Physics at LHC
Prague July 6 - 12, 2003

A/H -> ττ and H^+ -> τν in CMS

R. Kinnunen

Helsinki Institute of Physics
Helsinki, Finland

Contents

H/A -> ττ

Cross sections and branching fractions
Hadronic τ trigger
τ-jet identification and hadronic jet suppression
τ tagging with impact parameter measurement
b-jet tagging in bbH/A
Signal to background ratios and expected discovery reaches,
tanβ mesurement from event rates

H^+ -> τν

Cross sections and branching fractions
Trigger for H^+ -> τν in fully hadronic events
τ polarization in H^+ -> τν and W^+ -> τν
Signal to background ratios and expected discovery reaches,
tanβ mesurement from event rates

How to search for heavy neutral MSSM Higgs bosons

Relative to SM, H/A -> ZZ, WW are strongly suppressed but

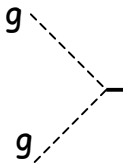
Hbb, Hττ, Hμμ couplings are enhanced at high tanβ

➡ use bbH for production with H/A -> ττ, μμ decay channels

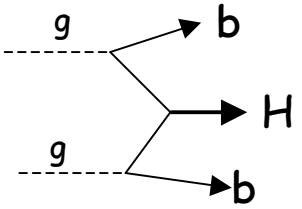
- Efficient background reduction with b tagging in bbH/A
- 3 final states for H/A -> ττ (jet+jet, lepton+jet, lepton+lepton)
- Higgs boson mass reconstruction for H,A -> ττ, μμ
- H/A -> bb may be also viable (under study)

Production and decay of H, A

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

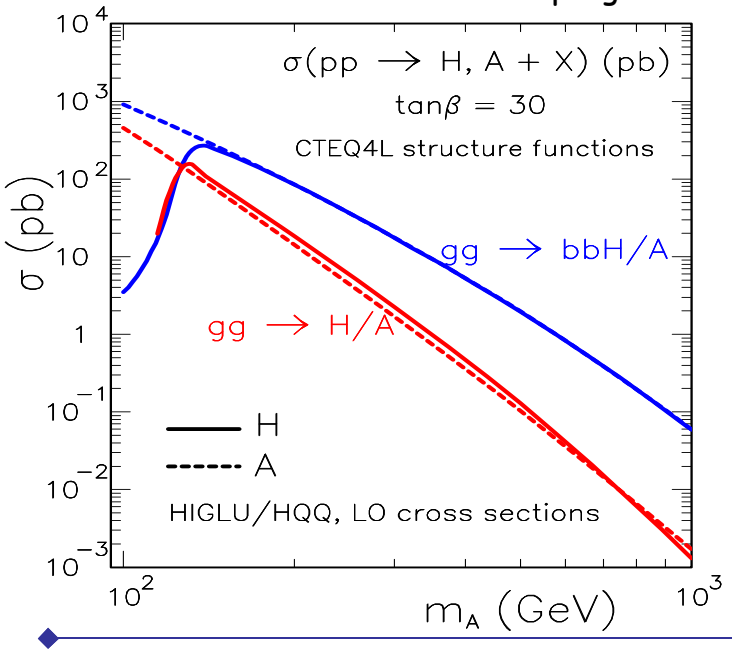


gg->bbH/A dominates the production at large tanβ:
~90% of the total production cros section

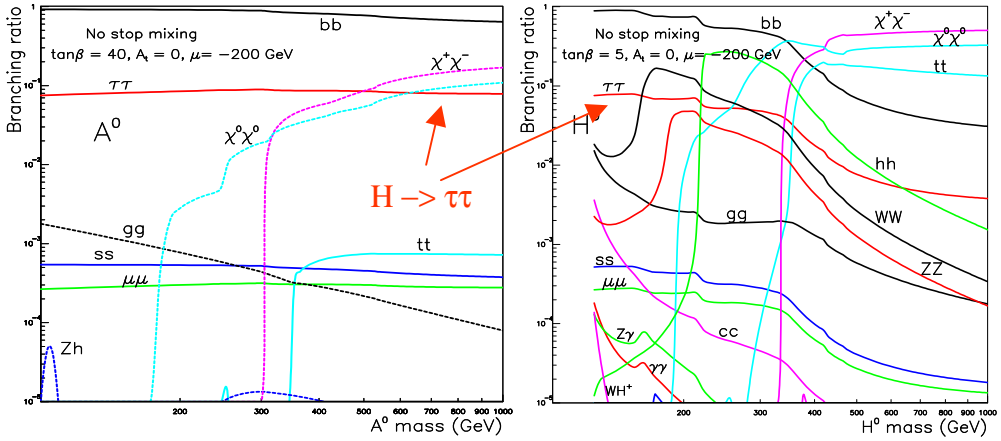


HIGLU,HQQ from of M. Spira et al.

Pole mass for Yukawa coupling



BR(H -> ττ) ~ 10% for tanβ > 10



For large m_A, enhancement of BR(H->ττ) for larger |μ| parameter due suppression of H,A -> χχ decays

Final states investigated for H, A -> ττ

H -> ττ -> 2 τ jets BR ~ 42.0%

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

H, A -> ττ -> lepton + τ jet BR ~ 45.6%

H, A -> ττ ->2 leptons BR ~ 12.4%

Backgrounds from Z,γ* ->ττ, tt, bb, Wt, WW, W+jets

Simulation tools

PYTHIA for event generation

HDECAY for normalization of cross sections and branching fractions for two-τ jet and two-lepton channels

Full simulation for trigger, τ selection, b tagging, mass reconstruction
Fast simulation for signal to background ratios

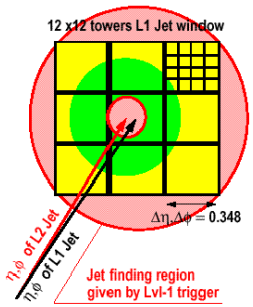
Hadronic Tau trigger

Trigger requirements:

Level-1 output rate of 1-Tau and 2-Tau triggers: 3 kHz at low luminosity
6 kHz at high luminosity

HLT output rate on tape for τ's: 4 (10) Hz at low (high) luminosity

Level-1 1-Tau and 2-Tau triggers



The required Level-1 rate can be achieved with the thresholds of

93 (112) GeV for 1-Tau for low (high) luminosity
66 (76) GeV for 2-Tau for low (high) luminosity

on the calorimeter jet reconstructed in 12x12 trigger towers with maximum E_t in the central 4x4 towers and no significant activity in the neighbouring towers (trigger tower = HCAL cell + 5x5 ECAL cells, $\Delta\eta \times \Delta\phi$ = 0.087x0.087 in the barrel)

Efficiency:

78 (54)% for $H \to \tau\tau$, m_H = 200 GeV, 1 or 2 Tau
81 (72)% for $H^+ \to \tau\nu$, m_{H^+} = 200 GeV, 1 Tau

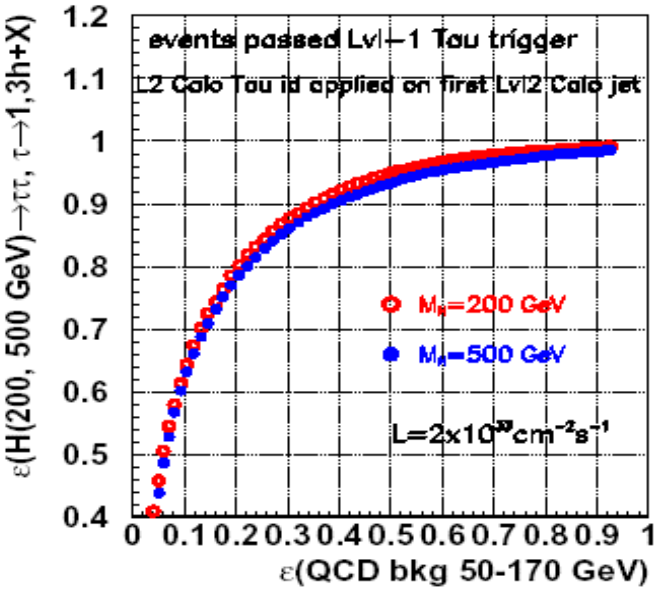
Level-2 Tau trigger

Reconstruction of a jet centered at the hardest Level-1 τ jet

Isolation in the EM calorimeter:

- sum of the E_t deposits in ECAL within $0.13 < \Delta R(\text{jet direction, cell}) < 0.4$

Efficiency (QCD vs H->ττ–> 1/3 prong jets) as a function of $E_t^{\text{cut-off}}$



τ jet definition: $\Sigma E_t^{em} < E_t^{\text{cut-off}}$

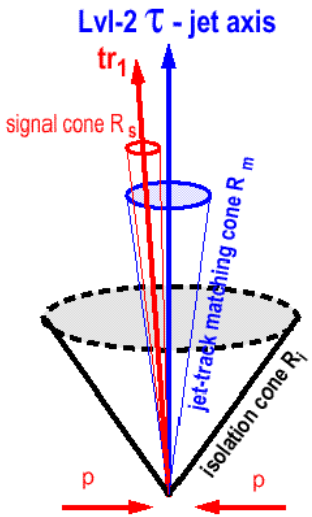
Suppression of 3 for QCD background with $\Sigma E_t^{em} < 5.6$ GeV

Signal efficiency ~ 85%
same for m_H = 200 and 500 GeV

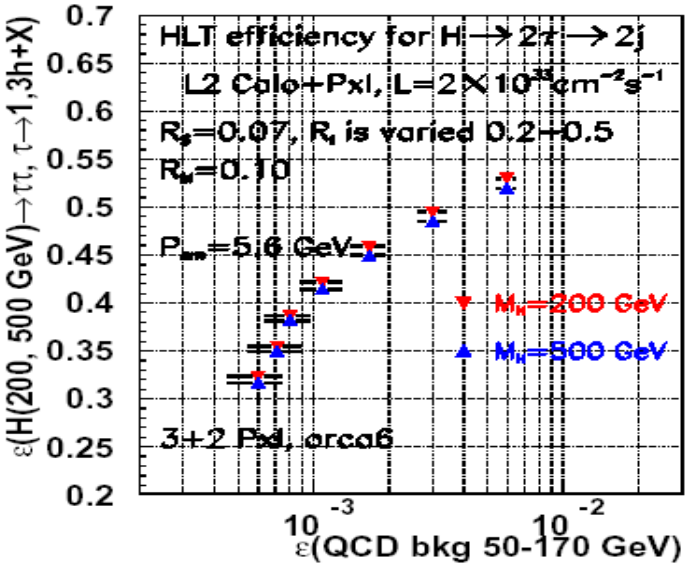
Level-3 Pixel Tau trigger

using track counting in the Pixel (vertexing) detector:
- good efficiency required, high p_t accuracy not needed

1. Reconstruction of tracks around the Level-1 jet direction
2. Small signal cone (ΔR_S = 0.07) around the hardest track
3. Larger isolation cone around jet direction



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



Accept tracks only in the signal cone

HLT efficiency for 1 or 3 tracks in the signal cone and for ΔR = 0.35:

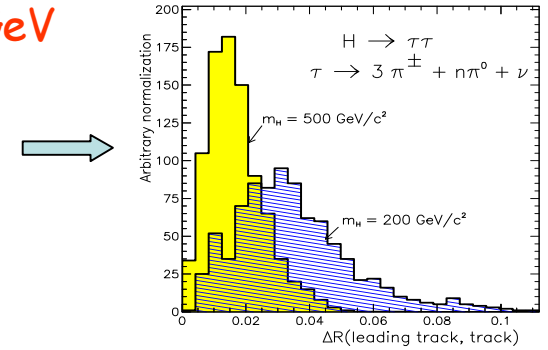
QCD suppression ~ 10^3
signal efficiency ~ 40%

Off-line τ jet identification

Exploits further the narrowness and the isolation of the τ jet in the full tracker

1. Leading track cut:
   Find the leading track in the L1 τ jet, set a cut p_t > 40 GeV

   Define a narrow signal cone Δr = 0.03 (0.07 for HLT) around the leading track direction



2. τ jet isolation:
   No track, p_t > 1 GeV, allowed within 0.03 < ΔR < 0.4

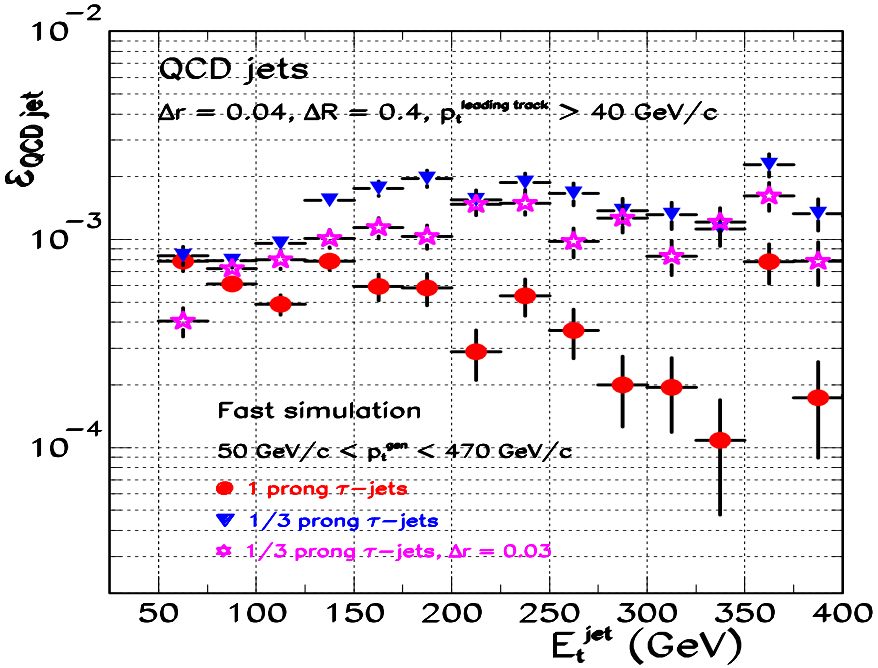
3. Number of tracks in the signal cone:
   1 or 3 tracks in the signal cone ($p_t^{leading}$ > 40 GeV)

4. Further reduction of hard QCD jets:
   Very hard QCD jets can be further suppressed with a cut in $p_t^{leading}$ / E_t^{jet}

Simulation of the QCD di-jet background

using (for the moment) a rejection factor as a function of E_t^{jet} (initial QCD di-jet rate ~10^{12} events for 60 fb^{-1})

τ selection efficiency for hadronic QCD jets from fast simulation



Suppression of ~ 1000 per jet can be obtained

Signal efficiency (per event) including Level-1 and HLT trigger from full simulation:

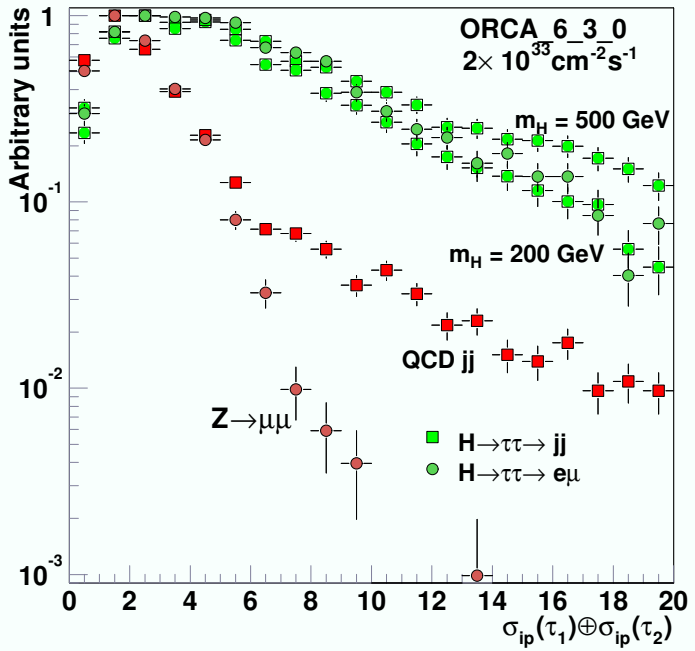
m_H = 200 GeV	0.8%
m_H = 500 GeV	8.9%

efficiency verified with full simulation and complet reconstruction for p_t^{gen} < 170 GeV

τ impact parameter tagging in H -> ττ

The τ lifetime is small, cτ ~ 90 μm, but can be still used to further supress the fake τ's from Z -> ll and from QCD multi-jet events using impact parameter measurement (1 or 3 prong τ's) and vertex reconstruction (3 prong τ's)

CMS full simulation and reconstruction



Best separation combining the measurements in the two τ jets into one variable

$$\mathrm{sqrt}(\sigma_{ip}(\tau_1)^2 + \sigma_{ip}(\tau_2)^2)$$

where $\sigma_{ip}(\tau_1)$ and $\sigma_{ip}(\tau_2)$ are significansies of the impact parameter measurements of the leading tracks in jets 1 and 2

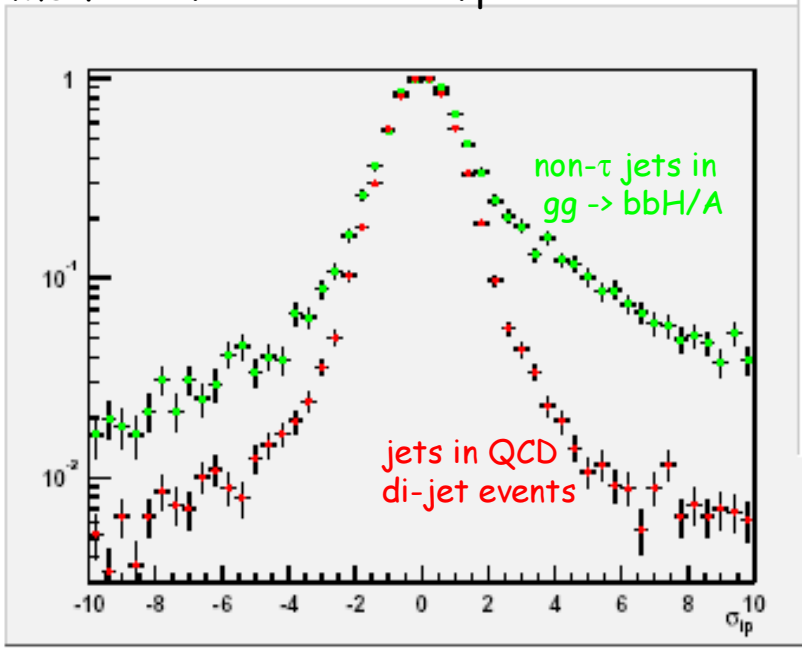
Signal efficisiency ~ 60%
QCD suppression factor of ~ 9

B jet tagging in gg -> bbH/A

Tagging of the associated b jets is the most efficient way to reduce the $Z,\gamma^* \rightarrow \tau\tau$ ($bbZ \sim 1\text{-}2\ \%$) and to further reduce the QCD multijet events

Associated b jets in gg -> bbH/A are soft and uniformly distributed over $|\eta| < 2.5$:
Efficiencies (E_t threshold + tagging propability) relatively low

Significance of the signed transverse impact parameter
CMS full simulation and complete reconstruction



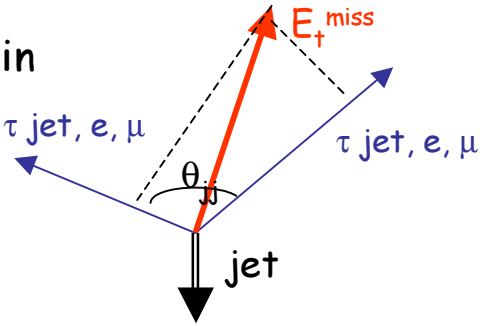
Tagging algorithm:
at least 2 tracks, $p_t > 1$ GeV, $\sigma_{ip} > 2$,
inside the jet cone

Efficiency per jet:
32% non-τ jets in bbH
~ 2 % light quark and gluon jets

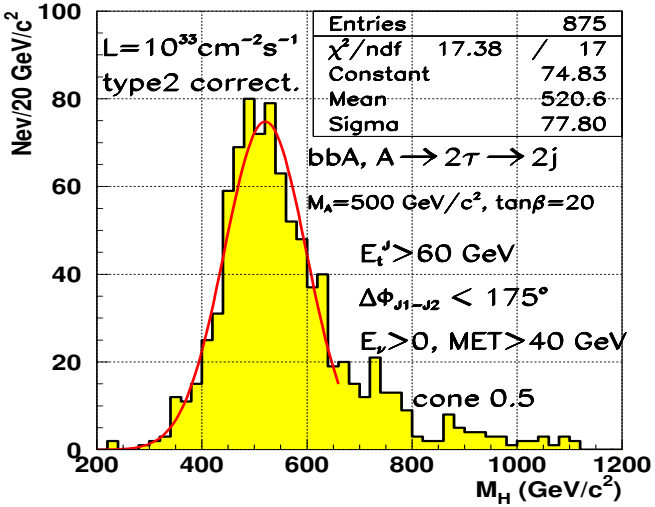
Higgs boson mass reconstruction in H -> ττ

The neutrinos from H -> ττ (τ -> hadrons+ν, τ -> ℓ+νν) are emitted close to the directions of the visible τ's (jets or leptons):

neutrino reconstruction possible using the E_t^{miss} measurement in events with $\Delta\phi(\tau_1,\tau_2) < 180^o$, efficiency ~ 50 % (for $E_{\nu 1}\ E_{\nu 2} > 0$)



$$m_H = \mathrm{sqrt}(2\ E_{\nu 1}\ E_{\nu 2}\ (1-\cos\theta_{jj}))$$



Higgs boson mass from full simulation for H -> ττ -> two jets, m_H = 500 GeV, tanβ = 20, with $\Delta\phi(\tau\ \mathrm{jet}_1, \tau\ \mathrm{jet}_2) < 175^o$

Efficiency ($\Delta\phi$ cut, $E_{\nu 1}\ E_{\nu 2}>0$)	36%
σ_{fit}	14.9%

Efficiency and resolution sensitive to the E_t^{miss} measurement and to the $\Delta\phi(\tau_1,\tau_2)$ cut

Event selection for A,H->ττ -> 2 τ jets

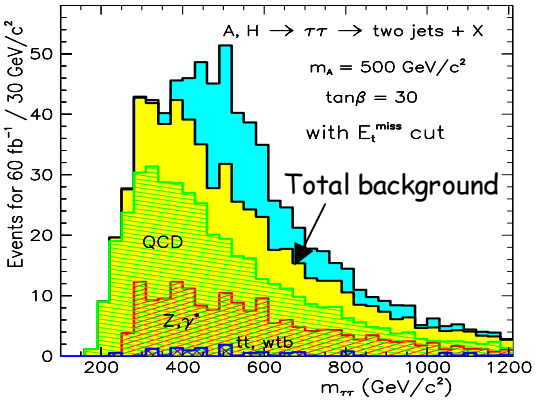
Basic event selection:

- 2 τ jets passing the Level-1 and HLT triggers
  and the off-line τ selection (1 or 3 hard tracks, isolation)
- τ tagging with impact parameters
- Higgs boson mass reconstruction ($\Delta\phi(\tau_1,\tau_2)$ cut, E_{v1}, E_{v2} > 0)

Two alternatives for further reduction:

i) Further selection with E_t^{miss}:

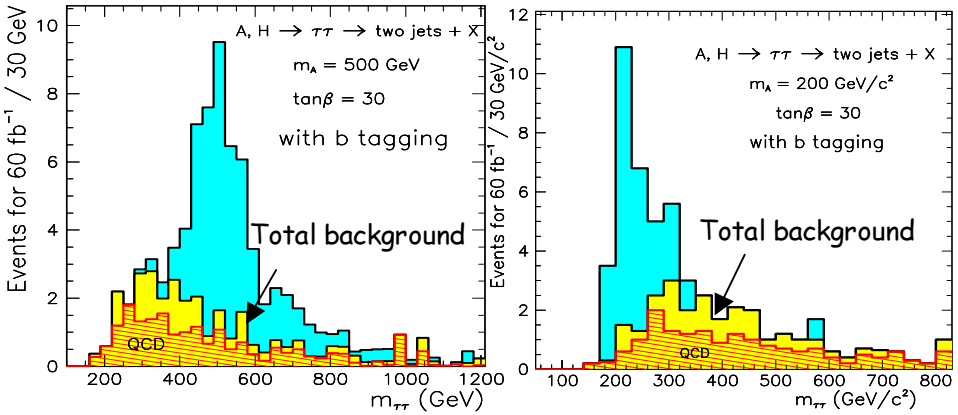
- E_t^{miss} > 40 GeV
-central jet veto beyond 30 GeV



larger staistics but poor S/B

ii) Further selection with b-jet tagging:

- one b-tagged jet, E_t > 20 GeV
- central jet veto beyond 30 GeV



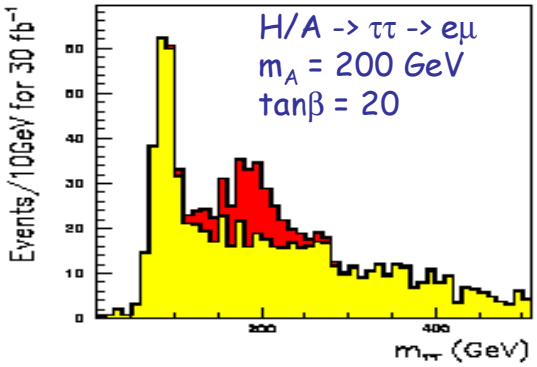
much improved S/B but lower statistics

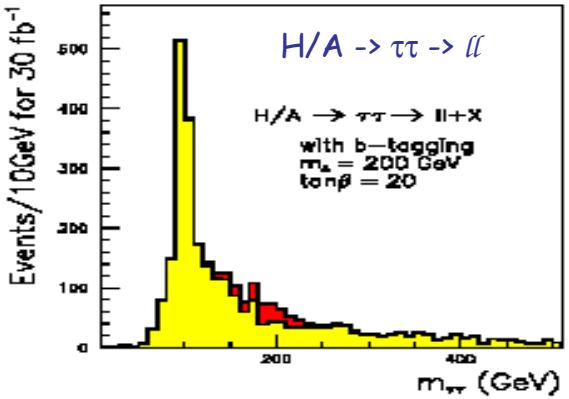
R. Kinnunen
Helsinki Institute of Physics

Leptonic final states, H/A -> ττ -> eμ, ℓℓ

Event selection:

- 2 isolated leptons, p_t > 20 GeV
- one tagged b jet, veto on second central jet beyond 30 GeV
- impact parameter τ tagging
  lepton+lepton final states can be used to double the statistics
- Higgs boson mass reconstruction





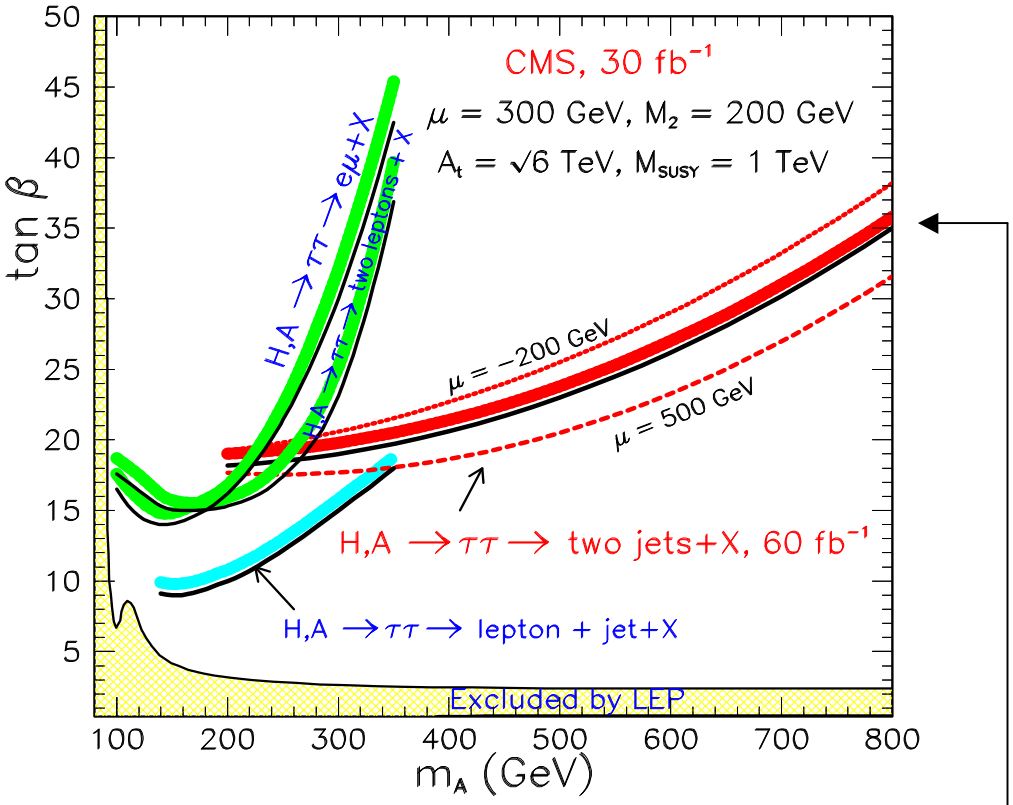
lepton + τ jet final states, H/A -> ττ ->ℓ + τ jet

Event selection:

- one isolated lepton (p_t > 20 GeV), one τ jet (E_t > 40 GeV)
- one tagged b jet, second jet veto
- Higgs boson mass reconstruction

Reach not yet optimized for large m_A (> 200 GeV) in CMS

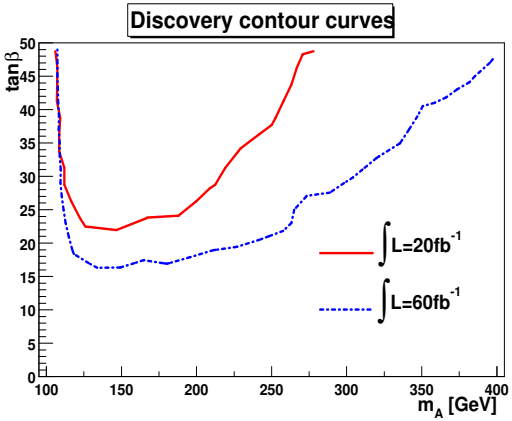
Expected 5σ-discovery reach for H/A -> ττ



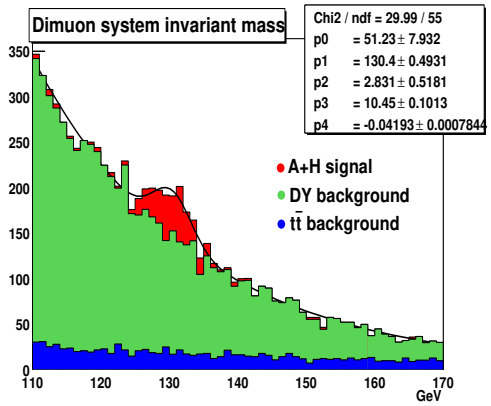
Variation of BR(H -> ττ) due to H -> $\chi_i\chi_j$ decay modes ~ 40% at m_H=500 GeV, tanβ=20, for -200 GeV < μ < 500 GeV

Results for H/A -> μμ

from full simulation and complete reconstruction



Higgs boson mass resolution ~ 2%



Measurement of tanβ in H -> ττ from event rates

using the tanβ dependence $\sigma * BR \sim \tan^2\beta * x$

$$\Delta\tan\beta/\tan\beta = \tfrac{1}{2} * \mathrm{sqrt}((N_S+N_B) / N_S^2 + (\Delta L/L)^2 + (\Delta x/x)^2)$$

- Luminosity uncertainty $\Delta L/L \sim 5\%$
- Theoretical uncertainty on the cross section for gg -> bbH: $dx/x \sim 30\%$
- The gg -> bbH component is selected by b jet tagging: 1b or 2b tagging, less theoretical uncertainty and higher experimental purity with 2b tagging

$\Delta\tan\beta/\tan\beta$

	1b tagging	2b tagging
H/A -> ττ -> 2 τ jets, m_A= 500 GeV, tanβ = 40, 60 fb^{-1}	16%	19%
H/A -> ττ -> lepton + τ jets, m_A= 200 GeV, tanβ = 20, 30 fb^{-1}	16%	dominated by rate uncertainty up to tanβ ~ 30
H/A -> ττ -> eμ, m_A= 140 GeV, tanβ = 14, 30 fb^{-1}	18%	

Precision of Higgs boson mass measurement in H/A -> ττ -> 2 τ jets

m_A= 500 GeV, tanβ = 40 , 60 fb^{-1}	$\Delta m_H/m_H$ = 1.5%
m_A= 200 GeV, tanβ = 40 , 60 fb^{-1}	$\Delta m_H/m_H$ = 1. 2%

R. Kinnunen
Helsinki Institute of Physics

How to search for charged Higgs bosons at LHC

If $m_{H^+} < m_{top}$:

Production through tt events, t -> bH^+

– accessible through the $H^+ \to \tau\nu$, t_2-> lepton+qq final state

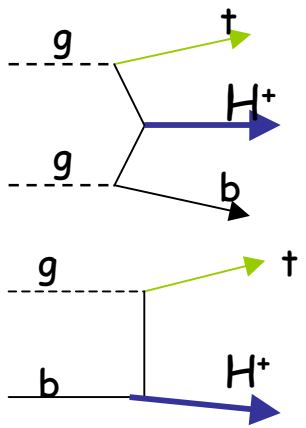
If $m_{H^+} > m_{top}$:

Production through gg -> tbH^+, gb -> tH^+, qq' -> H^+, gg -> H^+H^-, gg -> W^+H^-

- gg -> H^+H^-, gg -> W^+H^- have small production cross sections

-Event rate sufficient for qq' -> H^+-> $\tau\nu$ but suppression of the qq' -> W-> $\tau\nu$ background is difficult

-gg -> tbH^+, gb -> tH^+ most promising processes, cross sections large enough and the associated top and b jets can be used for background reduction



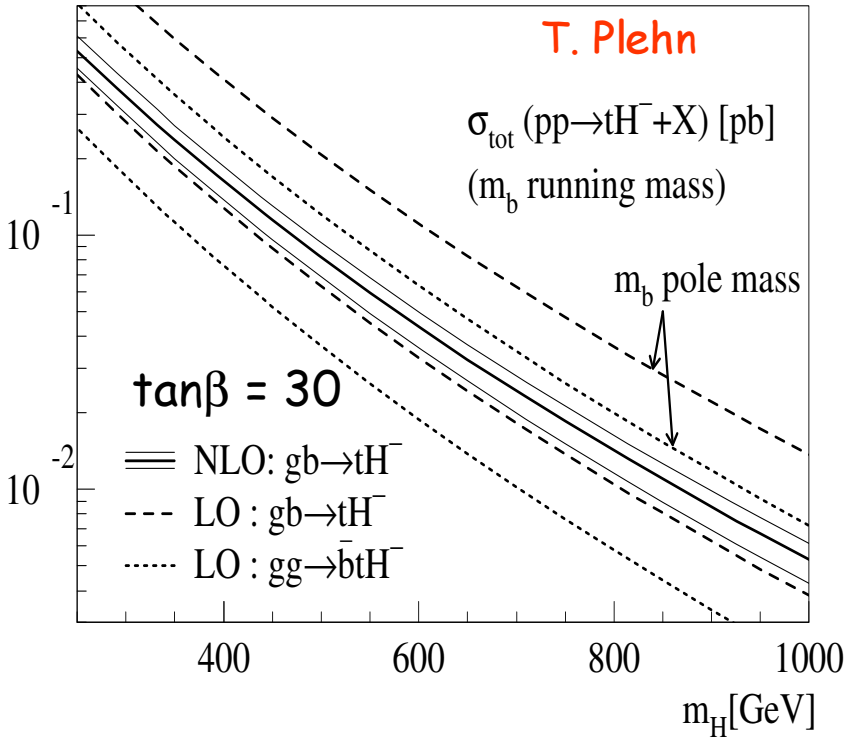
One tagged b jet enough to suppress the backgrounds, use

$gb \rightarrow tH^+$

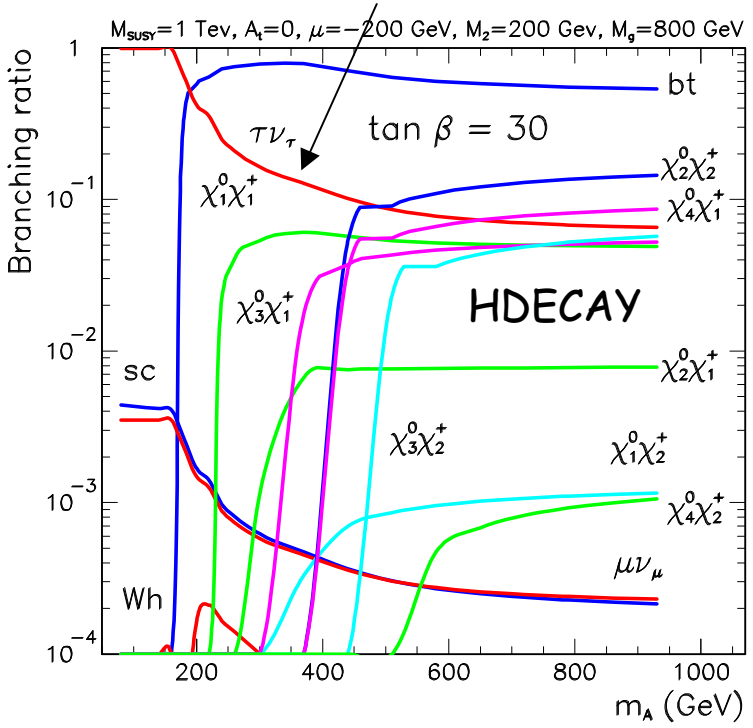
Event generation with PYTHIA

Normalization of the production cross sections to
T. Plehn, MADPH-02-1275

Normalization of branching fractions to HDECAY



$H^+ \rightarrow \tau\nu$



Trigger for $H^+ \to \tau\nu$, $\tau \to$ jet + ν

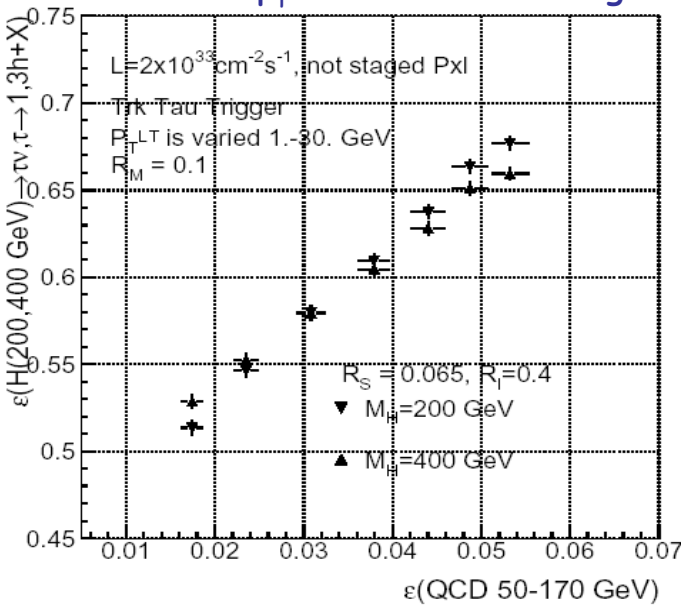
Level-1: single Tau trigger (E_t > 93 GeV, low luminosity)

High Level Trigger:

cut on E_t^{miss} in the calorimetry (possible due to off-line E_t^{miss} > 100 GeV)

QCD rejection ~ 100 for E_t^{miss} > 65 GeV

Efficiency (QCD vs H->ττ–> 1/3 prong jets) as a function of p_t cut for the leading track



Level-3 Single Tau:

-Cut on the leading track and isolation needed

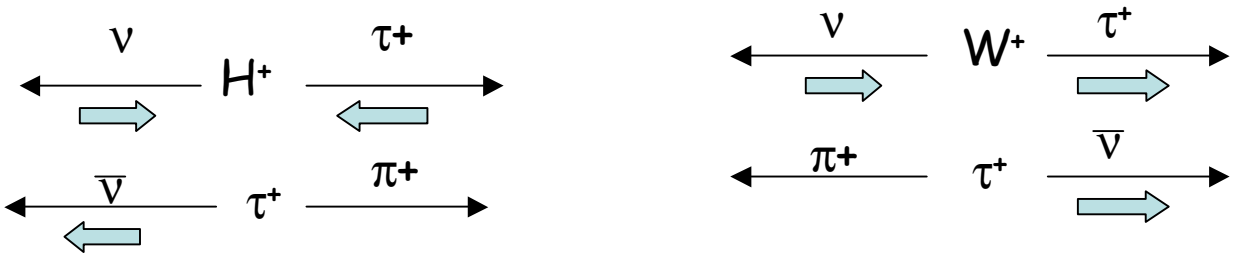
- Reconstruction of tracks in the full tracker within the L1 τ jet

Efficiency for $p_t^{leading\ track}$ > 20 GeV and isolation in 0.065 < ΔR < 0.4:

QCD rejection ~ 30

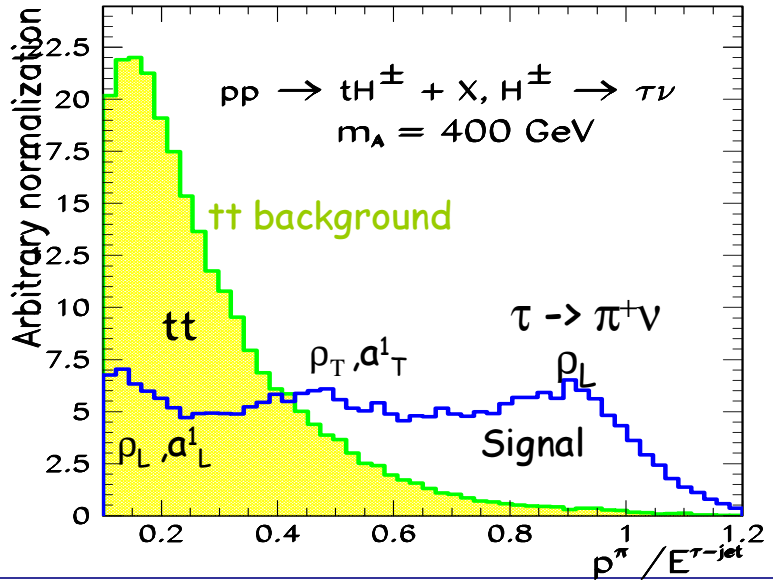
Signal efficiency ~ 58%

τ polarization in $H^+ \to \tau\nu$ and $W^+ \to \tau\nu$



$H^+ \to \tau^+\nu$ leads to harder pions from $\tau \to \pi^+\nu$ and from the longidutinal components of ρ and a_1 than the corresponding decays in $W^+ \to \tau^+\nu$

TAUOLA interfaced to PYTHIA



Large suppression of $W \to \tau\nu$ in tt, Wt, W+jet using the cut:

$p^{\text{leading track}} / E^{\tau\text{ jet}} > 0.8$:

τ jet = calorimeter jet from $\tau \to$ hadrons + ν

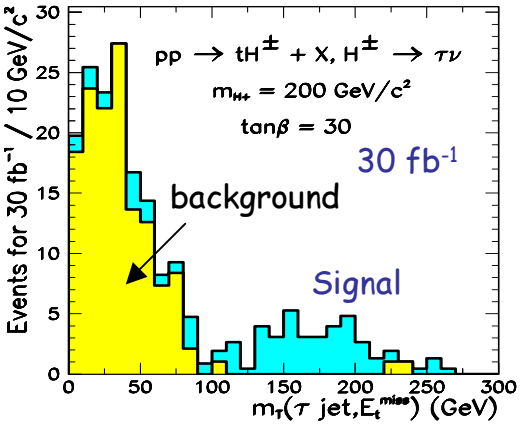
Signal, m_{H^+}= 400 GeV	46%
Signal, m_{H^+}= 200 GeV	22%
tt background	1.8%

Event selection for gb -> tH±, H± ->τν

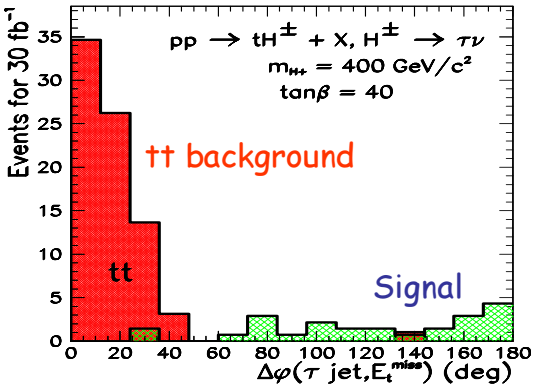
- $E_t^{\tau\ jet}$ > 80 – 100 GeV, containing a hard track with $p_t^{track}/E_t^{\tau\ jet}$ > 0.8
- E_t^{miss} > 100 GeV
- Reconstruction of associated hadronic top from two jetand one b-tagged jet
- Veto on 5th jet, veto on second top quark

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

$m_T(\tau\ jet, E_t^{miss})$

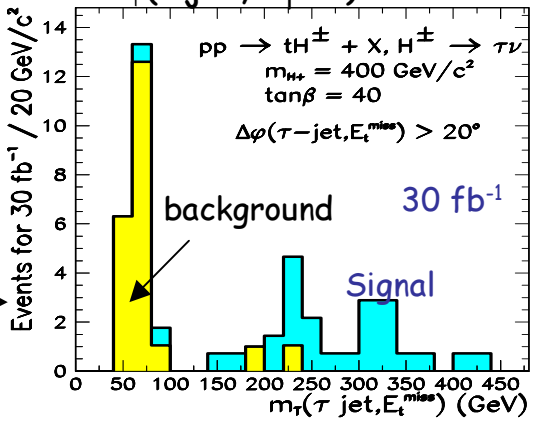


$\Delta\phi(\tau\ jet, E_t^{miss})$



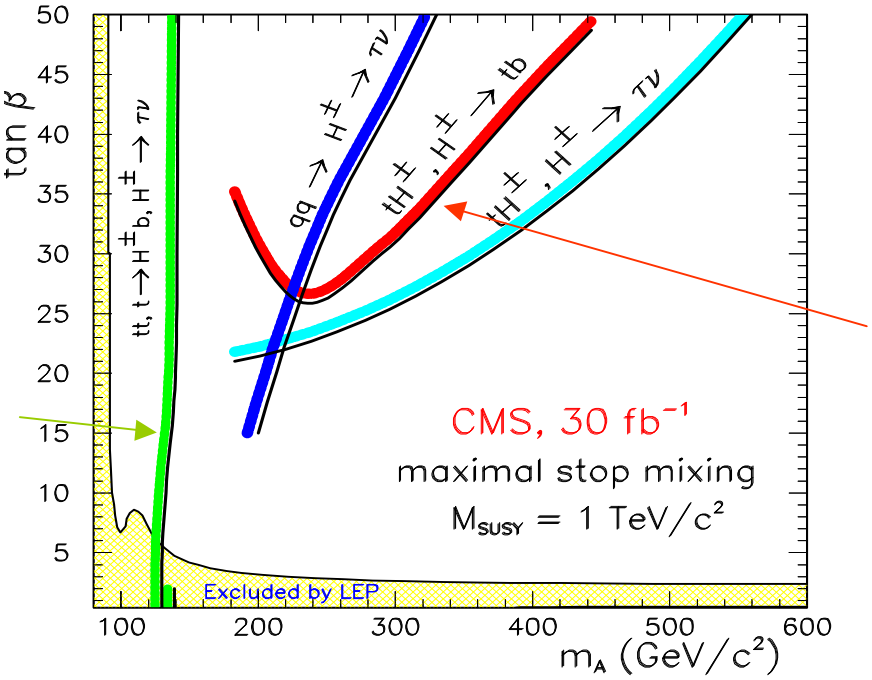
Cut on $\Delta\phi(\tau\ jet, E_t^{miss})$ -> low mass background can be suppressed

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

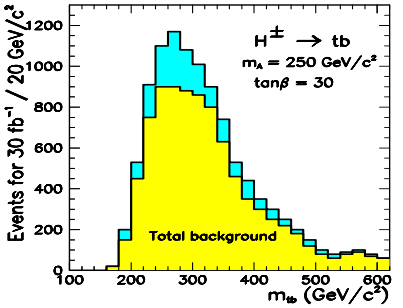


Expected 5σ-discovery reach for charged Higgs boson

Excess of τ's can be measured in tt, t -> bH⁺, H⁺ -> τν for $m_{H^+} < m_{top}$



H⁺ -> tb and qq' -> H⁺ -> τν are also promising



good background knowledge needed

No sensitivity for intermediate tanβ with gb -> tH⁺ (with SM decay channels):
H⁺ -> Wh, h -> bb accessible (in MSSM) only at small tanβ

tanβ measurement from event rates using σ ~ tan²β at high tanβ

Expected uncertainty for tanβ >30 with 20% theoretical uncertainty :

$\Delta\tan\beta/\tan\beta$ < 14% for m_{H^+} = 200 GeV

$\Delta\tan\beta/\tan\beta$ < 20% for m_{H^+} = 400 GeV

Conclusions

Search for H/A and H^+ can start early, with < 10 fb^{-1}
With ~ 60 fb^{-1} masses in the 500 – 800 GeV range accessible

more specifically:

H/A ->ττ accessible for 30 fb^{-1} with
eμ and ℓℓ final states for tanβ > 14 at m_A = 140 GeV
jet+ lepton final states for tanβ > 10 at m_A = 200 GeV
and for 60 fb^{-1} with
2 τ jet final states for tanβ > 18 at m_A = 200 GeV
tanβ > 25 at m_A = 500 GeV

H^+ -> τν accessible in gb -> tH^+ in fully hadronic final states with 30 fb^{-1} for
tanβ > 20 at m_A = 200 GeV
tanβ > 32 at m_A = 400 GeV

$\Delta m_H/m_H$ in H/A -> ττ -> 2 τ jets, tanβ = 40, 60 fb^{-1} : 1.2% for m_A = 200 GeV
1.5% for m_A = 500 GeV

tanβ determination with event rates:

$\Delta\tan\beta/\tan\beta$ = 16% for H/A ->ττ -> 2 jets, m_A = 500 GeV, tanβ = 40
16% for H/A ->ττ -> lepton+jet, m_A = 200 GeV, tanβ = 20
18% for H/A ->ττ -> eμ, m_A = 140 GeV, tanβ = 14
14% for gb -> tH^+ ,H^+ -> τν , m_A = 200 GeV, tanβ = 30

R. Kinnunen
Helsinki Institute of Physics