3th Nordic LHC Physics Workshop, Oslo, Norway

Expectations for Higgs production in CMS

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$H, h_{SUSY} \to \gamma\gamma$

$t\bar{t}H, t\bar{t}h_{SUSY} \to b\bar{b}$

→ $H \to \tau\tau \to 2\ \tau$-jets

$gg \to tbH^+, H^+ \to \tau\nu$

Simulation tools

Event generation with SPYTHIA (PYTHIA)

(BR, σ verifications from HDECAY)

Detector simulation:

Fast simulation package, CMSJET

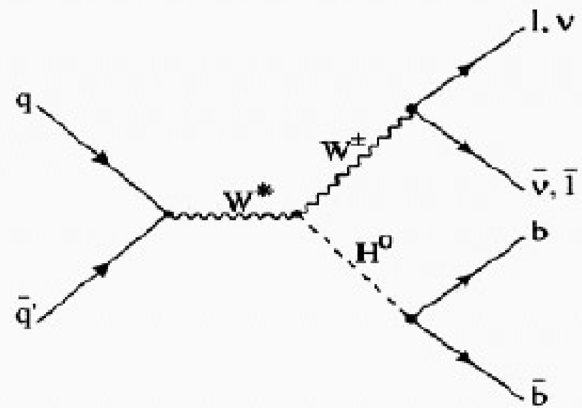
Full GEANT simulation for detector dependent issues

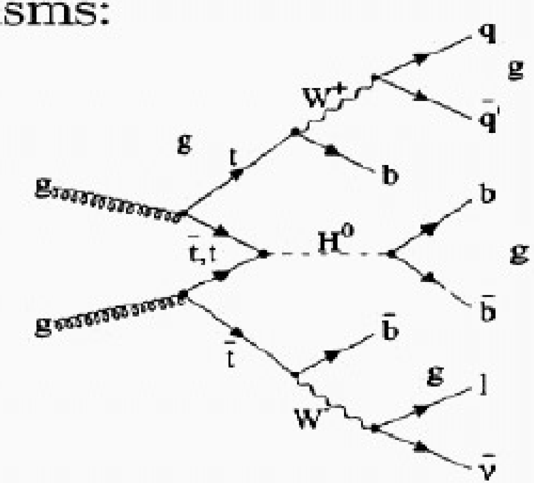
CMSIM, ORCA

$H^0_{SM}/h^0 \rightarrow b\bar{b}$

Volker Drollinger, IEKP, Karlsruhe University

- two production mechanisms:





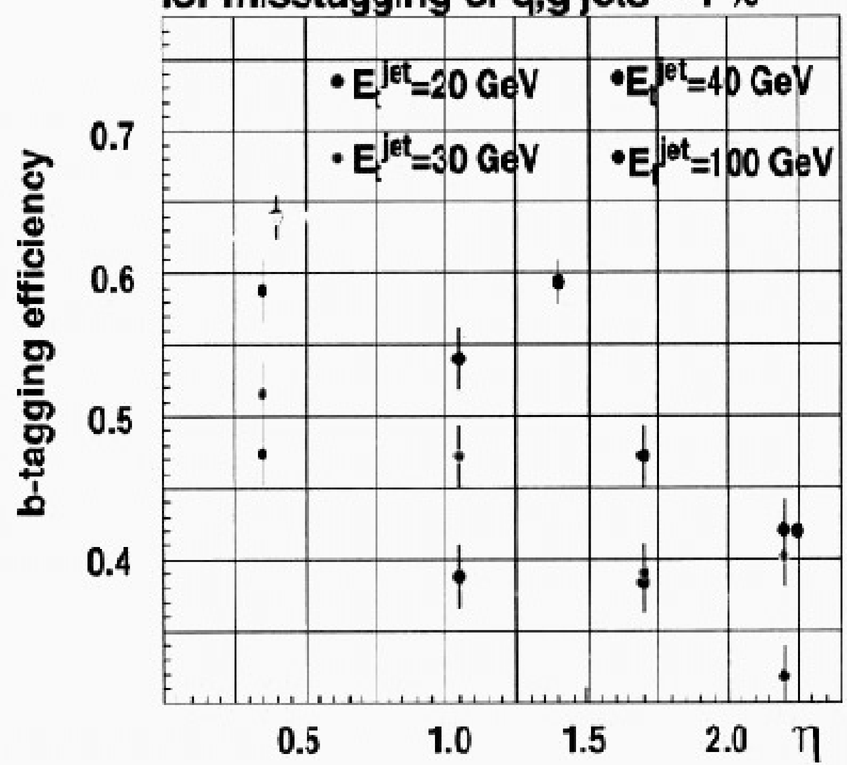
$+ \ldots$

- event generators:
  - $W^{\pm}H^0$: PYTHIA including pile up
  - $t\bar{t}H^0$: CompHEP (+ PYTHIA fragmentation)

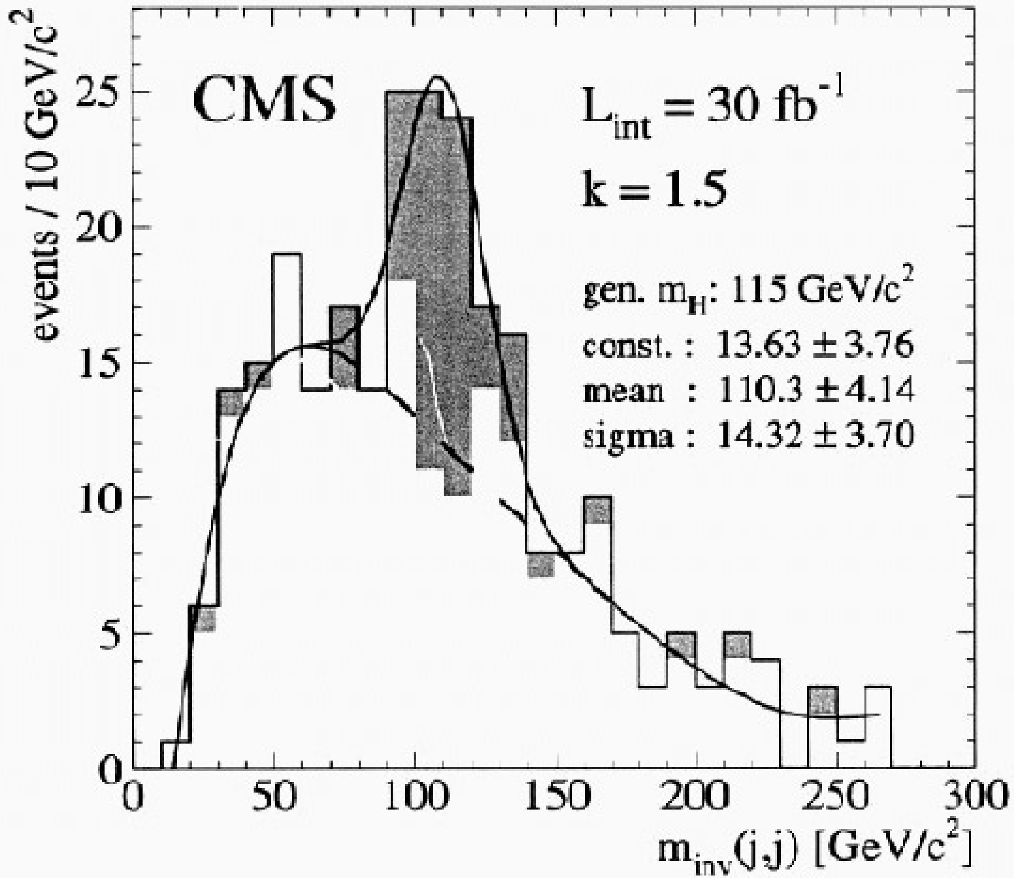
- detector simulation:
  CMSJET: leptons , jets , met (fast CMS simulation)
  FATSIM: tracks (parametrisation of CMSIM117 tracker)

CMS b-tagging with full detector simulation

b-tagging efficiency vs E_t^{jet} and η
for misstagging of q,g jets ~ 1 %



$t\bar{t}H^0_{SM} \rightarrow l^{\pm}\nu q\bar{q}b\bar{b}b\bar{b}$



◇ $90 < \mathrm{m} < 130\ GeV/c^2$:

N_{H115}	=	38 ev.
$N_{t\bar{t}Z^0}$	=	3 ev.
$N_{t\bar{t}b\bar{b}}$	=	23 ev.
$N_{t\bar{t}jj}$	=	26 ev.
N_{BG}	=	52 ev.

⇒ results (stat.):

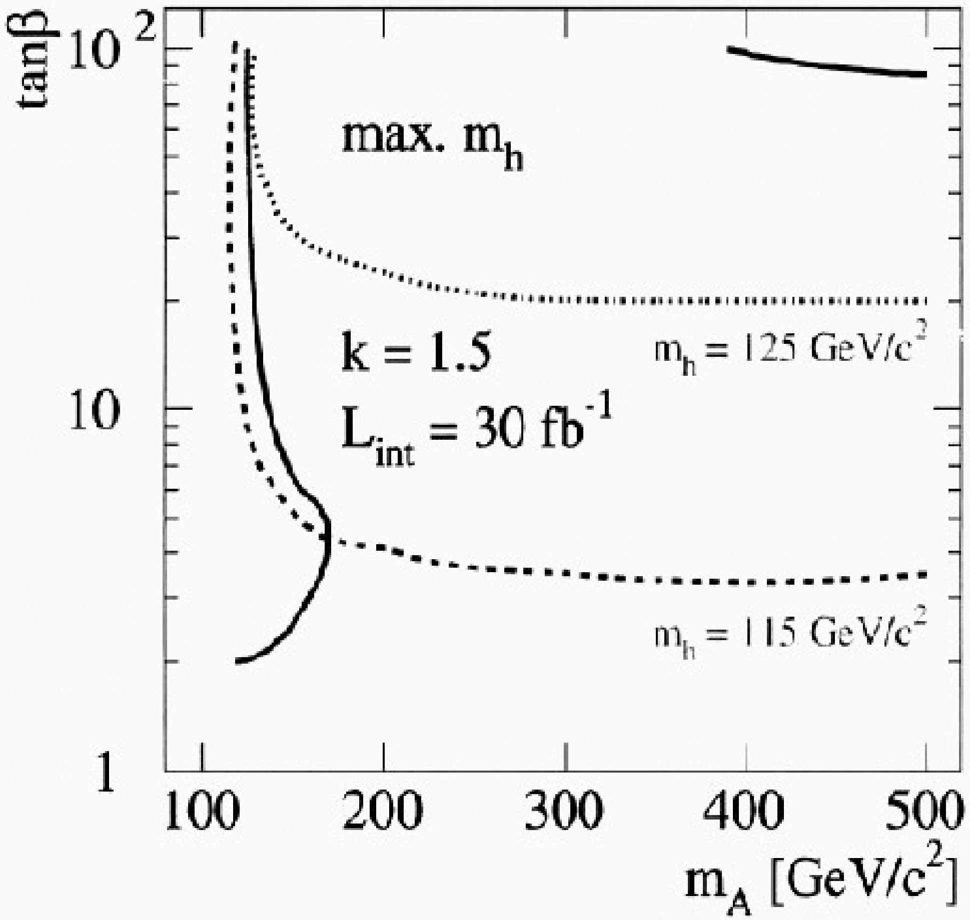
$S/B = 73\%$

$S/\sqrt{B} = 5.3$

$\Delta y_t/y_t = 13\%$

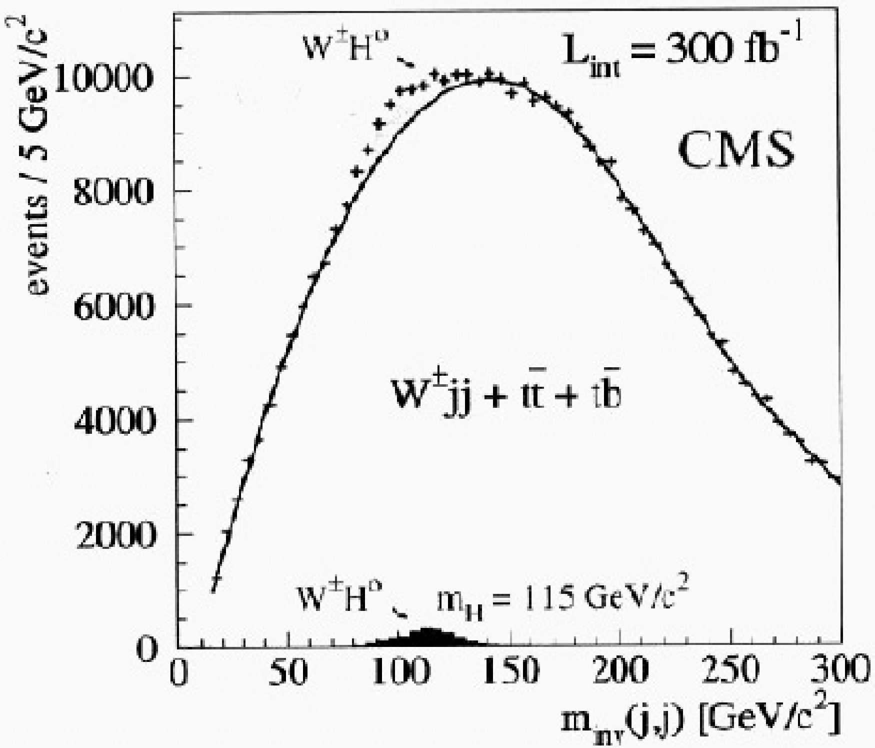
$\Delta m/m = 3.8\%$

MSSM: $t\bar{t}h^0 \rightarrow l^{\pm}\nu q\bar{q}b\bar{b}b\bar{b}$



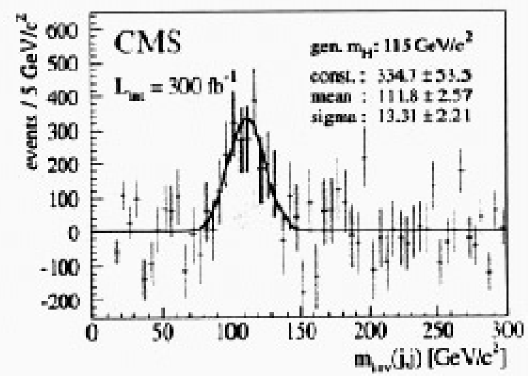
- max. m_h scenario:
  - $M_{SUSY} = 1\ TeV$,
  - $\mu = -0.2\ TeV$,
  - $M_2 = 0.2\ TeV$,
  - $M_{\tilde{g}} = 0.8\ M_{SUSY}$,
  - $X_t^{OS} = 2\ M_{SUSY}$,
  - $X_t^{\overline{MS}} = \sqrt{6}\ M_{SUSY}$,
  - $A_b = A_t$
- if no mixing:
  - $m_h < 115\ GeV/c^2$ ...
  - ... in plotted area

$W^{\pm}H^0_{SM} \rightarrow l^{\pm}\nu b\bar{b}$



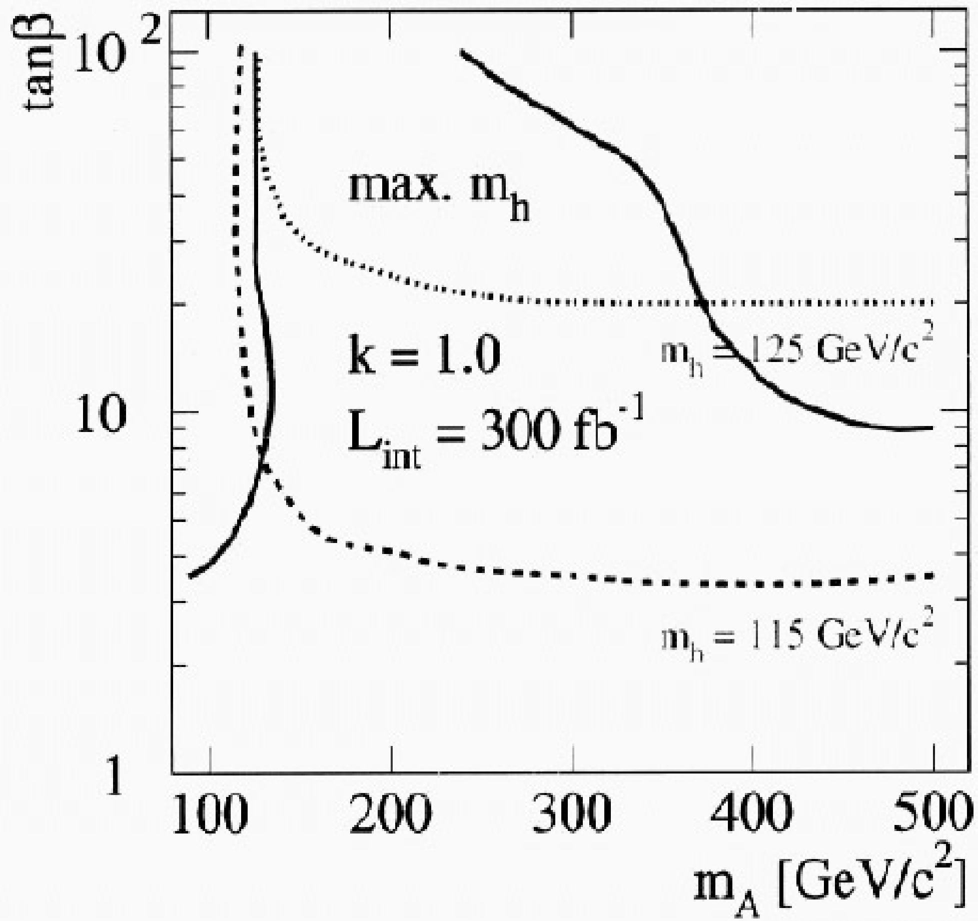
◇ $97 < \mathrm{m} < 130\ GeV/c^2$:

$N_{H\,115}$	=	1610
$N_{W^{\pm}Z^0}$	=	1198
$N_{W^{\pm}jj}$	=	27565
$N_{t\bar{t}}$	=	36089
$N_{t\bar{b}}$	=	6096
N_{BG}	=	70948



⇒ results (stat.): $S/B = 2.3\%$, $S/\sqrt{B} = 6.0$ and $\Delta m/m = 2.3\%$

MSSM: $W^{\pm}h^0 \rightarrow l^{\pm}\nu b\bar{b}$



- ◇ max. m_h scenario:
  - $M_{SUSY} = 1\ TeV$,
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  - $M_2 = 0.2\ TeV$,
  - $M_{\tilde{g}} = 0.8\ M_{SUSY}$,
  - $X_t^{OS} = 2\ M_{SUSY}$,
  - $X_t^{\overline{MS}} = \sqrt{6}\ M_{SUSY}$,
  - $A_b = A_t$
- ◇ if no mixing:
  - $m_h < 115\ GeV/c^2$ ...
  - ... in plotted area

A, H -> $\tau\tau$ -> 2 τ-jets in CMS

Fast simulation studies ->

significant extend of discovery range high $\tan\beta$

Backgrounds from: Z, γ^* -> $\tau\tau$, $t\bar{t}$, W+jets, QCD

Update of fast simulation: Cross sections (SPYTHIA), TAUOLA
study of jet fragmentation effects, ...

Full simulation: τ trigger
Higgs mass reconstruction
QCD rejection
E_t^{miss} reconstruction
τ tagging, b tagging

Cross sections

- The no-mixing scenario **used at LEP assumed in SPYTHIA with:**

  M_{SUSY} = 1 TeV, μ = -200 GeV, M_2 = 200 GeV, m_g = 0.8 M_{SUSY},
  X_t (mixing parameter) = 0

- **GRV94L structure functions (default)**

- **Comparison of cross sections for pp -> A + X:**

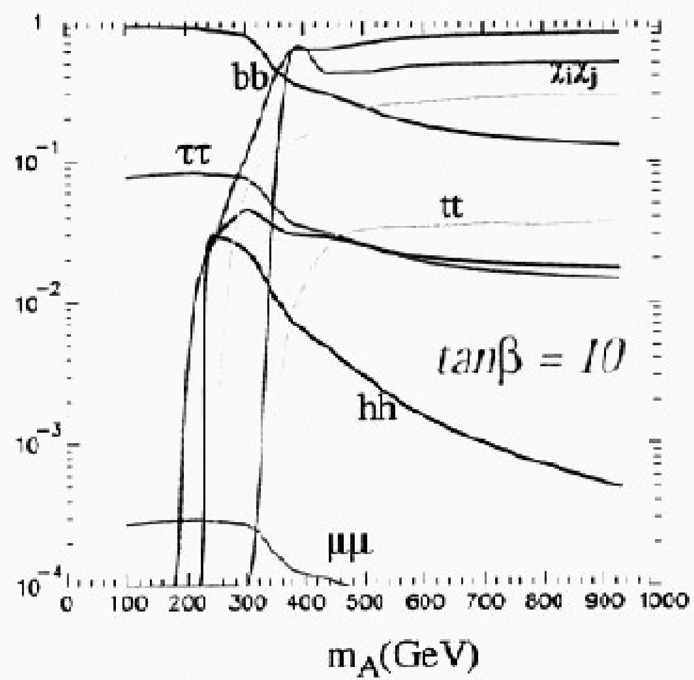
m_A, tanβ	(300,15)	(500,25)	(800,45)
SPYTHIA	**7.6 pb**	**2.12 pb**	**0.62 pb**
PYTHIA5.7	**8.6 pb**	**3.1 pb**	**1.31 pb**

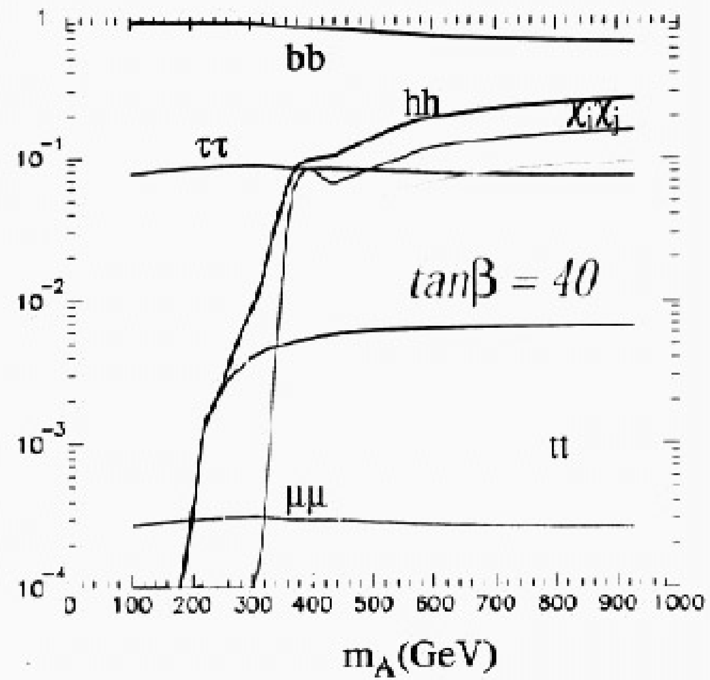
For m_A=500 GeV, tanβ = 25 event rate decreased by ~ 40%
m_A=800 GeV, tanβ = 45 event rate decreased by ~ 50%

Branching ratios for H^0 with SPYTHIA

no stop mixing

$M_{SUSY} = 1$ TeV, $\mu = -200$ GeV, $M_2 = 200$ GeV, $m_{\tilde{g}} = 800$ GeV, $X_t = 0$

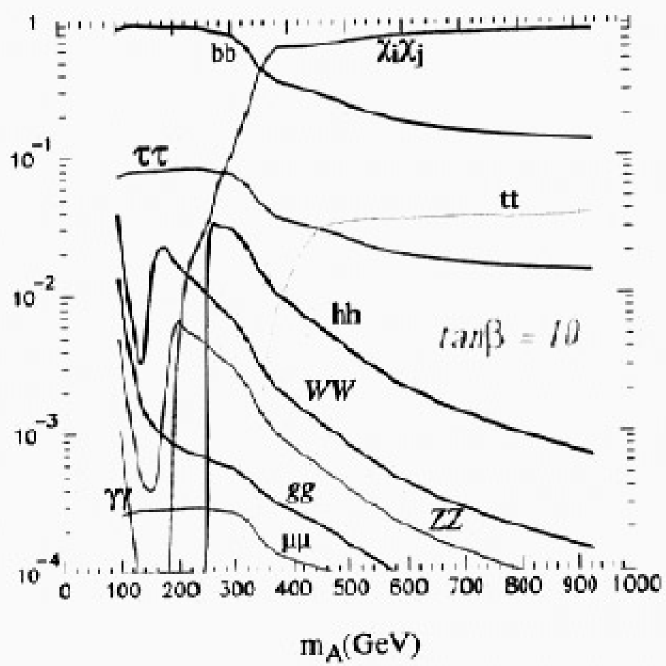


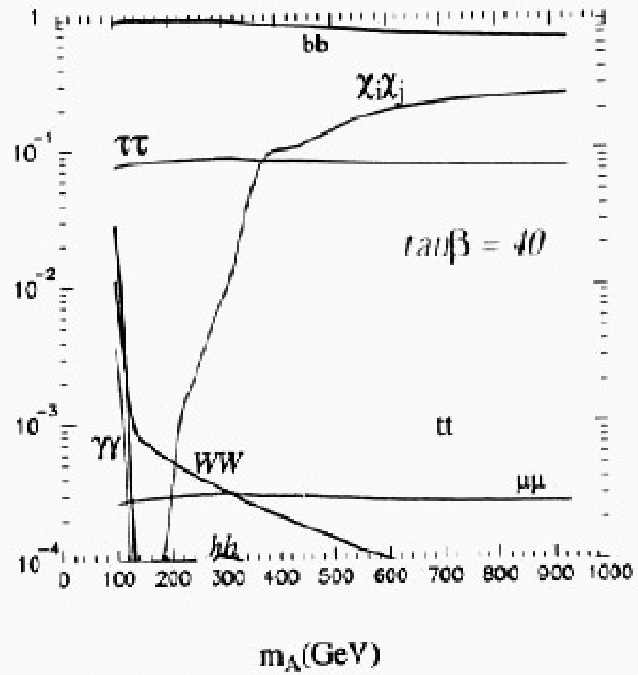


Branching ratio for H^0 with SPYTHIA

maximal stop mixing (m_h^{max}) scenario

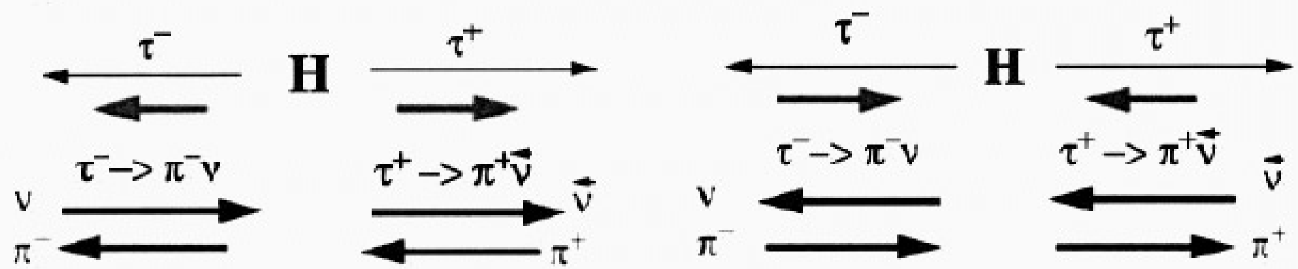
$M_{SUSY} = 1$ TeV, $\mu = -200$ GeV, $M_2 = 200$ GeV, $m_{\tilde{g}} = 800$ GeV, $X_t = 2450$ GeV



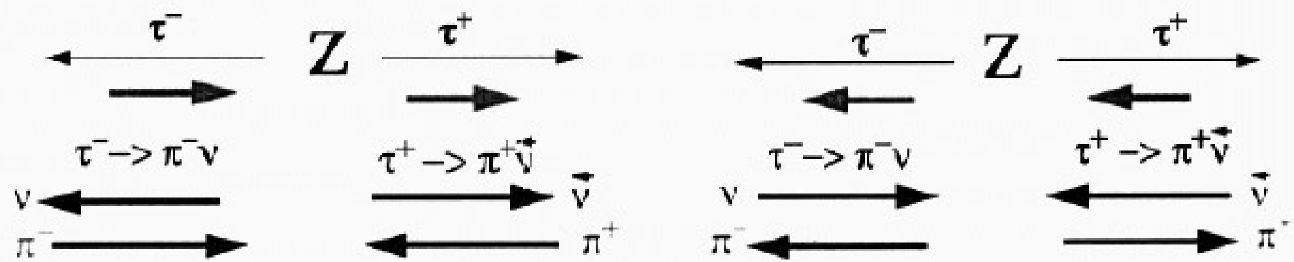


Spin correlations in H -> $\tau^+\tau^-$ -> $\pi^+\bar{\nu}\pi^-\nu$ and Z -> $\tau^+\tau^-$ -> $\pi^+\bar{\nu}\pi^-\nu$

Two possibilities for spin directions in H -> $\tau\tau$ and Z -> $\tau\tau$



➔ *asymmetry expected between π^+ and π^- energies*



➔ *no asymmetry expected between π^+ and π^- energies*

Effects of jet fragmentation on the QCD jet rejection factor

special thanks to T. Sjostrand

QCD 2-jet generation in PYTHIA with the symmetric Lund fragmentation function

$$f(z) \sim z^{-1} (1-z)^{a} \exp(-b m_T^2/z)$$

$a = 0.3$ (default), $b = 0.58\ GeV^{-2}$

QCD rejection factor as a function of a-parameter with values exceeding ~ 2 - 4 times LEP bounds:

- $a \sim 0.1$ hard fragmentation
- $a \sim 0.5$ soft fragmentation

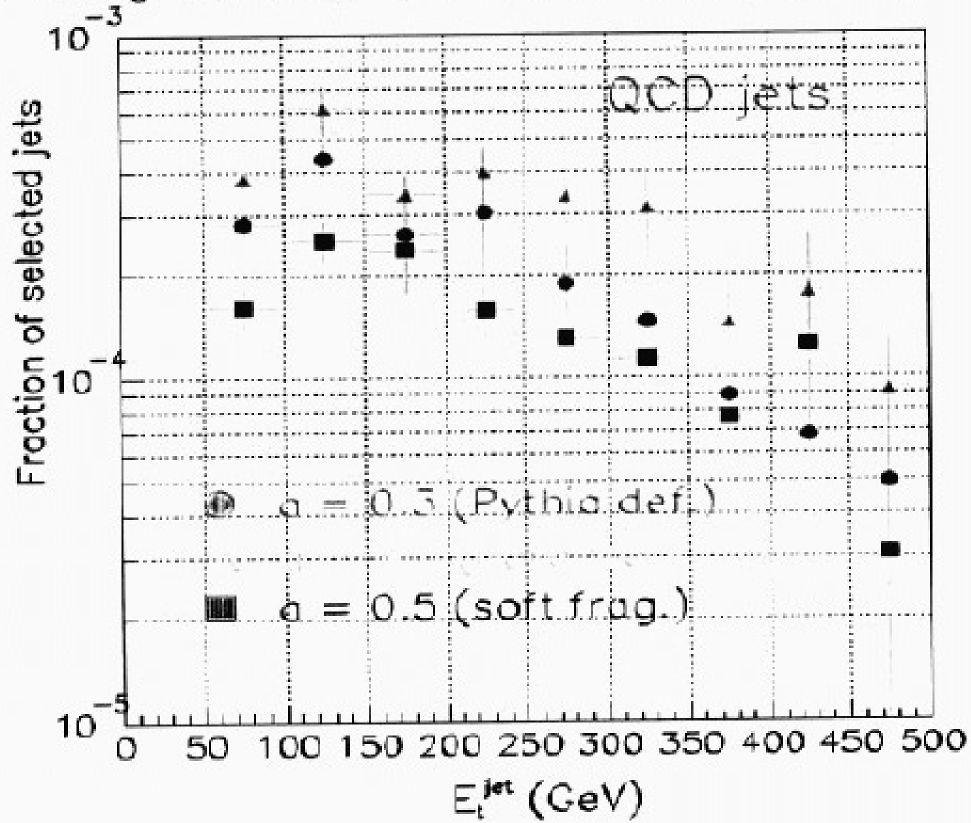
Other uncertainties from: parton virtuality in space like showers and parton virtuality in time like showers

No significant effect observed within the statistics generated (~ 1 500 000 events)

QCD rejection factor

$E_t^{jet} > 60$ GeV containing one charged hadron with $p_t > 40$ GeV within $\Delta R(\tau\text{-jet},h)<0.1$

no other charged hadrons with pt > 1.0 GeV within $\Delta R(\tau\text{-jet},h)<0.4$



$H \rightarrow \tau\tau \rightarrow 2\ \tau$-jets + X
including 1 and 3 prong τ decays

- ❒ BR($\tau \rightarrow$ hadrons + ν) ~ 65%
- ❒ BR($\tau \rightarrow$ one charged hadron + $n\pi^0$ + ν) ~ 50%

→ **Including 3 prongs enhancement of event rate by ~ 1.7**

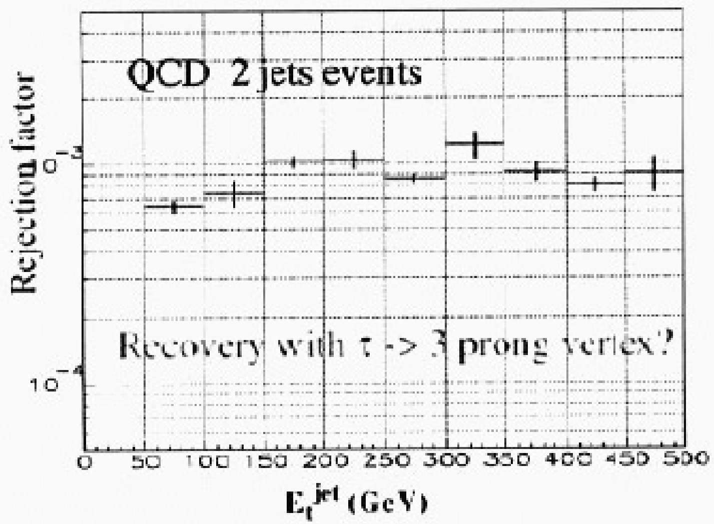
Algorithm for 1 and 3 prong selection:

1 or 3 tracks with $p_t^h(max) > 40$ GeV with $\Delta R(h_{max}, jet) < 0.1$, $\Delta R(h_{max}, h) < 0.03$

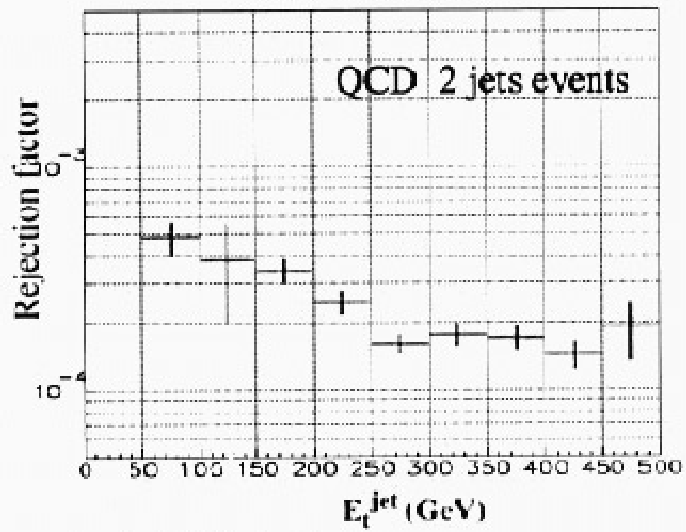
no track with pt > 1 GeV within $0.1 < \Delta R(h_{max}, jet) < 0.4$

Comparison of 1 and 1 or 3 prong selections

1 or 3 tracks with $p_t^h(max) > 40$ GeV with isolation



1 track with $p_t^h > 40$ GeV with isolation



Efficiency for $H \rightarrow \tau\tau$, $m_H = 500$ GeV per τ jet (with isolation):

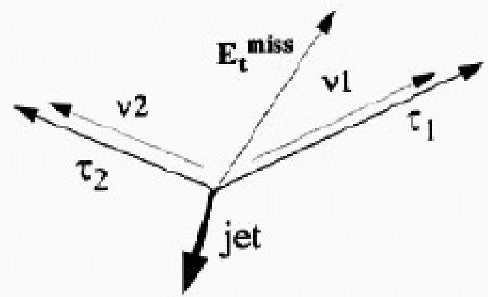
64% for 1 or 3 tracks with $p_t^h(max) > 40$ GeV

45% for 1 track with $p_t^h > 40$ GeV

Higgs mass reconstruction in H,A -> ττ

from the visible τ momenta (jets or leptons) and E_t^{miss}

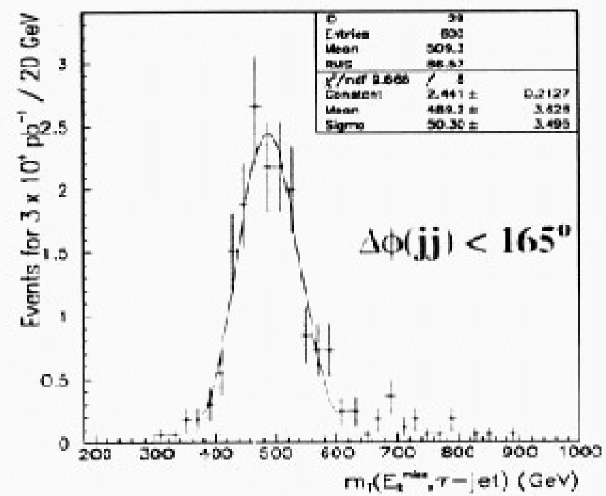
Assumption: $\nu_1 \parallel \tau_1$ and $\nu_2 \parallel \tau_2$



ν momenta can be resolved from

$$E_x^{miss} = |\nu_1|\ \hat{\tau}_{1x} + |\nu_2|\ \hat{\tau}_{2x}$$
$$E_y^{miss} = |\nu_1|\ \hat{\tau}_{1y} + |\nu_2|\ \hat{\tau}_{2y}$$

A,H -> ττ -> 2 τ-jets + X



Measurement error on E_t^{miss} -> unphysical neutrino

-> reconstruction fails for ~ 40% of events

Reconstruction fails also for $\Delta\phi(\tau_1,\tau_2) \sim 180°$

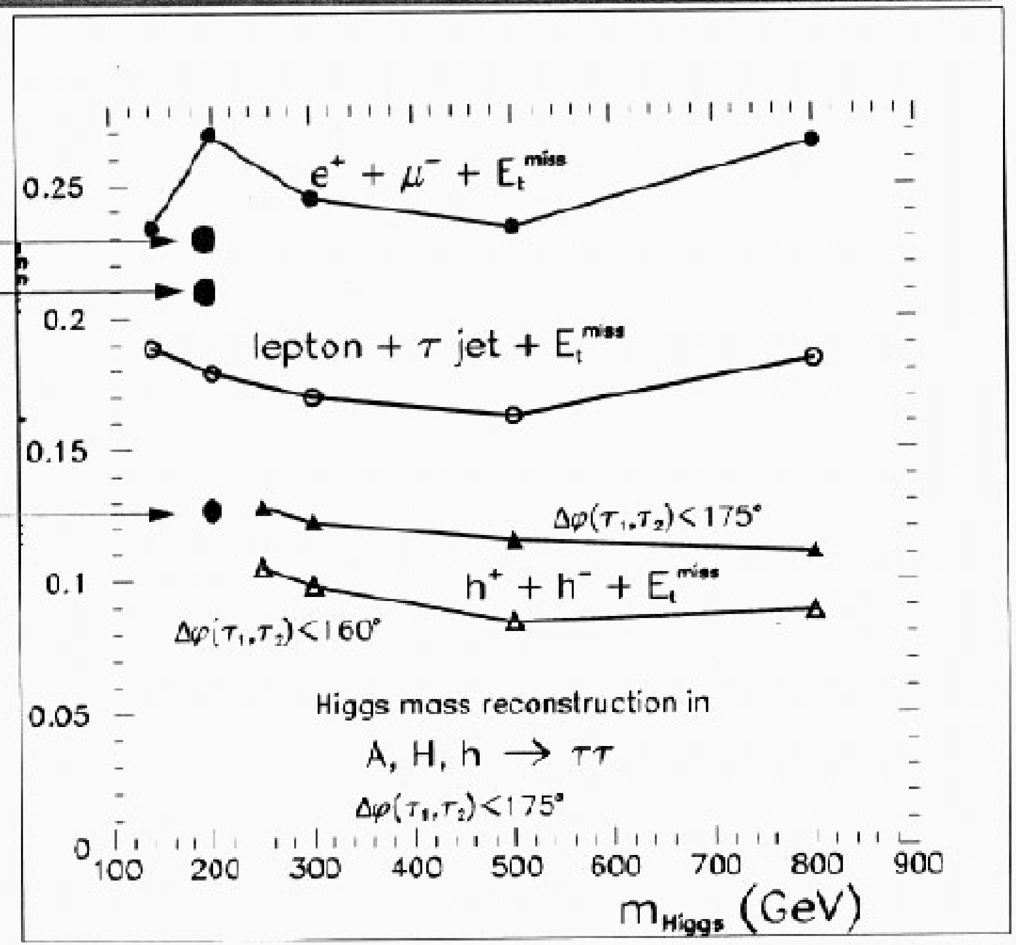
Higgs mass resolution in H -> ττ

ORCA 4:

e + μ

lepton + τ-jet

2 τ-jets



Event selection for H -> $\tau\tau$ -> 2 τ-jets + X

→ **2 jets, $E_t > 60$ GeV, $|\eta| < 2.5$**

satisfying the 1 or 3 prong τ selection:

1 or 3 tracks, with $p_t^h(\max) > 40$ GeV, within $\Delta R(h,h_{max}) < 0.03$

no track, $p_t > 1$ GeV, within $0.03 < \Delta R(h,h_{max}) < 0.4$

→ **Charge correlation: $\Sigma q_i(\text{jet1}) * \Sigma q_i(\text{jet2}) < 0$ in $\Delta R<0.03$**

→ **$E_t^{miss} > 40$ GeV**

→ $\Delta\phi(\tau\text{-jet1},\tau\text{-jet2}) < 175^o$

Selection with b-tagging:

No E_t^{miss} cut ($E_t^{miss} > 2\text{-}3\ \sigma$)

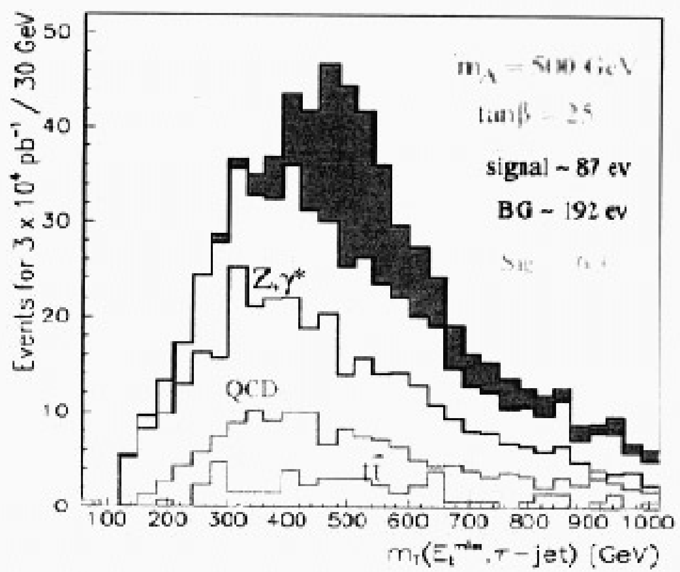
1 jet, $E_t > 30$ GeV, with b-tagging probability of

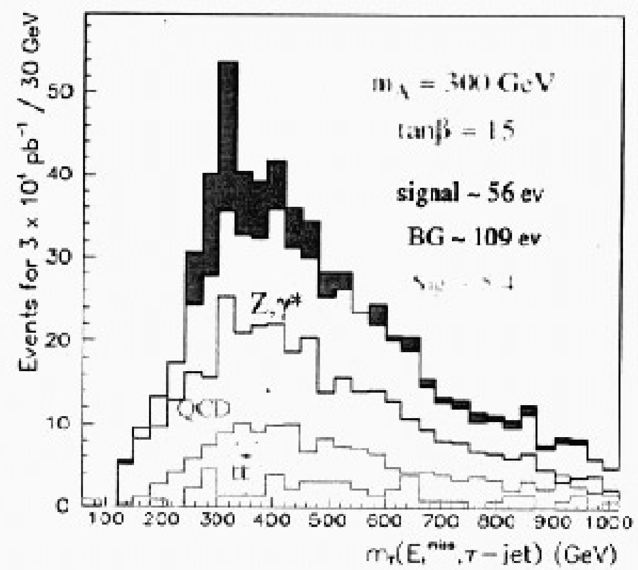
40% for H->$\tau\tau$, 60% for $t\bar{t}$, 2% for Z,γ^* and QCD

Signal superimposed on the total background for $3 * 10^4\ pb^{-1}$

$A, H \to \tau\tau \to h^+ + h^- + E_t^{miss} + X$

E_t^{miss} rejection factor for QCD ~ 20 (present ORCA study)





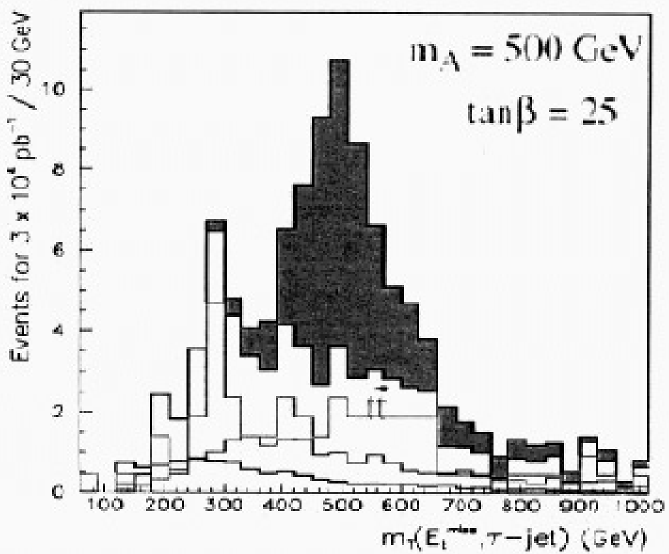
$E_t^{\tau\text{-jet}} > 60$ GeV, 1/3 prong sel. with $p_t^h > 40$ GeV, $E_t^{miss} > 40$ GeV, $\Delta\phi(j_1,j_2) < 175^0$

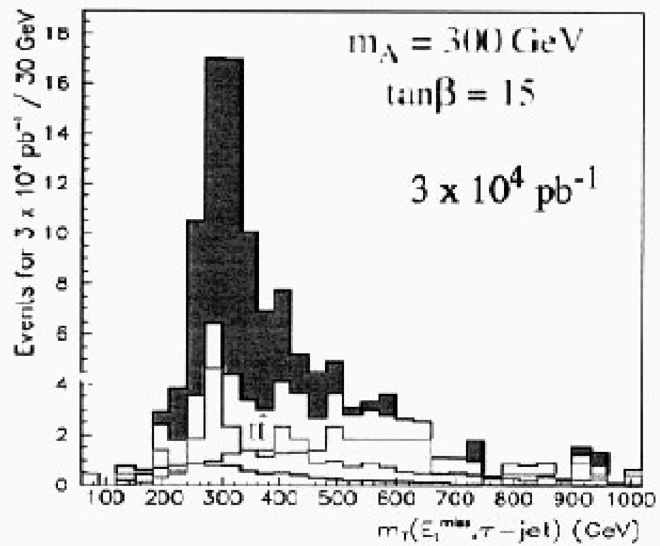
Signal superimposed on the background with b-tagging

A, H -> $\tau\tau$ -> 2 τ-jets + 1 bjet + X

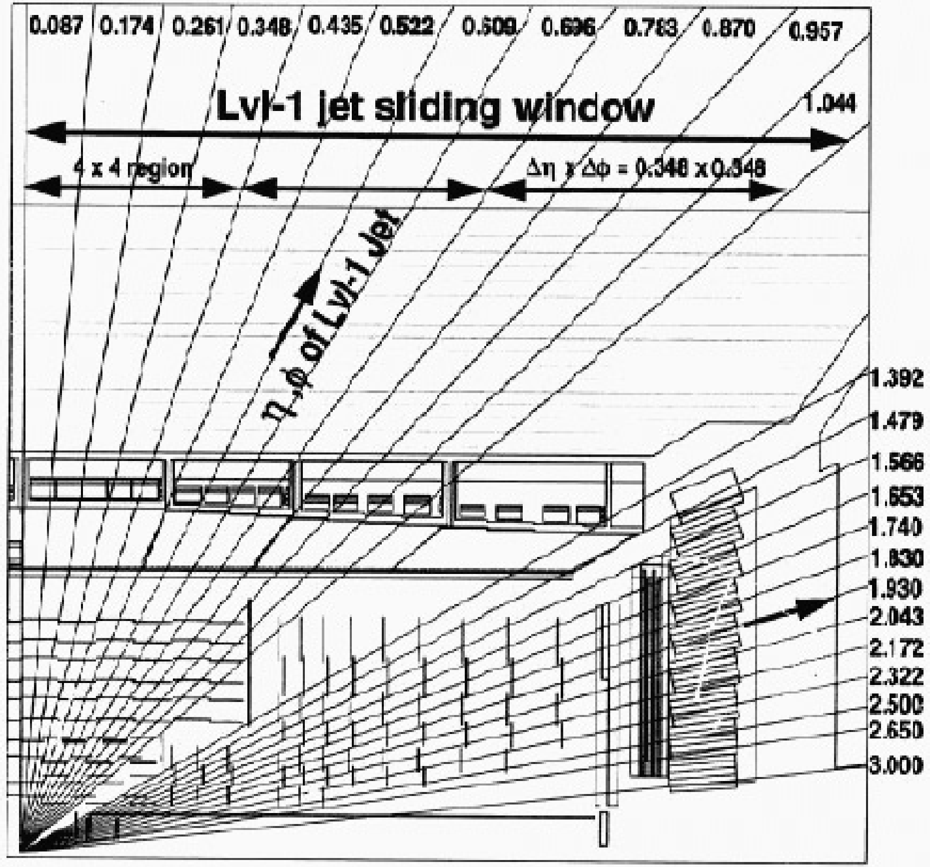
No E_t^{miss} cut, at least one jet with E_t>30 GeV for b-tagging

b-tagging efficiency assumed: 40% for signal, 60% for $t\bar{t}$, 2% for Z+jet and QCD





τ jet identification at Lvl-1 and Lvl-2



Lvl-1 Tau

redefine jet as τ jet :

- no τ-veto bit in any of the 9 4x4 regions
- τ-veto: > 3 active ecal or hcal towers in the 4x4 region

Lvl-2 Tau

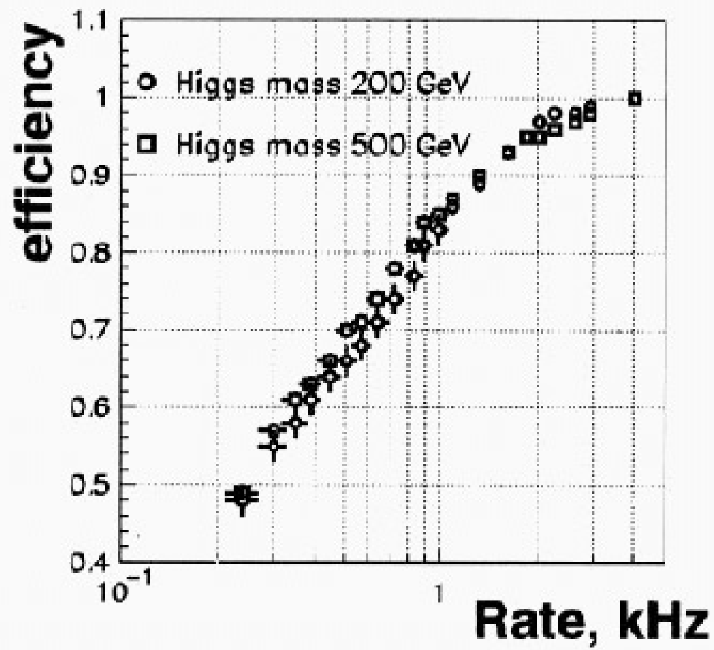
- reconstruct jet in a region given by Lvl-1
- use e.m. collimation:

$c = \sum E_t^{em}(r<0.4) - \sum E_t^{em}(r<0.13)$

- accept jet as τ jet if $c < c^{max}$

τ jet identification at Lvl-1 and Lvl-2

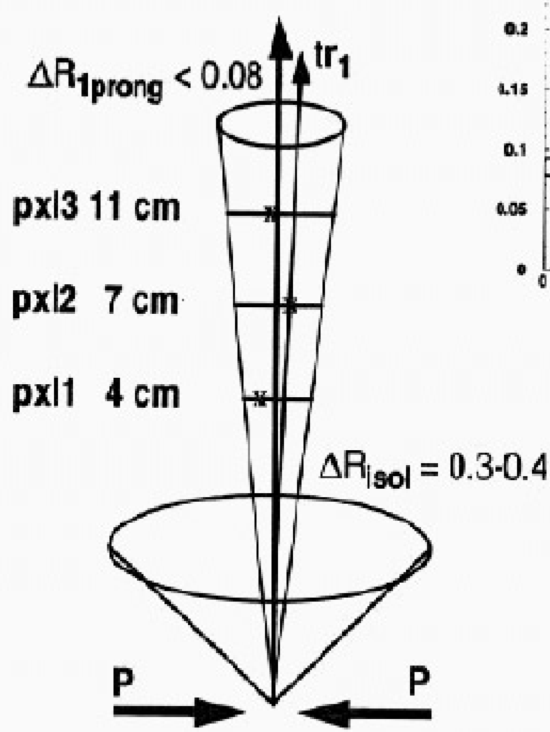
- for a 200-500 GeV Higgs, a factor 10 reduction in rate with respect to Lvl-1 implies a Lvl-2 efficiency ~ 65 %
- this is using only calorimeter data

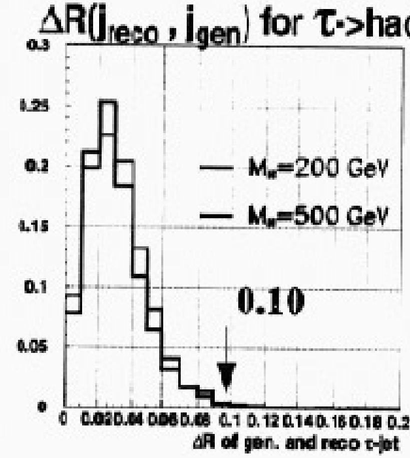


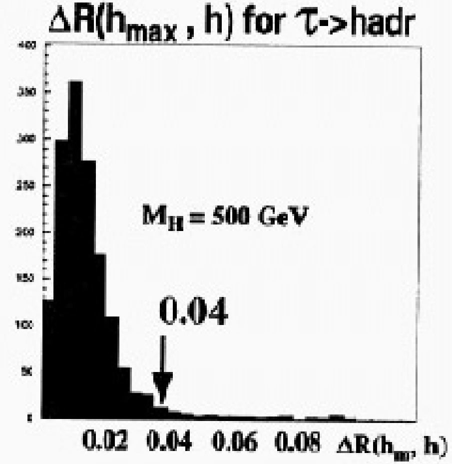
Lvl-1, Lvl-2 Tau trigger study is summarized in cms note 2000/055 by S. Eno, S. Dasu, R. Kinnunen, A. Nikitenko, W. Smith and in Lvl-1 Trigger TDR

τ jet selection at Lvl-3

Jet direction given by L2.0 Tau object

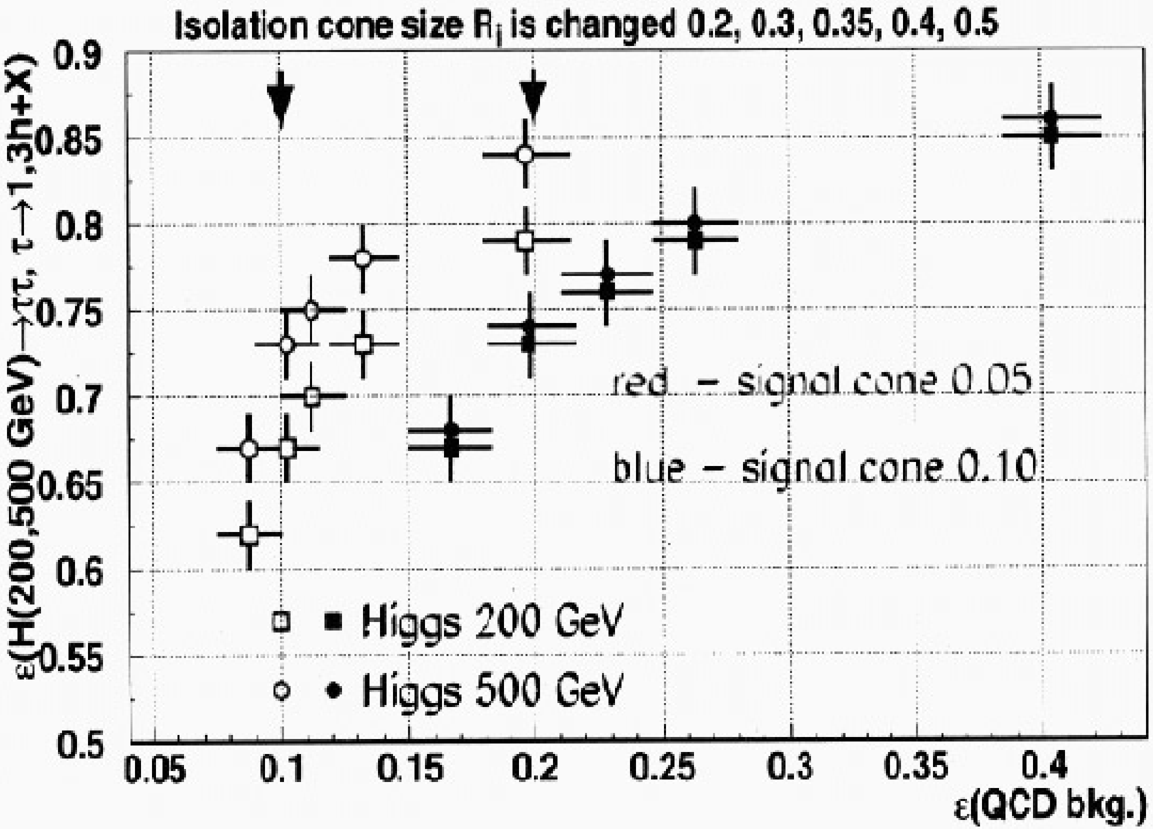






- ❑ find track (tr_1) with the best matching with Lvl-2 Tau jet
  $\Delta R(tr_1 - jet) < R_1$ (~0.10); $p_t^{tr1} > p_t^{cut\,1}$ (~5 GeV)
- ❑ at least one track in the inner cone
  $\Delta R(tr_1 - tr_i) < R_2$ (~0.04); $p_t^{tr\,i} > p_t^{cut\,2}$ (~1 GeV)
- ❑ no tracks in the outer cone
  $R_2 < \Delta R(tr_1 - tr_i) < R_3$ (~0.3); $p_t^{tr\,i} > p_t^{cut\,2}$ (~1 GeV)

Tau vs QCD efficiency at Lvl-3 with Pixel Detector

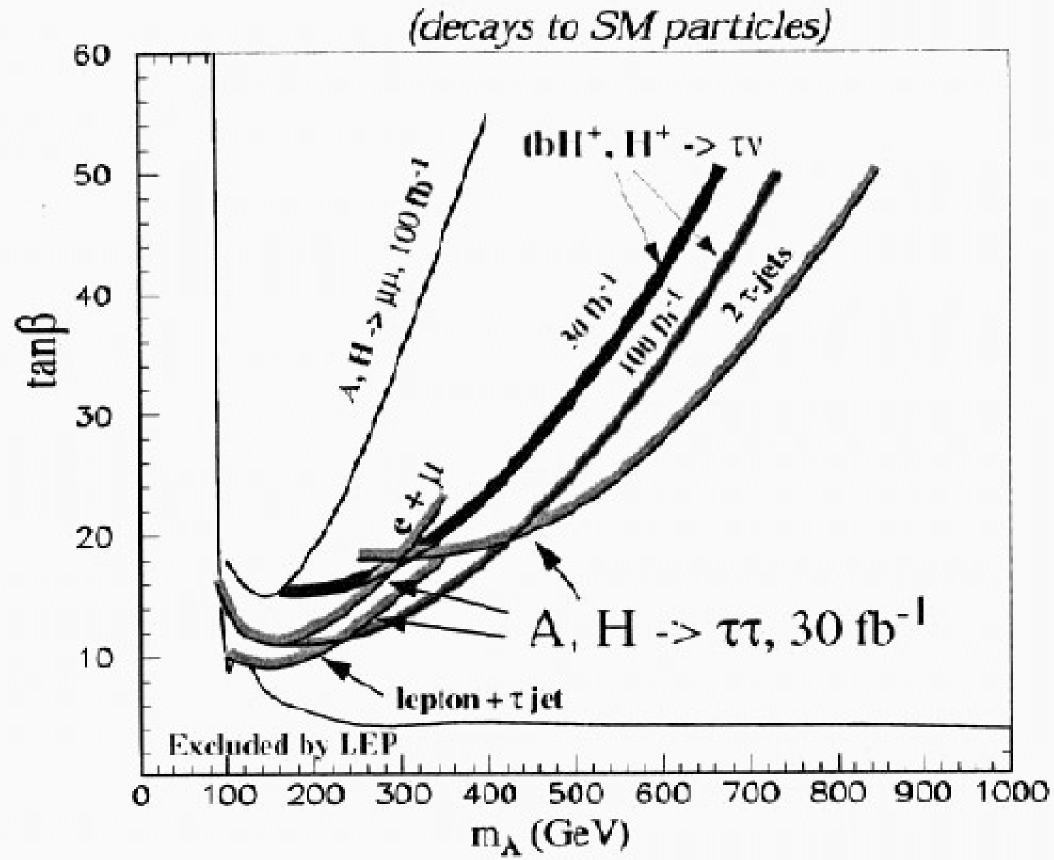


We will continue data taking for $H\to 2\tau$ channels at $L=10^{34} cm^{-2}s^{-1}$

Trigger path from Lvl-1 to tape for $A/H\to 2\tau \to 2jet$

Trigger level	QCD bkg.rate	N(A/H) for $10^5 pb^{-1}$ M_A=500 GeV, $\tan\beta$=25
Lvl-1, calo data	~ 4 000 ev. / s	3 337 ev.
Lvl-2, ecal data	~ 400 ev. / s	2 236 ev.
Lvl-3, pixels only	~ 40 (80) ev. / s	1 677 ev.
Lvl-3, regional tracking & 2-nd τ-jet analysis	work in progress	

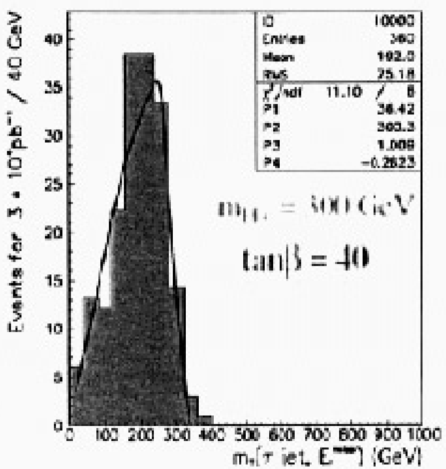
5σ significance contours for A, H, H+- in CMS



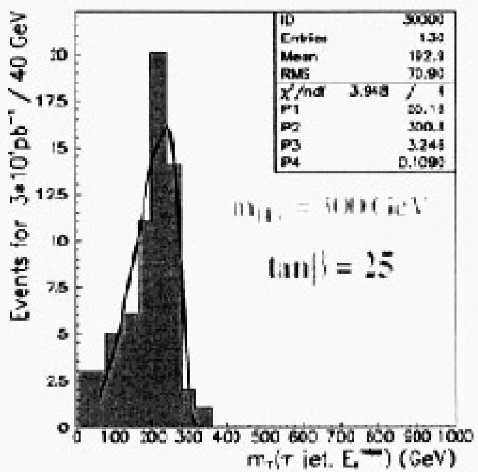
H^+ mass determination from $m_T(\tau\text{-jet}, E_t^{miss})$

A 4-parameter fit of the form: $dN / dm_T \sim \int D(z)\, dz / \sqrt{M_{fit}^2 - m_T^2}$

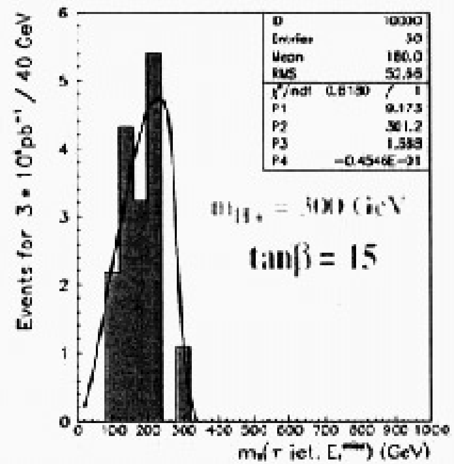
with $D(z) \sim z^{\alpha} (1 - z)^{\beta}$, $z = p_t^{\tau\text{-jet}} / p_t^{\tau}$



M_{fit} = 300.3 + 0.4 GeV



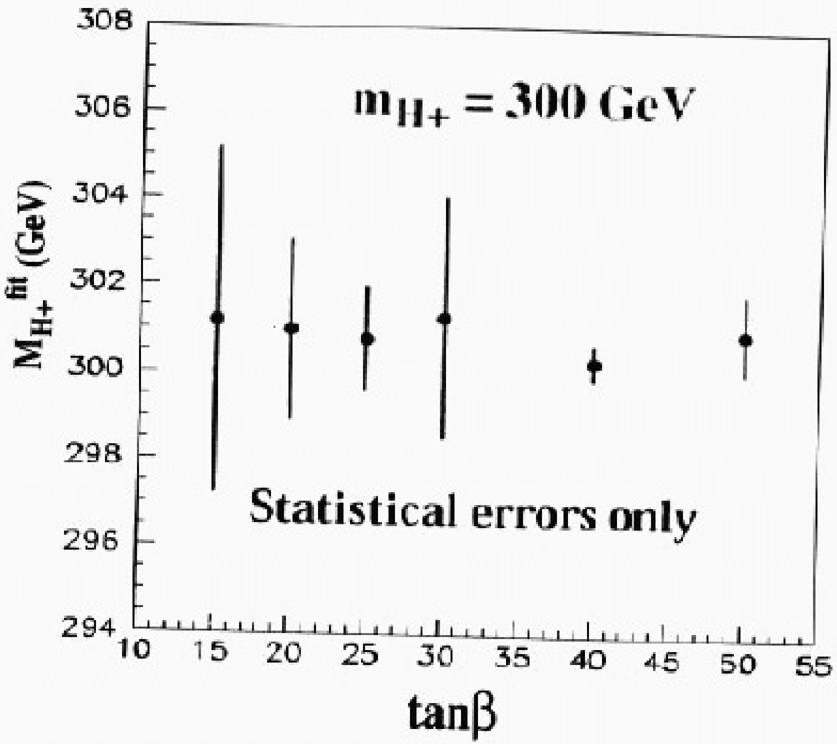
M_{fit} = 300.8 + 1.2 GeV



M_{fit} = 301.2 + 4.0 GeV

H^+ mass determination as a function of $\tan\beta$

in tbH^+, $H^+ \to \tau\nu$



Systematic errors from energy scale for jets and E_t^{miss} measurement

$W \to \tau\nu$ may be used to determine the mass scale of $m_T(\tau\text{-jet}, E_t^{miss})$ measurement

CMS Collaboration

Charged Higgs production via S-channel process

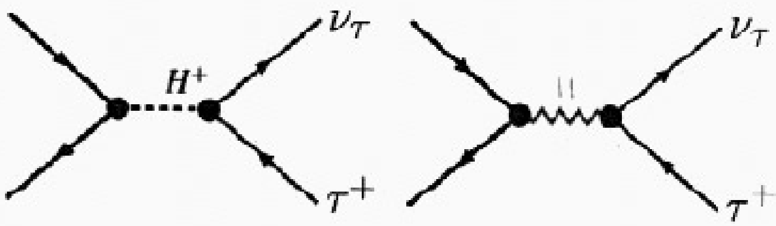
S. Slabospitsky
IHEP, Protvino, RUSSIA

$$q\bar{q}' \to H^{\pm} \to \tau \nu_{\tau}$$

- charged Higgs can be produced in s-channel process due to light quarks interaction

$$qq' \to H^{\pm}, \quad q(q') = d, u, s, c, b$$

- $H^{\pm} \to \tau\nu_\tau$ channel



- τ polarisation

for any $\tan\beta$ τ-lepton from $H^{\pm}$ decay has polarisation opposite to SM case

$$\mathcal{L}_{SM} \propto \bar{\nu}\,(P_R\gamma^\alpha P_L)\tau \quad \mathcal{L}_H \propto \bar{\nu}\,P_R\tau$$

SM	$\tau_L(\leftarrow)$	$\Rightarrow$	$\nu_L(\leftarrow)\pi$	$\Rightarrow$	$p_\pi \ll p_\tau,\ p_\nu \sim p_\tau$
H	$\tau_R(\rightarrow)$	$\Rightarrow$	$\nu_L(\leftarrow)\pi$	$\Rightarrow$	$p_\pi \sim p_\tau,\ p_\nu \ll p_\tau$

• uncertainty in the cross section

s-channel production cross section, $q\bar{q}' \to H^\pm$, has large uncertainty due to masses of light quarks

$$\sigma(\bar{q}' \to H^\pm) \propto (m_u^2 \cot^2\beta + m_d^2 \tan^2\beta)$$

for $M_H = 300$ GeV and $\tan\beta = 30$

$m_d = m_u = 300$ MeV $\quad \sigma(H^\pm \to \tau\nu) \approx 1.6$ pb

$m_d = 9$, $m_u = 5$ MeV $\quad \sigma(H^\pm \to \tau\nu) \approx 0.07$ pb

• we use RPP values for m_q

$m_d = 9$ MeV $\quad m_s = 150$ MeV $\quad m_b = 4.8$ GeV

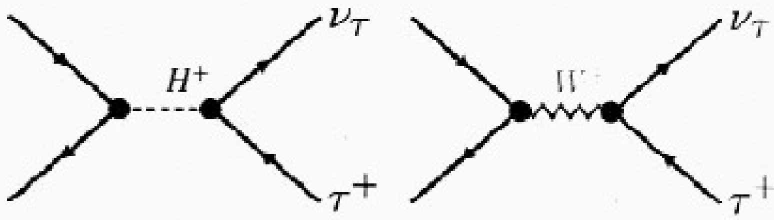
$m_u = 5$ MeV $\quad m_c = 1.25$ GeV

$M_H = 200$ GeV and $\tan\beta = 30, \quad 60$

$\tan\beta$	1	10	30	50
Γ, GeV	2.83	0.26	2.3	6.6
Br, %	0.015	16	16	16
σ, pb	3×10^{-5}	0.078	0.85	2.1

- $H^{\pm} \to \tau\nu_\tau$ channel,

$qq' \to H^{\pm}, \quad q(q') = d, u, s, c, b$



$M_H = 200$ GeV and $\tan\beta = 30(50)$

$\sigma(H^{\pm}) = 1.(2.4)$ pb

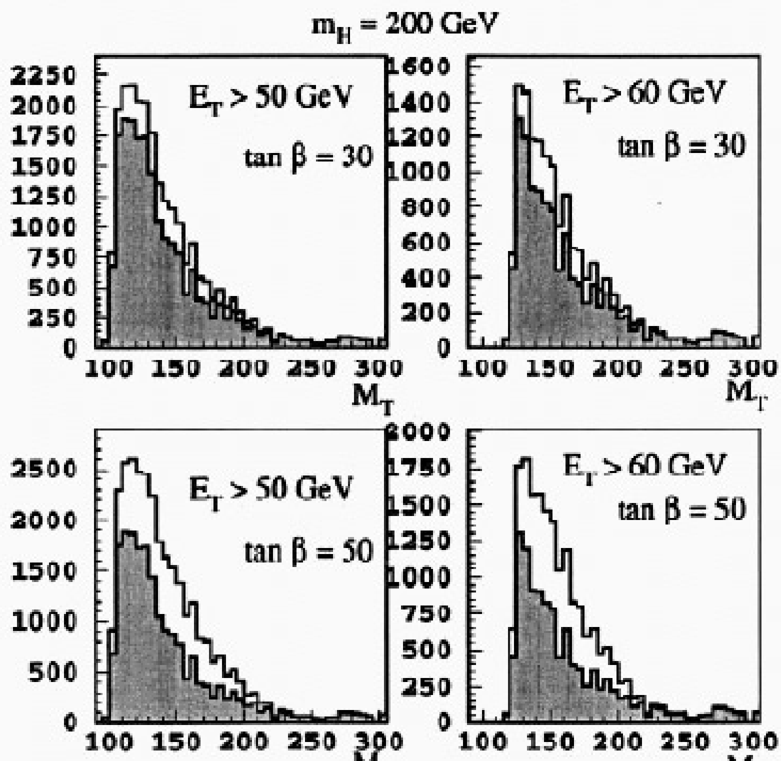
- background processes

◇ $W^{\pm}(\to \tau\nu)$, $\sigma \approx 2.4 \times 10^4$ pb

◇ $t\bar{t}$ production, $\sigma = 830$ pb

◇ $Wb\bar{b}$ production, $\sigma = 400$ pb

$$M_T = 2P_{T_\tau} E_{Tmis}(1 - \cos\phi_{\tau E_{Tmis}})$$

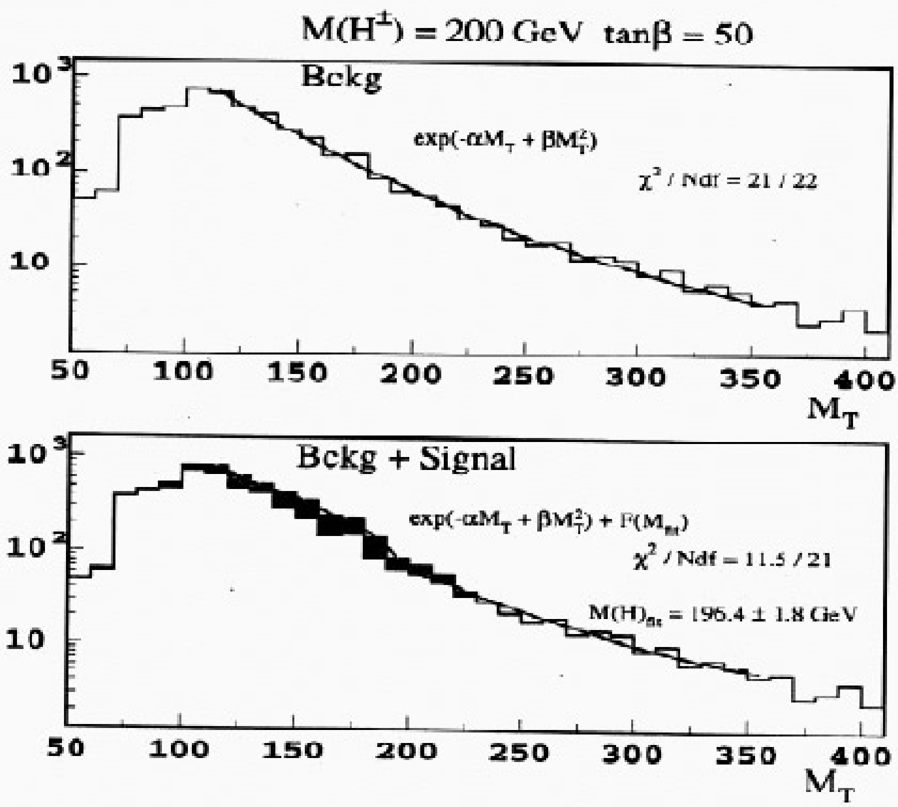


- background events (W, $t\bar{t}$, $Wb\bar{b}$) can be fitted by

$$\frac{dN}{M_T} \propto \exp(-aM_T + bM_T^2)$$

while for (background + signal) we use

$$\frac{dN}{M_T} \propto \exp(-aM_T + bM_T^2) \; + \; F(M_{fit})$$



• signal and backgrounds have similar shapes

$W^{\pm}$ is produced mainly in light quarks annihilation, since $N(u,d) > N(\bar{u},\bar{d})$

$$\sigma(W^{+}) > \sigma(W^{-}) \Rightarrow N(\tau^{+}) > N(\tau^{-})$$

$H^{\pm}$ is produced due to interaction of heavy s, c, b quarks, since $N(Q) = N(\bar{Q})$

$$\sigma(H^{+}) \approx \sigma(H^{-}) \Rightarrow N_H(\tau^{+}) \approx N_H(\tau^{-})$$

$$A_{\tau} \equiv \frac{N(\tau^{+}) - N(\tau^{-})}{N(\tau^{+}) + N(\tau^{-})}$$

$R_H = 0.85$, $E50 \equiv E_T > 50$, $E60 \equiv E_T > 60$

cut	$A_{\tau}(W)$	$A_{\tau}(H)$, 30	$A_{\tau}(H)$, 50
R_H	0.11 ± 0.001	0.110 ± 0.001	0.110 ± 0.001
$E50$	0.189 ± 0.019	0.167 ± 0.017	0.145 ± 0.016
$E60$	0.234 ± 0.025	0.197 ± 0.023	0.163 ± 0.020

Conclusions

Discovery of H -> $b\bar{b}$ in $t\bar{t}H$ and WH possible around $m_H = 115$ GeV

- matrix element calculation for the $t\bar{t}b\bar{b}$ background

Full update of A, H -> $\tau\tau$ -> 2 τ-jet channel in progress

- QCD background can be controlled
- b-tagging can be used to reduce Z and QCD backgrounds
  -> reduction from E_t^{miss} cut not crucial
- including 3 prong decays may increase the event rate by 1.7
- trigger for A, H -> $\tau\tau$ -> 2 τ-jet possible for 10^{34} cm^2s^{-1}
  including tracker at Level 3