [Akeroyd, Baek, '01; Mohn, Gollub, Assamagan, '05]

    $\longrightarrow$ Effects of CP violation, CP asymmetry [Akeroyd, Baek, '00]

$H^{\pm}W^{\mp}$ production at LHC

- At hadron colliders: $b\bar{b} \to H^{\pm}W^{\mp}$ and $gg \to H^{\pm}W^{\mp}$
- Here: focus on $m_{H^{\pm}} \sim m_t$ and large $\tan\beta$ with large $BR(H^{\pm} \to \tau\nu)$ $\to$ $b\bar{b} \to H^{\pm}W^{\mp}$ dominates:



- Neutral Higgs bosons in s-channel
  - CP-conserving MSSM (real parameters): $\{H_1, H_2, H_3\} \equiv \{h, H, A\}$
  - CP-violating MSSM (complex parameters):
    mass eigenstates $\{H_1, H_2, H_3\} \neq$ CP eigenstates

$H^{\pm}W^{\mp}$ production at LHC

- Cross section calculation
  - Implemented as external process in PYTHIA [Sjöstrand et al.]
  - PYTHIA standard for $\Gamma_{H^{\pm}}$ and Γ_W
    $\longrightarrow$ Breit-Wigner distributions for $m_{H^{\pm}}$ and m_W
  - Tree level, however running m_t, m_b and α_{em} in couplings
    $\longrightarrow$ reduction of cross section to $\frac{1}{3}$ $\Rightarrow$ better agreement with NLO
  - FEYNHIGGS: masses, mixing and BR of Higgs bosons
    [Hahn, Hollik, Heinemeyer, Weiglein]

Signature

- Simulation of $pp \longrightarrow W^\pm + H^\mp \longrightarrow jj + \tau\nu$
- Decays $H^\pm \to \tau\nu$ and $W^\pm \to jj$ in PYTHIA
  with $BR(H^\pm \to \tau\nu)$ from FEYNHIGGS
- Tau decay with TAUOLA $\longrightarrow$ spin effects [Golonka et al.]
  Focus on hadronic τ decays
- Signature: $2j + \tau_{\text{jet}} + \not{p}_\perp$
- $\not{p}_\perp$ from 2ν: $H^\pm \to \tau\nu \to \tau_{\text{jet}} + 2\nu$
  $\longrightarrow$ reconstruction of $H^\pm$ invariant mass not possible
  $\longrightarrow$ analysis of transverse mass from $p_{\perp\tau_{\text{jet}}}$ and $\not{p}_\perp$:

$$m_\perp = \sqrt{2 p_{\perp\tau_{\text{jet}}} \not{p}_\perp [1 - \cos(\Delta\phi)]}$$

$\Delta\phi$: angle between $p_{\perp\tau_{\text{jet}}}$ and $\not{p}_\perp$

Background for $2j + \tau_{\text{jet}} + \not{p}_\perp$ signature

- Dominant irreducible background: $pp \to W$ + 2 jets

- WZ + 2 jets and $Z \to \nu\nu$ ($\to$ potentially larger $\not{p}_\perp$):
  less than 3% contribution to background after cuts

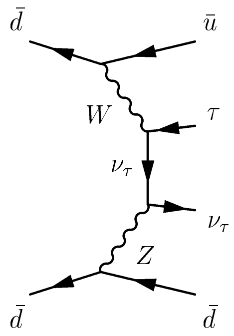
- Simulation of background with ALPGEN
  [Mangano, Moretti, Piccinini, Pittau, Polosa, ’02]

- Background distributions cross checked with MADGRAPH
  [Murayama, Watanabe, Hagiwara, ’91; Stelzer, Long, ’94; Maltoni, Stelzer, ’02]
  [Alwall, Demin, de Visscher, Frederix, Herquet, Maltoni, Plehn, Rainwater, Stelzer, ’07]

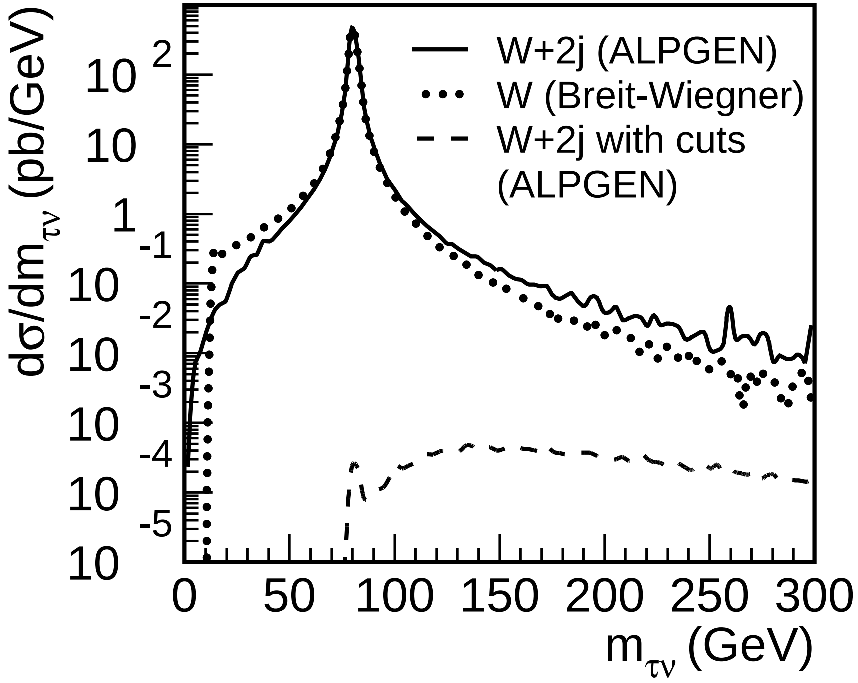
Background for $2j + \tau_{\text{jet}} + \not{p}_{\perp}$ signature

- Implementation of W + 2 jets production in ALPGEN
  - Exact tree-level matrix elements for $2j + \tau + \nu_\tau$ final state
  - Includes W + 2 jets, W pair production

    and contributions where τ and ν not from (virtual) W $\longrightarrow$ e.g.



$\longrightarrow$ Important for large invariant $m_{\tau\nu}$ mass tail:



$\longrightarrow$ factor 2 difference to Breit-Wigner distribution in tail

Cuts for background suppression

- Smearing of jet momenta $\longrightarrow$ first approximation of parton showering, hadronisation and detector effects

Basic cuts	Additional cuts
$\lvert\eta_{\tau_{\text{jet}}}\rvert < 2.5$	$p_{\perp\tau_{\text{jet}}} > 50$ GeV, $\not{p}_{\perp} > 50$ GeV
$\lvert\eta_j\rvert < 2.5$	70 GeV$< m_{jj} < 90$ GeV
$\Delta R_{jj} > 0.4$	$m_{\perp} > 100$ GeV
$\Delta R_{\tau_{\text{jet}}j} > 0.5$	$p_{\perp hj} > 50$ GeV, $p_{\perp sj} > 25$ GeV
$p_{\perp jet} > 20$ GeV	

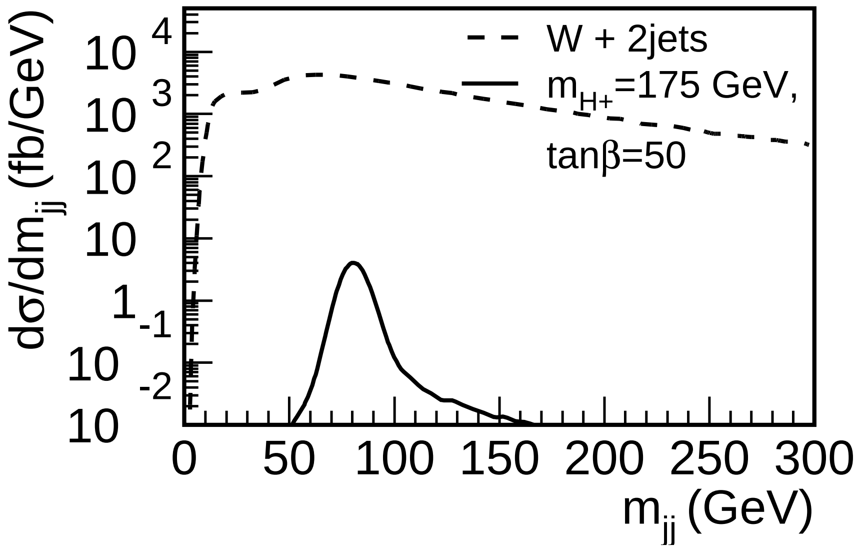
  - Basic cuts: define signal region $\leftrightarrow$ sensitive detector region
  - Additional cuts: suppress background, QCD background, detector miss-identifications

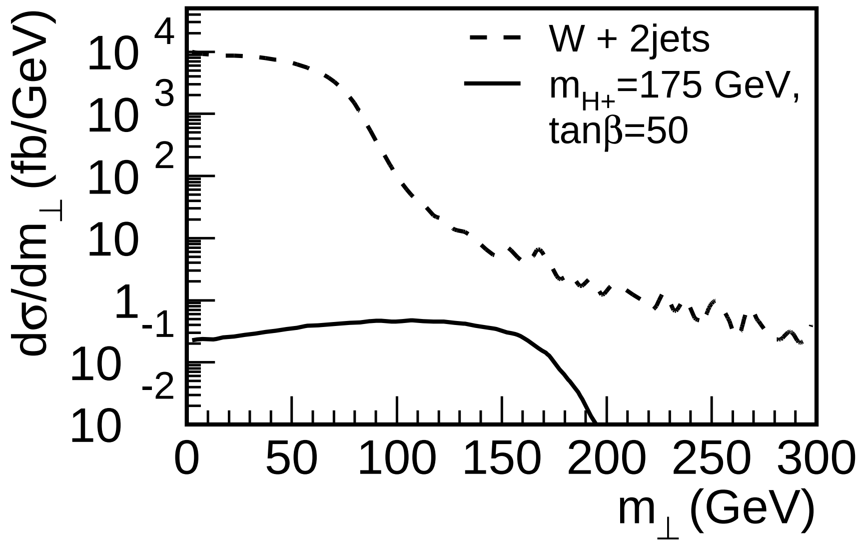
Cuts for background suppression

- Distributions of signal and background after basic cuts

  $\Rightarrow$ Additional cuts

- For example:





$\longrightarrow$ Cut: 70 GeV $< m_{jj} <$ 90 GeV

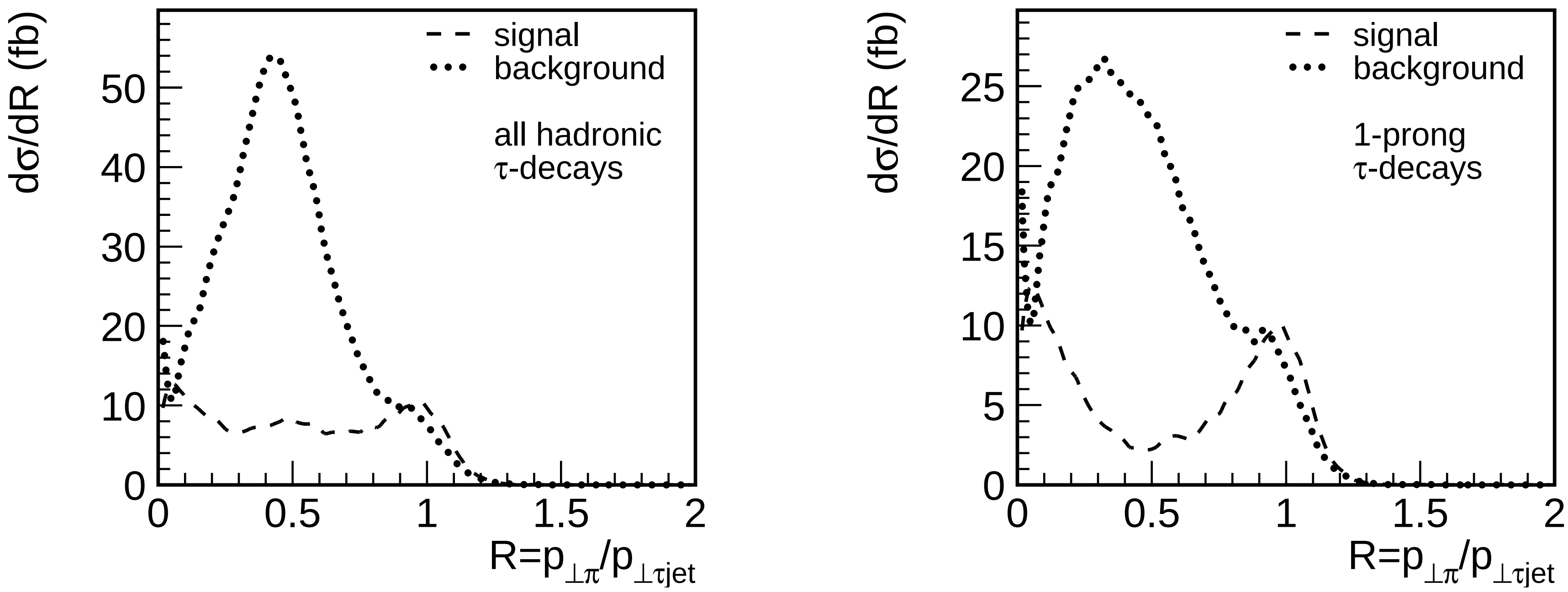
$\longrightarrow$ Cut: $m_{\perp} >$ 100 GeV

Cuts for background suppression

- Spin correlations in τ decays

  [Roy, '92, '99; Raychaudhuri, Roy, '95; Guchait, Kinnunen, Roy, '06]

  - τ_{jet} properties different for signal ($H^\pm$) and background (W)
  - Ratio $R = \dfrac{p_{\perp\pi}}{p_{\perp\tau_{\text{jet}}}}$ $\quad p_{\perp\pi}$: $p_\perp$ of leading charged π



$\longrightarrow$ However: cut $R > 0.8$ $\leftrightarrow$ no enhancement of $S/\sqrt{B}$

Cuts for background suppression

Results for maximal mixing scenario with $m_{H^\pm}$ = 175 GeV, tan β = 50

μ = 200 GeV, M_{SUSY} = 1 TeV, X_t = X_b = 2 TeV, M_2 = 200 GeV, $m_{\tilde{g}}$ = 800 GeV

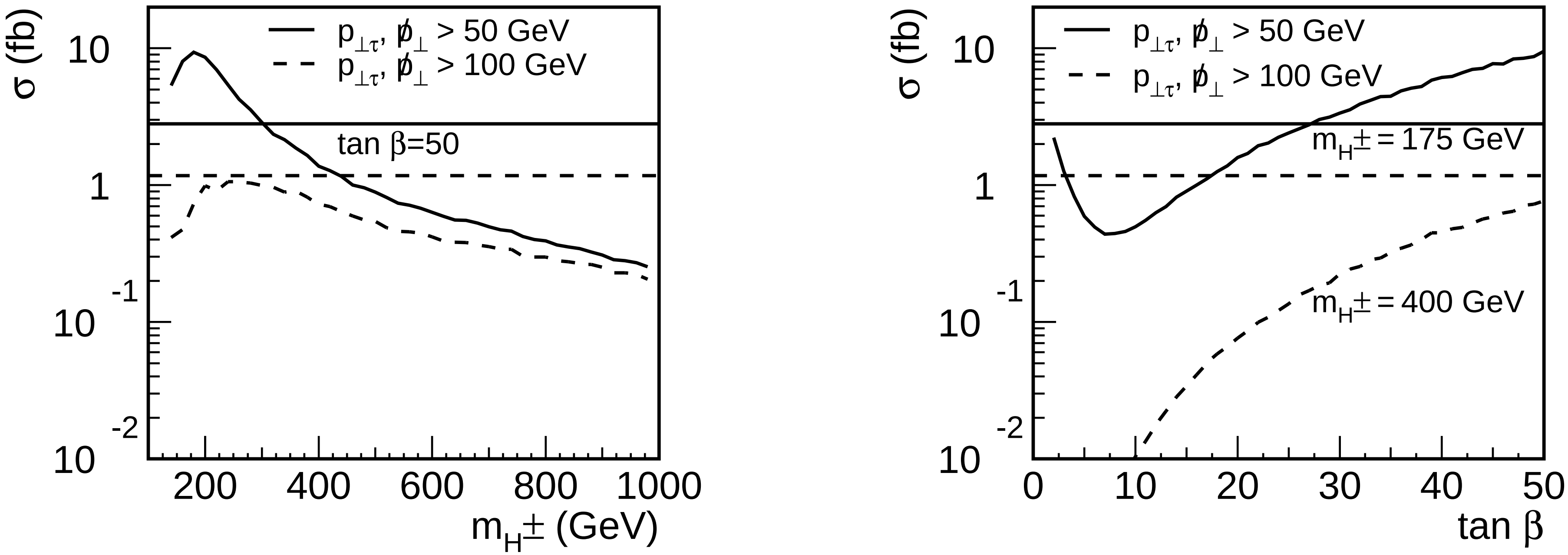
	Integrated cross-section (fb)		
Cut	Background	Signal	$S/\sqrt{B}$
Basic cuts	560000	63	0.8
$p_{\perp\tau_{\mathrm{jet}}} > 50$ GeV, $\not{p}_\perp > 50$ GeV	22000	25	1.6
70 GeV $< m_{jj} <$ 90 GeV	1700	21	5
$m_\perp > 100$ GeV	77	15	16
$p_{\perp hj} > 50$ GeV, $p_{\perp sj} > 25$ GeV	28	9.3	17

For calculation of $S/\sqrt{B}$: $\mathcal{L}_{\mathrm{int}}$ = 300 fb^{-1}; 30% τ detection efficiency

Results — MSSM with real parameters

Maximal mixing scenario

μ = 200 GeV, M_{SUSY} = 1 TeV, X_t = X_b = 2 TeV, M_2 = 200 GeV, $m_{\tilde{g}}$ = 800 GeV



Horizontal lines $\leftrightarrow$ $S/\sqrt{B}$ = 5

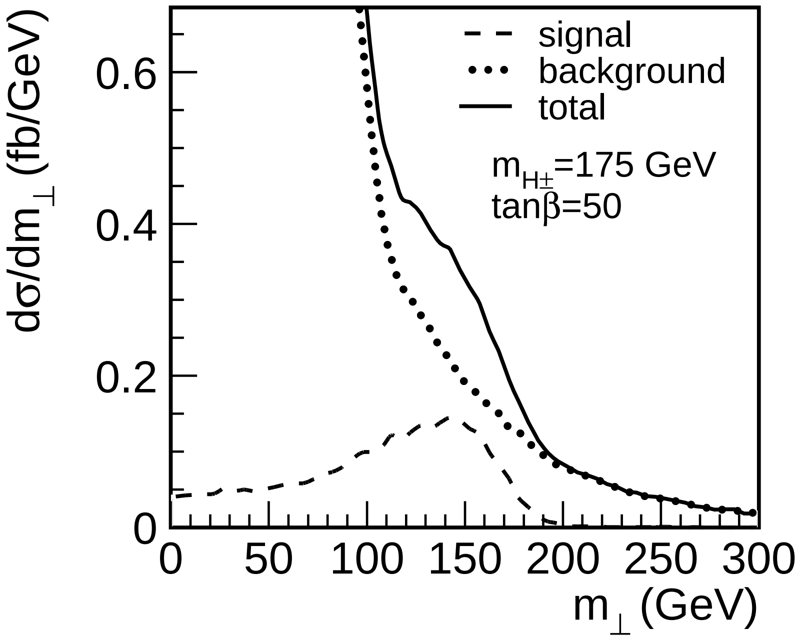
$\longrightarrow$ Detectable signal: 150 GeV $\lesssim m_{H^\pm} \lesssim$ 300 GeV if tan β = 50

tan $\beta \gtrsim$ 30 if $m_{H^\pm}$ = 175 GeV

Results MSSM with real parameters

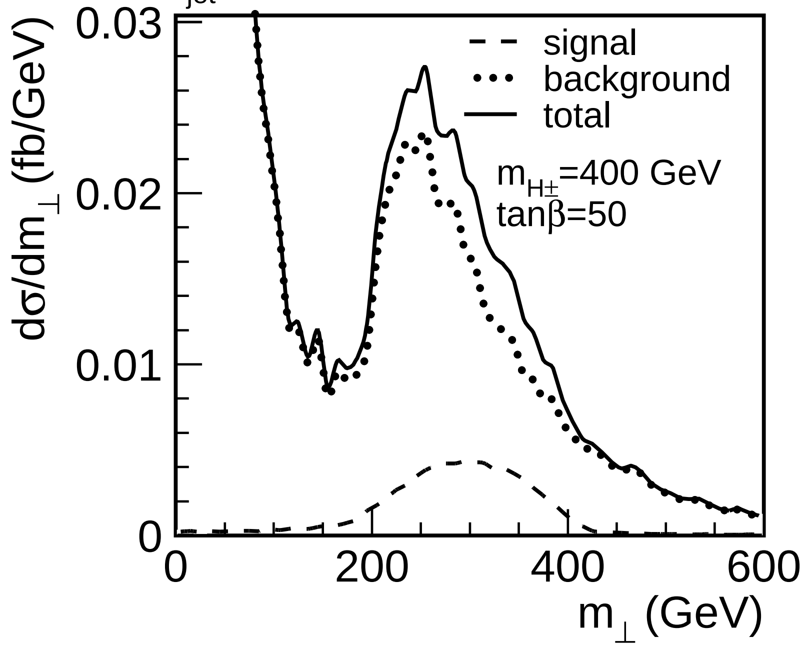
Maximal mixing scenario

μ = 200 GeV, M_{SUSY} = 1 TeV, X_t = X_b = 2 TeV, M_2 = 200 GeV, $m_{\tilde{g}}$ = 800 GeV



$\rightarrow S/\sqrt{B}$ = 17

$p_{\perp\tau_{\text{jet}}} > 100$ GeV, $\not{p}_\perp > 100$ GeV



$\rightarrow S/\sqrt{B}$ = 3

$\rightarrow$ Fake peak in background!

Results

MSSM with real parameters

Resonant scenario with $m_{H^\pm}$ = 175 GeV, tan β = 11

μ = 3.3 TeV, M_L = M_E = 500 GeV, M_Q = M_U = 250 GeV, M_D = 400 GeV,
A_t = A_b = 0, M_2 = 500 GeV, $m_{\tilde{g}}$ = 500 GeV

$\longrightarrow$ very large 1-loop corrections to CP-odd Higgs mass

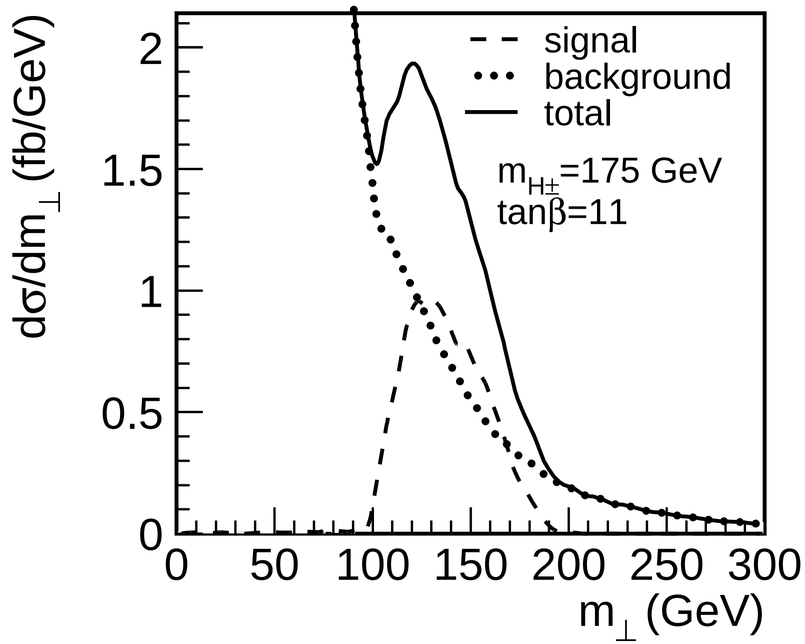
(2-loop effects much smaller $\longrightarrow$ perturbative expansion under control)

$\Rightarrow m_A > m_{H^\pm} + m_W$ possible [Akeroyd, Baek, ’02]

$\longrightarrow$ resonant s-channel production

$S/\sqrt{B}$ = 56 $\longrightarrow$

$p_{\perp hj} > 20$ GeV, $p_{\perp sj} > 20$ GeV



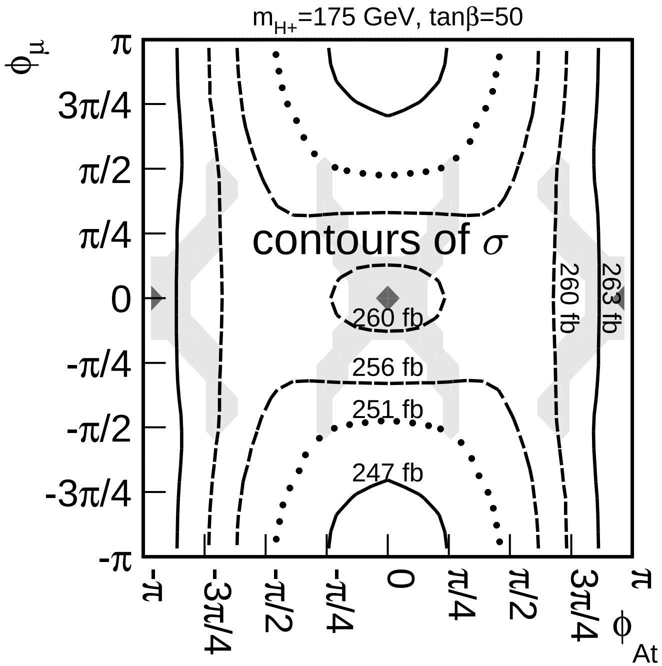
Results MSSM with complex parameters

- Higgs sector analyzed with FEYNHIGGS [Hahn, Hollik, Heinemeyer, Weiglein]

  Cross checks with CPSUPERH [Lee, Pilaftsis, Carena, Choi, Drees, Ellis, Wagner]

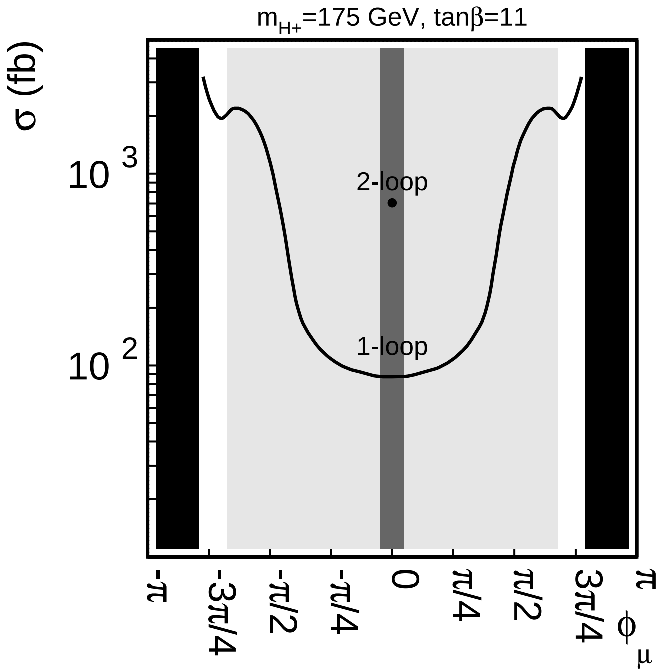
- Phases ϕ_μ and ϕ_{A_t}: largest effects on Higgs sector

- Maximal mixing scenario
  $(m_{H^\pm} \sim m_{H_2} \sim m_{H_3})$



$\Rightarrow$ small ($\sim$ 5%) phase effects on σ

Resonant scenario
$m_{H_3} > m_{H^\pm} + m_W$



$\Rightarrow$ large phase effects possible

Results   MSSM with complex parameters

- CP-odd rate asymmetry: $$A_{\text{CP}} = \frac{\sigma(b\bar{b} \to H^+W^-) - \sigma(b\bar{b} \to H^-W^+)}{\sigma(b\bar{b} \to H^+W^-) + \sigma(b\bar{b} \to H^-W^+)}$$

- In general CP-violating 2-Higgs-Doublet Models:

  Large A_{CP} possible in resonant scenarios with

  $m_{H_2} > m_{H^\pm} + m_W$ and $m_{H_3} > m_{H^\pm} + m_W$ [Akeroyd, Baek, '01]

- However in MSSM:
  - Typical scenarios $\longrightarrow m_{H_2} \sim m_{H_3} \sim m_{H^\pm}$
  - Resonant scenarios $\longrightarrow m_{H_3} > m_{H^\pm} + m_W,\, m_{H_2} < m_{H^\pm} + m_W$

$\Rightarrow$ $A_{\text{CP}} \lesssim 1\%$

Summary

- $pp \to W^\pm + H^\mp \to jj + \tau\nu$ at parton level with smearing of momenta
- Signature: $2j + \tau_{\text{jet}} + \not{p}_\perp$
- Dominant irreducible background: $pp \to W + 2$ jets
- Appropriate cuts on $p_\perp$, m_{jj}, $m_\perp$
- Detectable signal at LHC in MSSM

  $\longrightarrow$ maximal mixing scenario: $150\text{ GeV} \lesssim m_{H^\pm} \lesssim 300\text{ GeV}$ if $\tan\beta = 50$

  $\tan\beta \gtrsim 30$ if $m_{H^\pm} = 175$ GeV

  $\longrightarrow$ resonant scenarios: also for smaller $\tan\beta$

- CP-violating MSSM
  - Large phase effects possible in resonant scenarios
  - CP-odd rate asymmetry $\lesssim 1\%$