2004 LHC Days in Split
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Importance of τ's in the MSSM Higgs Boson Discovery

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Introduction

In the MSSM, the SM-like lighter scalar h is expected to be found in several decay channels in the region of large m_A and $\tan\beta$

To best disentangle between SM and MSSM, the heavy bosons, A, H and $H^{\pm}$ should be looked for !

Couplings to fermions and weak bosons (when compared to SM) lead to specific MSSM Higgs search strategies at large $\tan\beta$

	$g_{\phi uu}$	$g_{\phi dd}$	$g_{\phi VV}$
h	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\beta-\alpha)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\beta-\alpha)$
A	$\gamma_5/\tan\beta$	$\gamma_5 \tan\beta$	0

⇒

- suppression of HZZ/HWW couplings
- absence of AZZ/AWW couplings
- enhancement of ϕdd ($d=\tau$,b..) couplings

⇒ Importance of decays to τ's, H/A/h -> $\tau\tau$ and production in association with b´s in gg->bbH/A

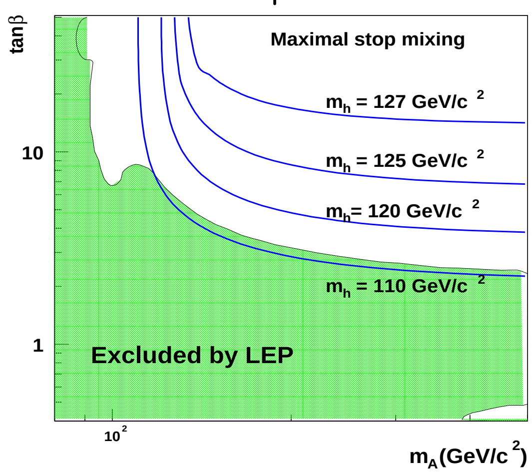
MSSM parameter space and mass spectrum

LEP-type SUSY scenario assumed (for most of the LHC studies):

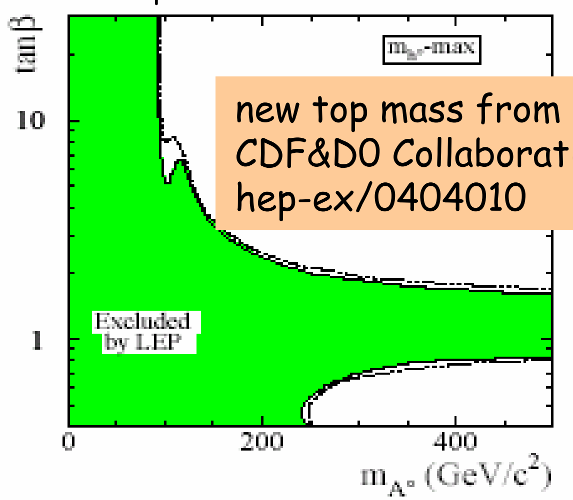
M_2 = 200 GeV/c^2, μ = -200 GeV/c^2, M_{gluino} = 800 GeV/c^2,$M_{squark,slepton}$ = 1 TeV/c^2

No stop mixing (X_t = 0) or maximal stop mixing (X_t = 2450 GeV/c^2)

LEP exclusion with m_{top} = 175 GeV

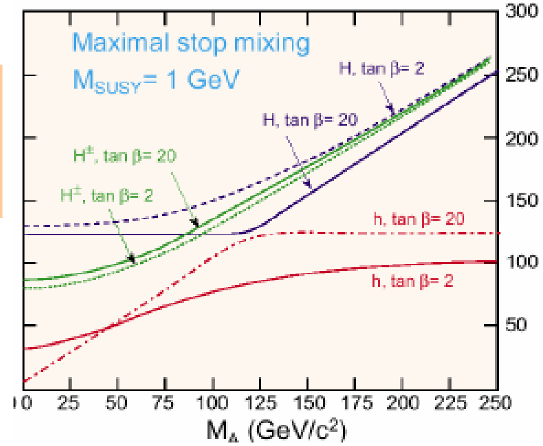


LEP exclusion with m_{top} = 179.3 GeV



new top mass from CDF&D0 Collaborations: hep-ex/0404010

MSSM Higgs boson mass spectrum with maximal stop mixing



Mass of the lighter scalar h with two-loop/RGE-improved radiative corrections:

m_h^{max} = 113 (116) GeV for no stop mixing

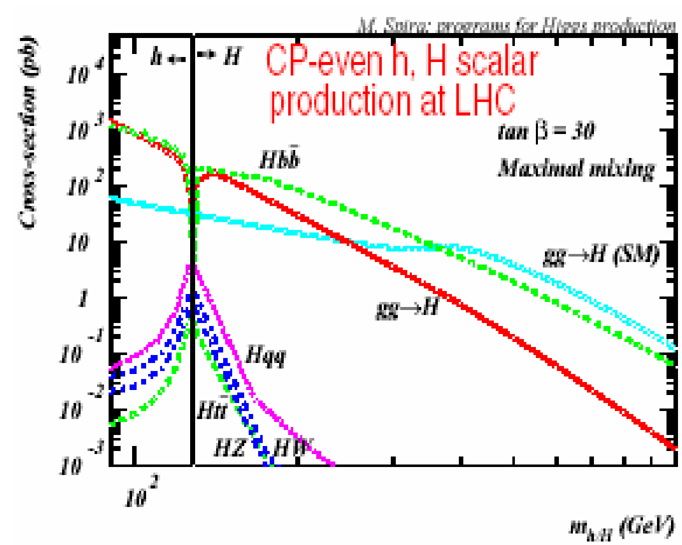
m_h^{max} = 127 (132) GeV for maximal stop mixing

with m_{top} = 175 (179.3) GeV, M_S = 1 TeV

Heavy neutral MSSM Higgs bosons H and A

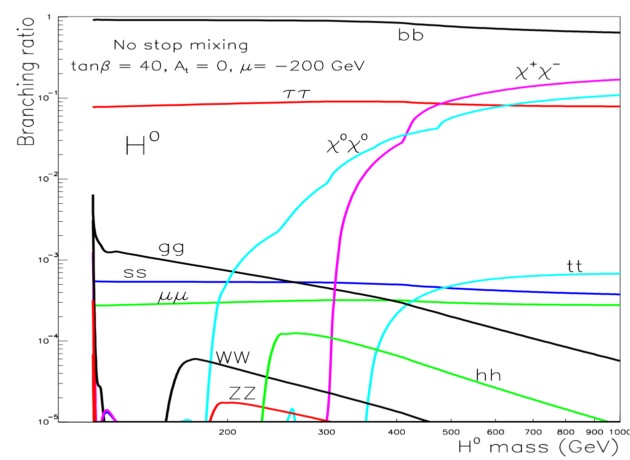
Production through gg->H/A and gg->bbH/A

Associated production gg -> bbH/A dominates at large tanβ
-> b taggging can be used to suppress Z, γ^*, W+jet and QCD multi-jet backgrounds leading to real (or fake) $\tau\tau$ pair production



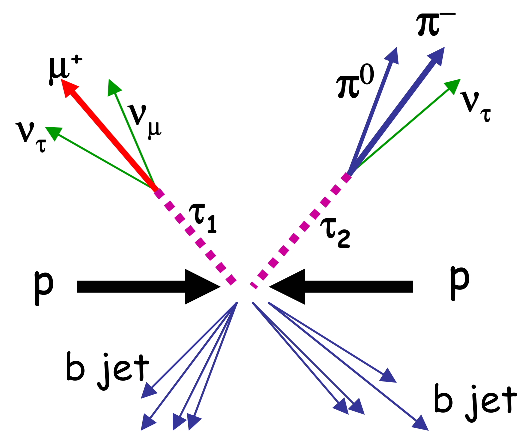
Branching fractions at large tanβ (>10):

BR(H,A -> $\tau\tau$) ~ 10%
H,A –> bb dominates
-but background reduction difficult, not yet shown to be really useful
BR(H,A -> $\mu\mu$) small ~ 3×10^{-4}
- but precise mass measurement possible



At large m_A, sensitivity to SUSY parameters (μ and M_2) due to opening of H,A -> $\chi\chi$ decay modes

gg->bbH/A, H/A -> ττ channels



Final states from H,A -> ττ:

2 leptons, BR ~ 12.4%
lepton + τ jet, BR ~ 45.6%
2 τ jets, BR ~ 42%
τ jet = hadronic τ decay

Backgrounds from
Z,γ*-> ττ, tt, Wt, W+jets, bb, QCD multi-jet events

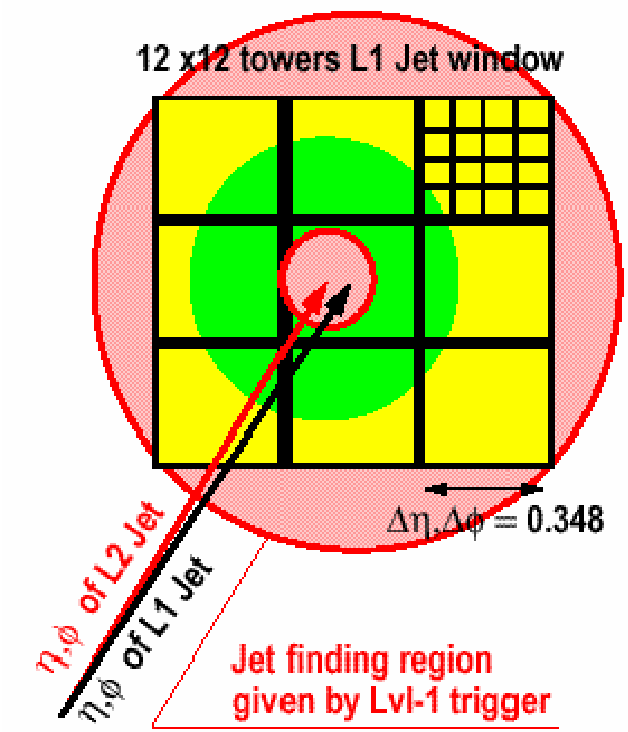
Challenges with ττ decay modes:
- Suppress the fake τ's from hadronic jets
  (QCD multi-jet, W+jet backgrounds)
- Trigger on fully hadronic final states, 2 τ jets (also at low m_A)
- Reconstruct the Higgs boson mass from E_t^{miss} + leptons, jets

Hadronic jet suppression (at trigger level and offline) is based on narrowness and low multiplicity (1 or 3 prongs) of a τ jet

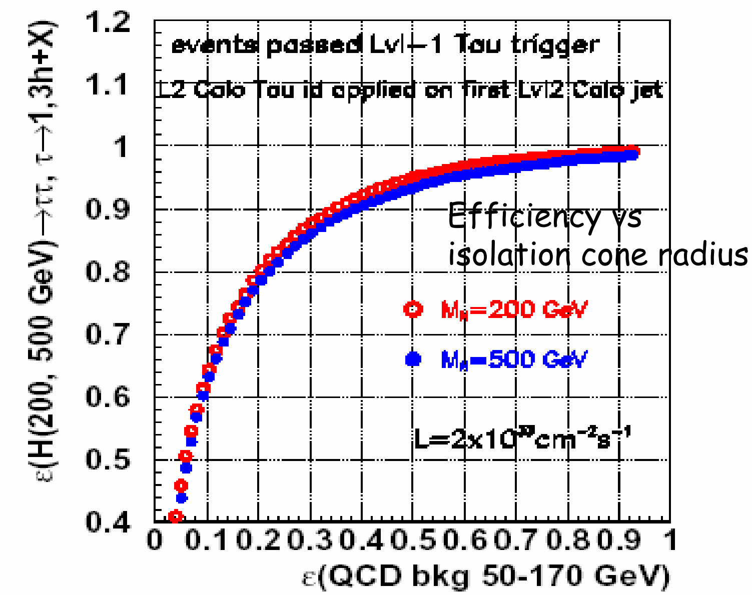
Hadronic Tau trigger

Requirements: 3(6) kHz output rate at Level-1 at low(high) luminosity
Reduction of hadronic QCD events by ~10^3 at HLT

Level-1: Narrow hadronic jet in calorimeters

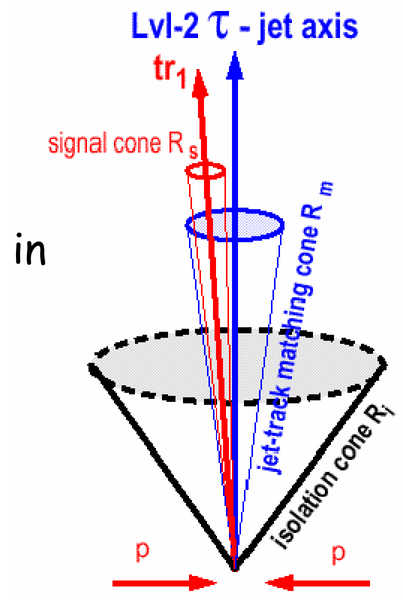


Level-2: Isolation of the jet core ($\Delta R < 0.13$) in the fine-grained EM calorimeter



Level-3 Tau trigger

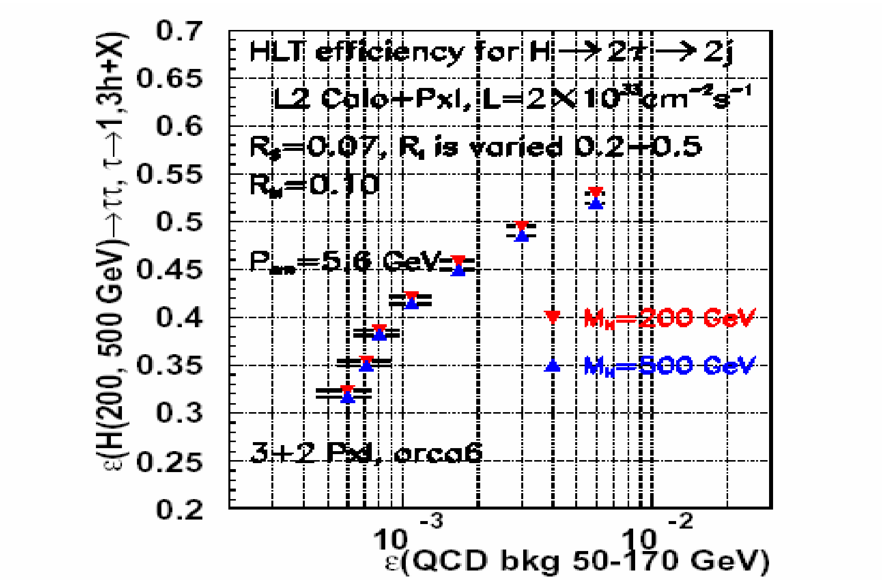
with isolation in the Pixel detector or in the full tracker (Pixel + Silicon)



Method:

- Reconstruction of tracks around the Level-1 jet direction in the Pixel detector or in the Pixel+Silicon tracker
- Small signal cone (ΔR_S = 0.07) around the hardest track
- Larger isolation cone around jet direction

Efficiency (QCD vs H->ττ–> 1/3 prong jets) as a function of the isolation cone size



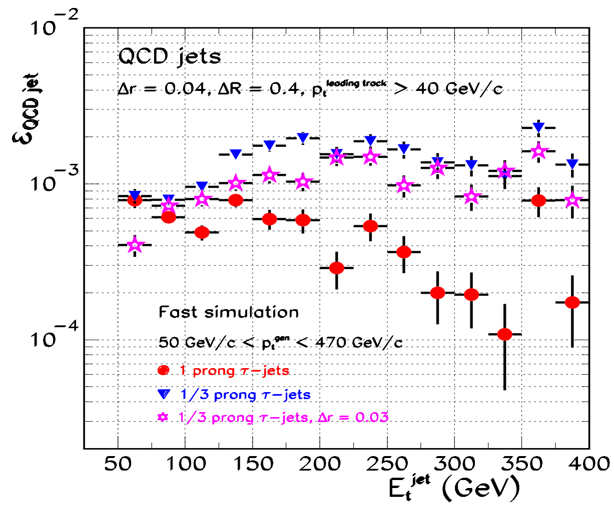
H->ττ–>2τ jets, m_H=200 GeV:

Signal efficiency for a QCD background suppression of 10^3 at L=10^{33}cm^{-2}s^{-1}

HLT path	eff.	cpu[ms]
Calo+Pixel	0.41	59
Calo+Tracker	0.45	130

Hadronic τ identification

Algorithm:
- p_T (leading track) > 40 GeV in a jet with E_T > 60 GeV
-two other tracks, p_T> 1 GeV, allowed in a small signal cone of Δr < 0.04 around the leading track
- isolation of the signal cone in a larger cone of ΔR = 0.4



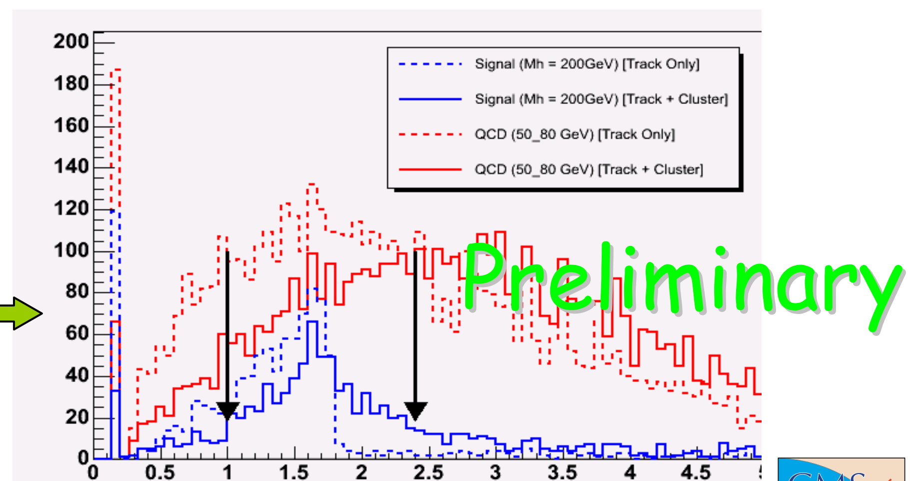
QCD jet suppression ~ 1000
τ jet efficiency ~ 30% for m_A = 500 GeV

τ -> 3 prong decays can be used too !

Further methods exploiting τ properties

τ tagging with mass

Reconstructed τ mass for
3 prongs and $h^{\pm} + n\pi^0$ final states
H->ττ–>2τ jets, m_H=200 GeV
and for QCD jets



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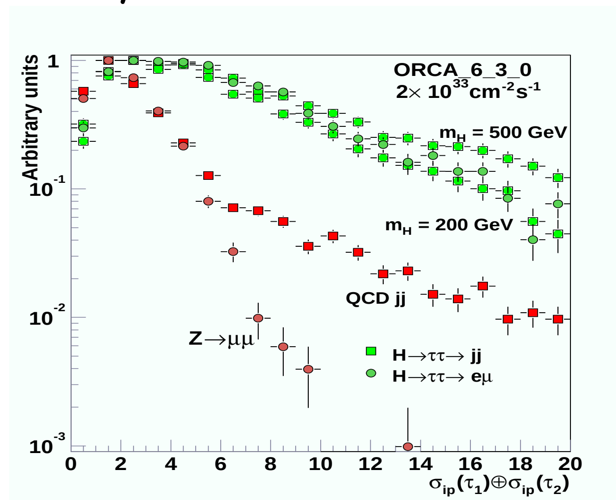
Methods exploiting τ lifetime: $c\tau \sim 90\ \mu m$

τ's from H->$\tau\tau$ with m_H = 200 GeV travel ~ 5 mm before decaying ->
Z -> $\ell\ell$ and QCD multijet backgrounds can be suppressed by

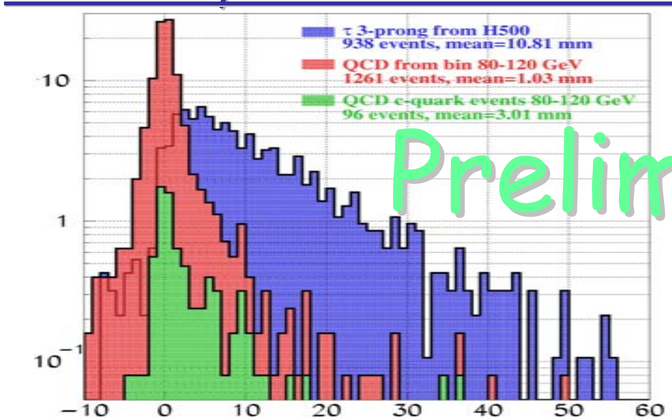
τ tagging with impact parameter

combining impact parameter measurements to
$((\sigma_{ip}^{\tau 1})^2 + (\sigma_{ip}^{\tau 2})^2)^{1/2}$
in two τ's for 1- and 3-prong τ's

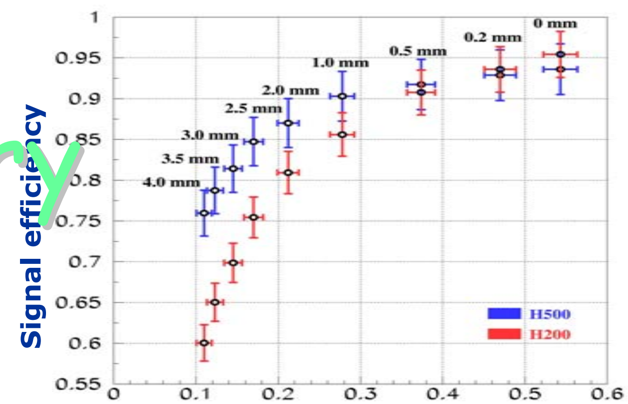
-> QCD di-jet suppression further by ~9
for ~60% signal efficiency



Secondary vertex reconsruction in 3-prong τ decays



3D reconstructed flightpath in mm



Background efficiency

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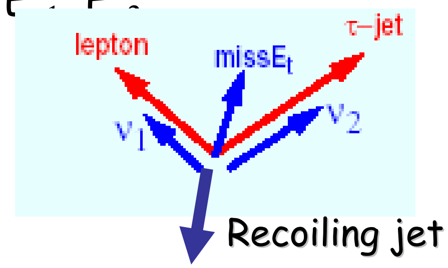
Higgs boson mass reconstruction in H,A -> $\tau\tau$

Assume ν's emitted in the two τ directions given by the visible decay products (leptons, hadrons), project E_t^{miss} on the two τ directions to give $E_{\nu 1}$, $E_{\nu 2}$

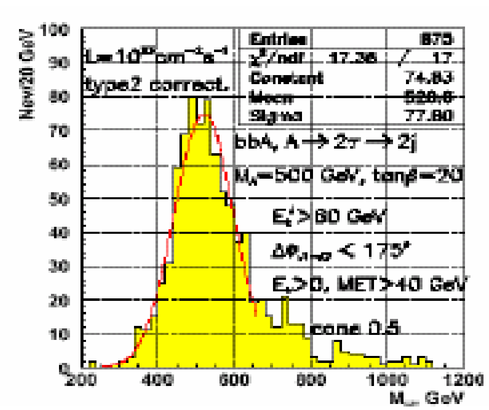
$$m_H = (2E_{\tau 1}E_{\tau 2}(1-\cos\theta_{\tau\tau}))^{1/2}$$

$$E_{\tau 1} = E_{jet} + E_{\nu}\ , \quad E_{\tau 2} = E_{lepton} + E_{\nu}$$

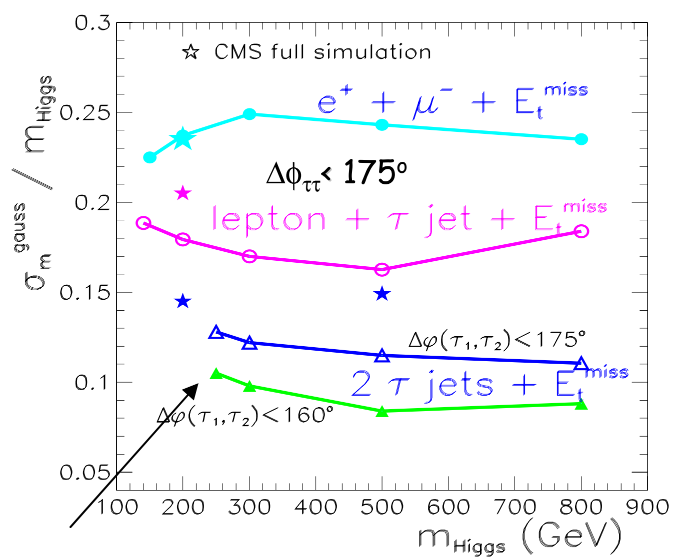


- Resolution and reconstruction efficiency sensitive to E_t^{miss} measurement
- Resolution depends on $\Delta\theta_{\tau\tau}$ as $1/\sin\theta_{\tau\tau}$

Mass reconstruction in H->$\tau\tau$–> 2 τ jets:



Resolution for
m_H = 500 GeV:
$\sigma/< m_H > \sim 15\%$
with $\Delta\phi_{\tau\tau} < 175°$



Best resolution obtained with fully hadronic τ final states

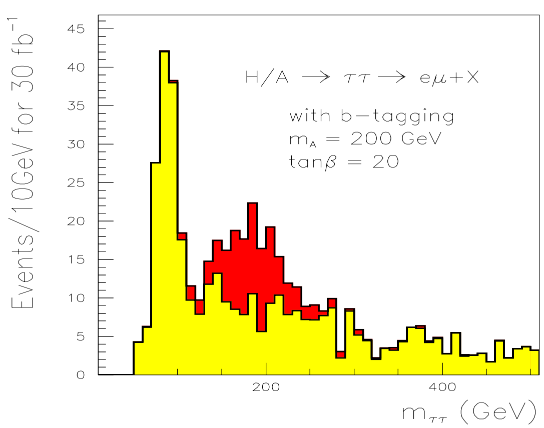
Discovery potential for H/A -> ττ

Background suppression with

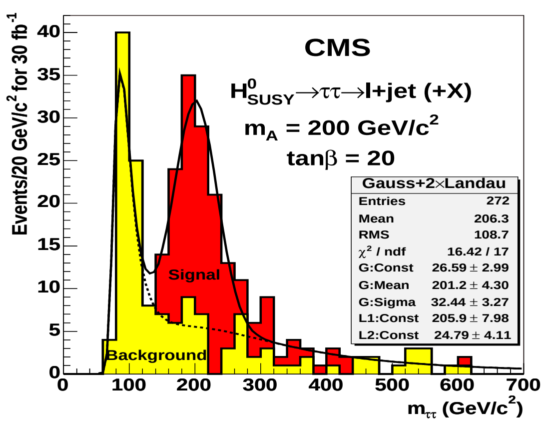
- lepton isolation in eμ and ℓℓ final states: bb background
- hadronic τ identification, lepton+jet and 2-jet final states: QCD multi-jets, W+jets
- b-jet tagging: Z-> ττ, QCD multi-jets, W+jets
- τ tagging with impact parameter: Z->ℓℓ, QCD multi-jets
- central jet veto: tt and Wt backgrounds

Signal superimposed on the total background in

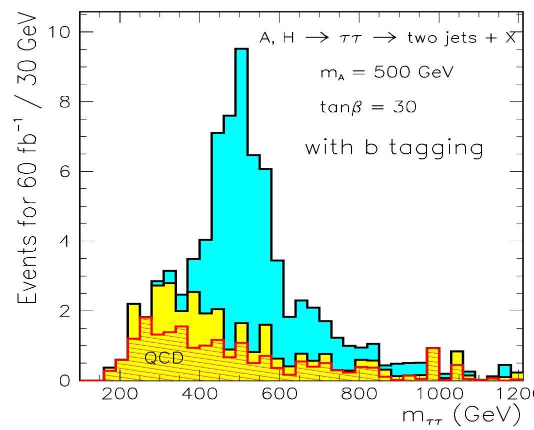
e-μ final state 30fb^{-1}



lepton+jet final state 30 fb^{-1}



two-jet final state 60 fb^{-1}



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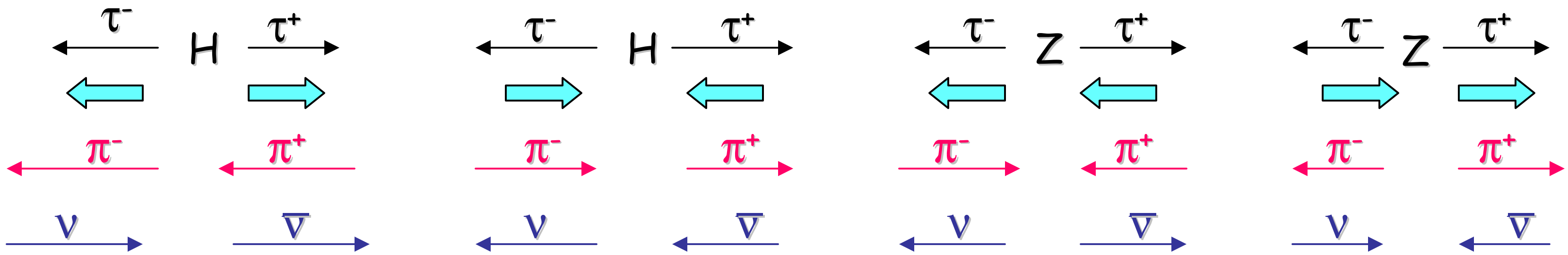
Helicity correlations in H,A -> $\tau\tau$ –> 2 τ jets

a possibility to suppress further Z,γ^* background?



Two possible spin configurations:

	H(A) -> $\tau\tau$	Z ->$\tau\tau$
τ helicity	LL	LR
	RR	RL
τ polarization	+-	++
	-+	--

τ(+pol) -> hard $\pi^{\pm}$, ρ_L, a_L, soft ρ_R,a_R

τ(-pol) -> soft $\pi^{\pm}$, ρ_L, a_L, hard ρ_R,a_R

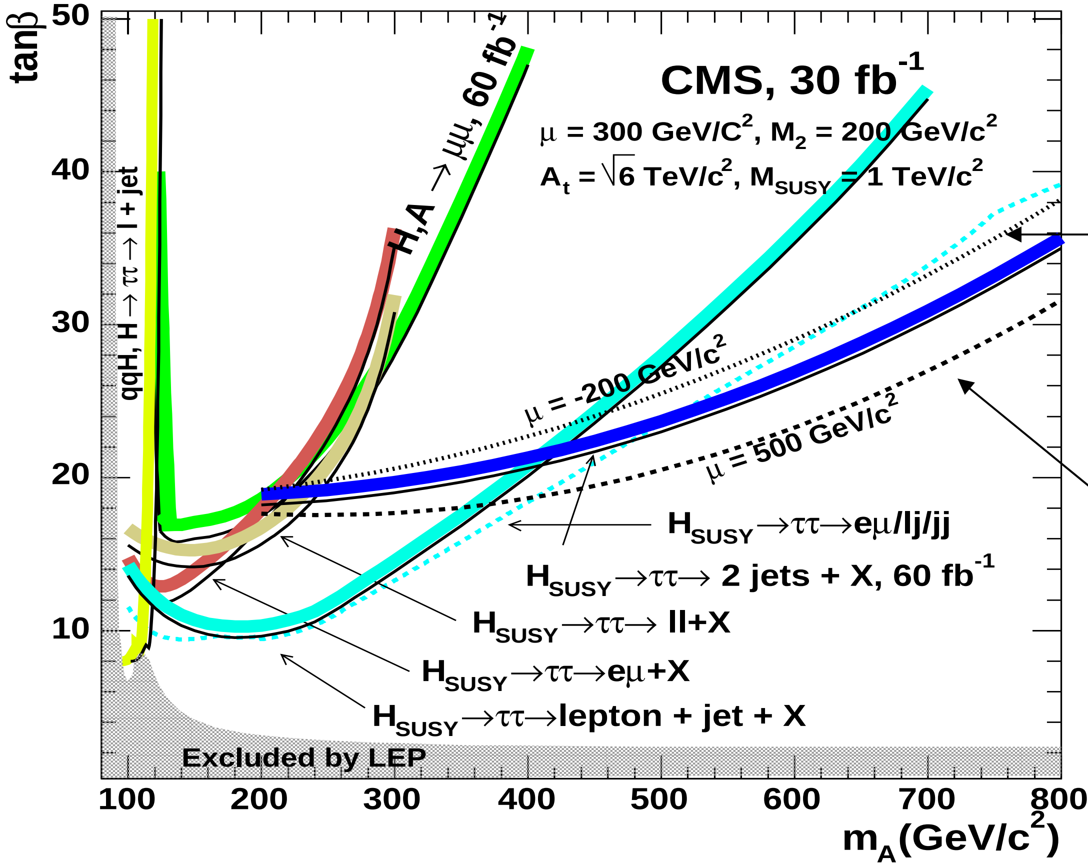
Expectation:

H(A) -> $\tau\tau$: $\Delta E(\tau_1)$ large and $\Delta E(\tau_2)$ small

Z -> $\tau\tau$: $\Delta E(\tau_1)$ and $\Delta E(\tau_2)$ small or $\Delta E(\tau_1)$ and $\Delta E(\tau_2)$ large

where $\Delta E(\tau) = E_{\pi\pm} - \Sigma E_{\pi 0}$

5σ discovery potential for the heavy neutral MSSM Higgs bosons



Reach sensitive to SUSY parameters (μ and M_2) at large m_A :

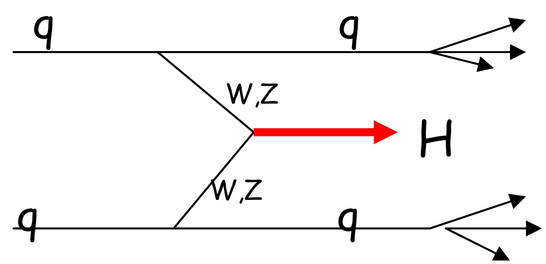
Reduction of the H-> ττ branching fraction for smaller μ and M_2
-> enhancement of H,A->χχ due to lighter gauginos

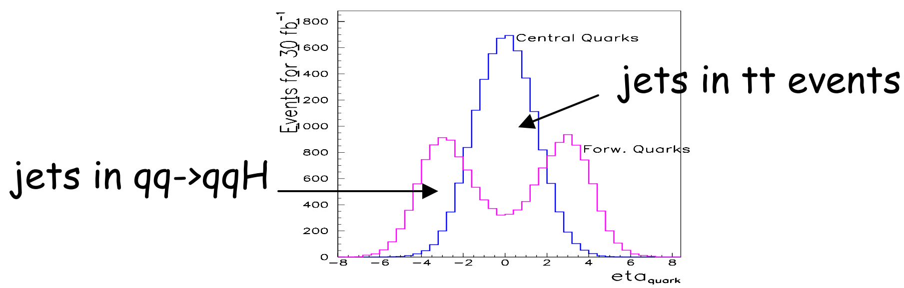
Enhancement of the H-> ττ branching fraction for larger μ and M_2
-> reduction of H,A->χχ due to heavier gauginos

H production in weak gauge boson fusion

Production characteristics:

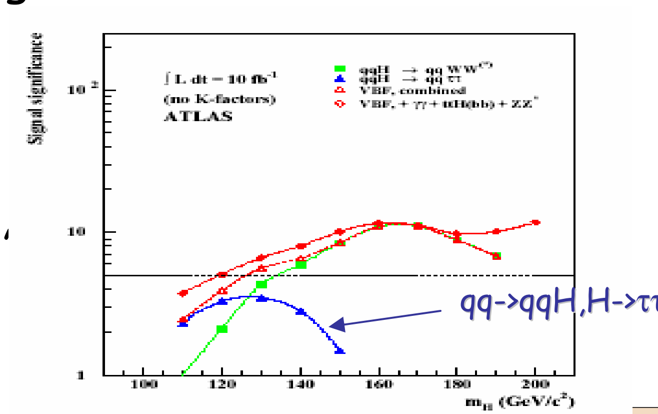
- the final state q-jets from qq->qqH are energetic and distributed in the forward regions
- no jets expected in the central region





Forward jet tagging and central jet veto can be used to suppress the QCD multi-jet, W+jet, Z+jet, γ+jet and tt backgrounds

qq -> qqH important for the SM Higgs boson searches with H->WW,WW*,γγ,ττ decay modes, in particular in the region of small (<120 GeV) and large (>500 GeV) m_H

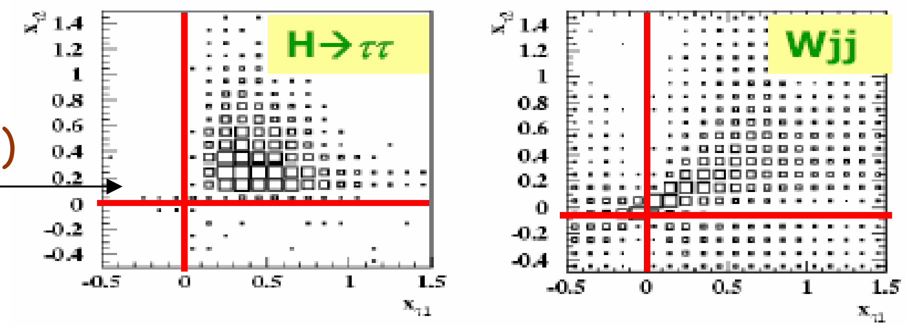


H -> $\tau\tau$ -> 2 leptons, lepton + τ jet in weak boson fusion

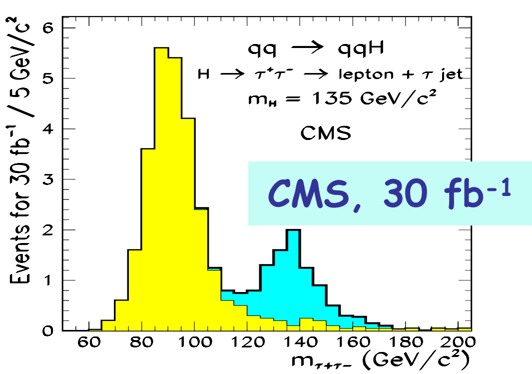
Backgrounds from Z+jets, W+jets, tt,WW
suppressed with forward jet tagging and central jet veto
The electro-weak qq->qqZ/W background is irreducible but initially smaller then the QCD induced ones

Higgs boson mass can be reconstructed from visible τ's (jets and leptons) and E_t^{miss} with collinear neutrino approximation

Further background suppression with
x_τ = p(τ decay products)/p(τ reconstructed)
$x_{\tau 1} x_{\tau 1} > 0$

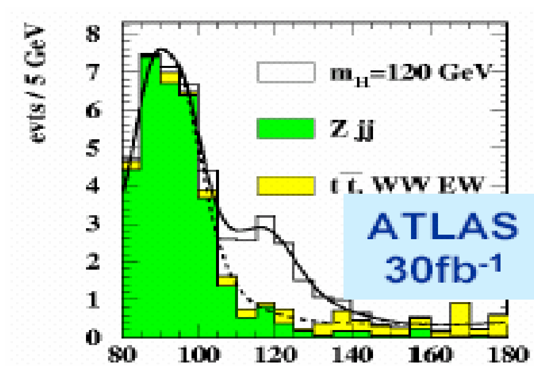


lepton+τ jet final state



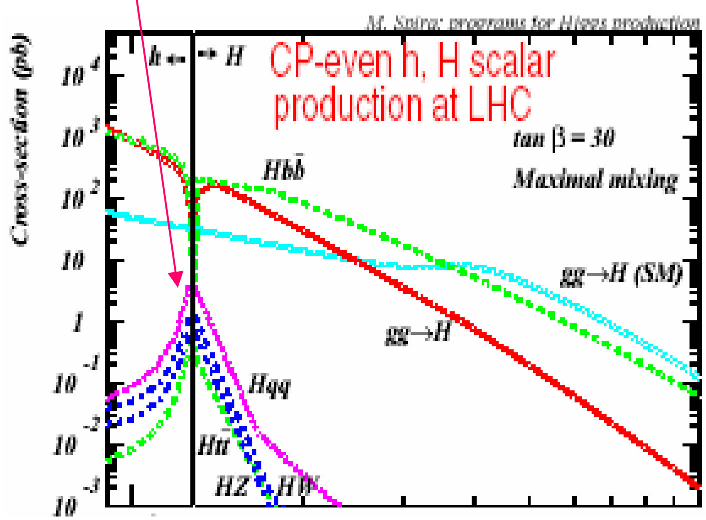
Integrated luminosity ~40 fb^{-1} needed for a 5σ–significance around m_H = 125 GeV in SM

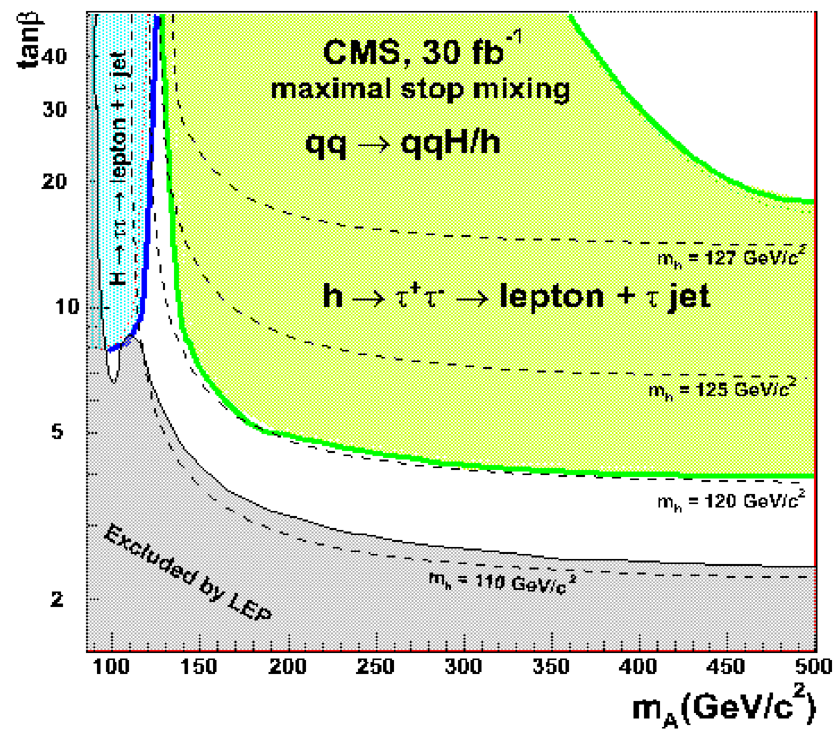
leptonic final state



qq ->qqH/h, H/h->ττ in MSSM

qq->qqH/h significant near the lower (upper) mass bound of H/h





In this region, H/h is SM-like
-> discovery region calculated
from the SM sensitivity

Large coverage in MSSM with qq -> qqh, h->ττ already with 30 fb^{-1} !

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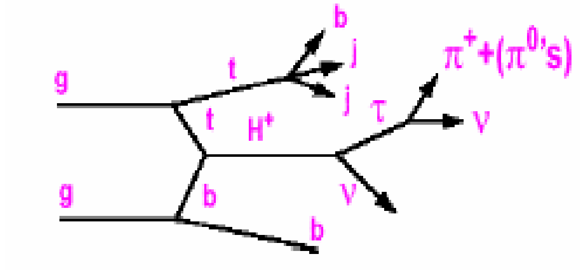
Charged MSSM Higgs bosons

Production:

- in $t\bar{t}$ events with $t \to bH^\pm$ if $m_{H+} < m_{top}$
- through $gg \to tbH^\pm$ if $m_{H+} > m_{top}$



For $m_{H+} > m_{top}$ no need to detect the associated b (at large rapidities) -> $gb \to tH^\pm$ can be used

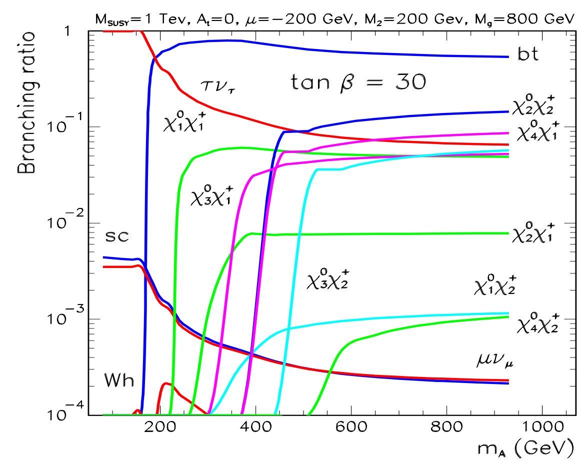
Decay channels

$m_{H+} > m_{top}$: BR($H^\pm \to \tau\nu$) ~100%

$m_{H+} > m_{top}$ and large tanβ (>10):

$H^\pm \to tb$ dominates

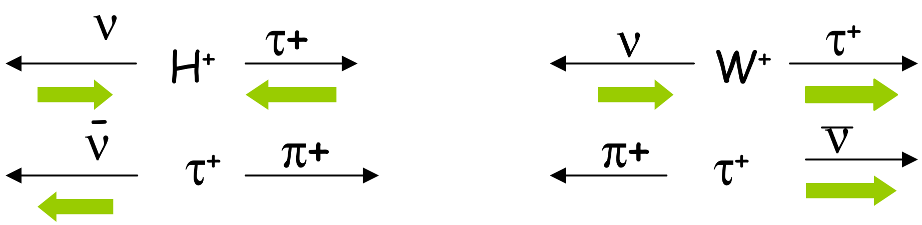
BR($H^\pm \to \tau\nu$) sizeable ~10%



Advantage with $H^\pm \to \tau\nu$, $\tau \to$ hadrons+ν:

Helicity correlations can be exploited to suppress irreducible backgrounds from $t\bar{t}$, Wt and W+jets with $W \to \tau\nu$

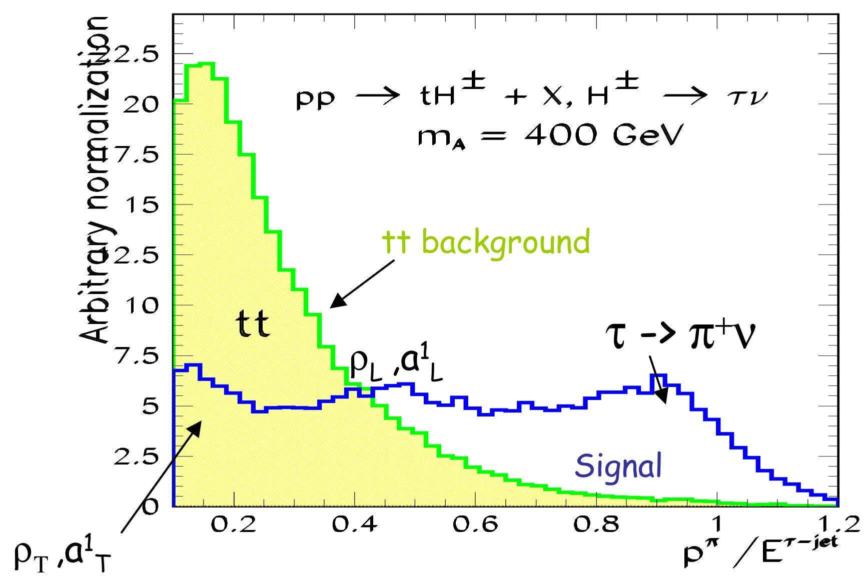
Helicity correlations in $H^+ \to \tau\nu$ and $W^+ \to \tau\nu$



Harder pions from $H^+ \to \tau^+\nu$ than from $W^+ \to \tau^+\nu$
(through $\tau \to \pi^+\nu$ and the longidutinal components of ρ and a_1)

Suppression of backgrounds with genuine τ's from $W \to \tau\nu$ with a cut in $p^\pi/E^{\tau\ jet}$

Efficiency with $p^\pi/E^{\tau\ jet} > 0.8$:
Signal, $m_{H\pm} = 400$ ~45%
tt background ~2%
(fast simulation)



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$H^{\pm} \to \tau\nu$, $\tau \to$ hadrons+ν for $m_{H+} < m_{top}$
in tt events with $t_1 \to bH^{\pm}$, $t_2 \to$ lepton + qq

Background from tt, Wt, W+jets

Background suppression with $p^{\pi}/E^{\tau\ jet}$ cut, lepton isolation, b-tagging, top mass reconstruction
$H^{\pm}$ mass reconstruction not possible, signal as an excess of τ´s in tt events

$H^{\pm} \to \tau\nu$, $\tau \to$ hadrons+ν for $m_{H+} > m_{top}$
in fully hadronic events from gg->tbH$^{\pm}$

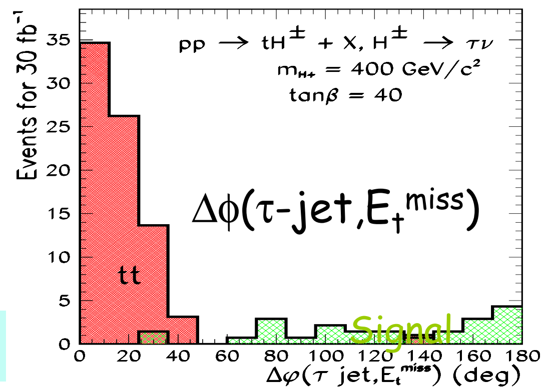
Background from tt, Wt, W+jets

Background suppression with $p^{\pi}/E^{\tau\ jet}$ cut, E_t^{miss} cut, b-tagging, hadronic top mass reconstruction, central jet veto

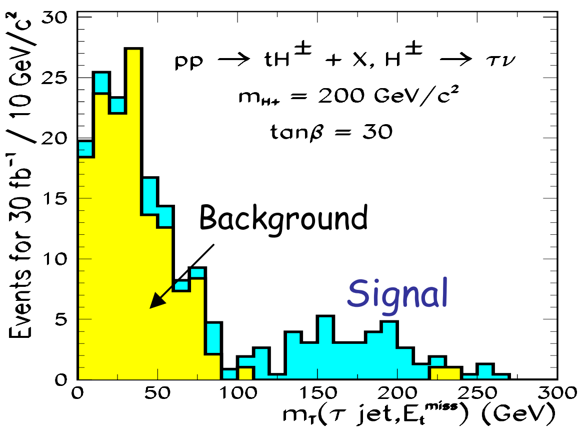
E_t^{miss} (mainly) from $H^{\pm} \to \tau\nu$: transverse mass $m_T(\tau\text{-jet}, E_t^{miss})$ can be reconstructed with an endpoint at $m_{H\pm}$

Transverse mass reconstruction in $tH^{\pm}$, $H^{\pm} \to \tau\nu$

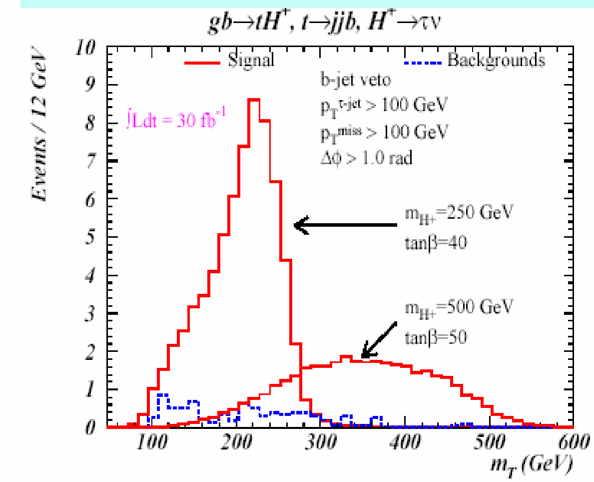
Quasi two-body decay between the τ jet and E_t^{miss} in fully hadronic events -> almost background-free situation in $m_T(\tau\text{-jet},E_t^{miss})$

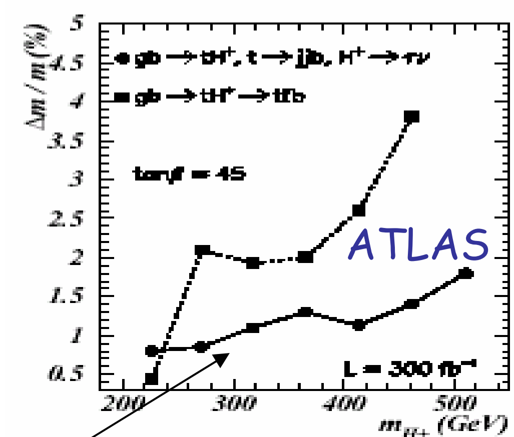


CMS, $\Delta\phi(\tau\text{-jet},E_t^{miss}) > 20^o$



ATLAS, $\Delta\phi(\tau\text{-jet},E_t^{miss}) > 57^o$

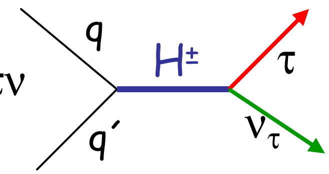


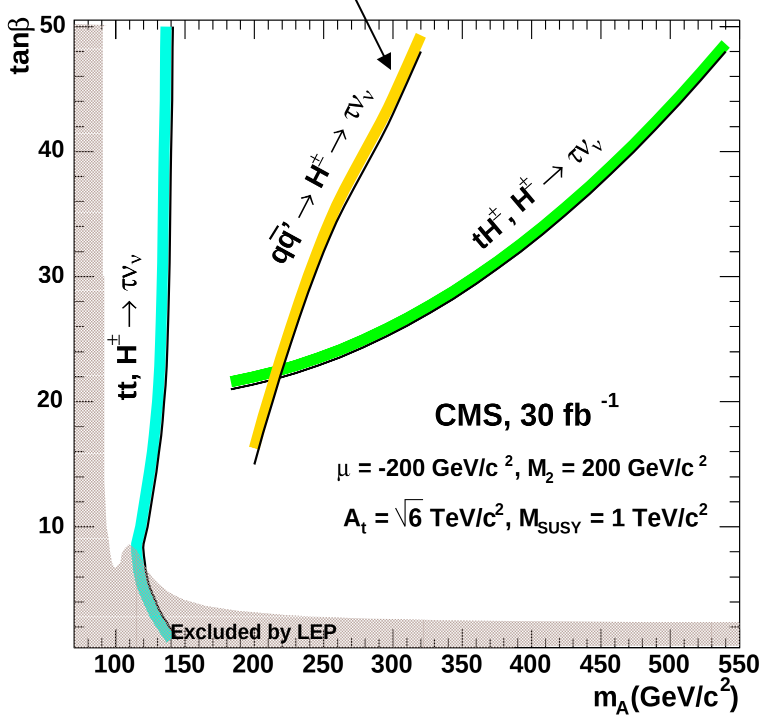


Precision of m_{H+} measurement from $m_T(\tau\text{-jet},E_t^{miss})$ with likelihood fits: $\Delta m_{H+}/m_{H+} \sim 1 - 1.5\%$

Discovery potential for charged Higgs bosons

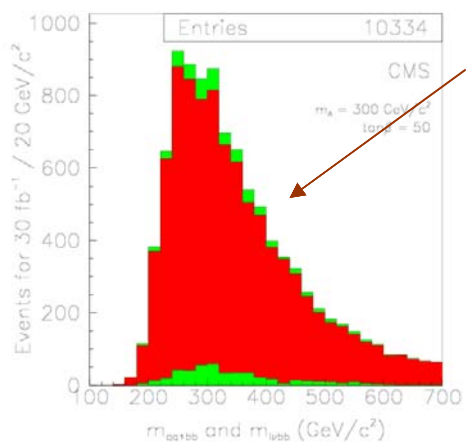
Production in $qq' \to H^+ \to \tau\nu$
large background from $qq \to W \to \tau\nu$

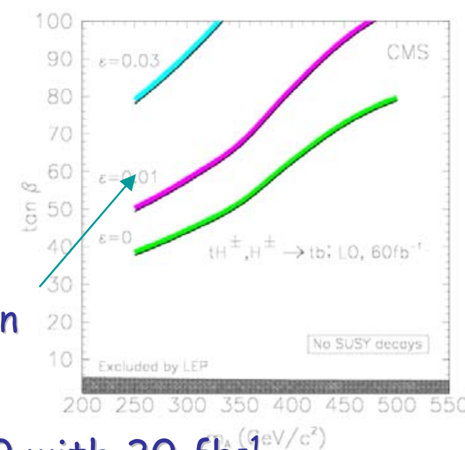




$H^\pm \to tb$ in $gg \to tbH$

- Modest mass resolution
- Difficult backgroud suppression





Background determination uncertainties important

Discovery for $\tan\beta \sim 50$ with 30 fb^{-1}

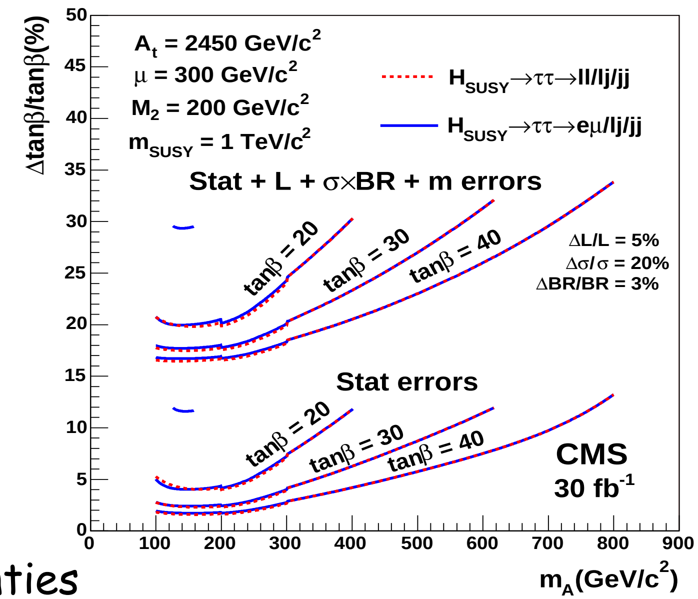
Measurement of tanβ in H -> ττ from event rates

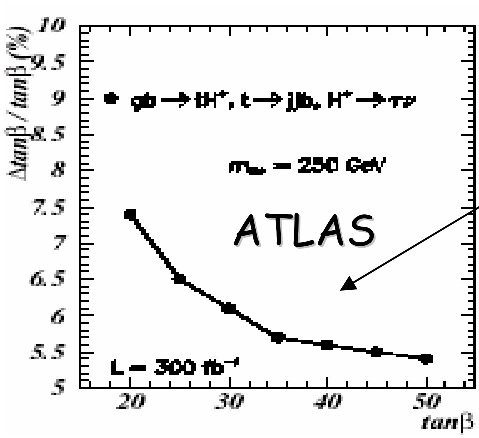
At large tanβ $\sigma_H \sim \tan^2\beta_{eff} \times f(m_A)$, BR(ττ) ~constant

$$\Delta\tan\beta/\tan\beta = \tfrac{1}{2} * ((N_S+N_B)^{1/2} / N_S + \Delta\tan\beta_{syst})$$

$\Delta\tan\beta_{syst}$ consists of:

- Theoretical (scale) uncertainty about 20% for σ(gg -> bbH) with NLO calculations
- Luminosity uncertainty ΔL/L ~ 5%
- Uncertainty of mass measurement, preliminary estimate 5%
- Uncertainty on event selections ~ 3%





Theoretical uncertainties not includes

Event rates (branching fraction) sensitive to SUSY parameters, uncertainty due to parameter measurement not yet included

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Conclusions

The main discovery potential for the heavy MSSM Higgs bosons H and A is through the H/A -> $\tau\tau$ decay modes, with $\ell\ell$, ℓ+jet and 2-jet final states, in the gg->bbH/A production at large tanβ

The most probable discovery mode for the charged Higgs bosons is the $H^{\pm}$ -> $\tau\nu$ decay in the tt events for $m_{H\pm} < m_{top}$ and in the gg -> tb$H^{\pm}$ production for $m_{H\pm} > m_{top}$.

Advantages with τ´s:

- Leptonic and hadronic (including 3-prongs) decay modes can be used
- τ lifetime can be exploited in H/A -> $\tau\tau$ with impact parameter or flightpath measurements
- τ mass tagging may be used
- Helicity correlations in H^{+} -> $\tau\nu$ (and in H/A -> $\tau\tau$?) can be used to suppress backgrounds from W->$\tau\nu$ (and Z->$\tau\tau$?) decays

Conclusions (cont.)

Requirements for efficient use of τ's in the search of MSSM Higgs bosons:

- Triggering hadronic τ decays on lowest possible thresholds is advantageous
- Identification of τ's is (largerly) based on isolation:
  high reconstruction efficiencies needed for tracks in jets, i.e.
  tracker performance is essentiel
- Good vertex and impact parameter measurement precisions for τ tagging
- E_t^{miss} measurement precision important for mass (m_T) reconstructions