U

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260
pt.1

Cours/Lecture Series

1991 – 1992 ACADEMIC TRAINING PROGRAMME

SPEAKER : F. PAUSS / ETH Zürich & CERN–PPE
TITLE : LHC – Physics beyond the Standard Model
TIME : Monday 16 & Tuesday 17 December : from 10.30 to 12.00 hrs
Wednesday 18 December : from 11.00 to 12.00 hrs
PLACE : Auditorium

ABSTRACT

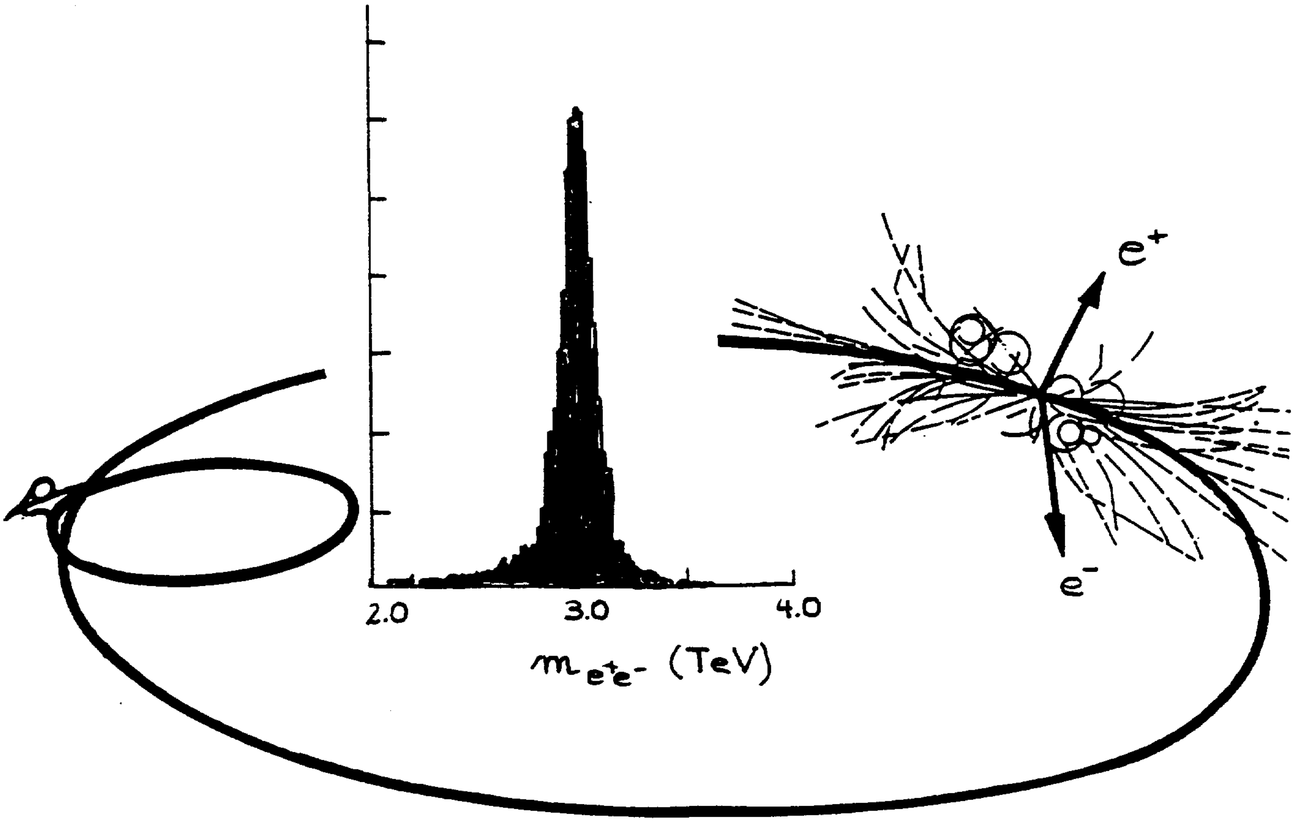
Physics beyond the Standard Model will be discussed in the context of possible experimental signatures at the LHC. This includes the following physics topics: Supersymmetry (the Higgs-sector, the gluino-squark sector, possible extension of the MSSM), Heavy Vector Bosons and alternative symmetry breaking mechanisms. The impact on the design of the detectors will be briefly discussed as well.

212745

Div. DG/PU
Distr. int. & ext.

Large Hadron Collider

PHYSICS BEYOND THE STANDARD MODEL

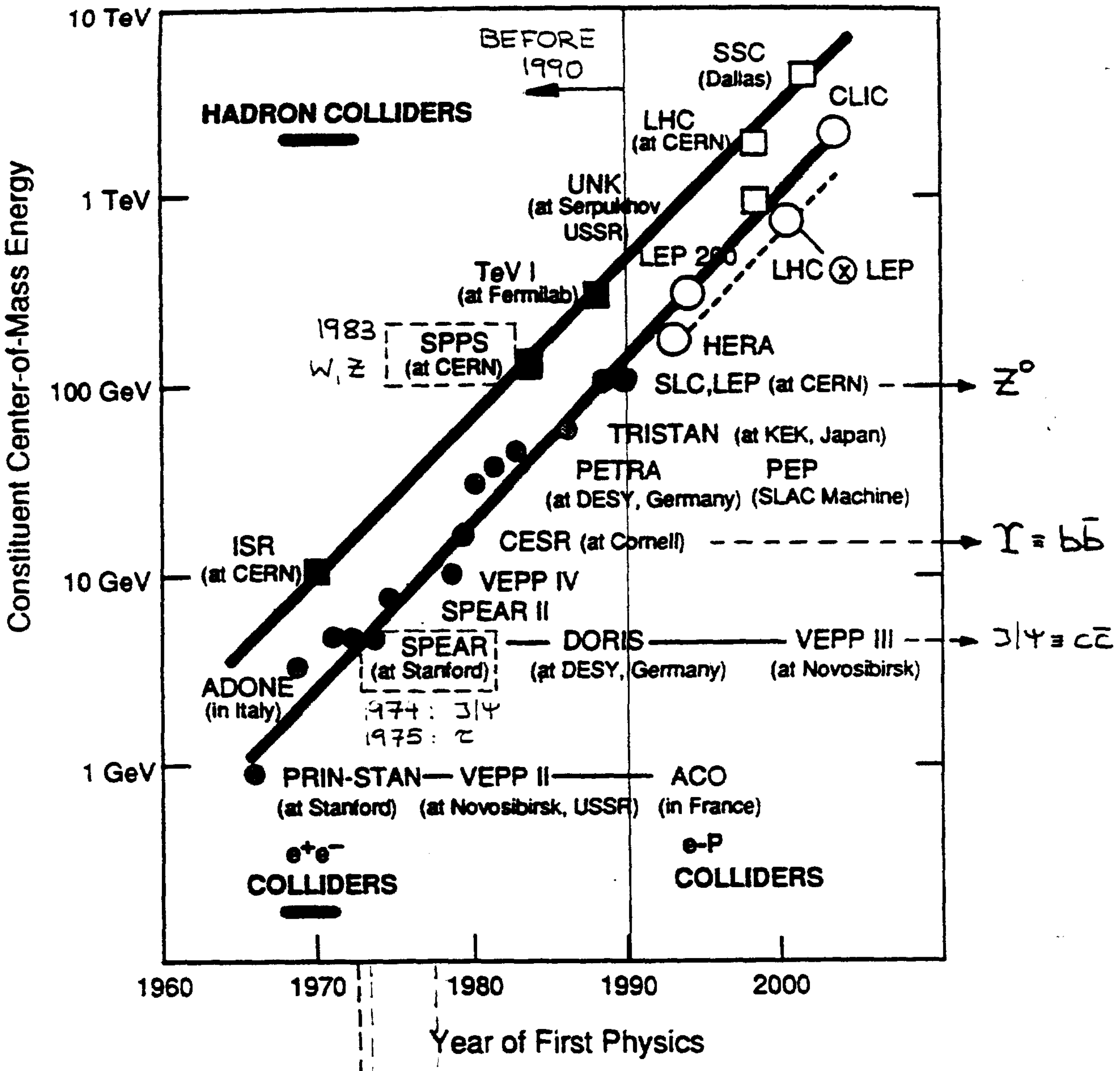


CERN ACADEMIC TRAINING PROGRAMME:
16, 17, 18. DEC. 1991

FELICITAS PAUSS
ETH - ZÜRICH

<u>DISCOVERIES</u> : COLLIDER AND FIXED TARGET

PREDICTED AND NOT PREDICTED



→ 1973 : NEUTRAL CURRENTS : CERN-PS
ν- SCATTERING : 1. EXPER. PROOF
FOR ELECTROWEAK THEORY

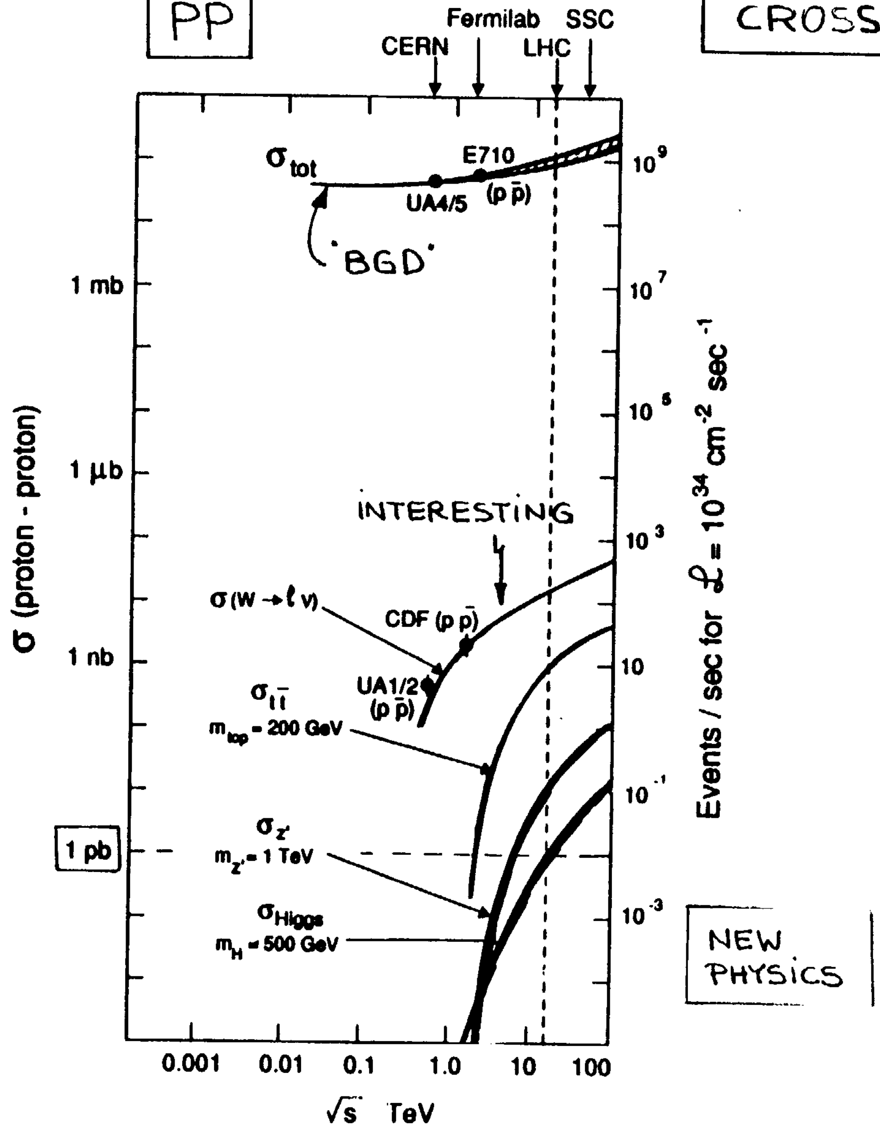
→ 1974 : BROOKHAVEN : $p + Be \rightarrow J/\psi \rightarrow e^+e^-$

→ 1977 : FERMILAB : $p + N \rightarrow \Upsilon \rightarrow \mu^+\mu^-$

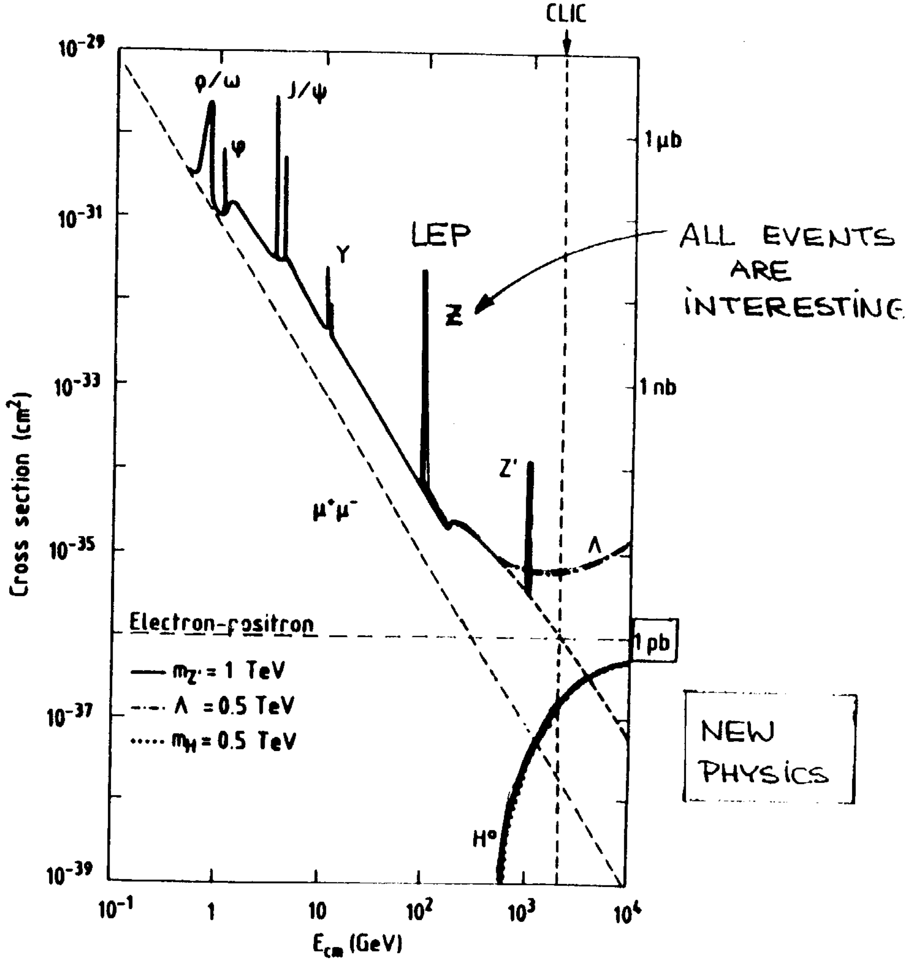
<u>REMARK</u> : J/ψ, τ, Υ, W AND Z DISCOVERY VIA LEPTON-CHANNEL
(e, μ)

CROSS - SECTIONS

PP



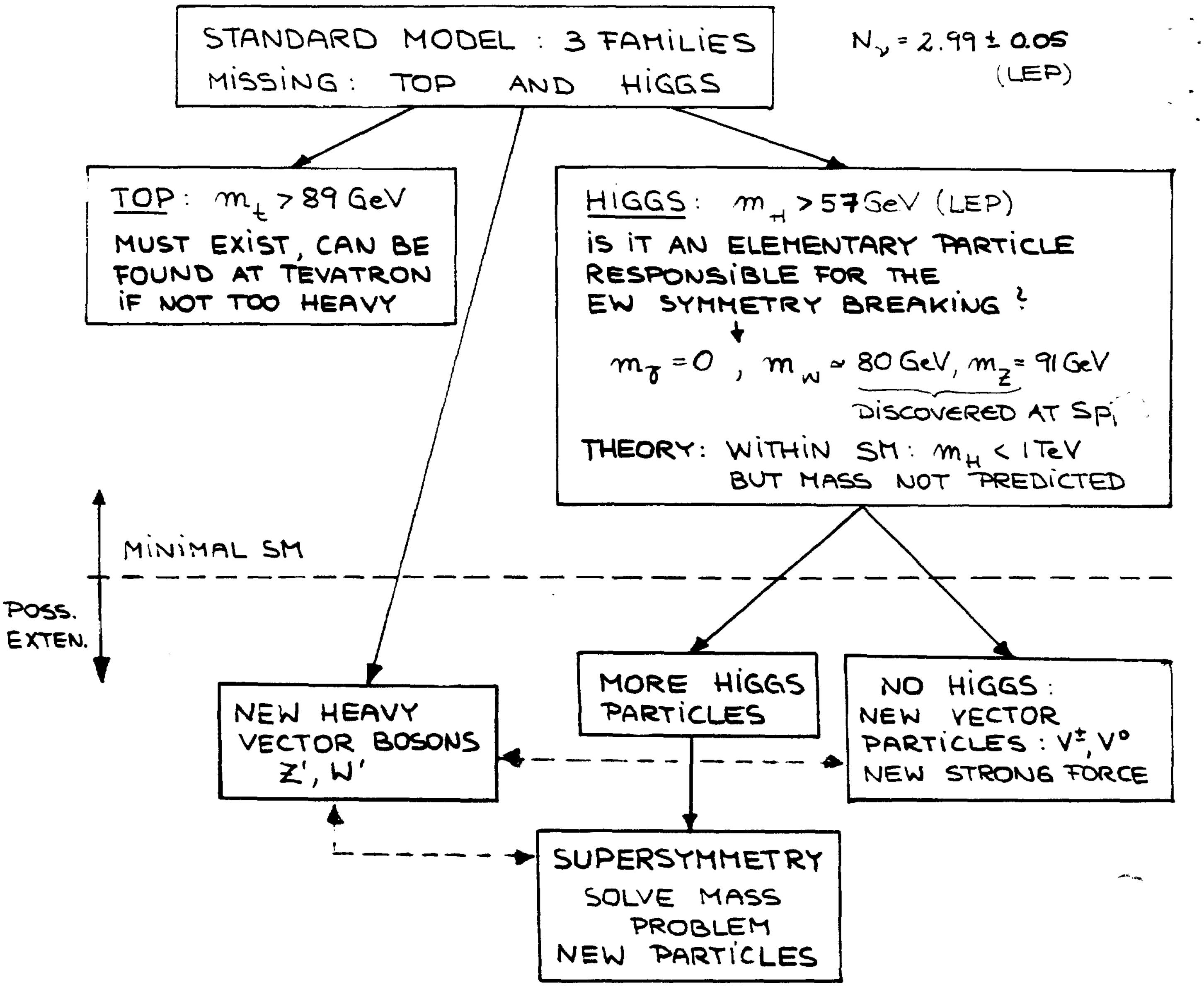
e^+e^-



LHC : $\sqrt{s} = 16$ TeV , $\mathcal{L} \gtrsim 10^{34} cm^{-2} s^{-1}$

SSC : $\sqrt{s} = 40$ TeV , $\mathcal{L} = 10^{33} cm^{-2} s^{-1}$

PHYSICS GOALS OF THE LHC



STANDARD MODEL : 3 FAMILIES
MISSING : TOP AND HIGGS

$N_\nu = 2.99 \pm 0.05$
(LEP)

TOP : $m_t > 89$ GeV
MUST EXIST, CAN BE FOUND AT TEVATRON IF NOT TOO HEAVY

HIGGS : $m_H > 57$ GeV (LEP)
IS IT AN ELEMENTARY PARTICLE RESPONSIBLE FOR THE EW SYMMETRY BREAKING ?

$$\downarrow$$

$$m_\gamma = 0 \; , \; m_W \simeq \underbrace{80\,\text{GeV}, \; m_Z = 91\,\text{GeV}}_{\text{DISCOVERED AT Sp}}$$

THEORY : WITHIN SM : $m_H < 1$ TeV
BUT MASS NOT PREDICTED

MINIMAL SM

POSS. EXTEN.

NEW HEAVY VECTOR BOSONS
Z', W'

MORE HIGGS PARTICLES

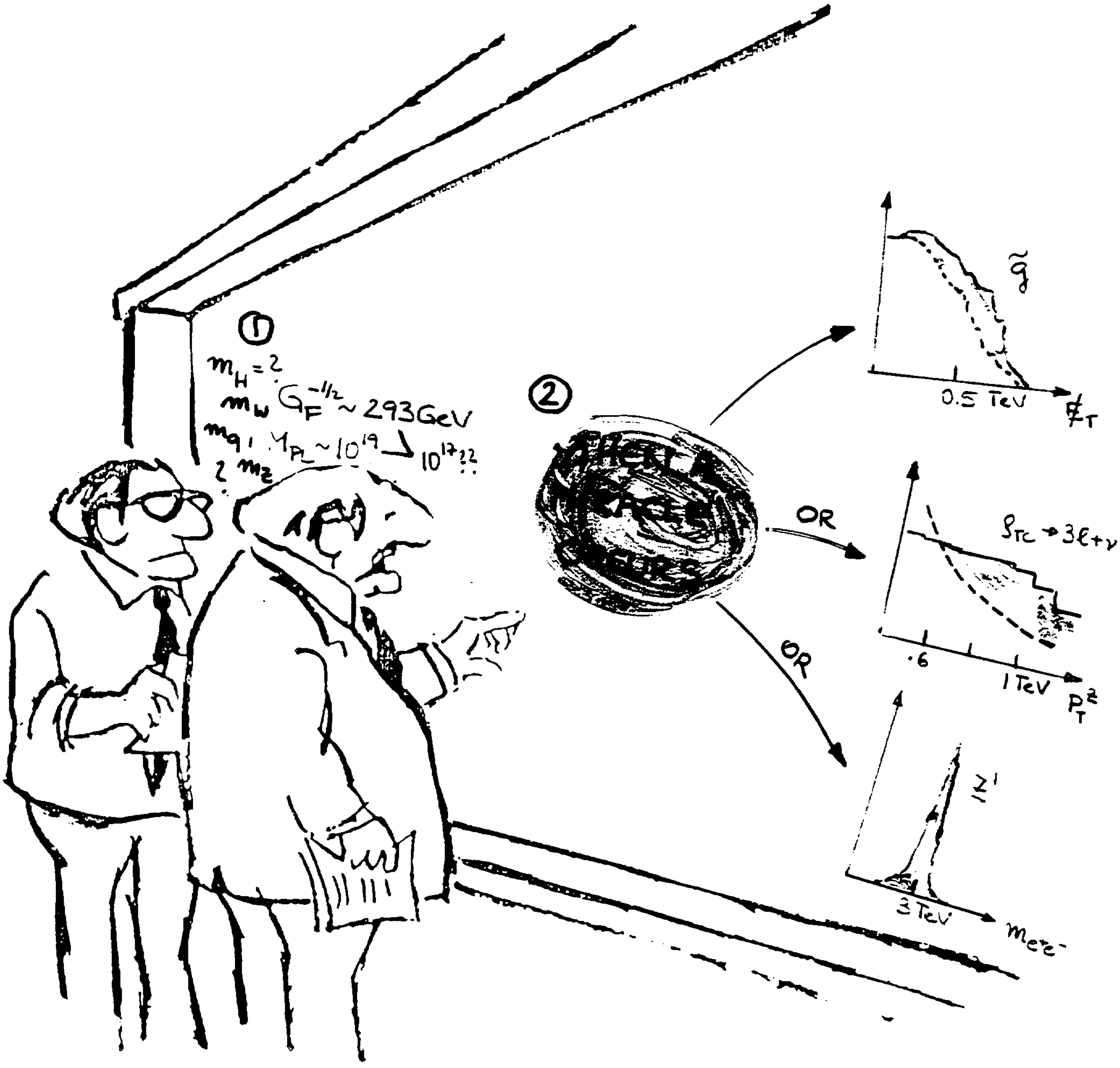
NO HIGGS :
NEW VECTOR PARTICLES : $V^\pm, V^0$
NEW STRONG FORCE

SUPERSYMMETRY
SOLVE MASS PROBLEM
NEW PARTICLES

➡ ONE OF THE MAIN QUESTIONS :

DO WE HAVE ONE OR MORE FUNDAMENTAL HIGGS PART-
OR ARE NEW STRONG FORCES REPLACING THE HIGGS ?

GENERAL CONSENSUS : "SOMETHING" MUST HAPPEN IN THE TeV ENERGY REGION
THIS ENERGY REGION IS ACCESSIBLE AT LHC



"I think you should be more explicit here in ~~step two~~."

CONTENT OF LECTURES
(WHAT COULD BE THE POSSIBLE MIRACLE?)

- SUPERSYMMETRY
  - GENERAL REMARKS
  - THE HIGGS SECTOR IN THE MSSM
  - GLUINOS, SQUARKS
  - BROKEN R-PARITY: AN EXTENSION OF THE MSSM

- NEW HEAVY VECTOR BOSONS
  - GENERAL REMARKS
  - EXPERIMENTAL SIGNATURES

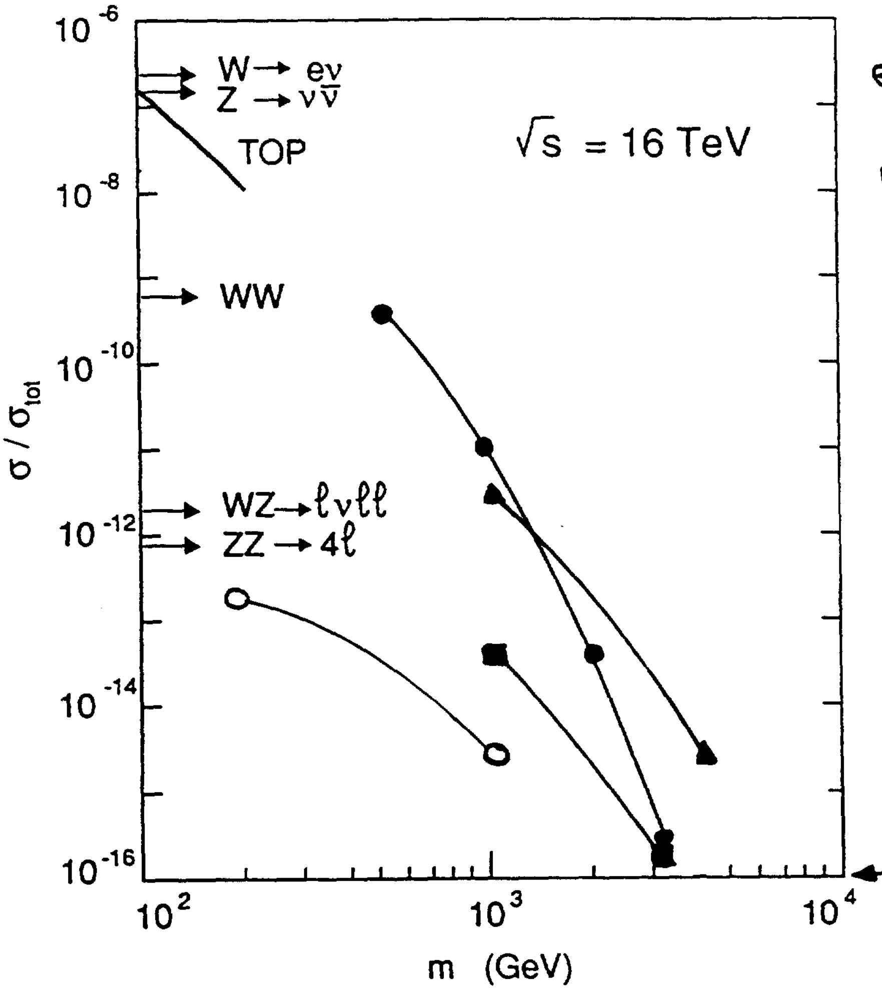
- ALTERNATIVE SYMMETRY BREAKING
  - GENERAL REMARKS
  - EXPERIMENTAL SIGNATURES

REF.: L. IBANEZ: "PHYSICS BEYOND THE STAND. MODEL"
ACAD. TRAINING, 2.-6. DEC. 1991

ECFA-LHC WORKSHOP, AACHEN, OCT. 1990
CERN 90-10, VOL I AND II

+ UPDATES ON SUSY-HIGGS:
Z. KUNSZT, F. ZWIRNER: CERN-TH.6150/91.
ETH-TH/91-7
+ PRIVAT COMMUNICATIONS....

PHYSICS BEYOND THE SM — THE EXPERIMENTAL CHALLENGE



$\sigma_{TOT} = 100$ mb USED

$\sigma_{b\bar{b}}/\sigma_{TOT} \sim 5 \times 10^{-3}$

○ $H_{SM} \rightarrow$ 4 LEPTONS

● $\tilde{q}\tilde{g}$: NO BR INCLUDED ($m_{\tilde{q}} = 2 m_{\tilde{g}}$)

▲ $Z' \rightarrow e^+e^-$ EXAMPLE OF E_6

■ $W_L^+ Z_L^0 \rightarrow \ell^+\nu\ell^+\ell^-$ BESS MODEL

← 1 EVT FOR $10^5 \, pb^{-1}$

1 YEAR AT $\mathcal{L} = 10^{34} \, cm^{-2} s^{-1}$

<u>RECALL</u>: AT $Sp\bar{p}S$: $\sigma(Z^0 \rightarrow e^+e^-)/\sigma_{TOT} \sim 10^{-9}$

ONE PROBLEM OF STANDARD MODEL:

BY DIRECT EXTRAPOLATION OF SM ARRIVE AT GRAND UNIFIED THEORIES WHERE $\alpha_{em}^{-1} = \alpha_W^{-1} = \alpha_S^{-1}$

GUT SCALE : $M_{GUT} \sim 10^{15}$ GeV

IF GRAVITY ADDED : $M_{PL} \sim 10^{19}$ GeV

→ CAN NOT IGNORE THESE SCALES

IN SM : ALL MASSES GIVEN IN TERMS OF WEAK SCALE : $G_F^{-1/2} \sim 293$ GeV

⇨ CAN SM BE VALID UP TO M_{PL} ?
FROM $G_F^{-1/2}$ TO M_{PL} : FACTOR ~ 10^{17} !!

CONSEQUENCES FOR HIGGS:

IF SM VALID UP TO SUCH LARGE SCALES CORRECTIONS TO m_H WILL INCREASE m_H

→ $m_H \sim$ LARGE SCALE

→ NEED NEW PHYSICS (NEW SCALE) TO STABILIZE HIGGS

ONE SOLUTION: SUPERSYMMETRY

PREDICT FOR EACH KNOWN PARTICLE ITS SUPER-PARTNER:

$e \leftrightarrow \tilde{e}$, $q \leftrightarrow \tilde{q}$, $Z \leftrightarrow \tilde{Z}$, $g \leftrightarrow \tilde{g}$, ...

FOR NATURAL EXPLANATION OF WEAK SCALE NEED:

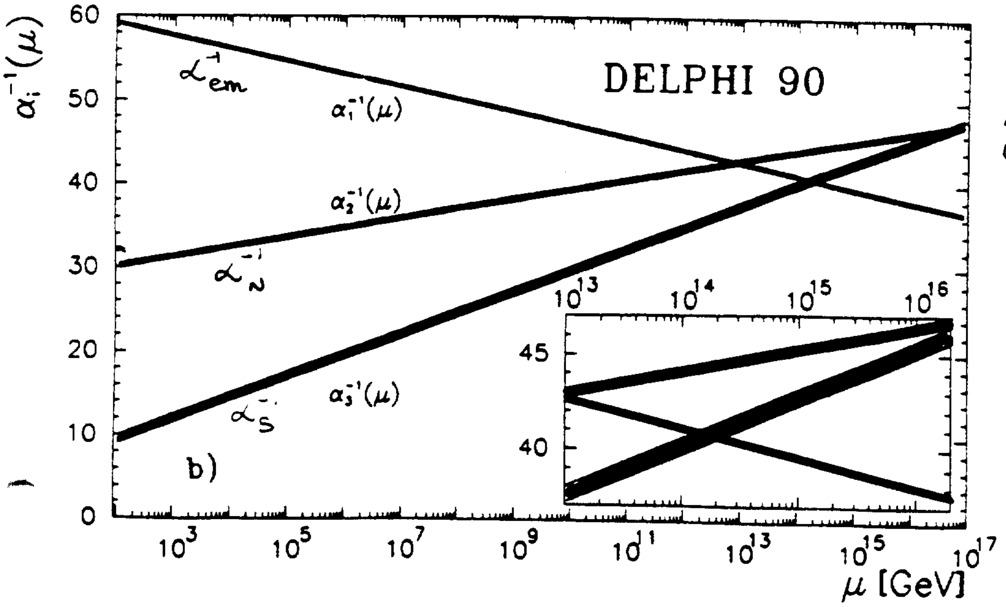
NEW SCALE ~ (FEW TIMES $G_F^{-1/2}$) ~ $\mathcal{O}$(1TeV)

NEW SCALE ~ m_{SUSY} PARTNERS

$\updownarrow$

CAN BE DISCOVERED AT LHC

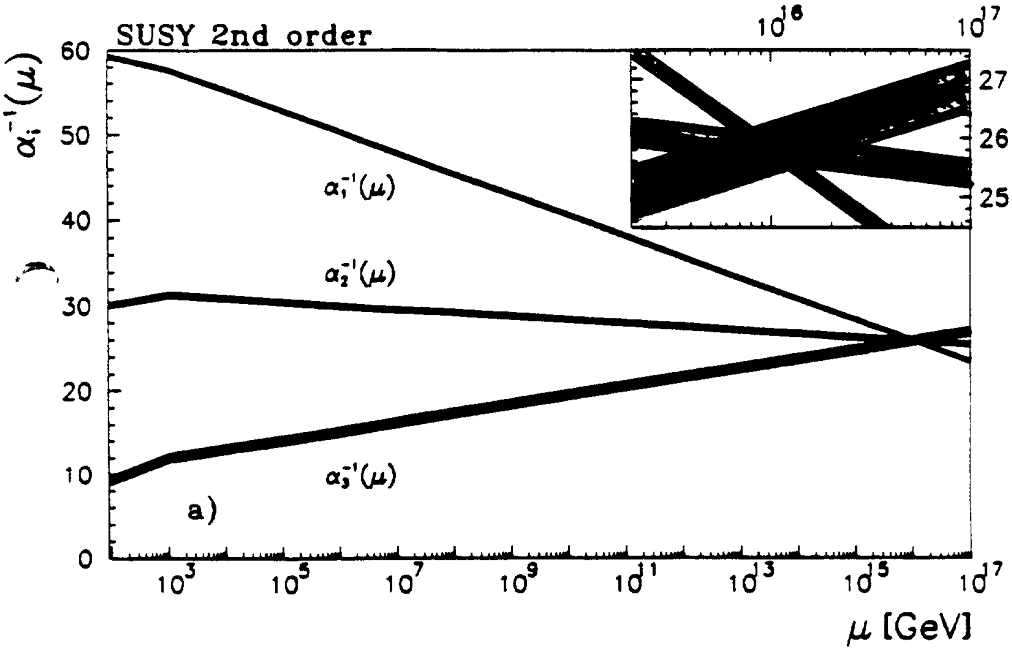
EVOLUTION OF COUPLING CONSTANTS WITHIN MSM DOES NOT LEAD TO GRAND UNIFICATION:



AMALDI et al.
CERN - PPE/91-44

USING m_Z AND $\alpha_s(m_Z)$:
DISAGREE > 7 s.d.

MSS EXTENSION OF SM LEADS TO UNIFICATION AT SCALE $10^{16 \pm 0.3}$ GeV:



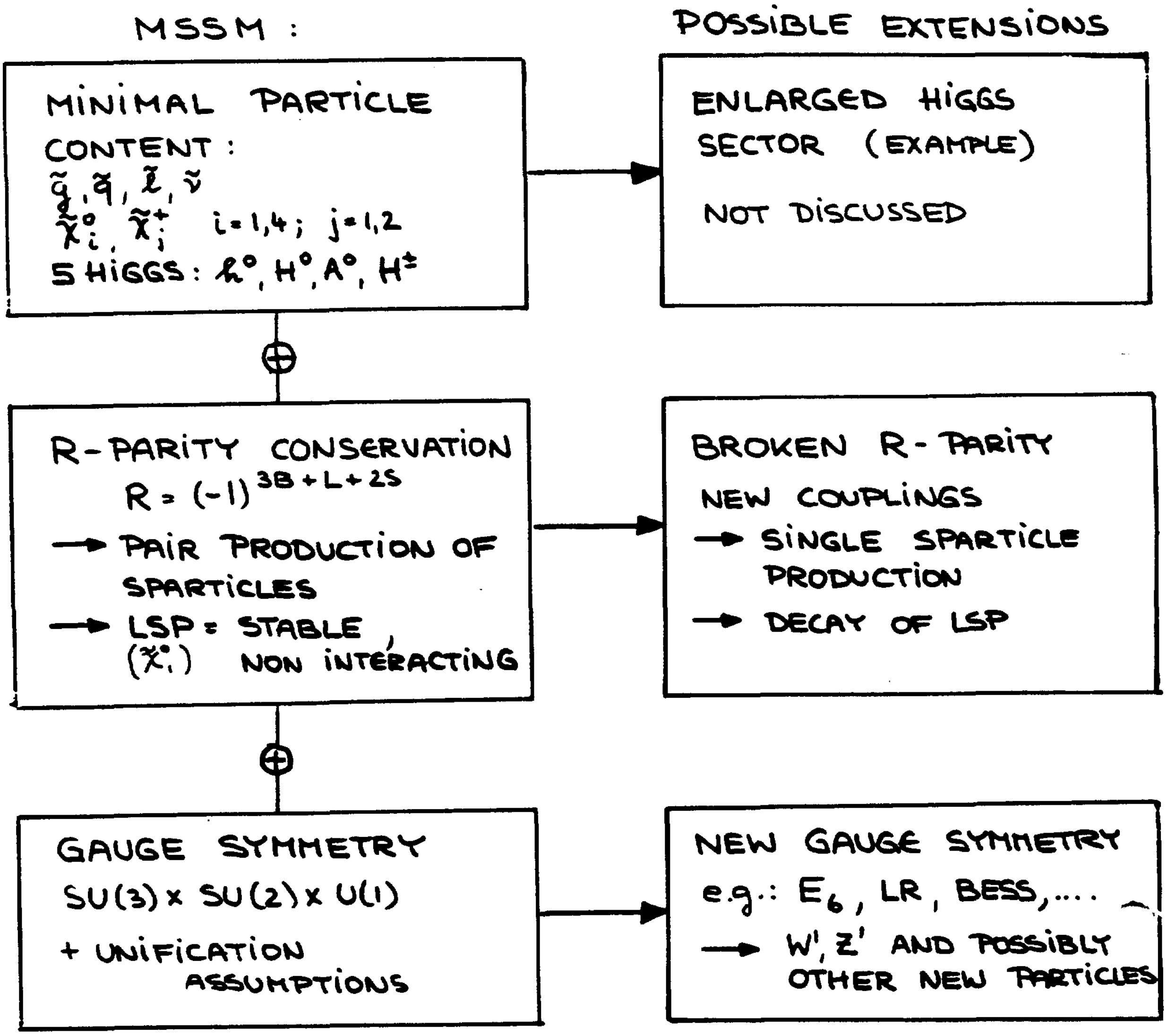
COMPATIBLE WITH LIMIT OF
p - LIFETIME ~10^{32} y.

→ BEST FIT WITH MSSM FOR

$$\boxed{m_{SUSY} = 10^{3\pm1} \text{ GeV}}$$

(ERROR MOSTLY FROM α_s)

THE MINIMAL SUPERSYMMETRIC MODEL AND POSSIBLE EXTENSIONS



MSSM:

POSSIBLE EXTENSIONS

MINIMAL PARTICLE CONTENT:
$\tilde{q}, \tilde{g}, \tilde{l}, \tilde{\nu}$
$\tilde{\chi}^0_i, \tilde{\chi}^+_j$ $i = 1,4;\ j = 1,2$
5 HIGGS: $h^0, H^0, A^0, H^\pm$

ENLARGED HIGGS SECTOR (EXAMPLE)

NOT DISCUSSED

$\oplus$

R-PARITY CONSERVATION
$R = (-1)^{3B+L+2S}$
→ PAIR PRODUCTION OF SPARTICLES
→ LSP = STABLE, NON INTERACTING ($\tilde{\chi}^0_1$)

BROKEN R-PARITY
NEW COUPLINGS
→ SINGLE SPARTICLE PRODUCTION
→ DECAY OF LSP

$\oplus$

GAUGE SYMMETRY
SU(3) × SU(2) × U(1)
+ UNIFICATION ASSUMPTIONS

NEW GAUGE SYMMETRY
e.g.: E_6, LR, BESS, ...
→ W', Z' AND POSSIBLY OTHER NEW PARTICLES

THE HIGGS SECTOR IN MSSM

NEED 2 COMPLEX HIGGS DOUBLETS TO AVOID GAUGE ANOMALIES → 5 PHYSICAL HIGGS BOSONS:

$h^0 \quad H^0 \quad A^0 \quad H^\pm$

CP-EVEN CP-ODD
NEUTRAL CHARGED

AT TREE LEVEL: ALL HIGGS MASSES AND COUPLINGS CAN BE EXPRESSED IN TERMS OF 2 PARAMETERS : USE $\boxed{m_{A^0}\,,\ \tan\beta = \frac{v_2}{v_1}}$

RATIO OF V.E.V's
$(1 < \tan\beta < m_t/m_b)$

$$m_{h^0} = \frac{1}{2}\left(m_A^2 + m_Z^2 - \sqrt{(m_A^2 - m_Z^2)^2 + 4 m_Z^2 m_A^2 \sin^2 2\beta} \right)$$

→ IMPORTANT TREE LEVEL MASS RELATIONS:

$m_{h^0} \leq m_Z \,,\ m_{H^0} > m_Z \,,\ m_{A^0} > m_{h^0} \,,\ m_{H^\pm} > m_W$

↑ IN LEP200 REACH!

HOWEVER: RADIATIVE CORRECTIONS TO HIGGS MASSES HAVE TO BE TAKEN INTO ACCOUNT

CORRECTIONS TO m_{h^0}:

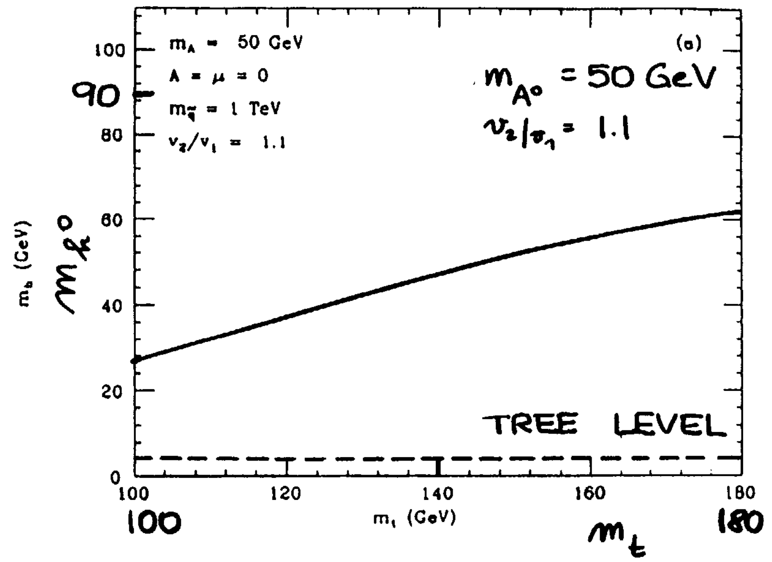
$$\varepsilon = \frac{2\alpha_W m_t^4}{2\pi m_W \sin^2\beta} \log\left(1 + \frac{m_{\tilde{q}}^2}{m_t^2}\right)$$

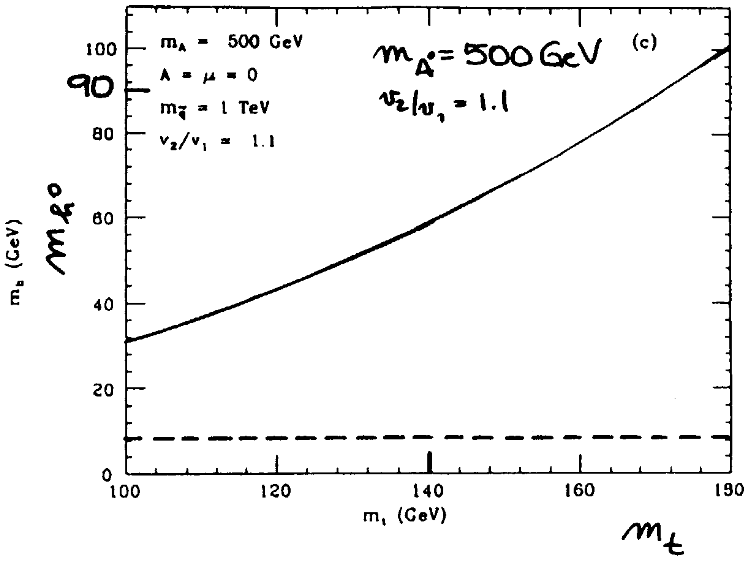
→ IN GENERAL INCREASE WITH m_t, $m_{\tilde{q}}$ INCREASE

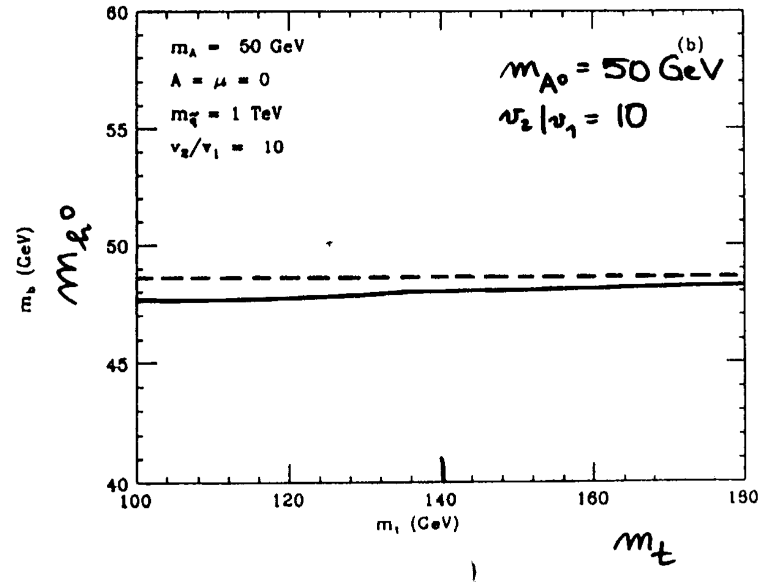
→ IMPORTANT CONSEQUENCES: $\boxed{\text{LEP200} \longleftrightarrow m_{h^0}}$

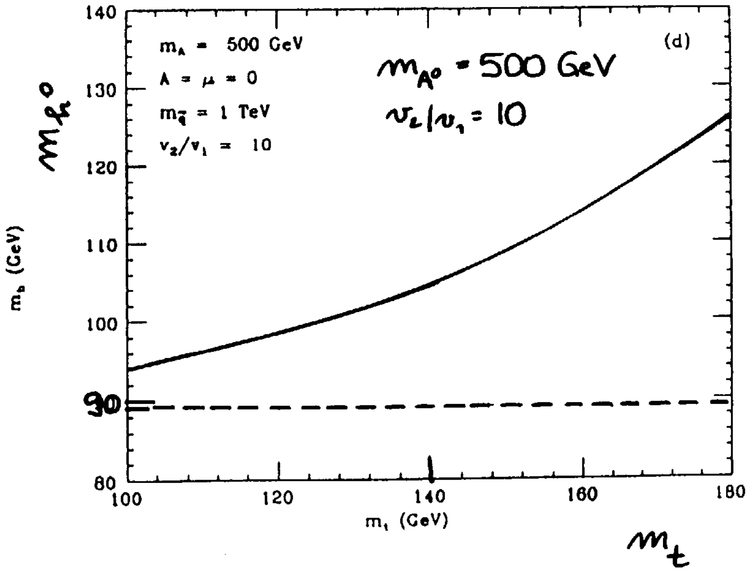
→ FREE PARAMETERS: m_{A^0}, $\tan\beta$, m_t, $(m_{\tilde{q}})$

RADIATIVE CORRECTIONS TO $\boxed{m_{h^0}}$ AS FUNCTION OF m_t , FOR $m_{\tilde{q}}$ = 1TeV:



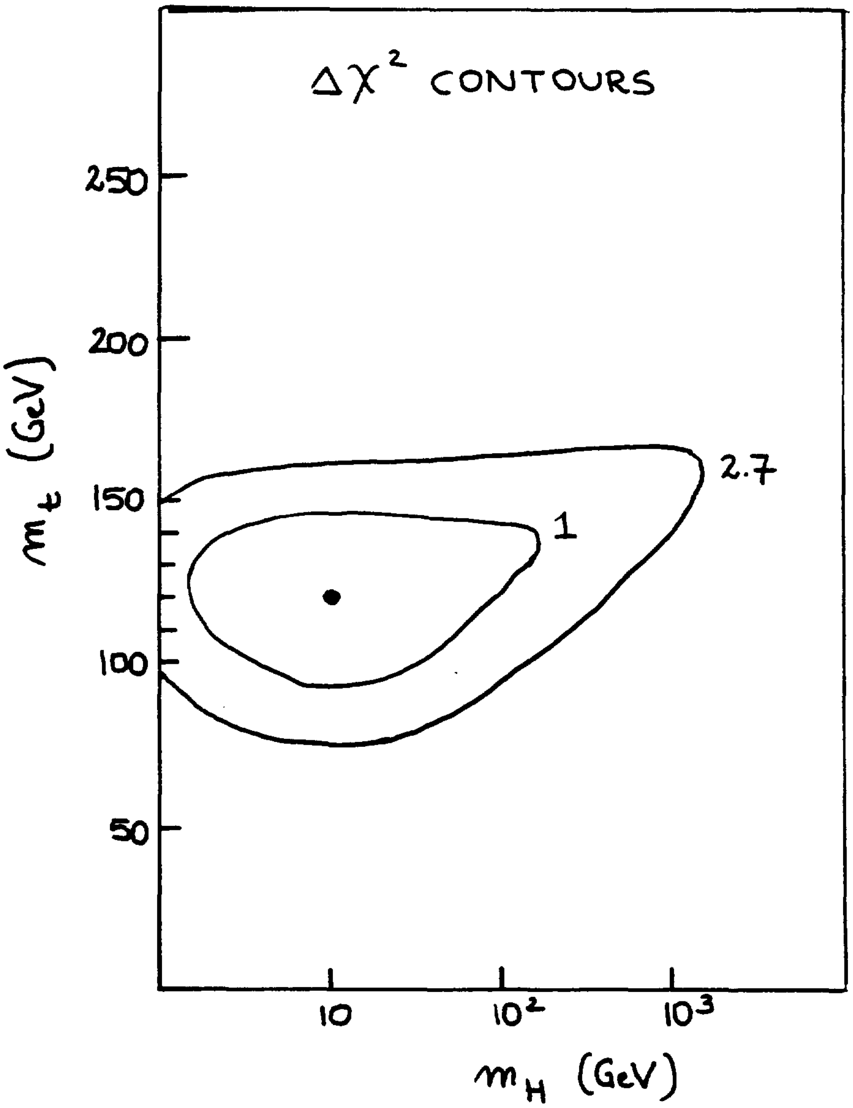






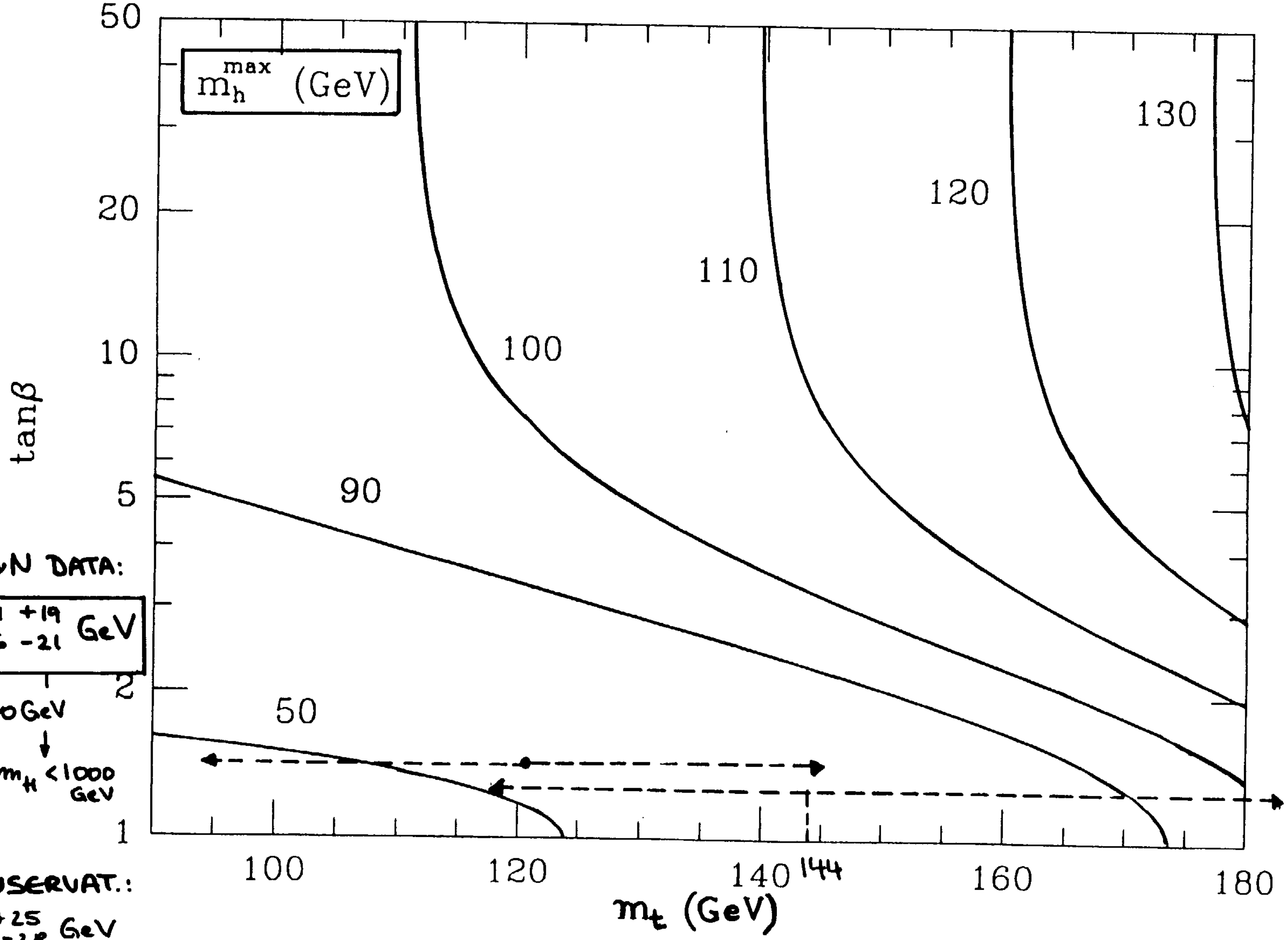
ELLIS
RIDOLFI
ZWIRNER
PHY. LETT. B257
(1991), 83

UNCONSTRAINED GLOBAL FIT USING ALL DATA



ELLIS
FOGLI
LISI

$m_{h^0}^{MAX}$ = MAX. VALUE FOR m_{h^0} REACHED FOR $m_{A^0} \to \infty$, $m_{\tilde{q}}$ = 1TeV:



KUNSZT
ZWIRNER

1σ FOR m_H = 300 GeV

--- ELLIS, FOGLI, LISI

LEP, $p\bar{p}$, νN DATA:

$$\boxed{m_t = \underbrace{144^{+39}_{-26}}_{m_H = 300\,\text{GeV}} \underset{\substack{\downarrow \\ 50 < m_H < 1000\ \text{GeV}}}{{}^{+19}_{-21}}\ \text{GeV}}$$

LESS CONSERVAT.:

$m_t = 124^{+25}_{-28}$ GeV,

$m_H = 50^{+192}_{-\dots}$: EXP. CONSTR. IMPOSED

SEE : D. SCHAILE , CERN-PPE/91-187)

SUSY HIGGS SECTOR : COUPLINGS TO FERMIONS AND VECTOR BOSONS

	$u\bar{u}$	$d\bar{d}, \ell\bar{\ell}$	WW, ZZ
h^0	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\sin(\beta-\alpha)$
H^0	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\cos(\beta-\alpha)$
A^0	$\cot\beta$	$\tan\beta$	0
	$u\bar{d}$	$\tau\nu$	$WZ, W\gamma$
$H^\pm$	$m_u \cot\beta$ $m_d \tan\beta$	$m_\tau \tan\beta$	0

} FACTOR SM-COUPLINGS HAVE TO BE MULTIPLIED WITH

WITH $\cos 2\alpha = -\cos 2\beta \left(\frac{m_{A^0}^2 - m_Z^2}{m_{H^0}^2 - m_{h^0}^2} \right)$ $\left(-\frac{\pi}{2} < \alpha < 0\right)$

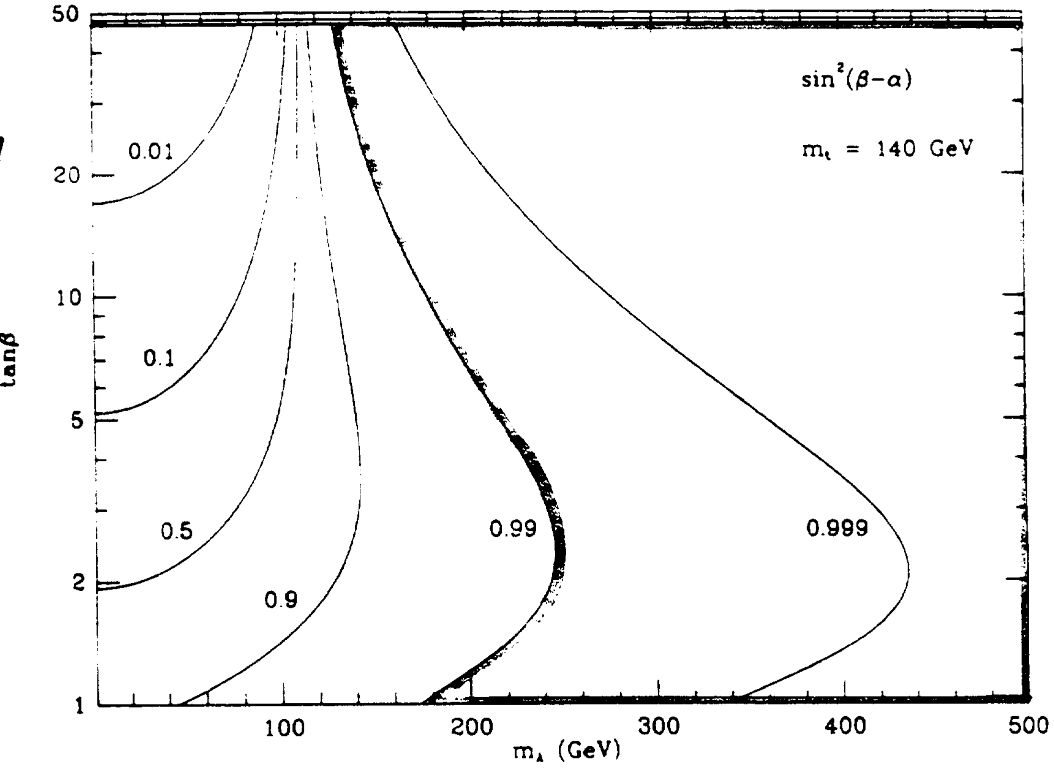
➡ STUDY GENERAL FEATURES IN $(\tan\beta - m_{A^0})$-PLANE USING $m_t = 140$ GeV, $m_{\tilde{q}} = 1$ TeV

IN AREA WHERE COUPLINGS ~ 1 : $H_{SUSY} \sim H_{SM}$

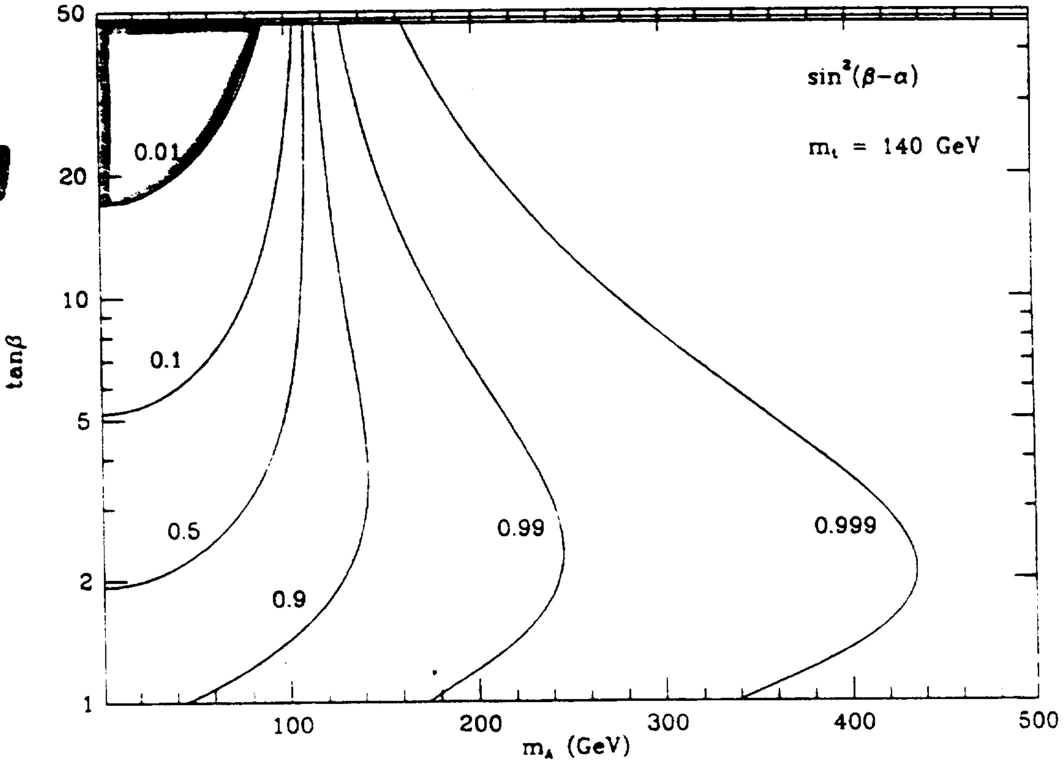
$\Longrightarrow$

CURVES FROM KUNSZT & ZWIRNER
CERN -TH. 6150/91
ETH -TH/91-7

h° VV
>0.99 ≈ ■

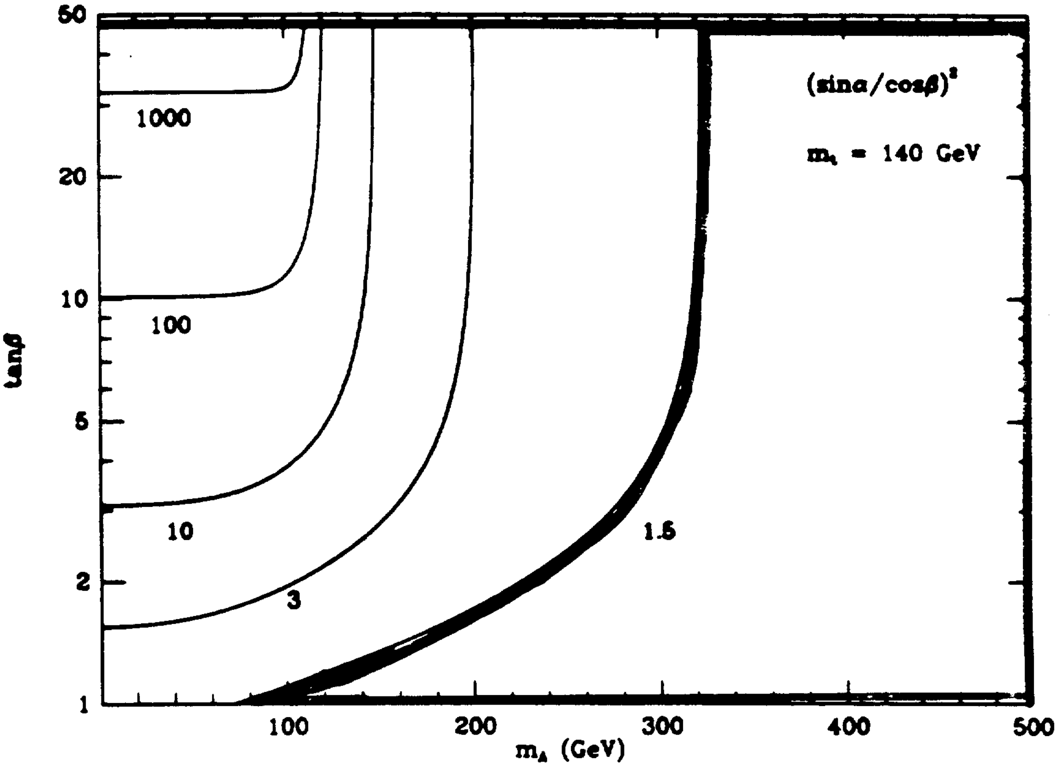


H°VV
>0.99 ≈ ■



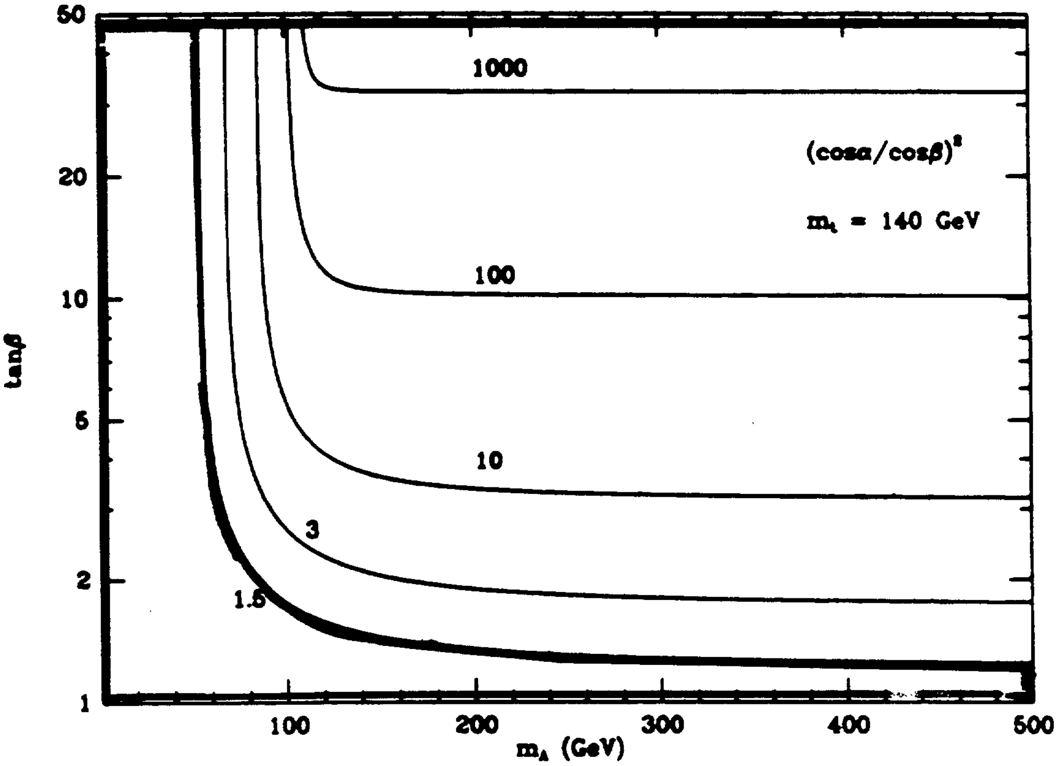
$h^0 b\bar{b}$

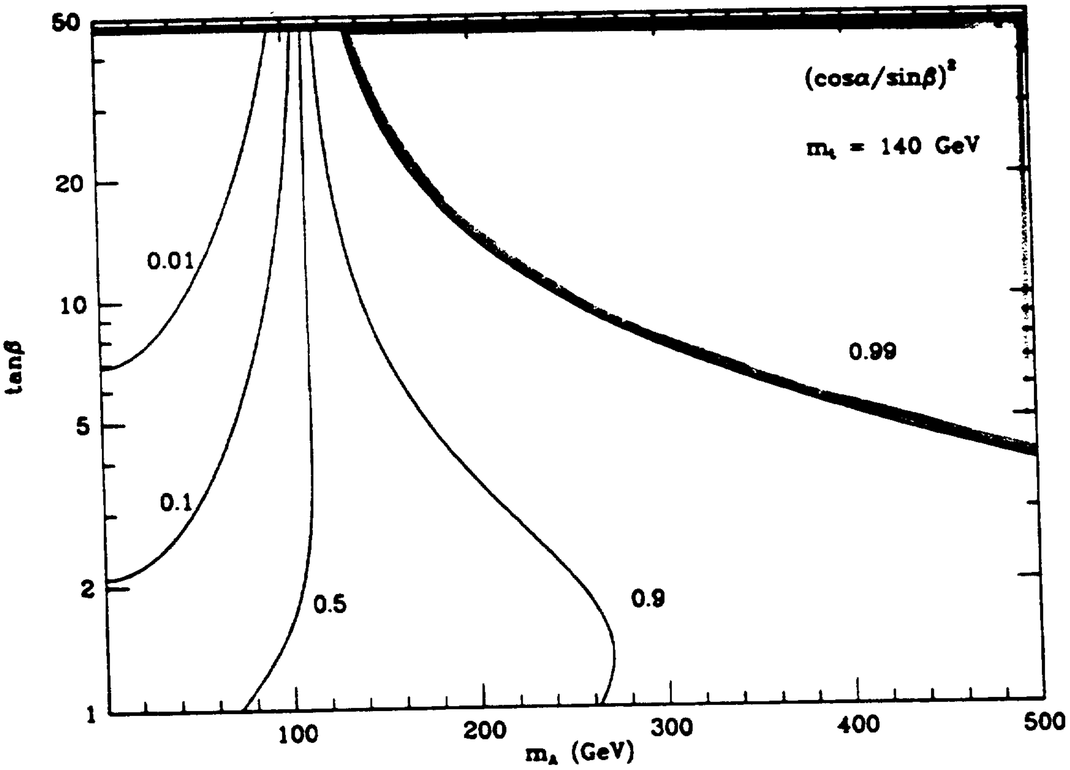
A BIT LARG. THAN SM



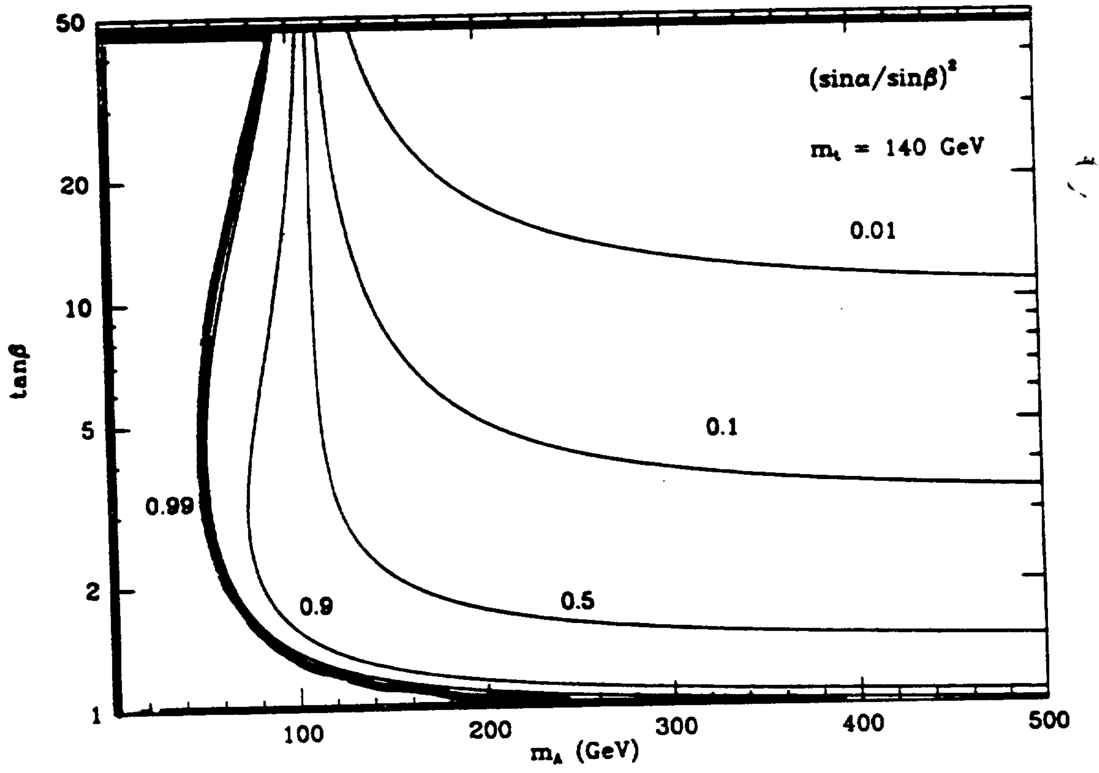
$H^0 b\bar{b}$

A BIT LARG. THAN SM

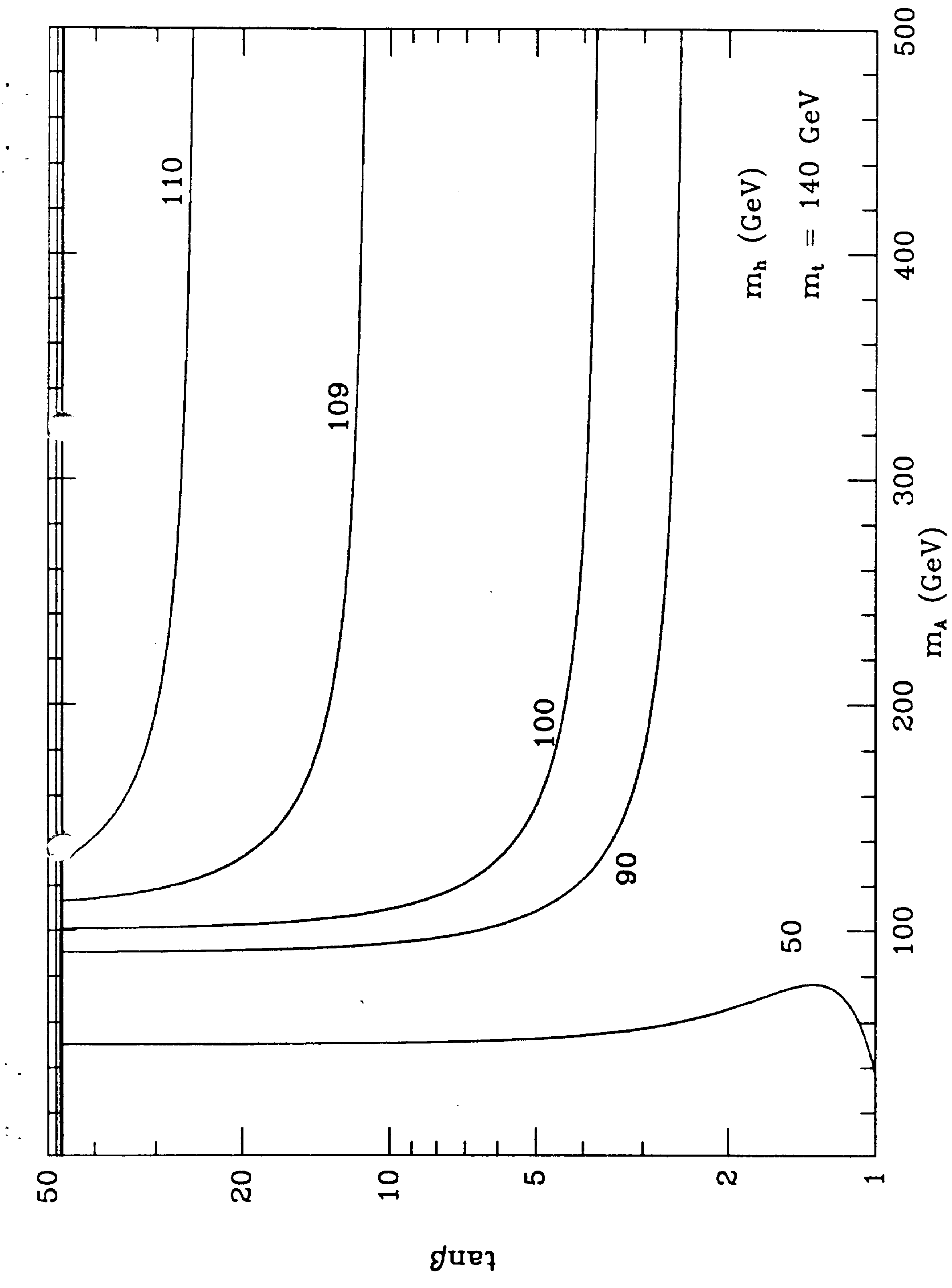


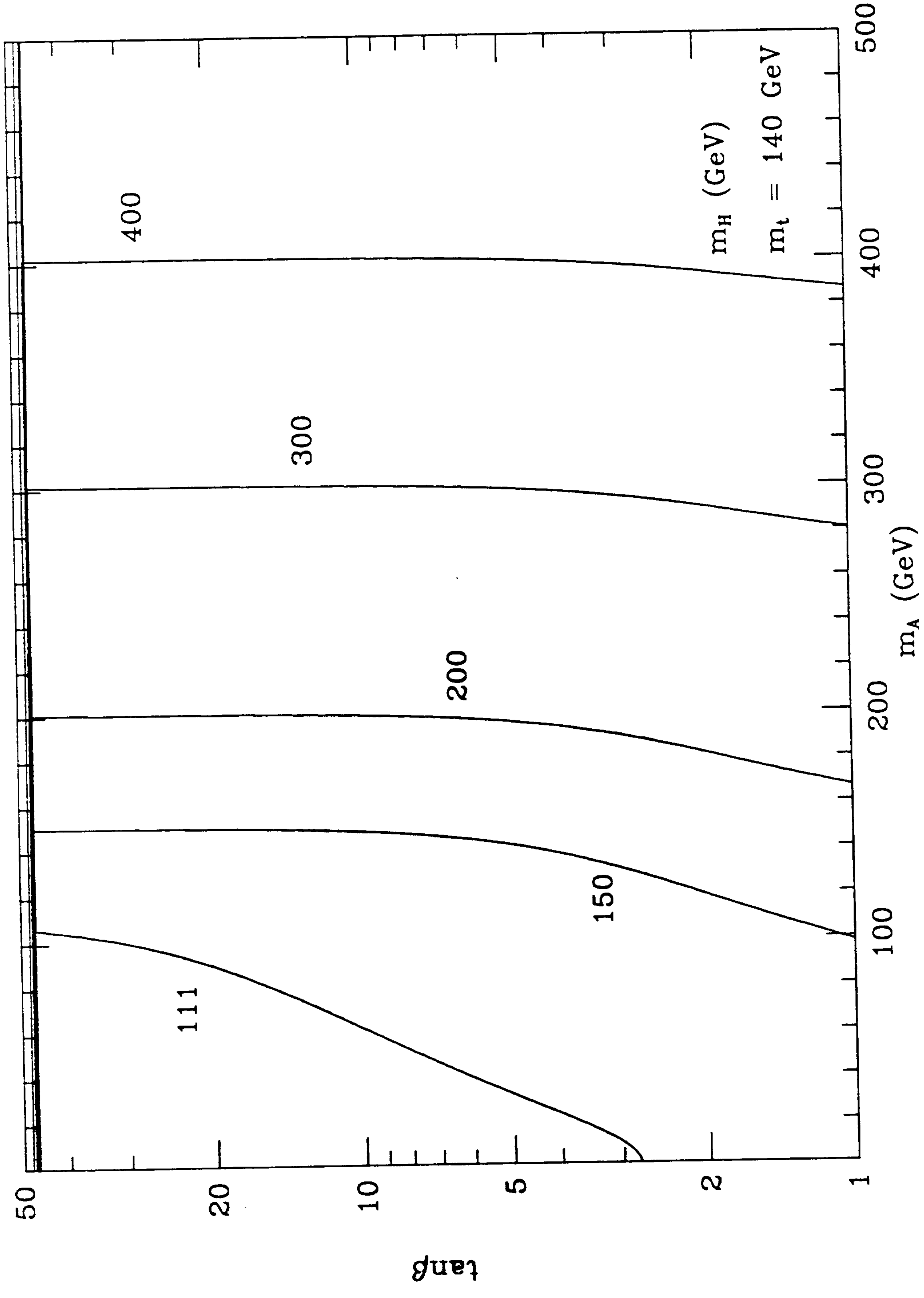


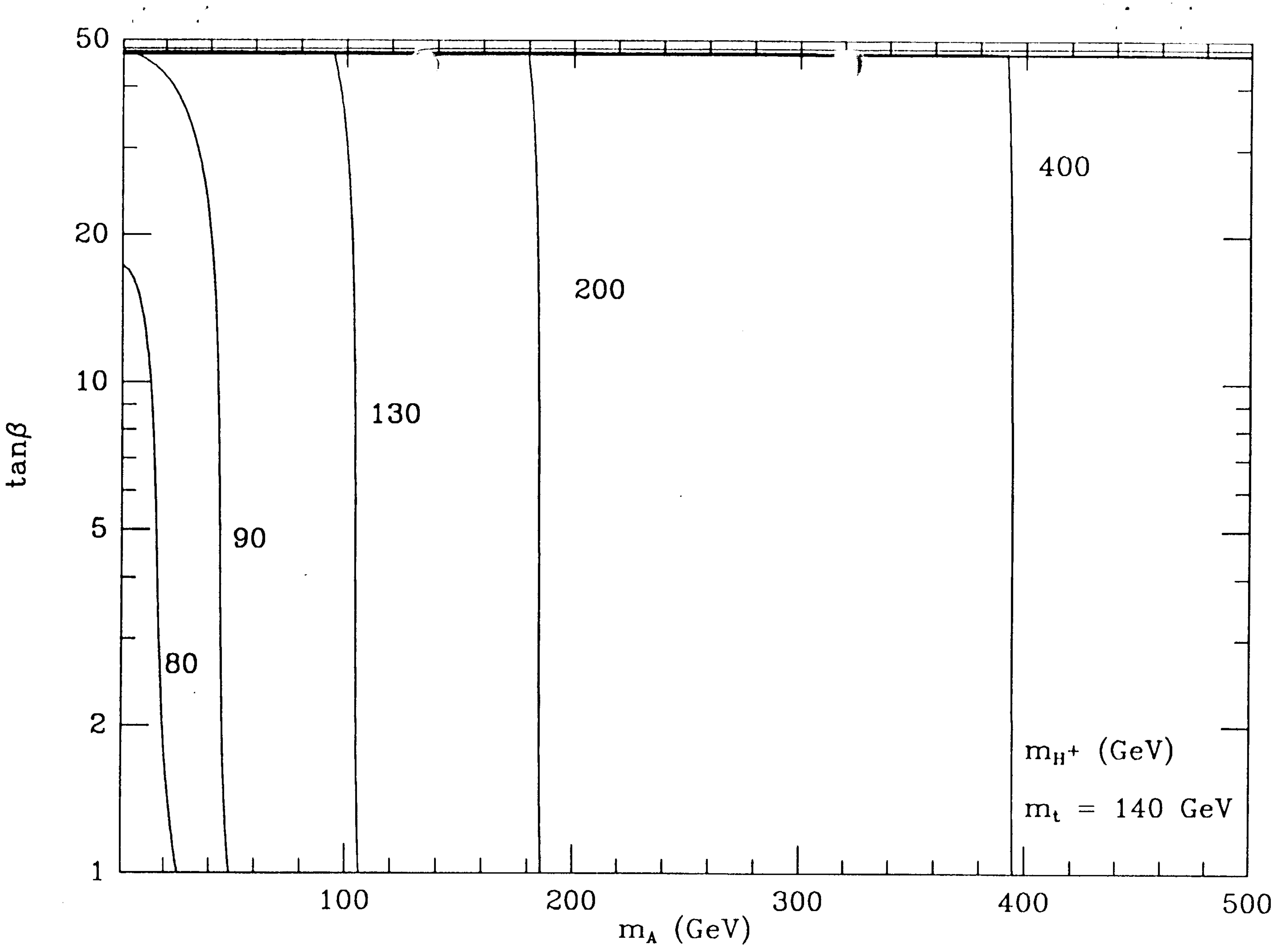
$h^o t\bar{t}$



$H^o t\bar{t}$


$\tan\beta$
50
20
10
5
2
1
100
200
300
400
500
m_A (GeV)
110
109
100
90
50
m_h (GeV)
m_t = 140 GeV


tanβ
50
20
10
5
2
1
m_A (GeV)
100
200
300
400
500
111
150
200
300
400
m_H (GeV)
m_t = 140 GeV


50
20
10
5
2
1
$\tan\beta$
100
200
300
400
500
m_A (GeV)
80
90
130
200
400
m_{H^+} (GeV)
m_t = 140 GeV

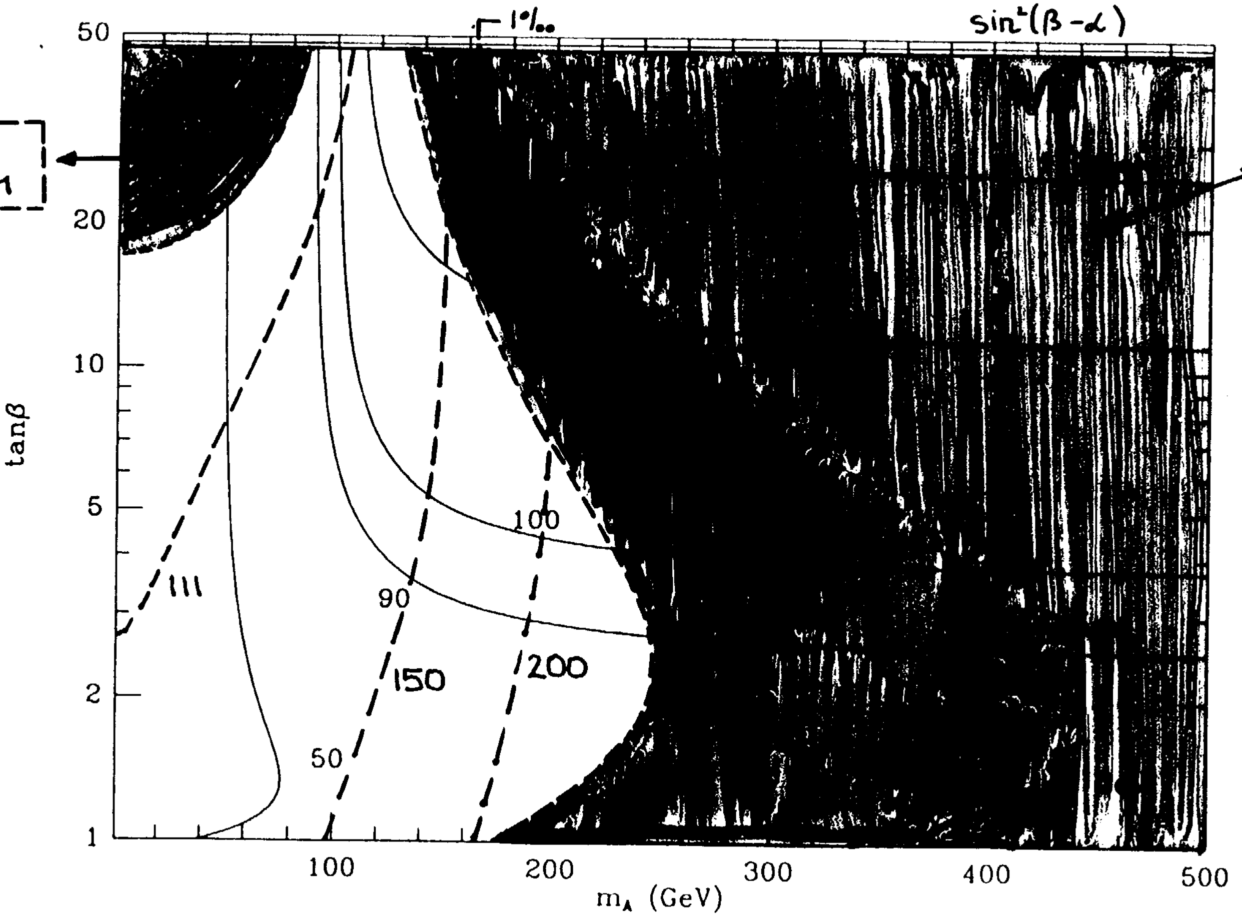
[redacted] WHERE h^0 OR H^0 LIKE SM HIGGS TO 1%

H^0 LIKE H_{SM}

$m_A < m_Z$

$\tan\beta \gg 1$

$m_{H^0} \sim 100$ GeV



h^0 LIKE H_{SM}

$m_A \gg m_Z$: $\forall \tan\beta$

$m_A > m_Z$: FOR LARGE $\tan\beta$

$m_{h^0} \sim 100$ GeV

FOR $m_A \gtrsim 200$ GeV:

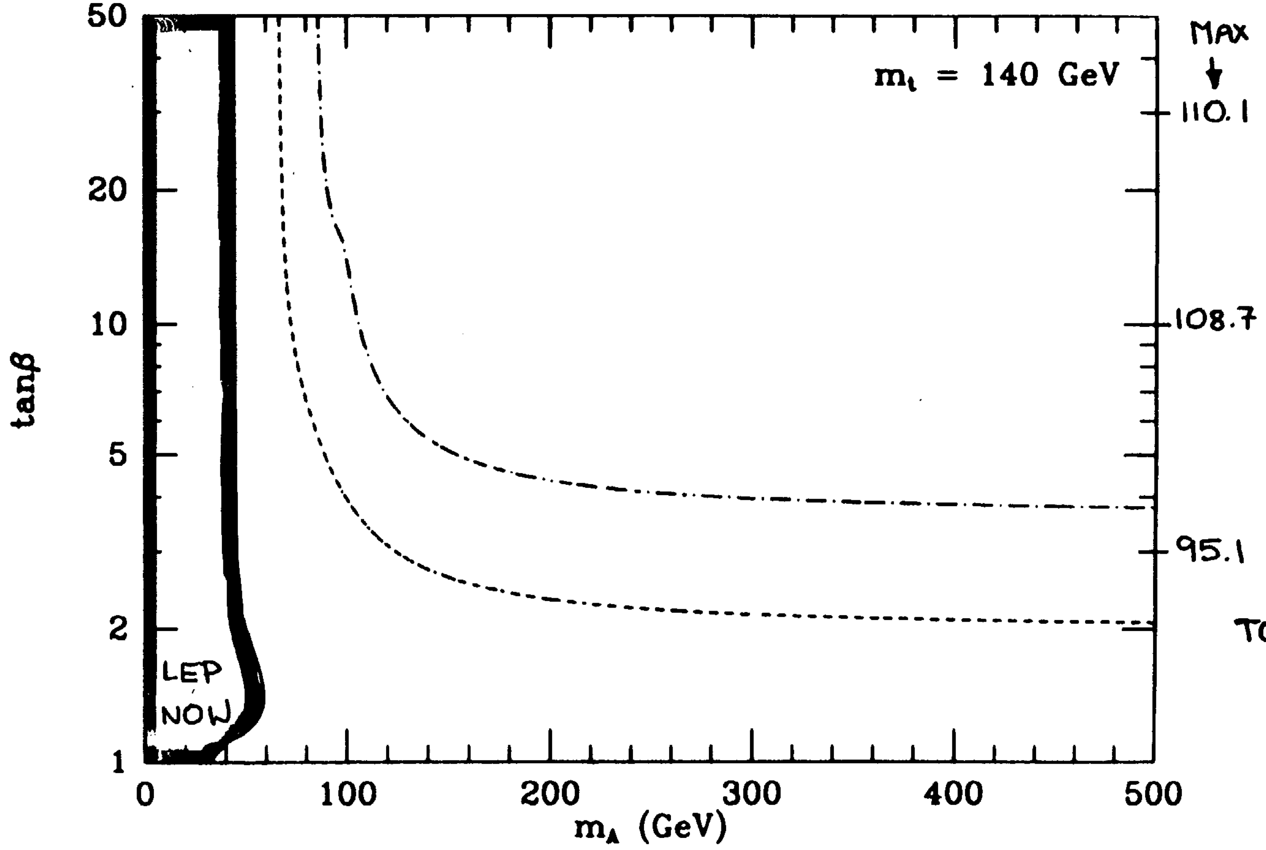
$m_A \sim m_{H^0} \sim m_{H^\pm}$

- → WHAT OF HIGGS PARAMETER SPACE CAN BE COVERED BY LEP200?
- → WHAT ARE THE POSSIBLE SIGNATURES AT THE LHC FOR h^0, H^0?

PRESENT LEP LIMITS AND FUTURE EXPECTATIONS FROM LEP200 :

--- $\sigma(e^+e^- \to hZ, HZ, hA, HA) = 0.2\ \text{pb}$ AT $\sqrt{s} = 175\ \text{GeV}$

-·-· $= 0.05\ \text{pb}$ AT $\sqrt{s} = 190\ \text{GeV}$

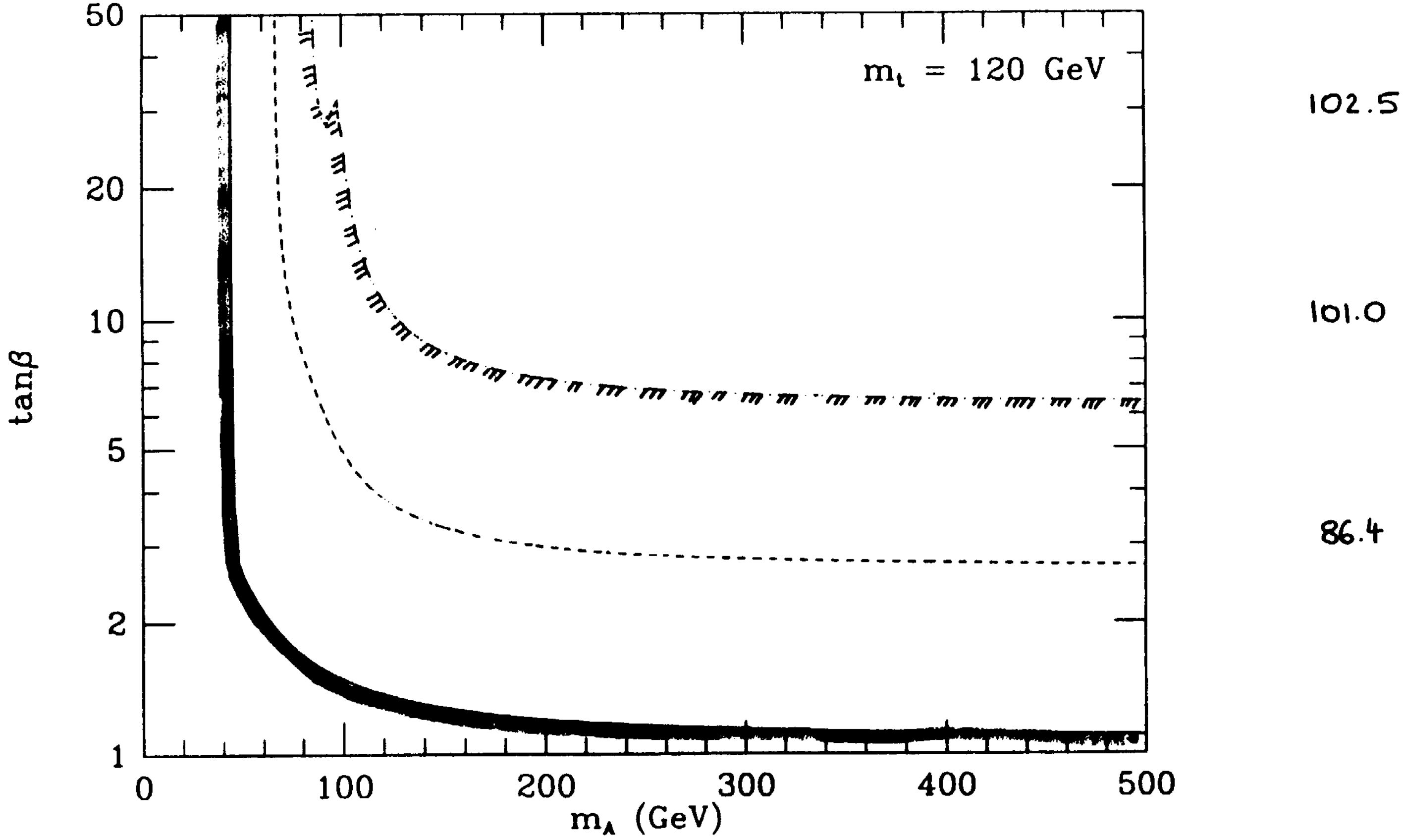


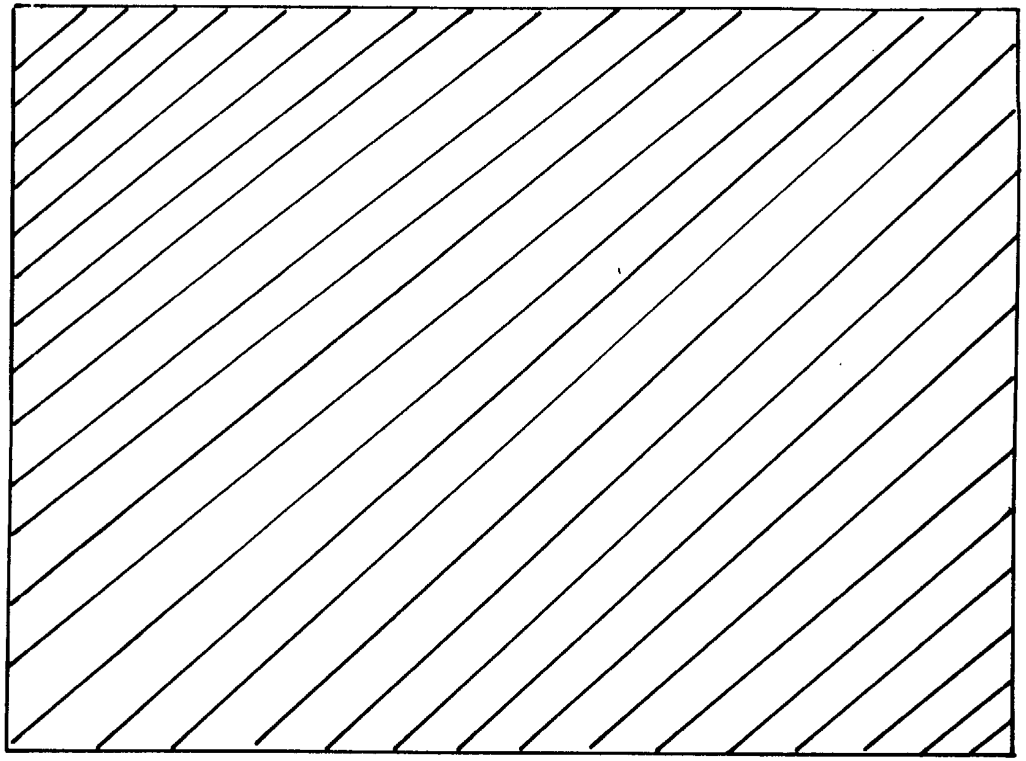
MAX m_{h^0} FOR $m_{A^0} = 500\ \text{GeV}$, $m_{\tilde{q}} = 1\ \text{TeV}$

TO REACH $m_{h^0}^{MAX}$ NEED:

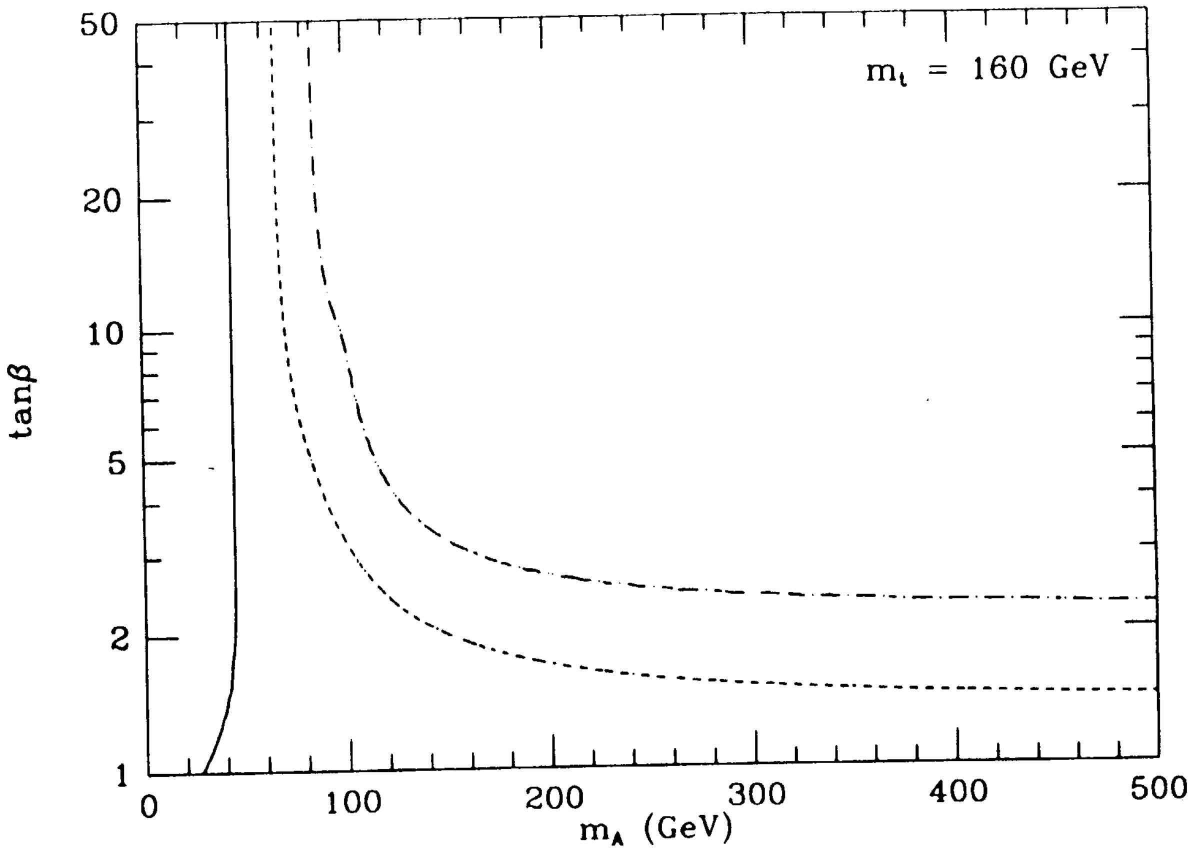
$$\sqrt{s} \approx \underbrace{m_Z + 10\ \text{GeV}}_{100\ \text{GeV}} + m_{h^0}$$

THRESHOLD EFFECT !


m_t = 120 GeV
tanβ
50
20
10
5
2
1
0
100
200
300
400
500
m_A (GeV)
102.5
101.0
86.4



▨ $m_t = 120$ GeV, $\sqrt{s} \simeq 200$ GeV } DISCOVERY (EXCLUSION) REGION

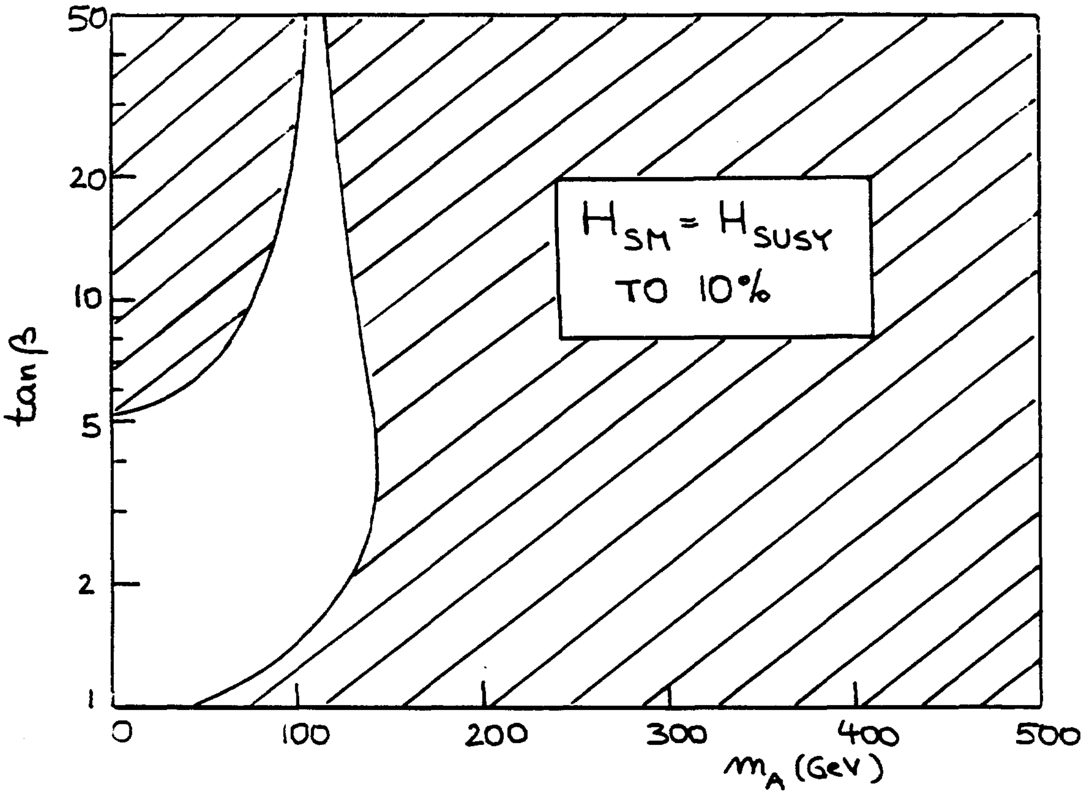


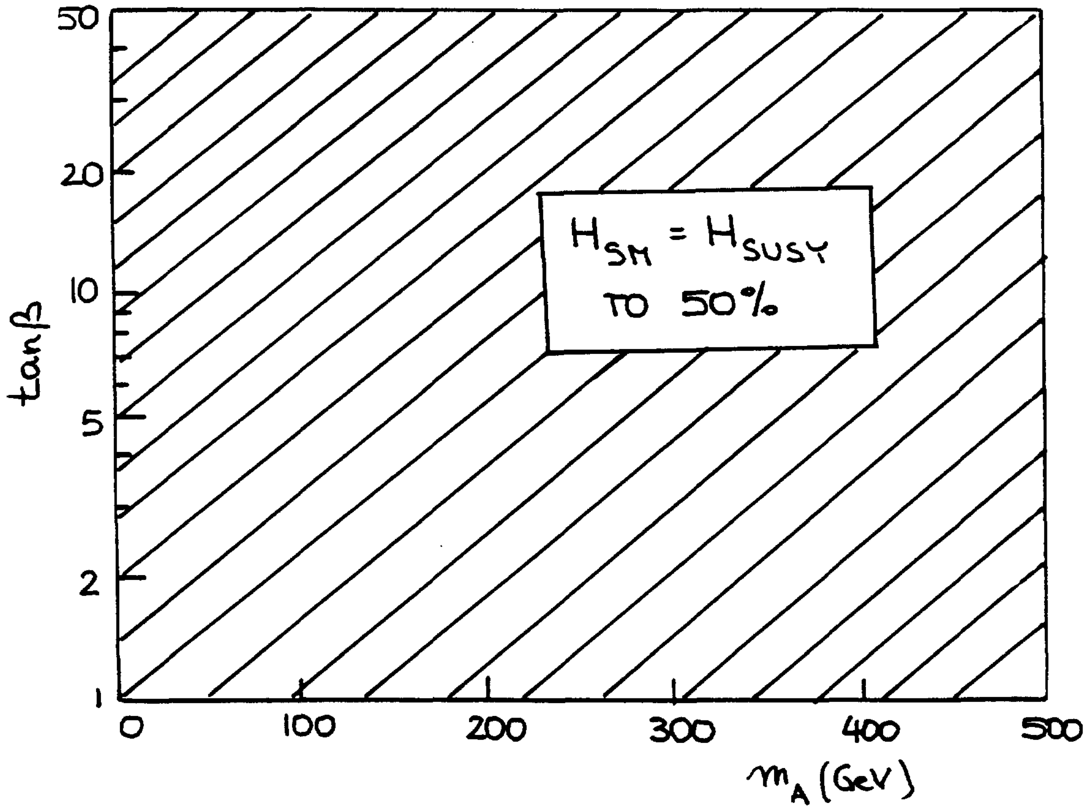
120.0

118.7

106.3

AREA WHERE $H_{SM} = H_{SUSY}$ DEPENDS ON EXPERIMENTAL ACCURACY OF THE CROSS SECTION MEASUREMENT AT LEP :

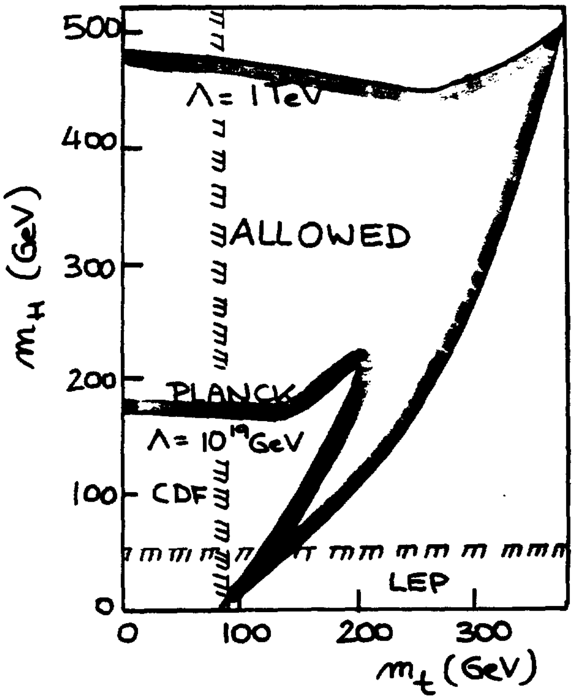




HOW LIKELY IS A HIGGS OF ~100 GeV ?

STANDARD MODEL: HIGGS CANNOT BE TOO HEAVY:

LINDNER



Λ : SCALE WHERE
PERTURB. THEORY
BREAKS DOWN

SUPERSYMMETRY: AT LEAST ONE HIGGS ($\equiv h^0$)
HAS TO BE IN THE 100 GeV
MASS RANGE

IF HIGGS FOUND AT LEP : FOR $H = H_{SUSY}$ NEED LHC TO FIND
OTHER HIGGS BOSONS

→ HOW TO DISCOVER SUSY-HIGGS BOSONS AT LHC ?

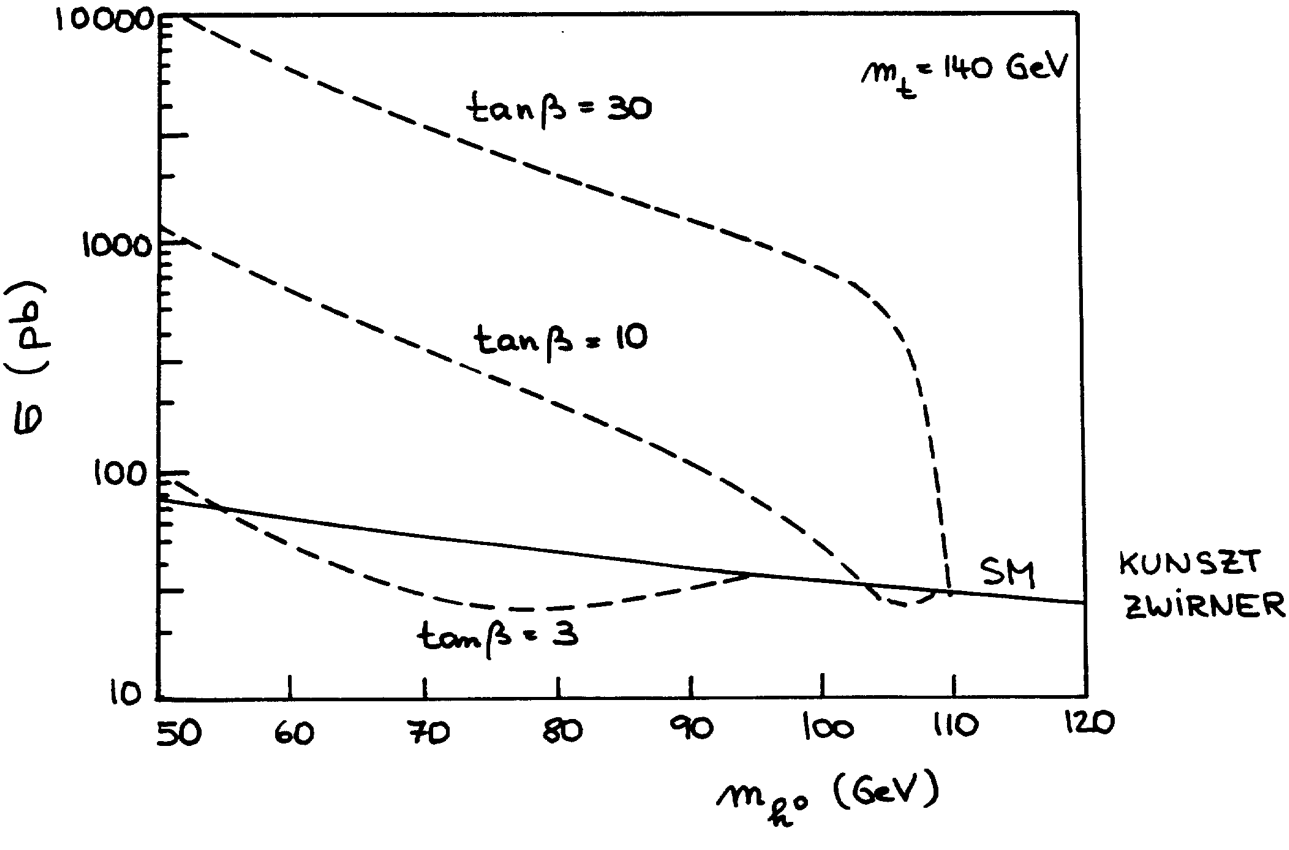
→ CAN ONE RULE OUT THE MSSM AT THE LHC VIA THE HIGGS SECTOR ?

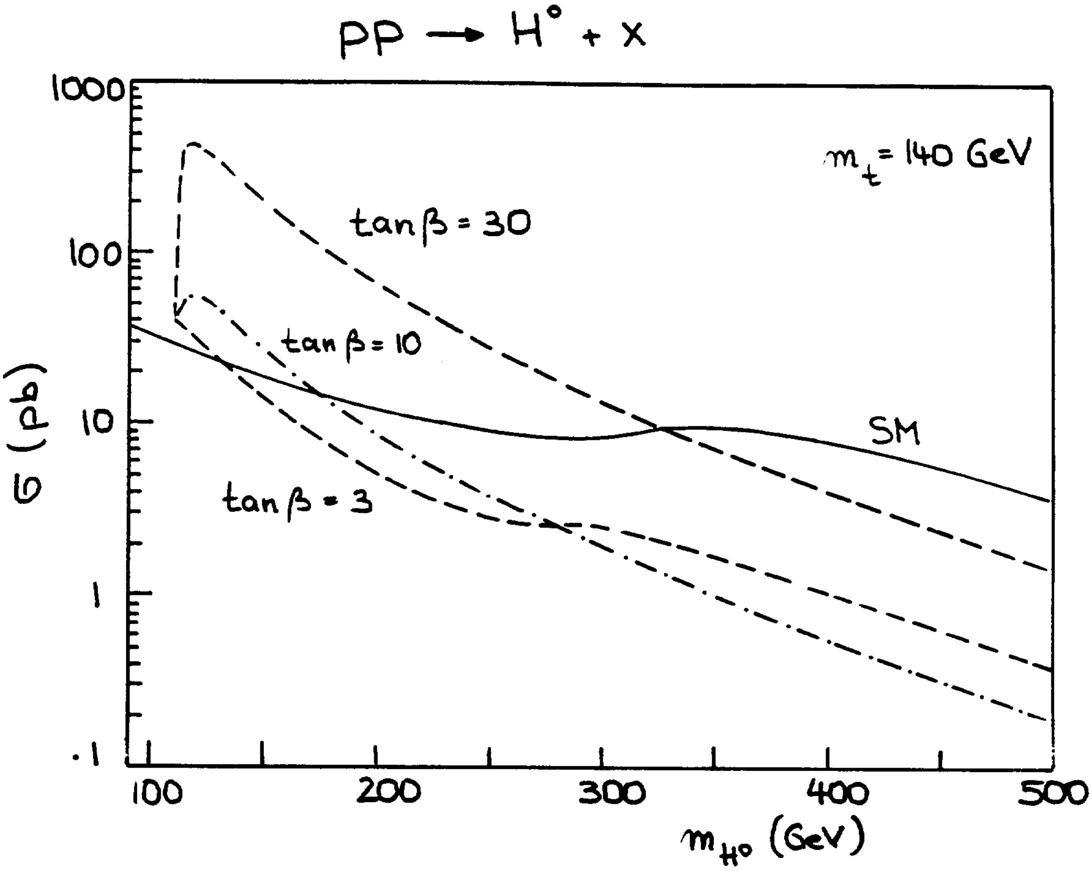
PRODUCTION CROSS SECTIONS FOR $h^\circ, H^\circ, A^\circ$

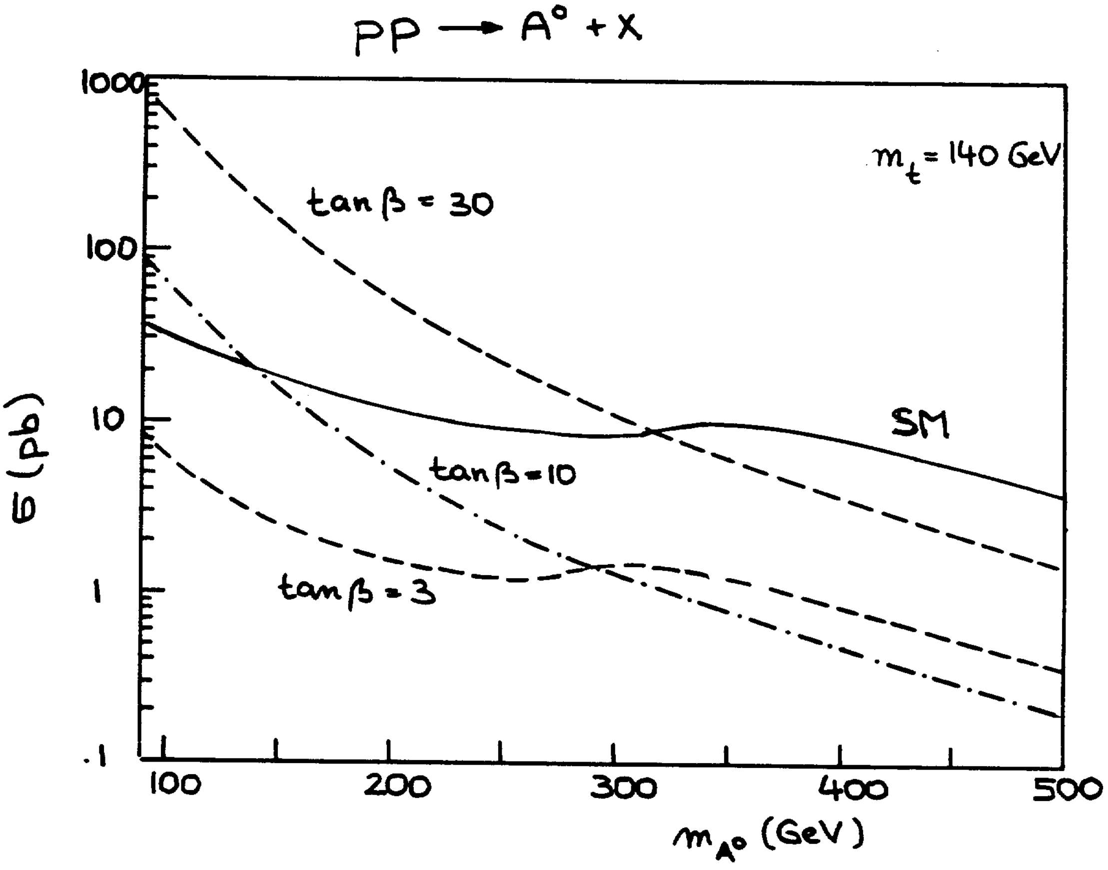
PRODUCTION MECHANISM:

- gg FUSION
- ASSOCIATE PRODUCTION: $Hb\bar{b}$
  LARGE CONTRIBUTION FOR
  SMALL HIGGS MASSES

$pp \rightarrow h^\circ + X$: $\sqrt{s} = 16$ TeV



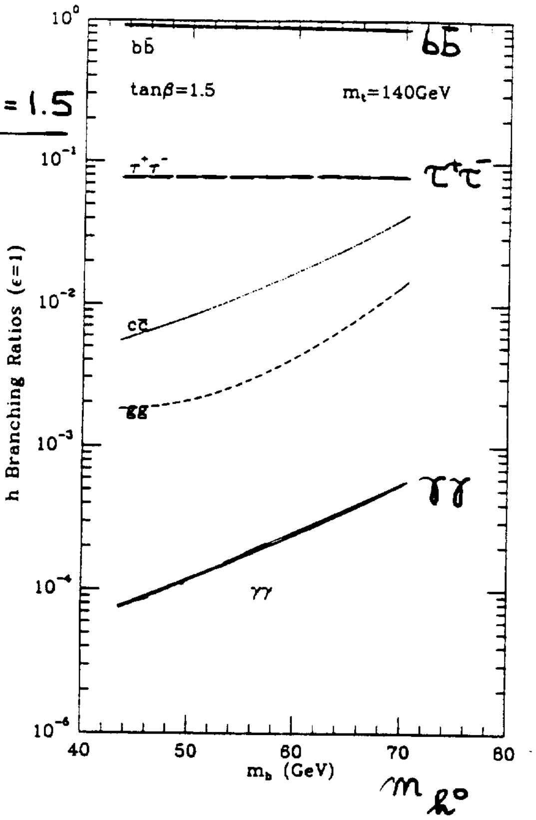

PP → H° + X
m_t = 140 GeV
tanβ = 30
tanβ = 10
tanβ = 3
SM
σ (pb)
1000
100
10
1
.1
100
200
300
400
500
m_H° (GeV)


PP → A° + X
m_t = 140 GeV
tanβ = 30
tanβ = 10
tanβ = 3
SM
σ (pb)
1000
100
10
1
.1
100
200
300
400
500
m_A° (GeV)

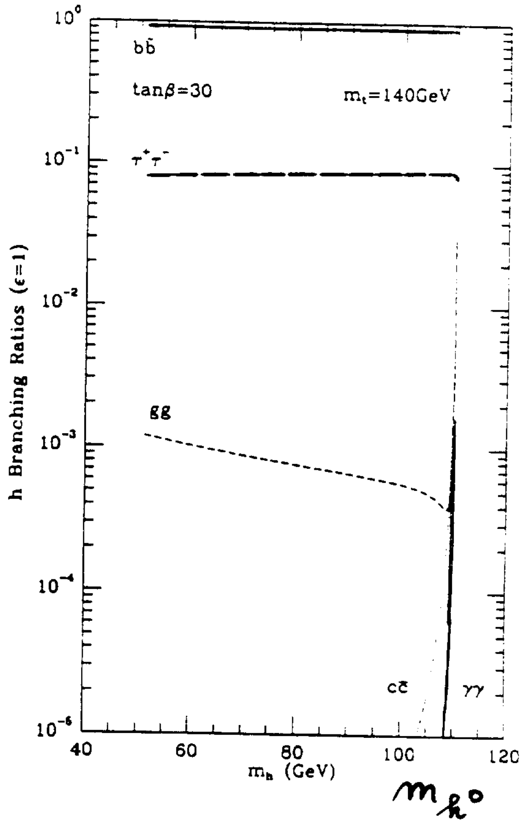
MSSM : BRANCHING RATIOS OF h^0

FOR $m_t = 140$ GeV

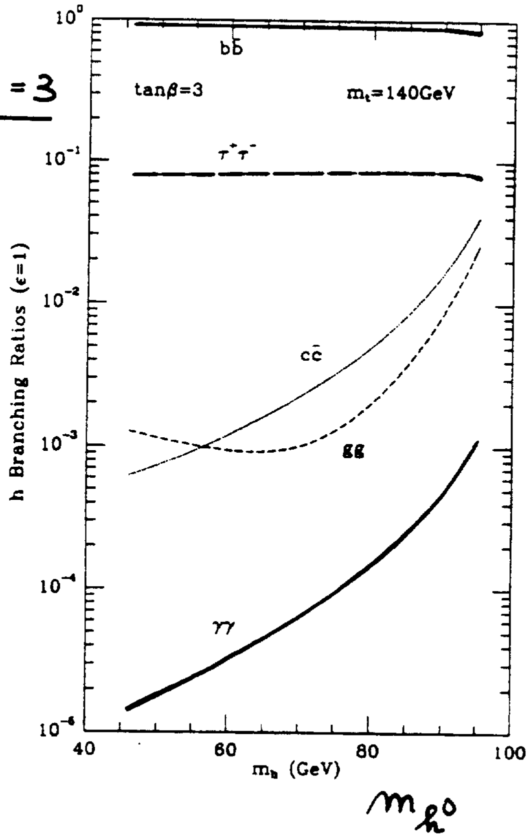
tanβ = 1.5



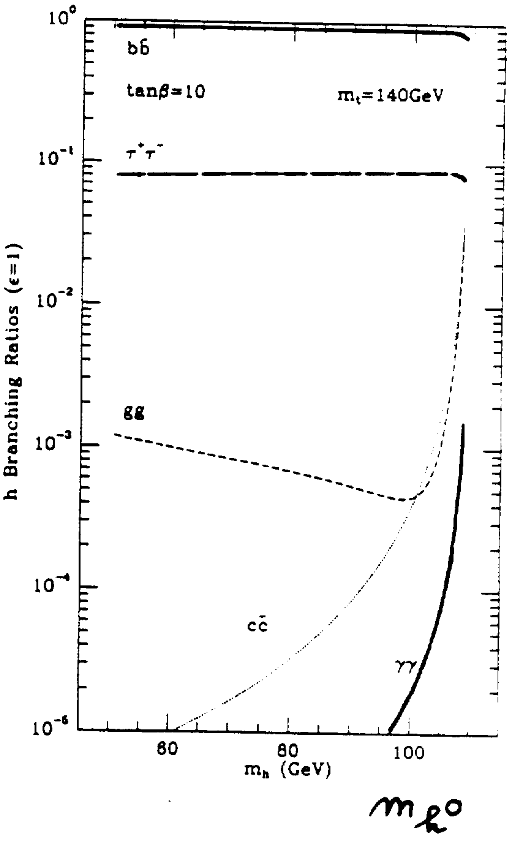
tanβ = 30



tanβ = 3



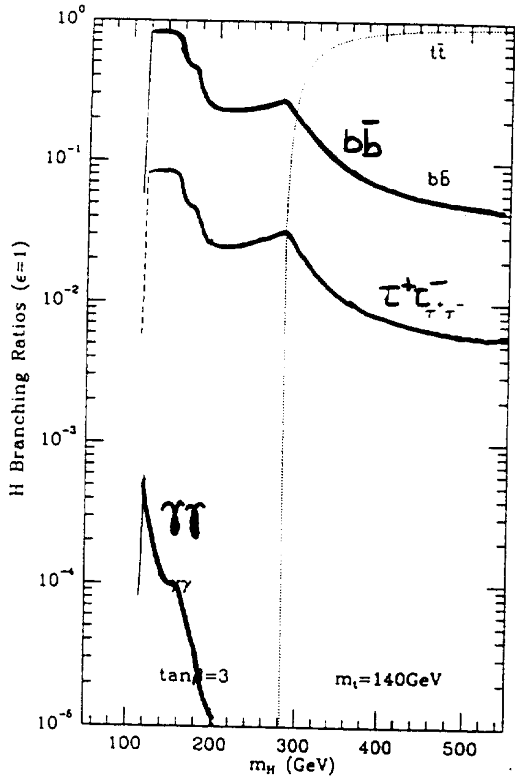
tanβ = 10

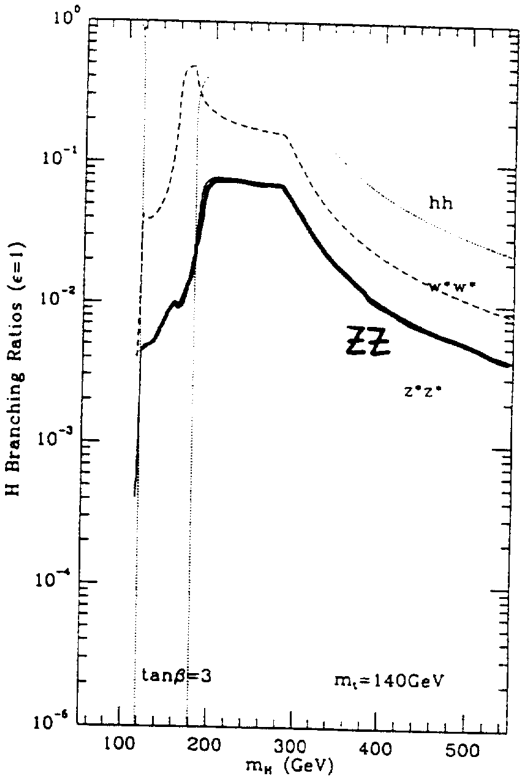


KUNSZT
ZWIRNER
ETH -TH/91-7

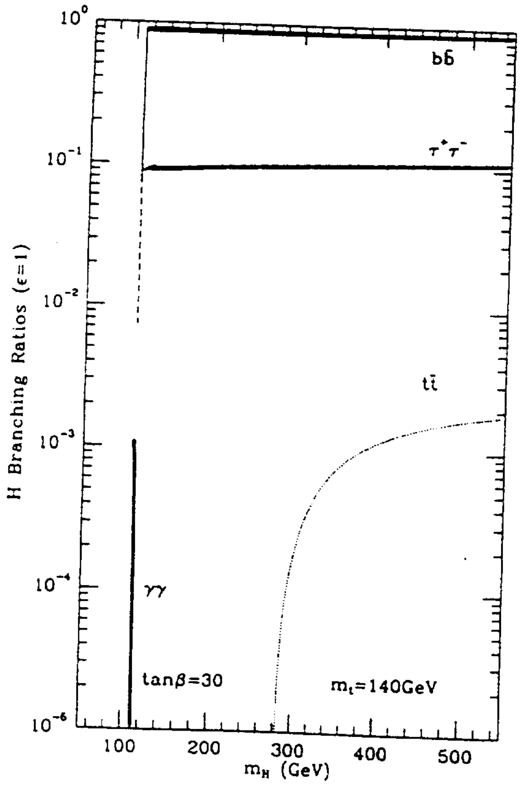
MSSM : BRANCHING RATIOS OF H^0

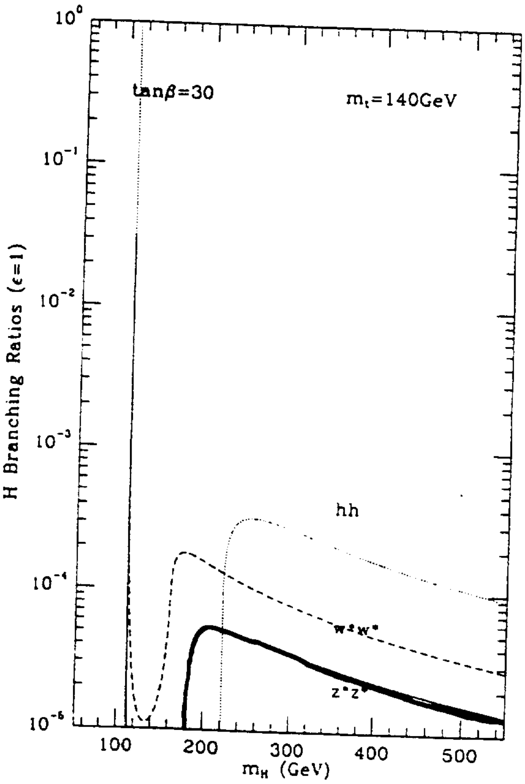
FOR $m_t = 140$ GeV





$\tan\beta = 3$



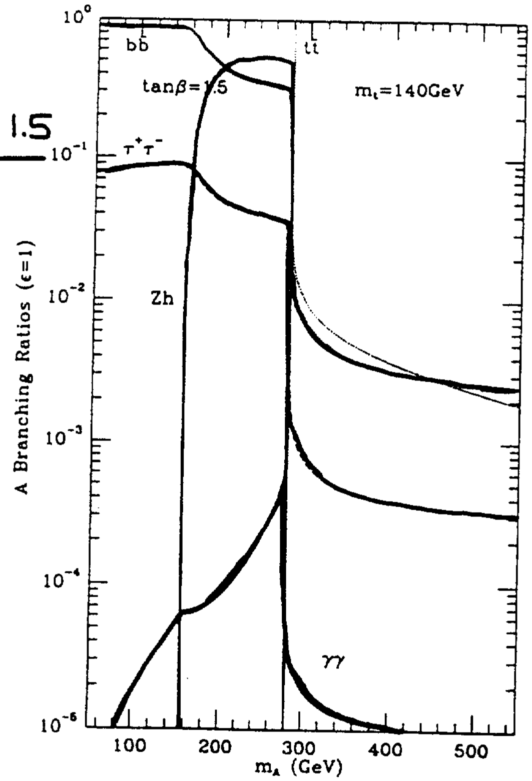


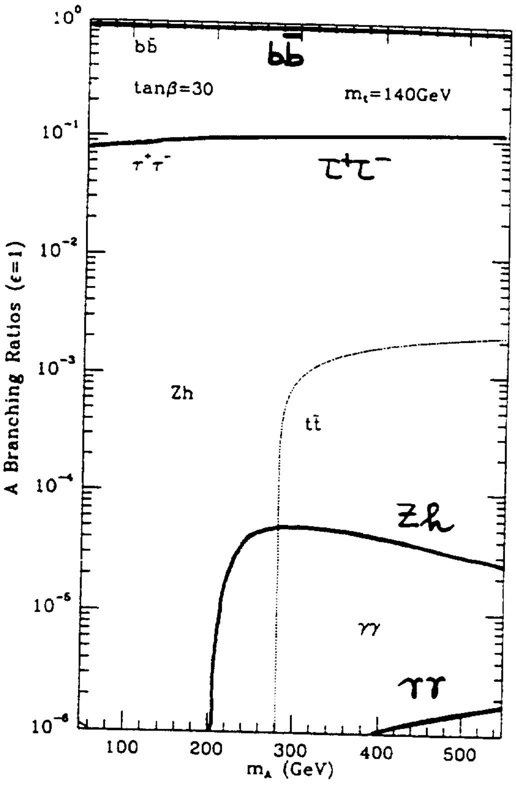
$\tan\beta = 30$

MSSM: BRANCHING RATIOS OF A°

FOR m_t = 140 GeV

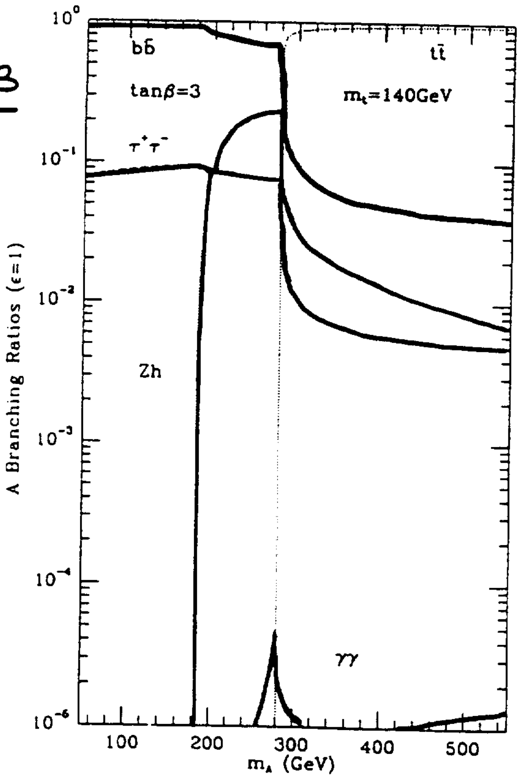
$\tan\beta = 1.5$

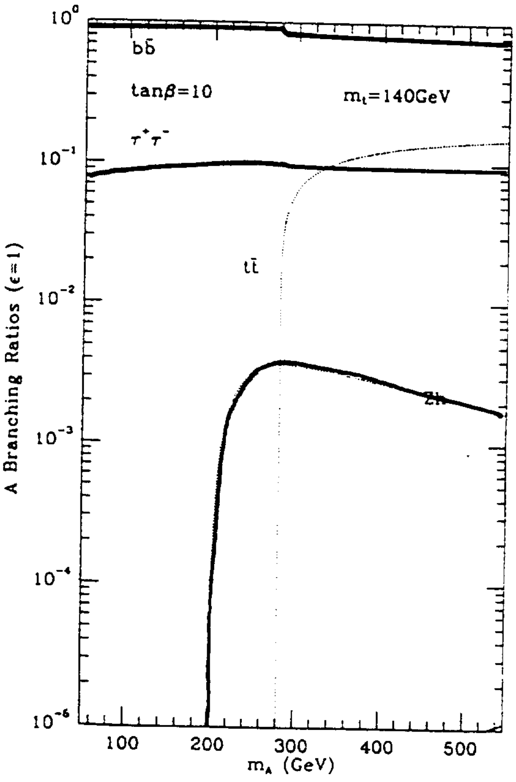




$\tan\beta = 30$

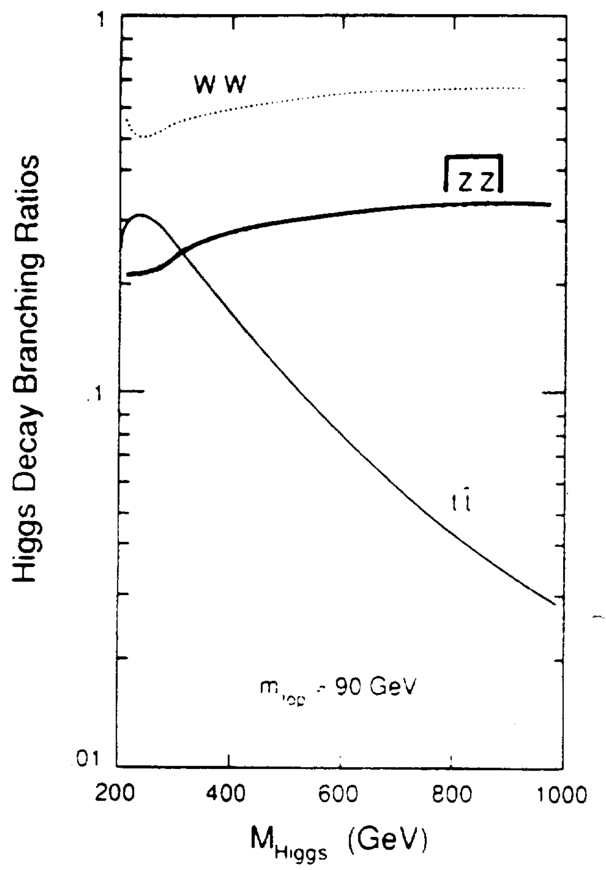
an$\beta = 3$

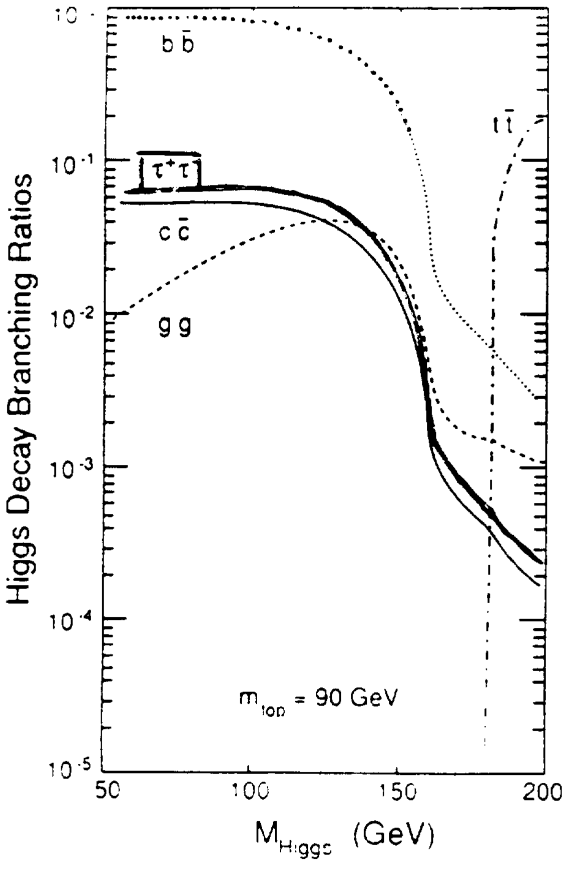


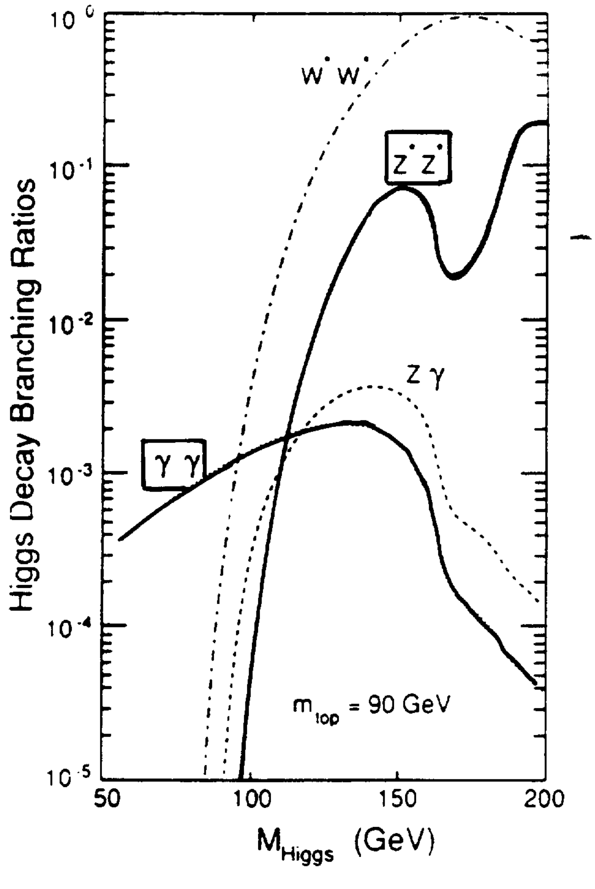


$\tan\beta = 10$

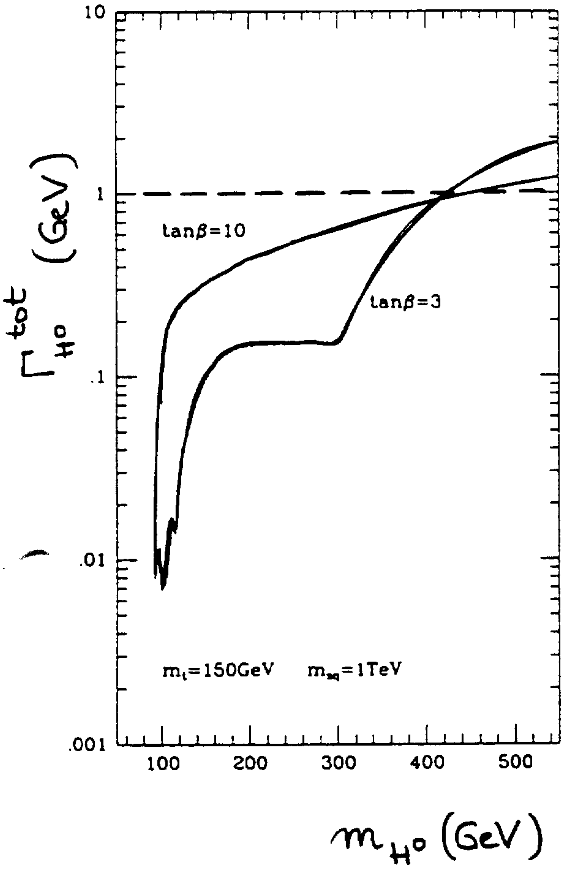
SM - HiGGS


Higgs Decay Branching Ratios
1
.1
01
W W
Z Z
t t̄
m_top = 90 GeV
200
400
600
800
1000
M_Higgs (GeV)

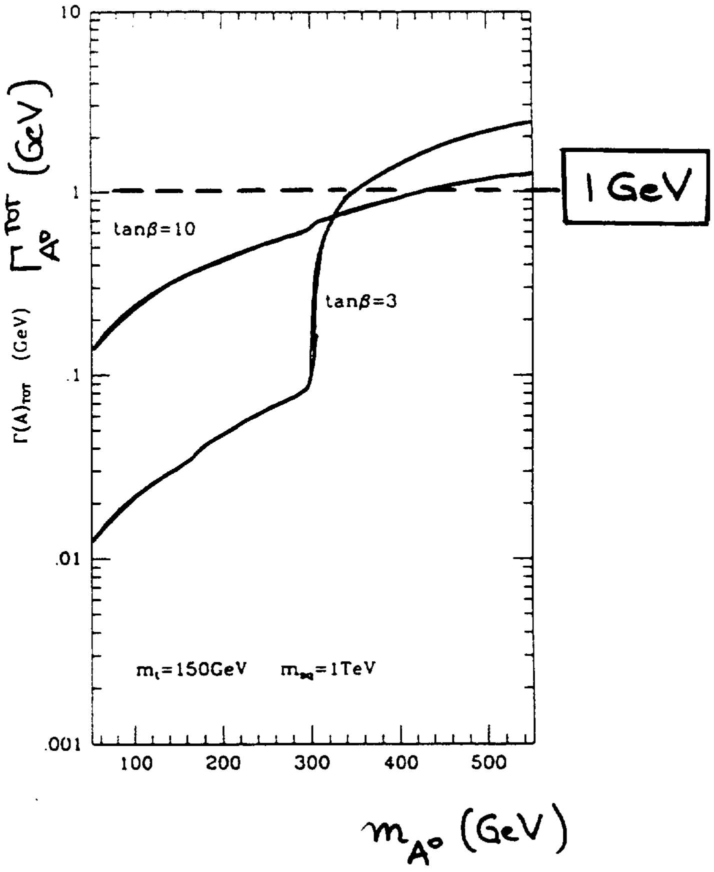

Higgs Decay Branching Ratios
10
10^-1
10^-2
10^-3
10^-4
10^-5
b b̄
τ⁺τ⁻
c c̄
g g
t t̄
m_top = 90 GeV
50
100
150
200
M_Higgs (GeV)


Higgs Decay Branching Ratios
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
W*W*
Z*Z*
Z γ
γ γ
m_top = 90 GeV
50
100
150
200
M_Higgs (GeV)

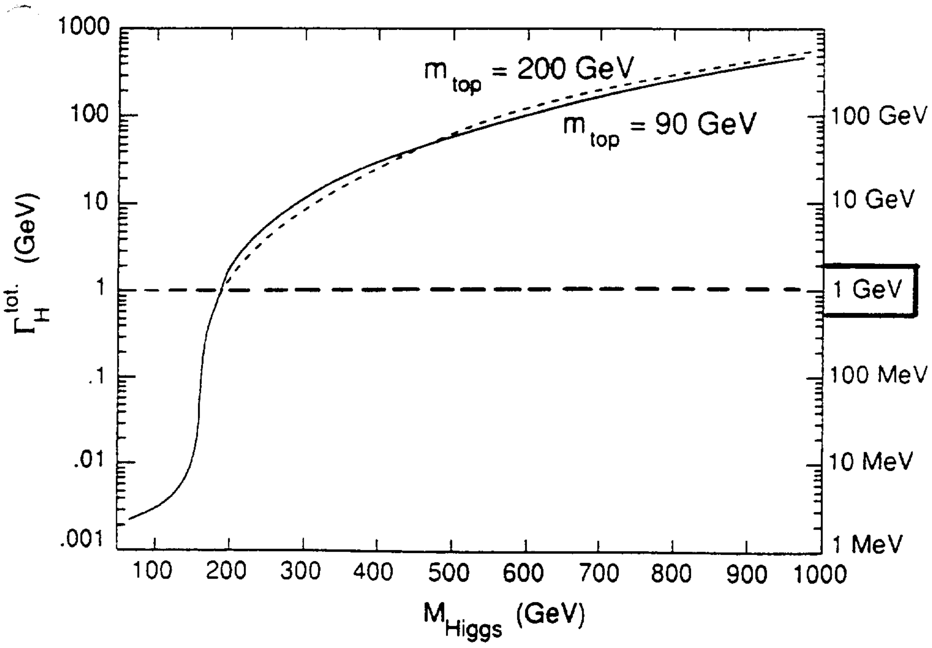
WIDTH OF H°

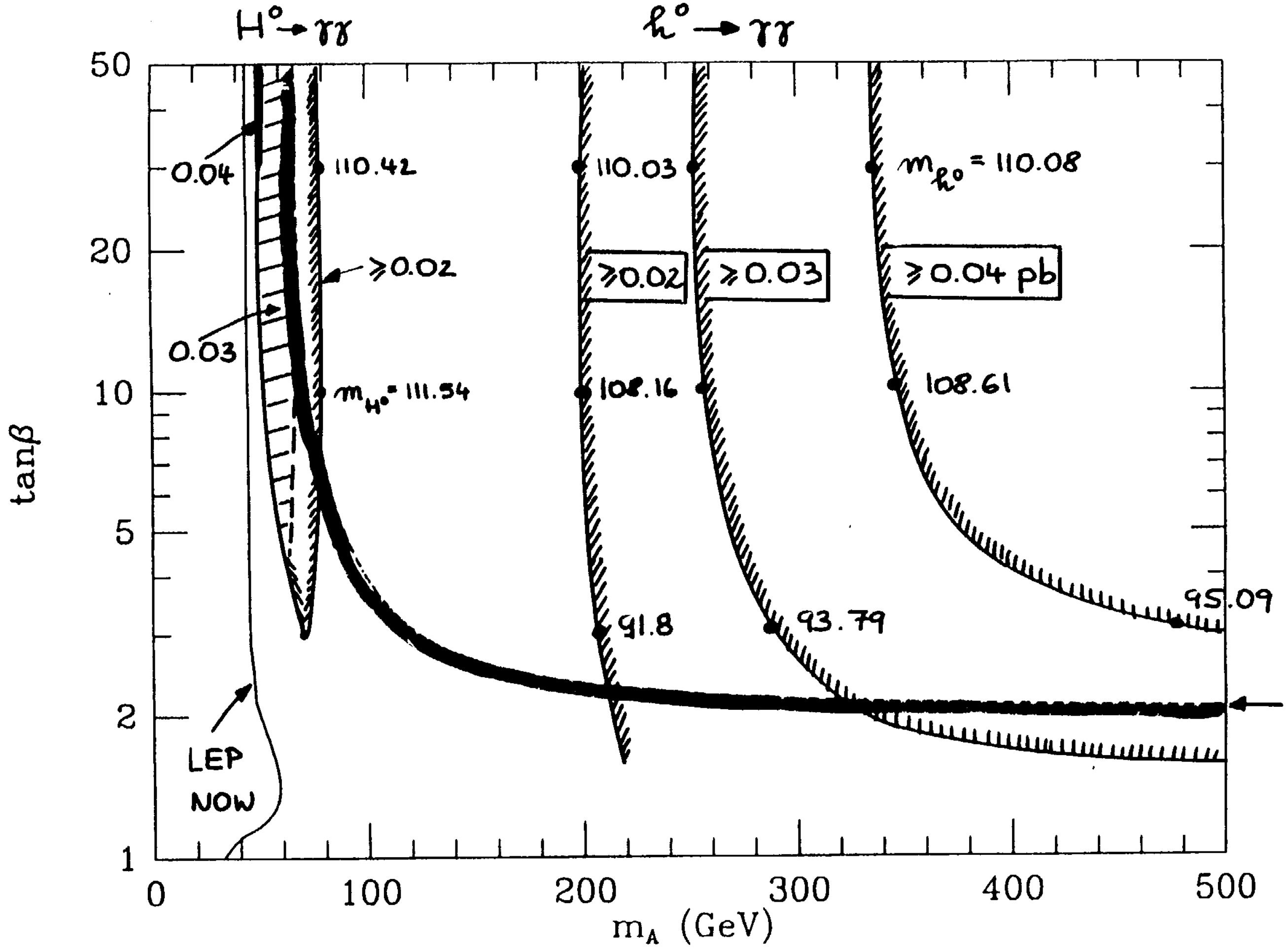


WIDTH OF A°



WIDTH OF SM HIGGS





σ * BR CONTOURS
FOR
$m_t = 140\,\mathrm{GeV}$, $m_{\tilde{q}} = 1\,\mathrm{TeV}$

(ESTIMATES)

$h^0 \to \gamma\gamma$
$H^0 \to \gamma\gamma$

← LEP : $E_{cm} = 175$ GeV
$\sigma = 0.2$ pb

<u>SM HIGGS</u> : $m_H = 100$ GeV
$\sigma \cdot BR\,(H \to \gamma\gamma) = 0.055$ pb (g- AND W - FUSION)
↳ ~ 20%

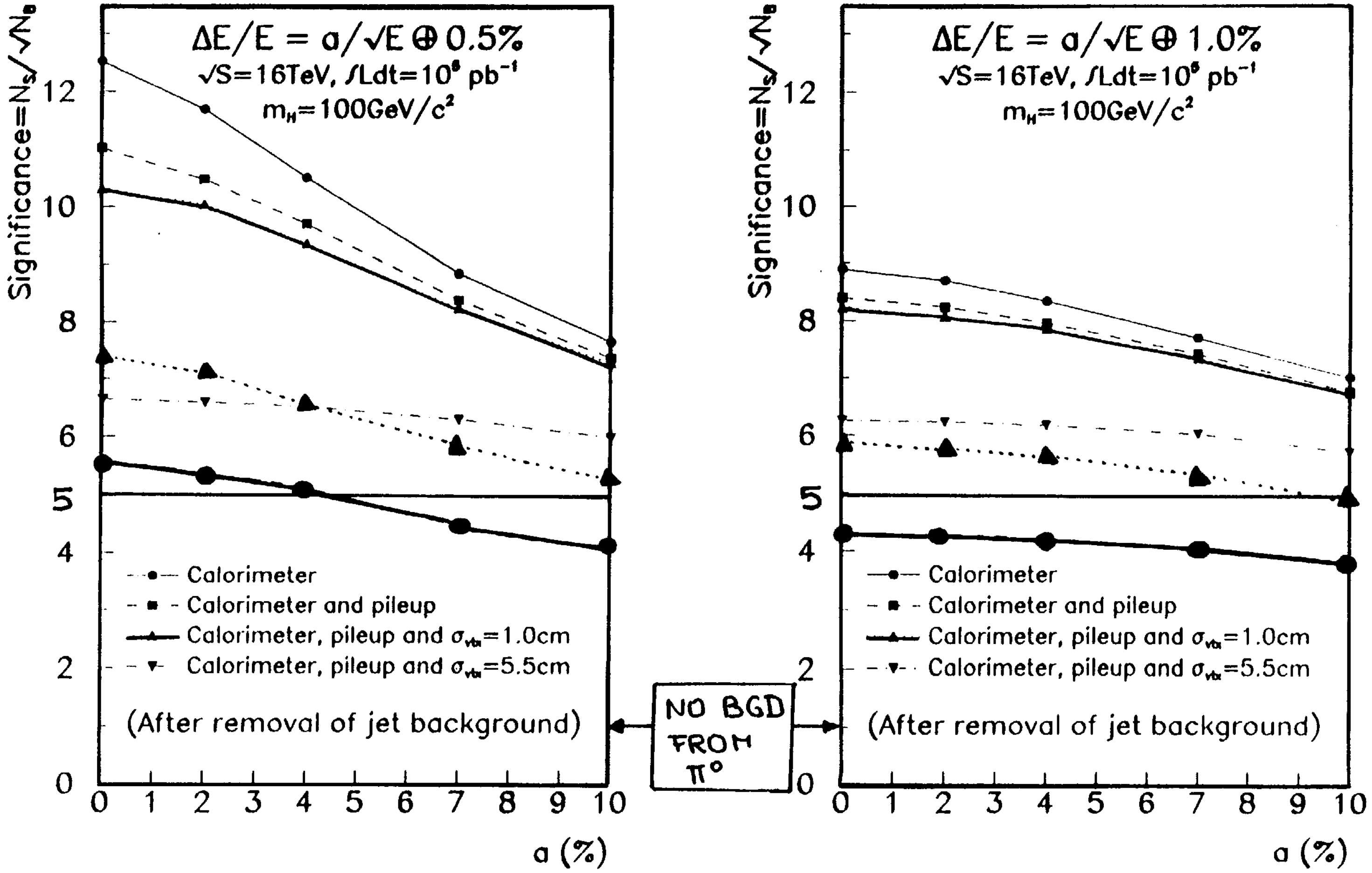
SCALED SIGNIFICANCE FOR $\sigma \cdot BR(h^0 \to \gamma\gamma)$: $m_{h^0} = 100$ GeV

···▲··· $\sigma \cdot BR = 0.04$ pb
—●— $\sigma \cdot BR = 0.03$ pb
} USE : INCLUDING PILE UP AND $\sigma_{VTX} = 1$ cm

$\boxed{H_{SM} \to \gamma\gamma}$

$m_H = 100$ GeV
$\sigma \cdot BR = 0.0553$ pb
FOR SM HIGGS

C. SEEZ
(CAPRI, 1991)

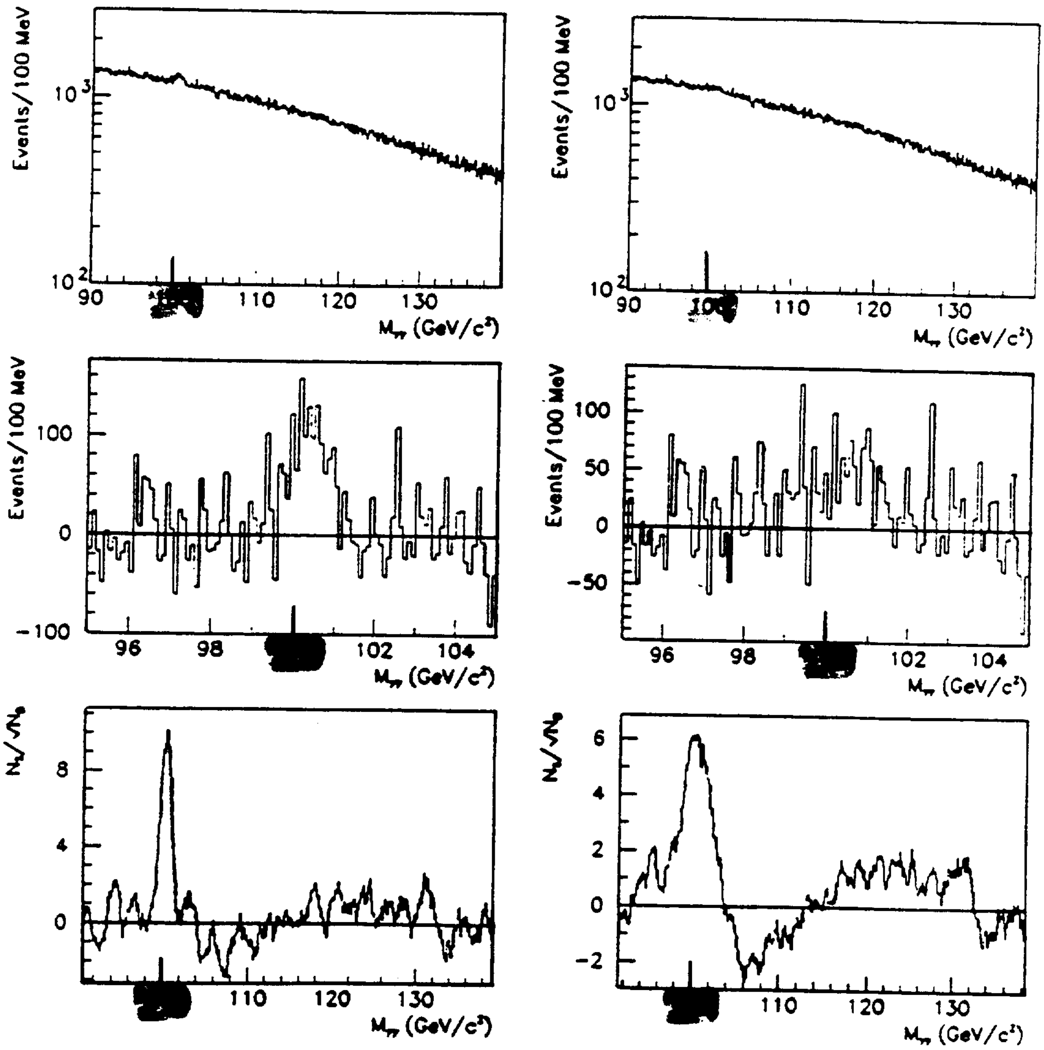


SIGNAL : $H \rightarrow \gamma\gamma$, $m_H = 100$ GeV (SM)

BGD FROM QCD $\gamma\gamma$ - PRODUCTION (IRREDUCIBLE)

ASSUME : $10^5\ pb^{-1}$ ($\mathcal{L} = 10^{34} cm^{-2} s^{-1}$; $\sigma_{inel} = 60 mb$)
PILE-UP INTEGRATED IN $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
CALO GIVES γ-DIRECTION TO ± 7 mrad

$\Delta E/E = 2\%/\sqrt{E} \oplus 0.5\%$ $\Delta E/E = 10\%/\sqrt{E} \oplus 0.5\%$ (E in GeV)



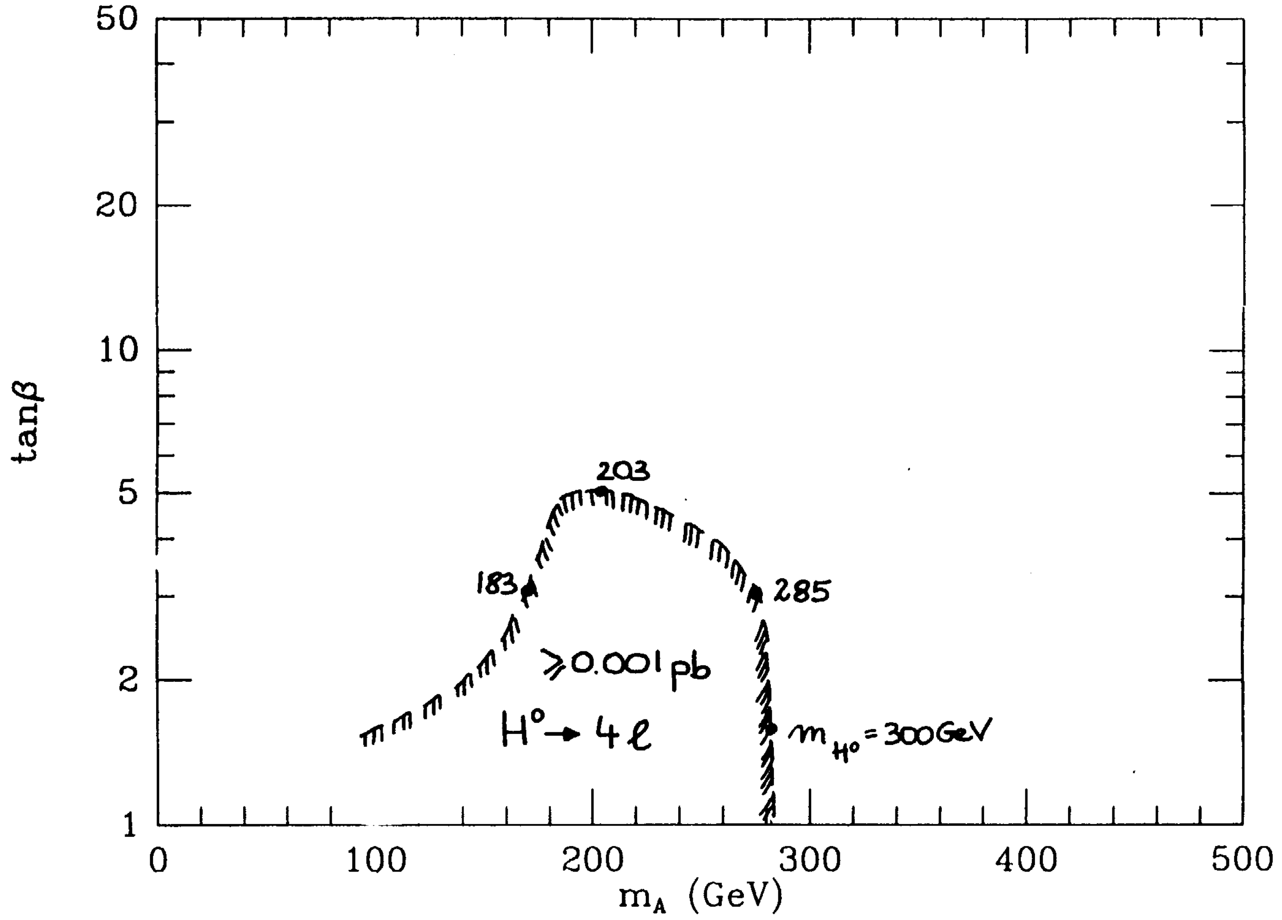
C. SEEZ
(CAPRI, 1991)

100 MeV
BINS

SCAN
$\Delta m = 1.5$ GeV

$$\boxed{\frac{N_S}{\sqrt{N_B}} = 10.1}$$

$$\boxed{\frac{N_S}{\sqrt{N_B}} = 6.1}$$



$\sigma \times$ BR CONTOUR FOR
$H^0 \to \ell^+\ell^-\ell^+\ell^-$

SM - HIGGS RATES FOR $10^5 pb^{-1}$:

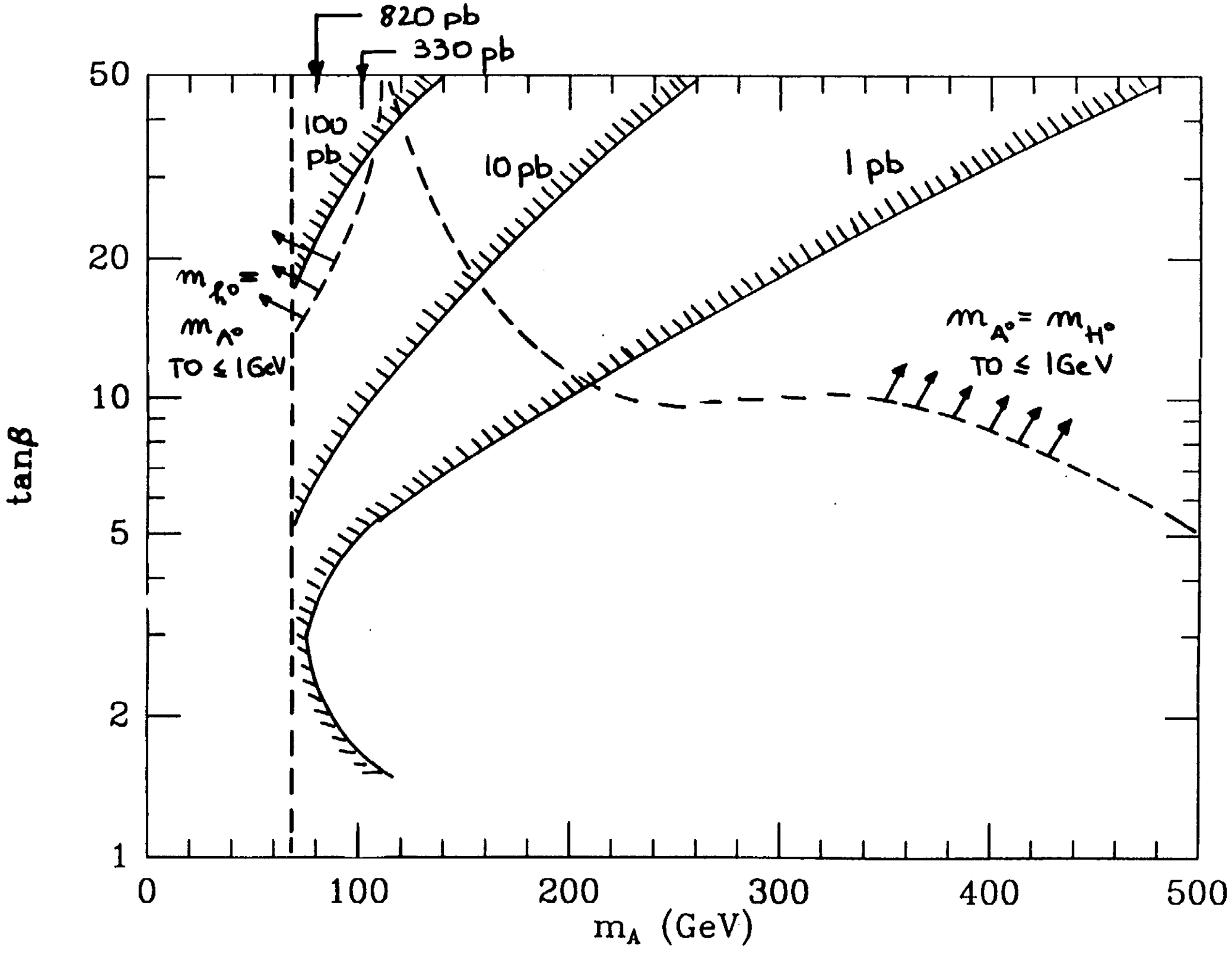
$m_H = 180$ GeV : $\sigma BR_{4e} = 0.00145$ pb
SIGNAL: 4e : ~45 EVTs ($\varepsilon = 30\%$)
BGD: ~ 6

(DELLA NEGRA et al)

$m_H = 200$ GeV : $\sigma BR_{4\mu} = 0.0043$ pb
SIGNAL: 4μ : 197 EVTs ($\varepsilon = 46\%$)
($p_T^{\mu} > 20$, $|\eta| < 2.5$,
$m_Z \pm 16$ GeV)

(A. NISATI)

➡ FOR σ.BR = 0.001 pb
NEED e AND μ



σ∗BR CONTOURS FOR $m_{A^0} \overset{OR}{=} m_{H^0} \overset{OR}{=} m_{h^0}$ FOR GIVEN m_A INTO $\tau^+\tau^-$

(ESTIMATES!)

SEARCH FOR SUSY HIGGS INTO $\tau^+\tau^-$

$$pp \rightarrow \begin{pmatrix} A^0 \\ H^0 \\ h^0 \end{pmatrix} \rightarrow \tau^+\tau^-$$

$\tau \rightarrow \ell\nu\nu : \sim 36\%$
$\tau \rightarrow \text{had}\ \nu : \sim 64\%$

POSSIBLE τ-SIGNATURES DEPEND IF ℓ OR HAD MODES USED:
$BR_{\ell\ell} \approx 13\%$, $BR_{\ell h} \approx 46\%$, $BR_{hh} \approx 41\%$

EXPECTED <u>TRIGGER RATES</u> AT $\mathcal{L} = 10^{33} cm^{-2} s^{-1}$: (HELLMAN et al)

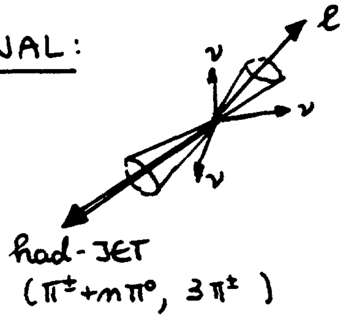
ℓ-ℓ MODE : $2e : E_T^e > 30$ GeV ~ 200 Hz (ISOLATION)
$2\mu : p_T^\mu > 30$ GeV ~ 0.2 Hz
$e+\mu : p_T > 50$ GeV ~ 10 Hz
PROBLEM OF LOW RATE : BR , p_T^ℓ-CUT : $\tau \rightarrow \ell\nu\nu$

ℓ-h MODE : INCLUSIVE μ : $p_T^\mu > 30$ GeV ~ 40 Hz
INCLUSIVE e : $p_T^e > 30$ GeV ~ $\underbrace{1.1 \text{ TO } 0.2}_{\text{ISOLATION}}$ kHz

h-h MODE : 2 JETS : $E_T^J > 50$ GeV ~ 24 kHz
NEED τ - JET REJECTION OF ~ FEW % AT TRIGGER LEVEL TO GET ABOUT TRIGGER RATE OF INCL. e's WITH $p_T^e > 30$ GeV

$\boxed{\Rightarrow \text{ STUDY } (\ell - h) \text{ MODE}}$

<u>SIGNAL:</u>



ISOLATED LEPTON
ISOLATED τ-JET : 1-3 TRACKS
NARROW JET
SOFT $\not{E}_T$

MAIN (IRREDUCIBLE) BGD : ISOLATED $\tau^+\tau^-$ IN FINAL STATE
$Z \rightarrow \tau^+\tau^-$, $t\bar{t} \rightarrow \tau^+\tau^- X$, $\tau\ell X$

MAIN BGD FROM τ-JET MISIDENT. : $W \rightarrow \underset{\substack{\downarrow \\ (e,\mu)}}{\ell}\nu + \underset{\hookrightarrow \tau}{\text{JET}}$

HIGGS $\rightarrow \tau^+\tau^- \longrightarrow$ LEPTON + τ-JET + $\not{E}_T$

M.FELCINI
F.PAUSS

SIGNAL : $m_H = 100$ TO 400 GeV CONSIDERED

BGD: $Z^0 \rightarrow \ell^+\ell^- + X$
$W \rightarrow \ell\nu + X$
$t\bar{t}$: ALL DECAY MODES ($m_t = 140$ GeV)

ISAJET MC USED FOR SIGNAL AND BGD EVALUATION

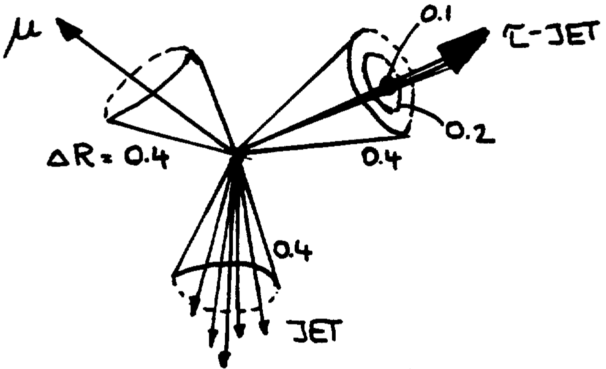
CALORIMETER : em : $15\%/\sqrt{E} \oplus 1\%$, had : $50\%/\sqrt{E} \oplus 2\%$

GRANULARITY : $\Delta\eta \times \Delta\phi \sim 0.06 \times 0.06$, $|\eta| < 5$

e-τ REJECTION FACTOR DIFFICULT TO EVALUATE :
i.e.: NON-ISOLATED e's FAKING τ's , BECAUSE NO MODEL OF em AND had SHOWER INCLUDED

$\rightarrow$ USE μ-τ CHANNEL TO DISCUSS PRINCIPLE STRATEGY

ℓ AND τ-JET DEFINITION



CONE $\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2}$
$\varepsilon_\mu = 100\%$

ISOLATED μ : $P_T^\mu > 20$ GeV
$\sum_{\Delta R = 0.4} E_T \leq 10$ GeV

ISOLATED τ : $E_T^J > 30$ GeV
WITH $\leq$ 3TRACKS IN $\Delta R < 0.1$ AROUND JET
$\sum_{0.2} E_T / \sum_{0.4} E_T > 0.96$

JETS : $E_T^J > 30$ GeV , $\Delta R \leq 0.4$
$E_T^{ini} = 10$ GeV, $E_T^c > 1$GeV

$\rightarrow$ τ-JET AND JET DEFINITION RATHER INSENSITIVE TO PILE-UP

REMARK: ISOLATION REQUIREMENT FOR τ-JET

$$\Sigma E_T (\Delta R \leq 0.2) / \Sigma E_T (\Delta R \leq 0.4)$$

TAKE CALORIMETER WITH CELL SIZE $10 \times 10\ cm^2$ AT DISTANCE OF $R = 2\ m$ AND $R = 3.5\ m$ FROM INTERACT. POINT:

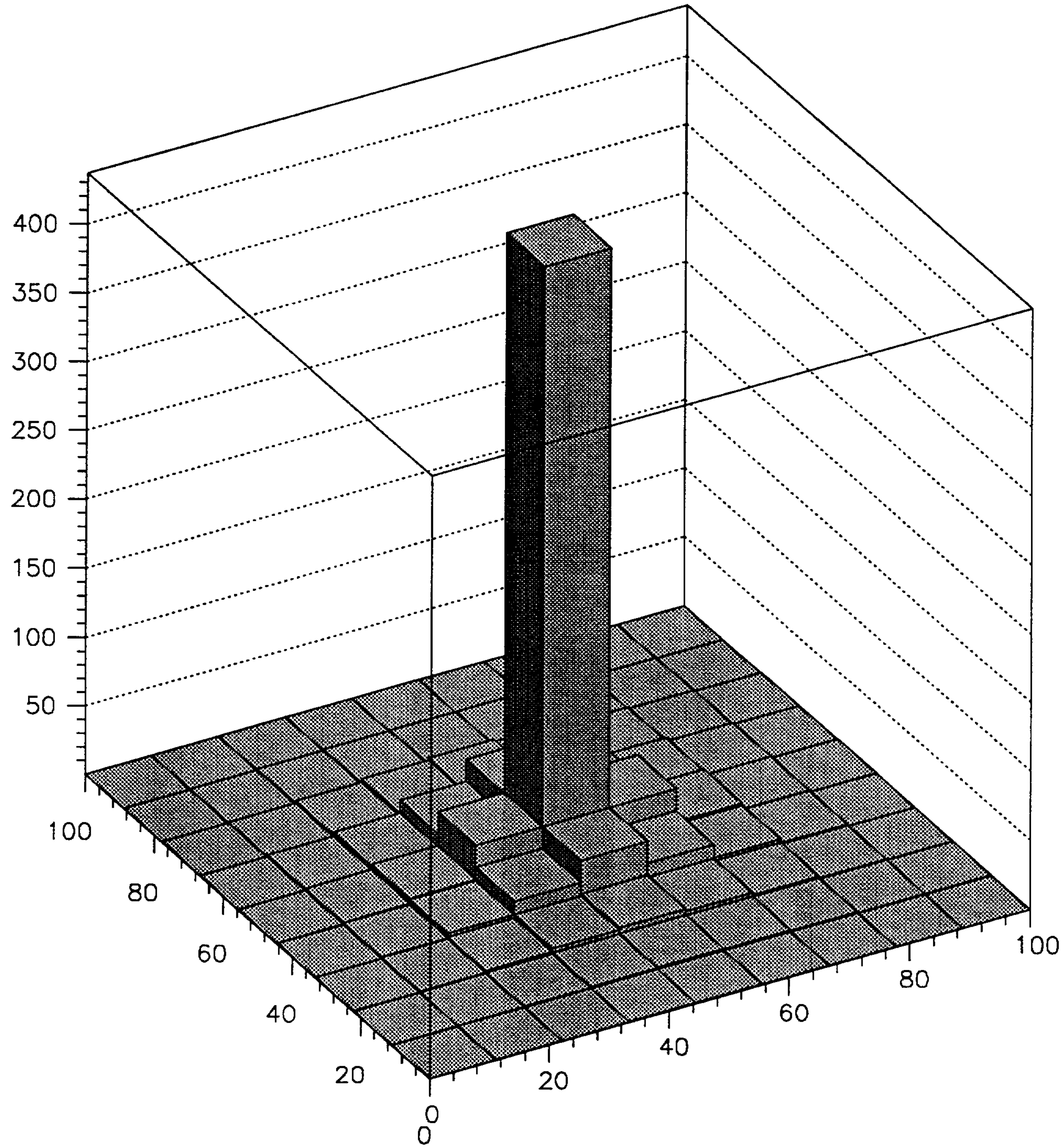
	$R = 2\ m$	$R = 3.5\ m$
1 CELL : $\Delta\eta \times \Delta\phi$	0.05×0.05	$\sim 0.03 \times 0.03$
1 CELL : ΔR	0.07	0.04
ΔR FOR HAD. ENERGY IN 3×3 CELLS	0.21	0.12
$\Delta R = 0.4$ CORRESPONDS	6×6 CELLS	10×10 CELLS

↑
WOULD CHANGE
ISOLATION CONES
FOR THIS CALO

SELECTION REQUIREMENTS:

- ONLY 1 ISOLATED μ AND ONLY 1 ISOLATED τ-CAND. IN EVENT $(E_T^{\tau} = E_T^{J_1})$, IN $|\eta| < 2$
- NO OTHER JET ACTIVITY $(E_T^{J} > 30\ GeV)$ AND OVERALL LOW (SOFT) ENERGY DEPOSITION (REDUCES $t\bar{t}$ BGD CONSIDERABLY)
- ADJUST CUTS FOR LOW MASS $(m_H \leq 200\ GeV)$ AND HIGH MASS $(m_H > 200\ GeV)$ SELECTION

Charge per tower U(5mm)/TMP



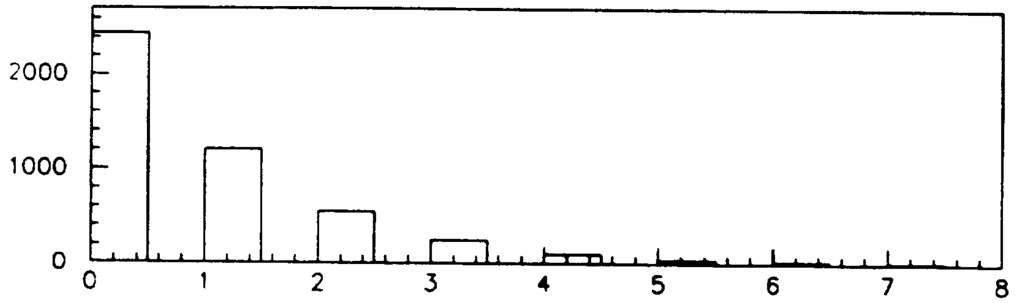
pions, 30 GeV

A. GIVERNAUD

$H \rightarrow \tau\tau \;: m_H = 400$ GeV

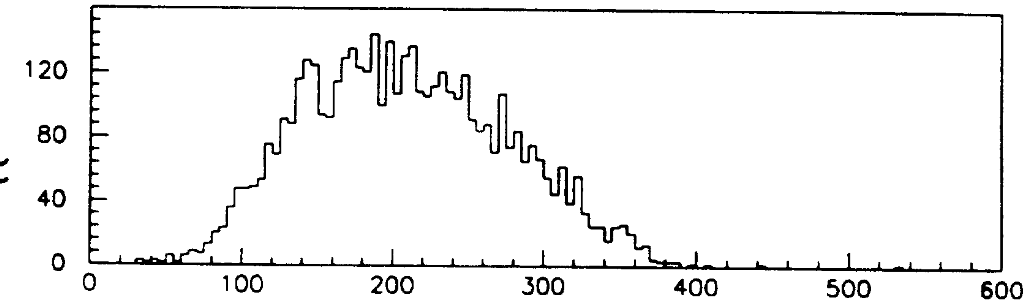
$E_T^\tau > 30$ GeV, $p_T^\mu > 20$ GeV, $E_T^J > 30$ GeV ($|\eta|<2$)

#OF JETS



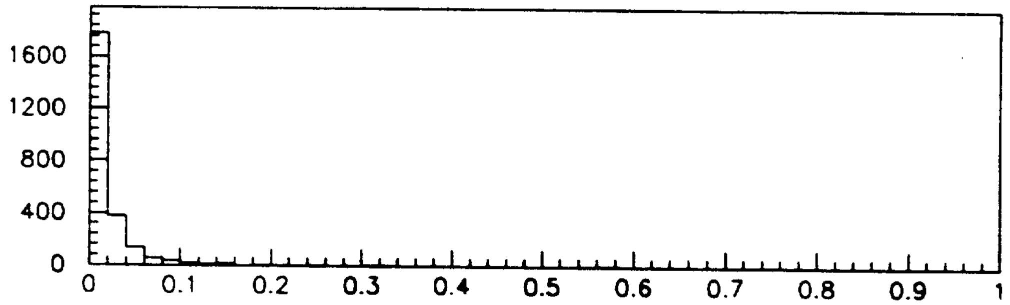
Number of non-τ jets

$\overline{m}_{\ell\tau}$



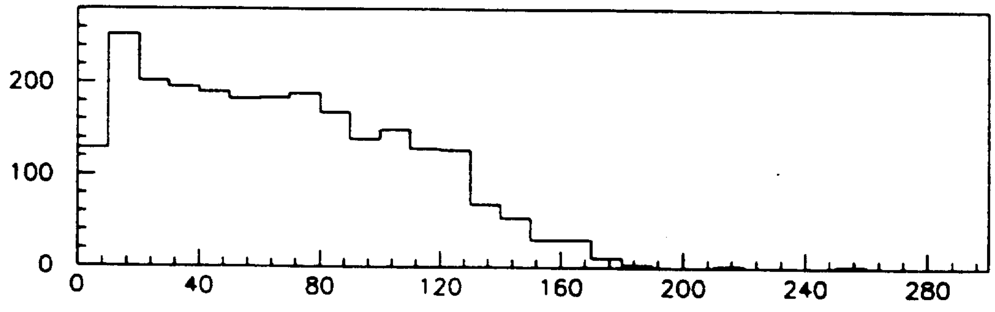
M(τ-jet lepton)

C



Circularity(calo-cells+lepton)

$\not{E}_T$
$|\eta|<5$

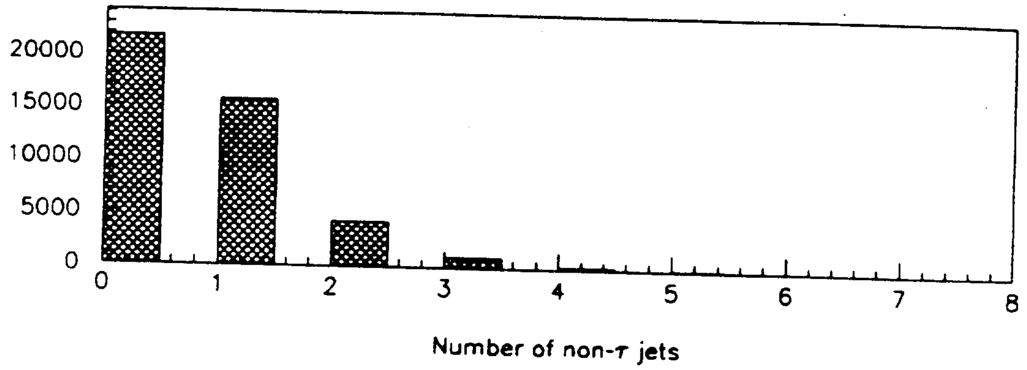


E_t[illegible]

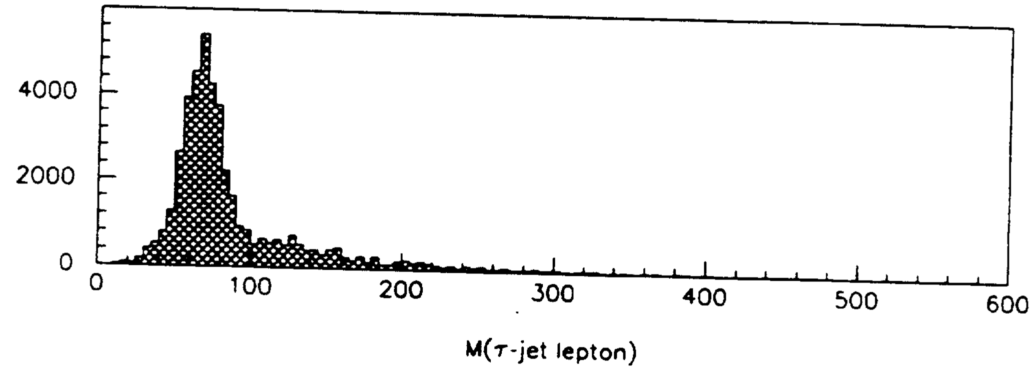
FOR $N_J = 0$

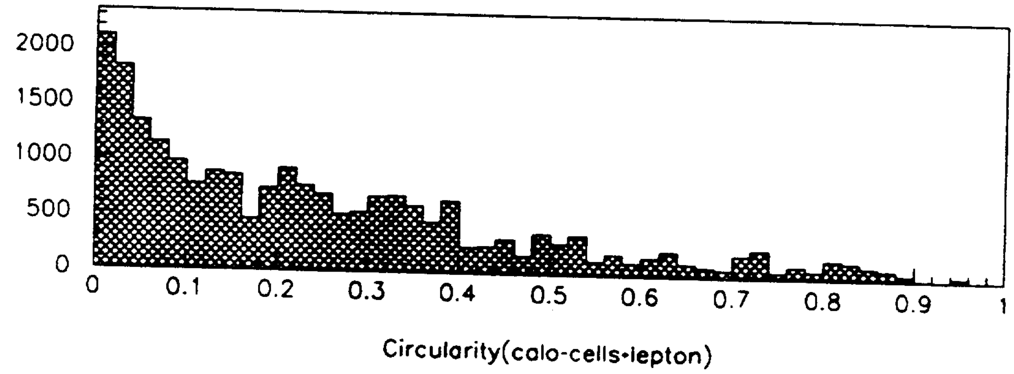
$C := \frac{1}{2} \min \left(\Sigma E_T \cdot \vec{n}\right)^2 / \Sigma E_T^2$

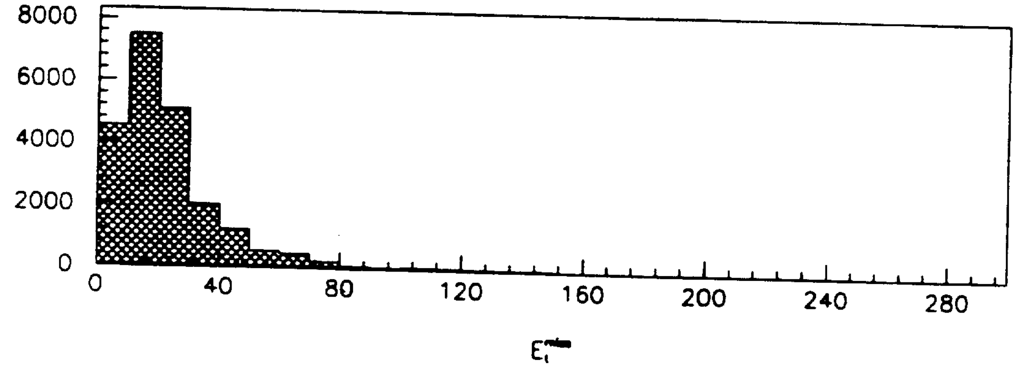
$Z^0 \rightarrow \ell^+\ell^-$ + JETS



Z^0

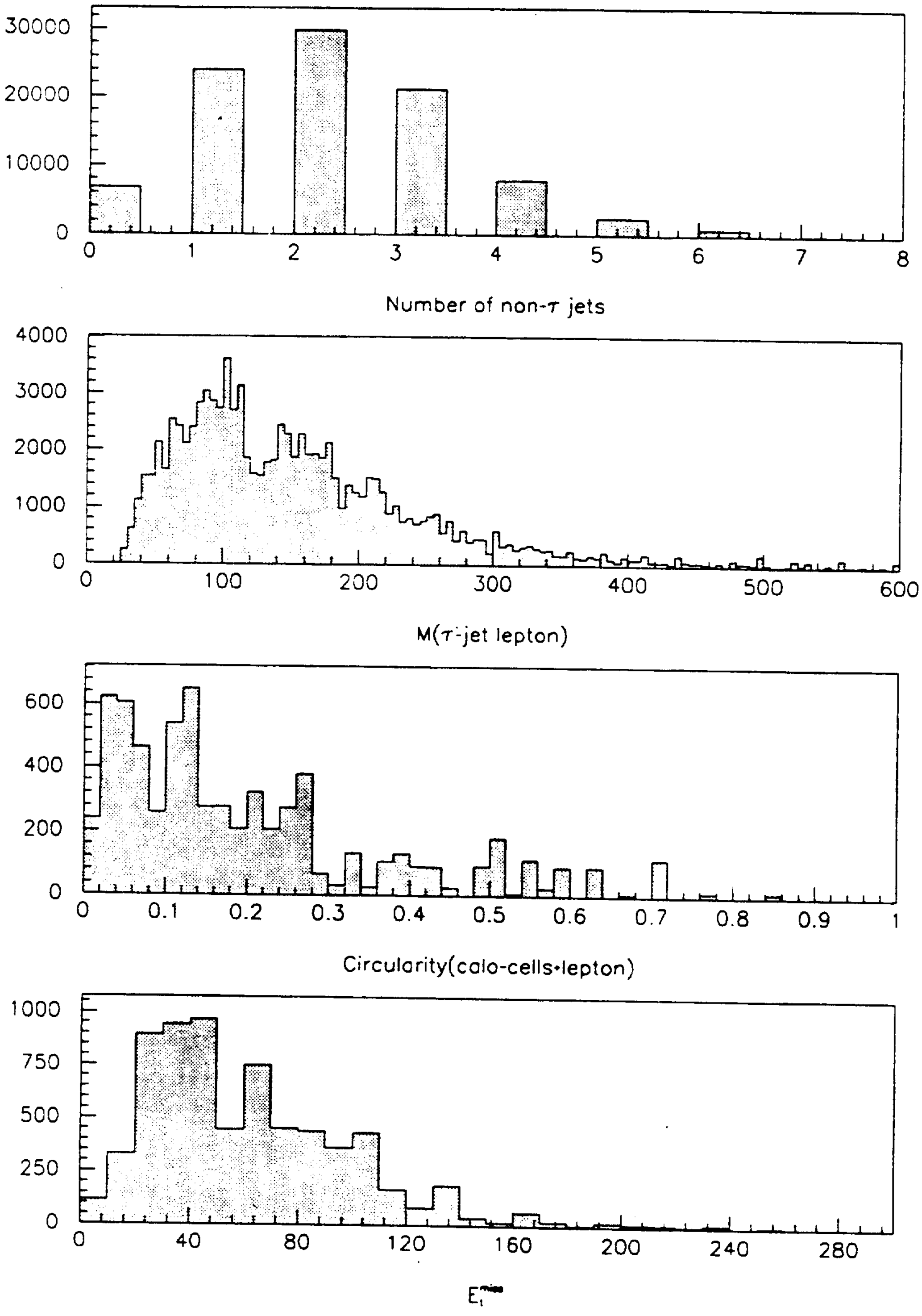






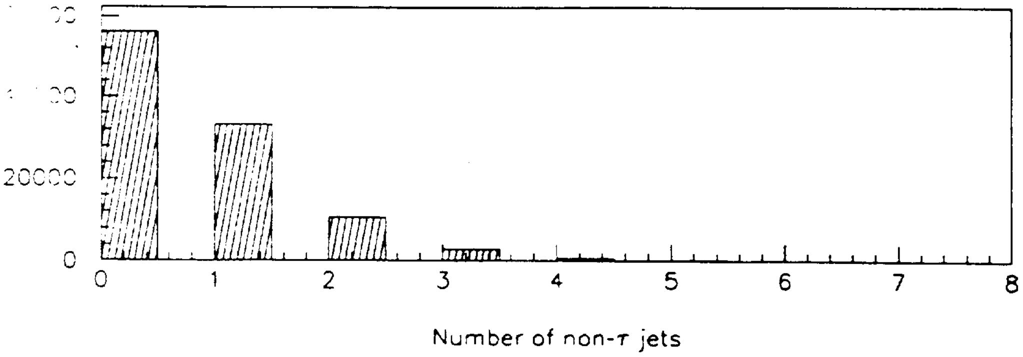
$t\bar{t}$: $m_t = 140$ GeV

$E_T^{\tau} > 80$ GeV, $p_T^{\mu} > 20$GeV , $E_T^{J} > 30$ GeV ($|\eta| < 2$)

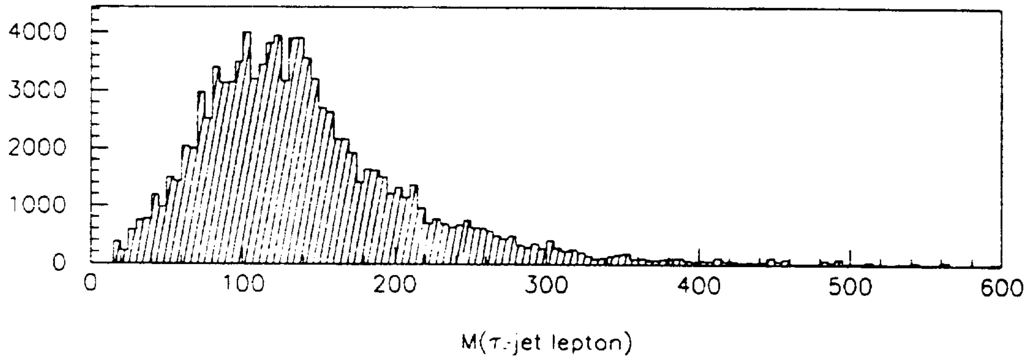


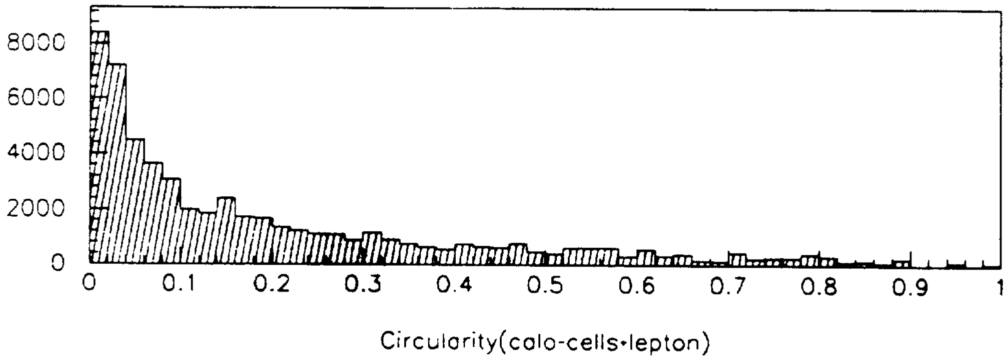
$t\bar{t}$

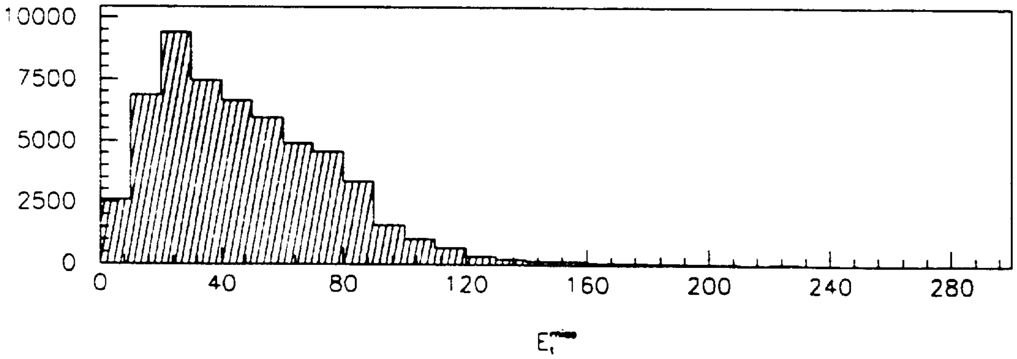
$W \rightarrow \ell\nu$ + JETS



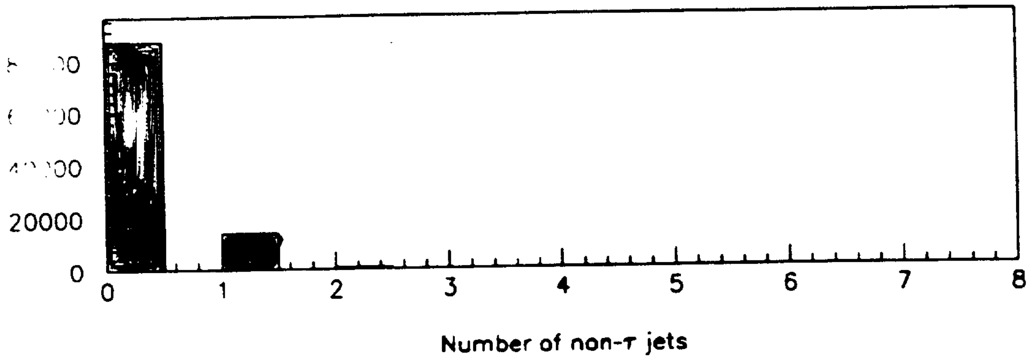
W

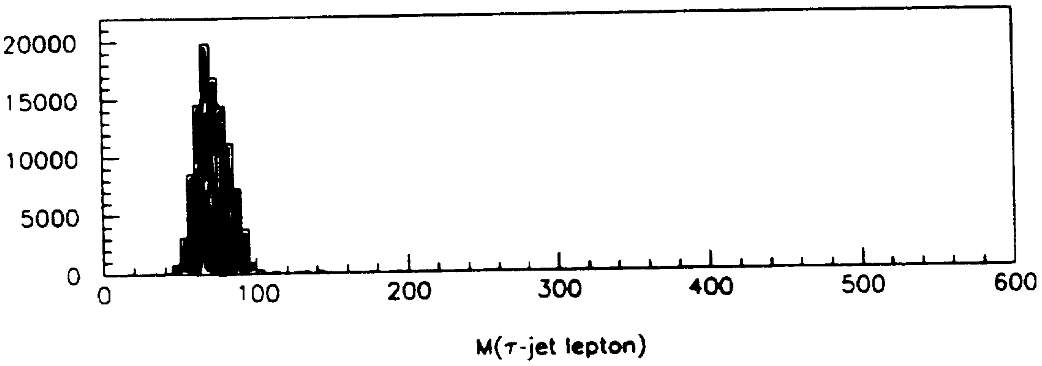


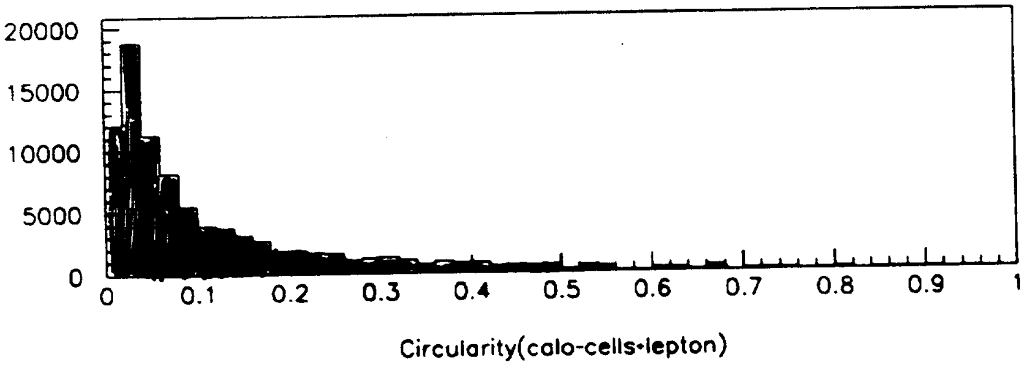


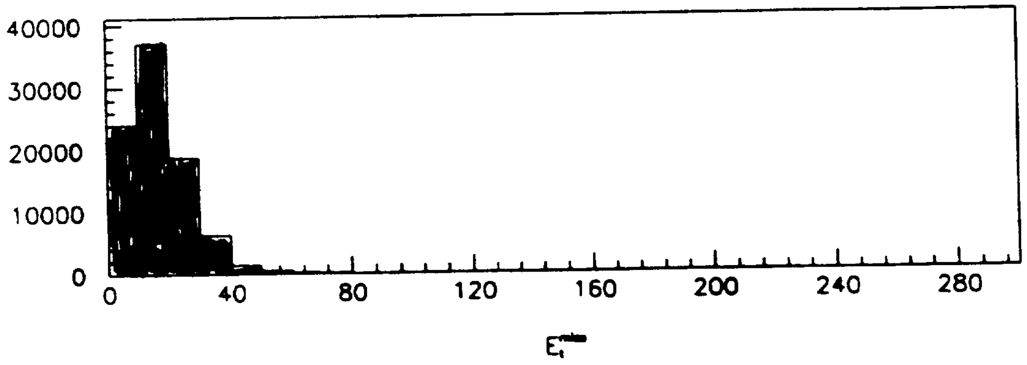


$H \rightarrow \tau\tau$: $m_H = 100$ GeV



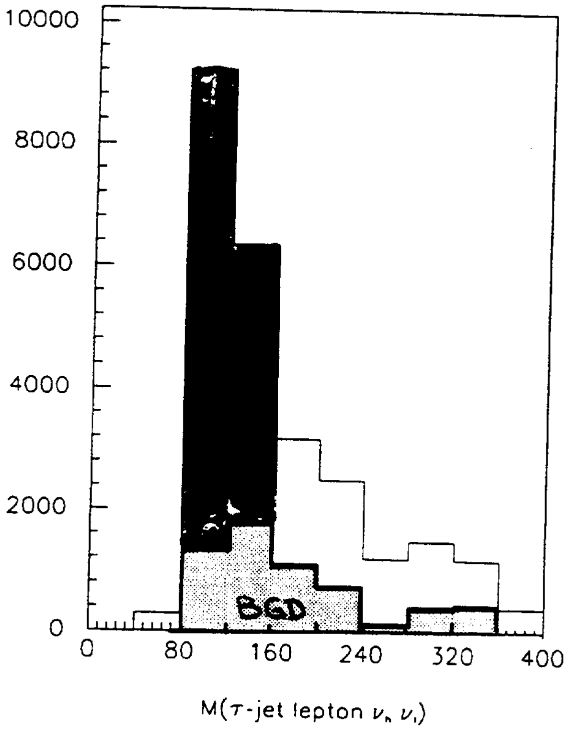






$\boxed{H \longrightarrow \tau\tau \; : \; m_H = 100 \text{ GeV}}$

$H \hat{=} A^0, h^0$
$m(A^0 - h^0) \sim 300$ MeV
FOR $\tan\beta = 50$



TOTAL $\sigma \times BR = 333.7$ pb : $\tan\beta = 50$

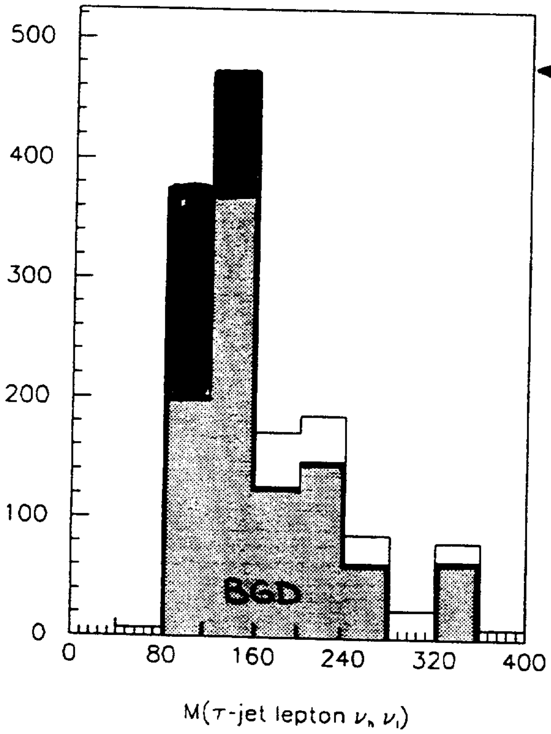
SELECTION : $E_T^\tau > 30$ GeV, $p_T^\ell > 30$ GeV
NO JET ($E_T^j > 30$ GeV)
$60 < m_{\tau\ell} < 100$ GeV
$C < 0.1$

EVENTS IN $\Delta m = 80 - 160$ GeV
AND 10^4 pb^{-1}

SIGNAL: 12260 EVTS
TOTAL BGD: 3184 EVTS } S = 217

Z + JETS: 1600 ± 214 EVTS
$t\bar{t}$: 576 ± 197
W + JETS: 1008 ± 227

S = 10 CORRESPONDS TO A
SENSITIVITY OF 15.4 pb



← SAME SELECTION AS ABOVE
BUT ONLY IRREDUCIBLE BGD
$Z \rightarrow \tau\tau$, $t\bar{t} \rightarrow \tau\tau + X$
$\tau\mu + X$

← PLOT FOR $S = \frac{N_S}{\sqrt{N_B}} = 10$

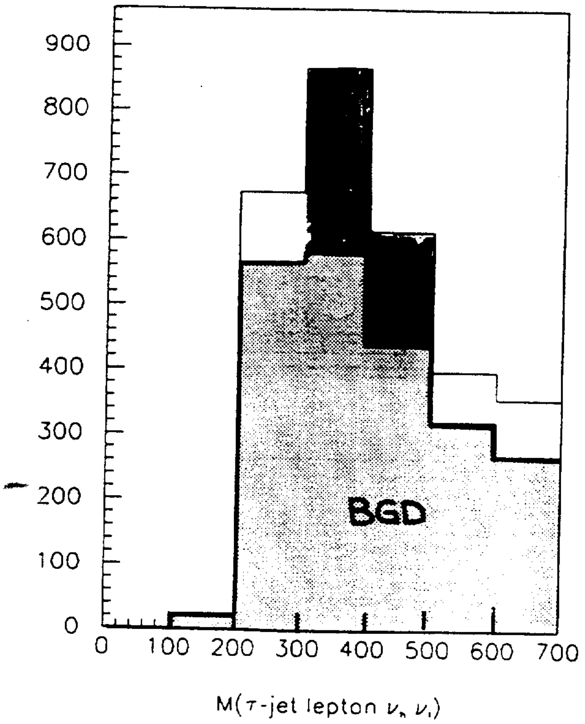
THIS CORRESPONDS TO A
SENSITIVITY OF $\sigma \times BR = 7.5$ pb

SIGNAL : 275 EVENTS
BGD : 751 EVENTS ($Z \sim t\bar{t}$)

($\not{E}_T$ in $|\eta| < 5$)

$H \rightarrow \tau\tau$: $m_H = 400$ GeV

$H \hat{=} H^\circ, A^\circ$
$m(H^\circ - A^\circ) \sim 20$ MeV
FOR $\tan\beta = 50$



TOTAL $\sigma * BR = 2.25$ pb

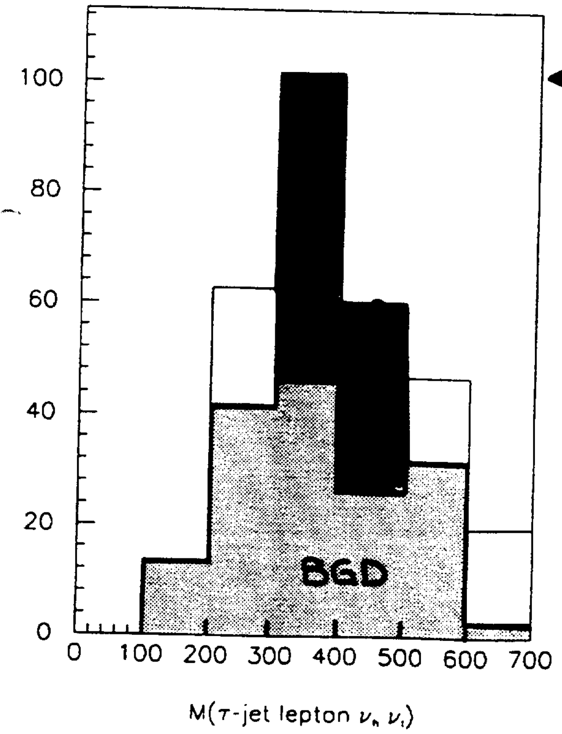
<u>SELECTION</u>: $E_T^\tau > 80$ GeV, $p_T^\ell > 20$ GeV
NO JET ($E_T > 30$ GeV)
$m_{\tau\ell} > 120$ GeV
$C < 0.02$, $\not{E}_T > 50$ GeV

EVENTS IN $\Delta m = 300 - 500$ GeV
AND 10^4pb^{-1}:

SIGNAL: 455 EVENTS } S = 14
TOT. BGD: 1021 EVENTS }

Z+JETS: 77 ± 12
$t\bar{t}$: 94 ± 26
W+JETS : 850 ± 72

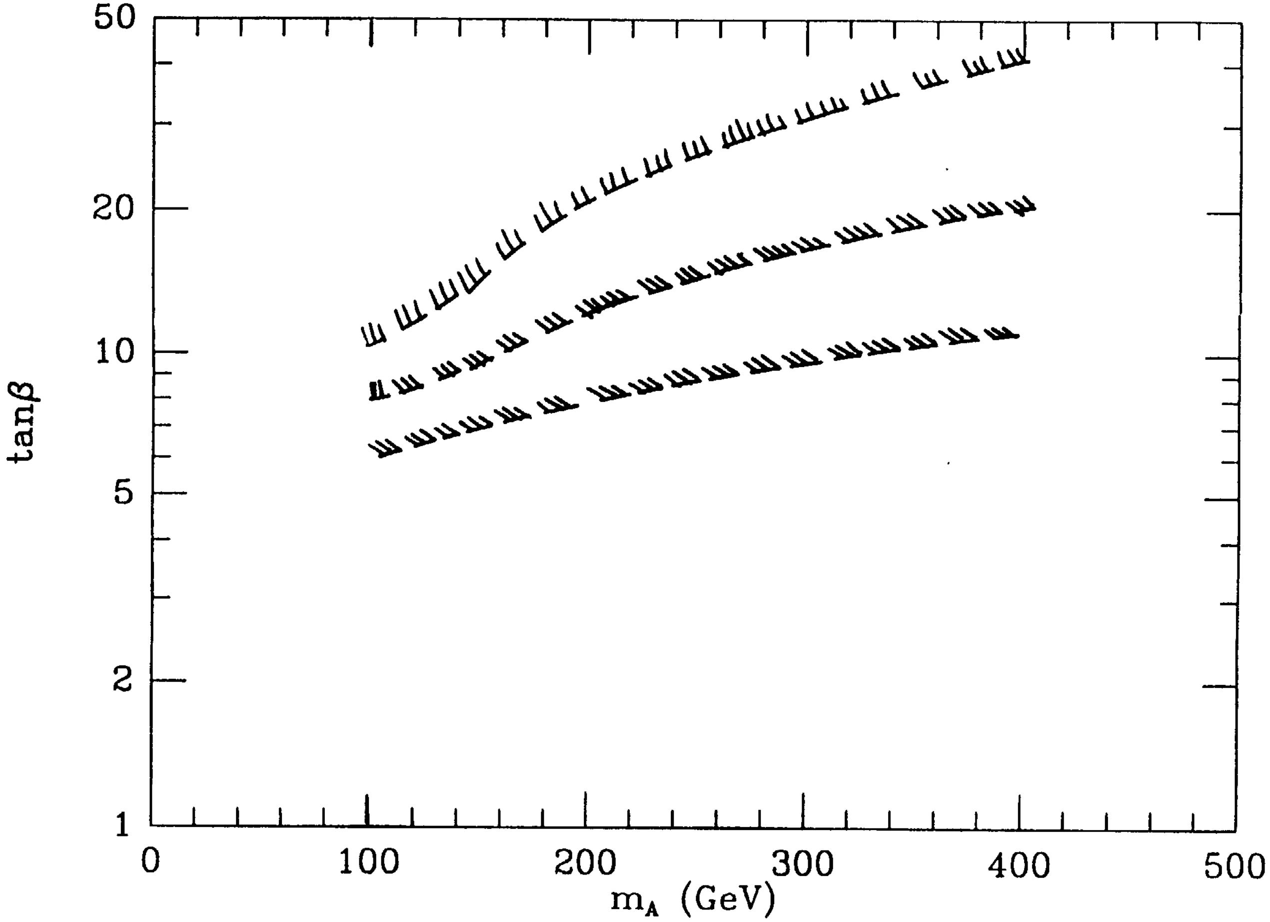
S = 10 CORRESPONDS TO A
SENSITIVITY OF <u>1.6 pb</u>



← SAME SELECTION AS ABOVE
BUT <u>ONLY</u> <u>IRREDUCIBLE</u> BGD:
$Z \rightarrow \tau\tau$, $t\bar{t} \rightarrow \tau\tau + X$
$\tau\mu + X$

← PLOT FOR $S = \frac{N_S}{\sqrt{N_B}} = 10$

THIS CORRESPONDS TO A
SENSITIVITY OF: <u>$\sigma * BR = 0.43$ pb</u>



PRELIMINARY ESTIMATES
ON $\sigma \times BR\ (H \to \tau\tau)$ FOR
$m_A = 100$ TO 400 GeV

USE $S = \frac{N_S}{\sqrt{N_B}} = 10\ ,\ 10^4 pb^{-1}$:

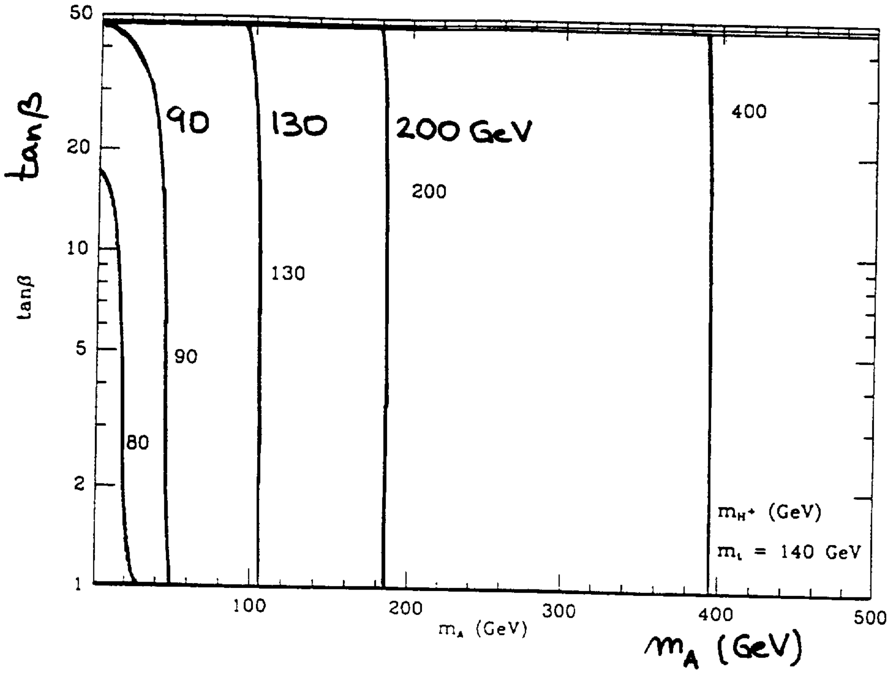
▨ SELECTION

▨ ONLY IRREDUCIBLE BGD

▨ LIKE (--) BUT FOR $10^5 pb^{-1}$

(FOR μ-τ AND e-τ WITH $\varepsilon_\mu = \varepsilon_e = 100\%$)

CHARGED HIGGS : $H^\pm$

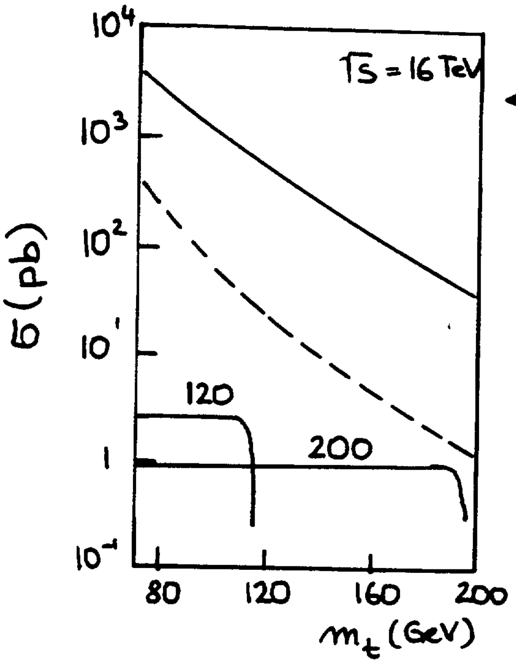


$m_t = 140$ GeV

$m_{\tilde{q}} = 1$ TeV

PRODUCTION AND DECAY: ($H^\pm$ DOES NOT COUPLE TO $WZ, W\gamma$)

- $gg \to t\bar{t}$: $t \to H^\pm b$ if $m_{H^\pm} < m_t - m_b$
  $\hookrightarrow \tau\nu$
  LARGE TOP PROD. CROSS-SECTION
  COULD HELP IN DIFFICULT AREA ($m_A - \tan\beta$)
- $gb \to tH^\pm$: $H^\pm \to \tau\nu$: IF $m_t - m_b < m_{H^\pm} < m_t + m_b$
- $gb \to tH^\pm$: $H^\pm \to t\bar{b}$: IF $m_H > m_t + m_b$



← FOR $\tan\beta = 2$

— SIGNAL : $gb \to tH^-$
$\hookrightarrow \bar{t}b$

— QCD : $gg \to t\bar{t}g$ } BGD
-- QCD : $gb \to t\bar{t}b$

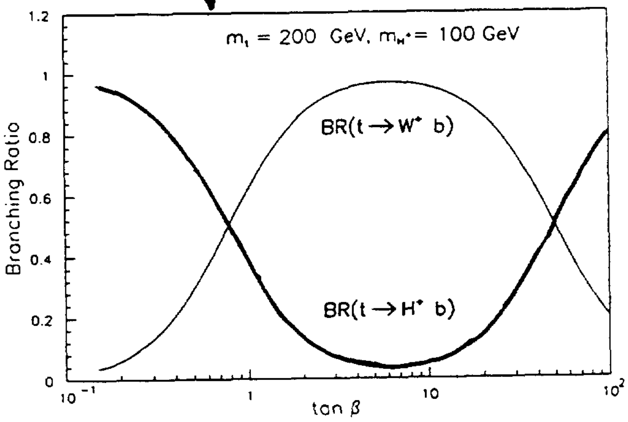
→ HOPELESS

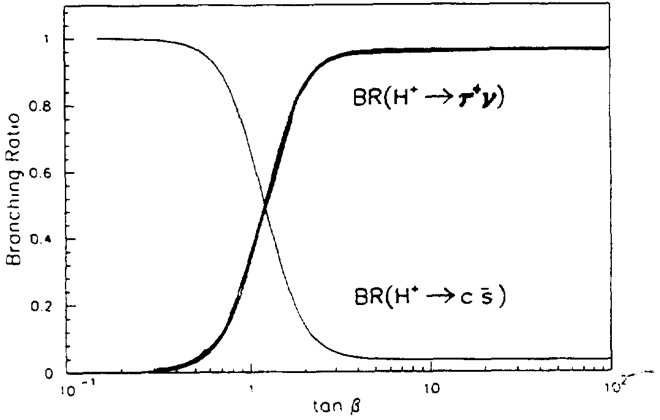
BAWA, KIM, MARTIN
Z.PHY. C47 (1990) 75

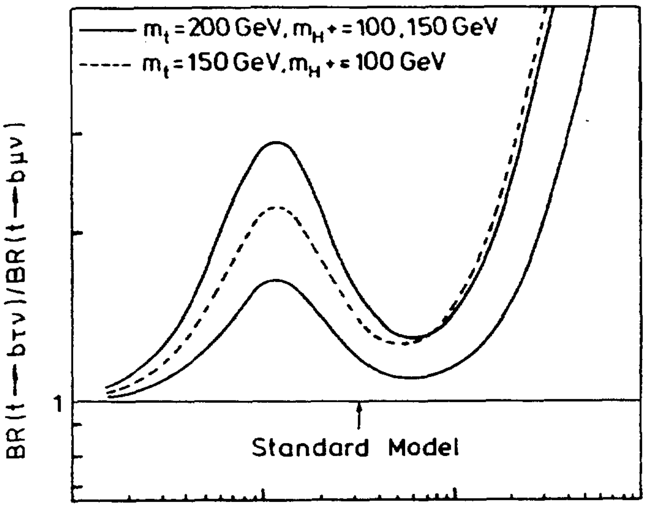
THE CHARGED HIGGS IN TOP DECAYS

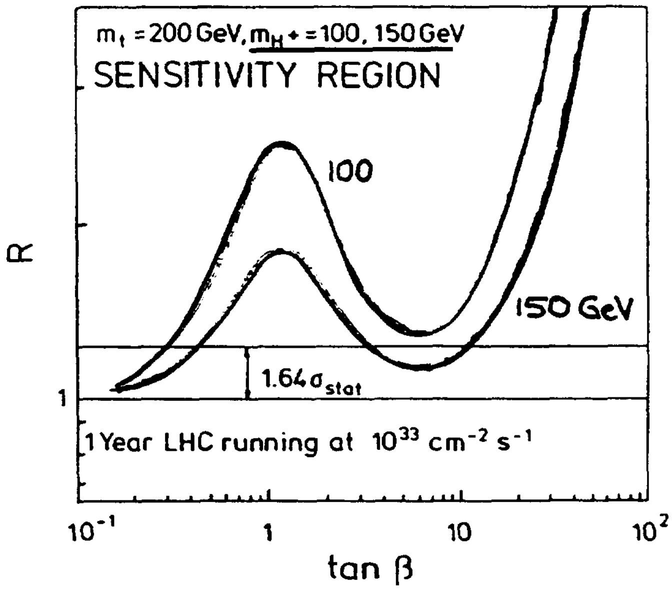
IF $m_{H^\pm} < m_t - m_b$: $t \to H^\pm b$ POSSIBLE

BR INTO $H^\pm$ AND $H^\pm$ DECAY MODES DEPEND ON $\tan\beta$.









STRATEGY:

MEASURE LEPTON-UNIVERSALITY VIOLATION

$t\bar{t} \to WWbb$ VS $t\bar{t} \to H^\pm Wbb$

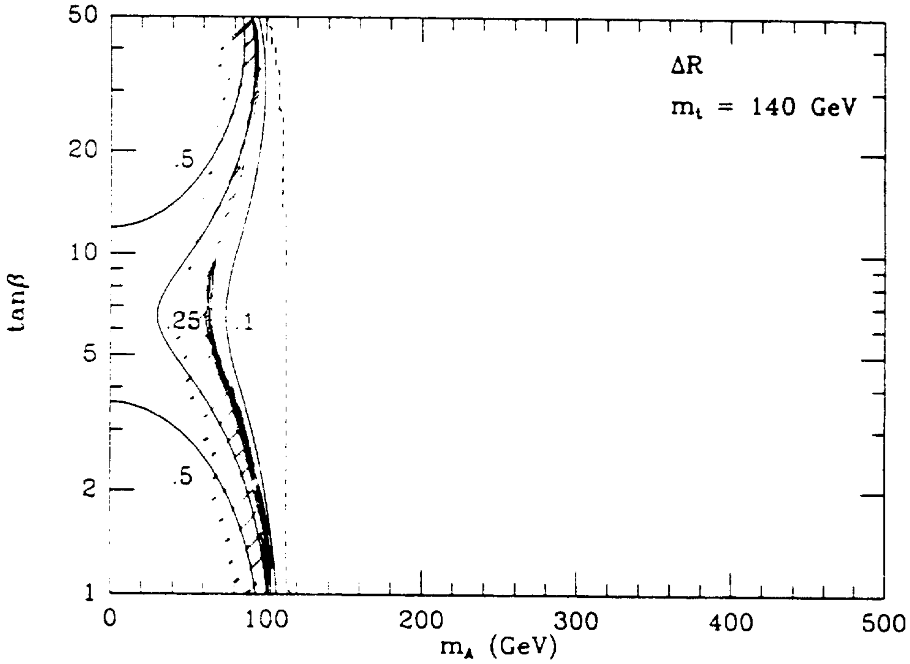
TAG TOP VIA : $t \to Wb$
$\hookrightarrow \ell\nu$

AND SEARCH FOR EXCESS OF ISOLATED τ's COMPARED TO μ's (e's) IN THE SECOND TOP DECAY:

$$\boxed{R_{\tau\mu} \sim \frac{BR(t \to \tau\nu b)}{BR(t \to \mu\nu b)}}$$

USING HADRONIC DECAY OF τ

(M. FELCINI)



ESTIMATE:

m_t = 200 GeV
FOR 17% ERROR
ON R ➡
SENSITIVITY : 0.28
(90% CL)

m_t = 140 GeV
SENSITIVITY : 0.14
(90% CL)

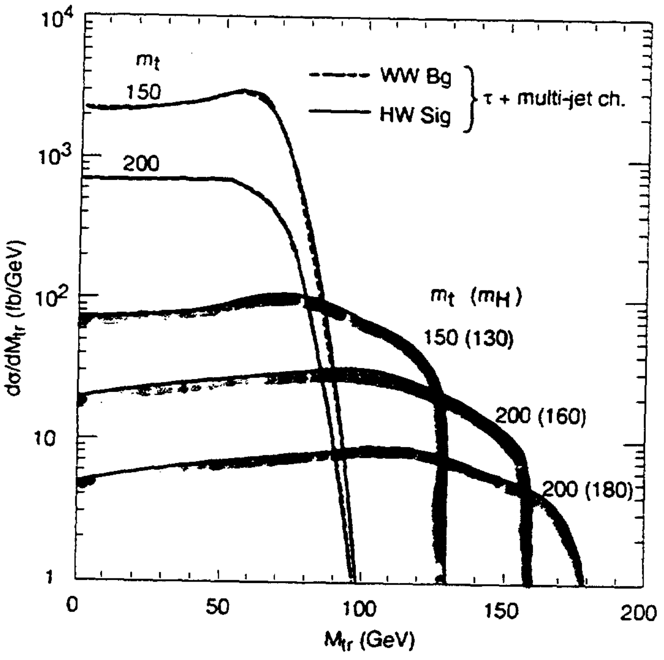
CHARGED HIGGS IN TOP DECAY

D.P. ROY
CERN-TH.6247/91

STUDY $H^\pm$ - SIGNATURE FOR $m_{H^\pm} > m_W$ WITH PARTON LEVEL MC FOR DIFFERENT CHANNELS: $H^\pm \to \tau\nu$
IN $t\bar{t} \to b\bar{b}\,(H^+H^-, H^\pm W, WW)$ EVENTS $(\tau \hat{=} \tau \to \text{HAD}+\nu)$

- 2τ - CHANNEL: $p_T^\tau > 10$ GeV, $\not{E}_T > 20$ GeV ; ISOLAT.: $\sum_{0.4\,\text{rad}} p_T < 5$ GeV
- τ + HARD μ - CHANNEL: $p_T^\mu > 20$ GeV ; $p_T^\tau > 10$ GeV, $\not{E}_T > 20$ GeV
- τ + SOFT μ - CHANNEL: $p_T^\mu = 5$ TO 20 GeV, - " -
  SMALL RATE, WOULD NEED HIGH $\mathcal{L}$
- τ + MULTIJET - CHANNEL: $p_T^\tau > 10$ GeV, $\not{E}_T > 20$ GeV
  $N_J \geq 2$ FOR $E_T^J > 40$ GeV

FOR FIRST 3 CHANNELS USE b-JET E_T AS REJECTION
$(E_T^{J_1} < 30$ GeV$)$



$\longleftarrow$ EXAMPLE FOR τ + MULTIJETS

m_T DISTRIBUTION IS SENSITIVE TO m_H

CONCLUSION:
$S/B > 1$ FOR $m_{H^\pm} \simeq m_t - 20$ GeV
FOR ALL $\tan\beta$

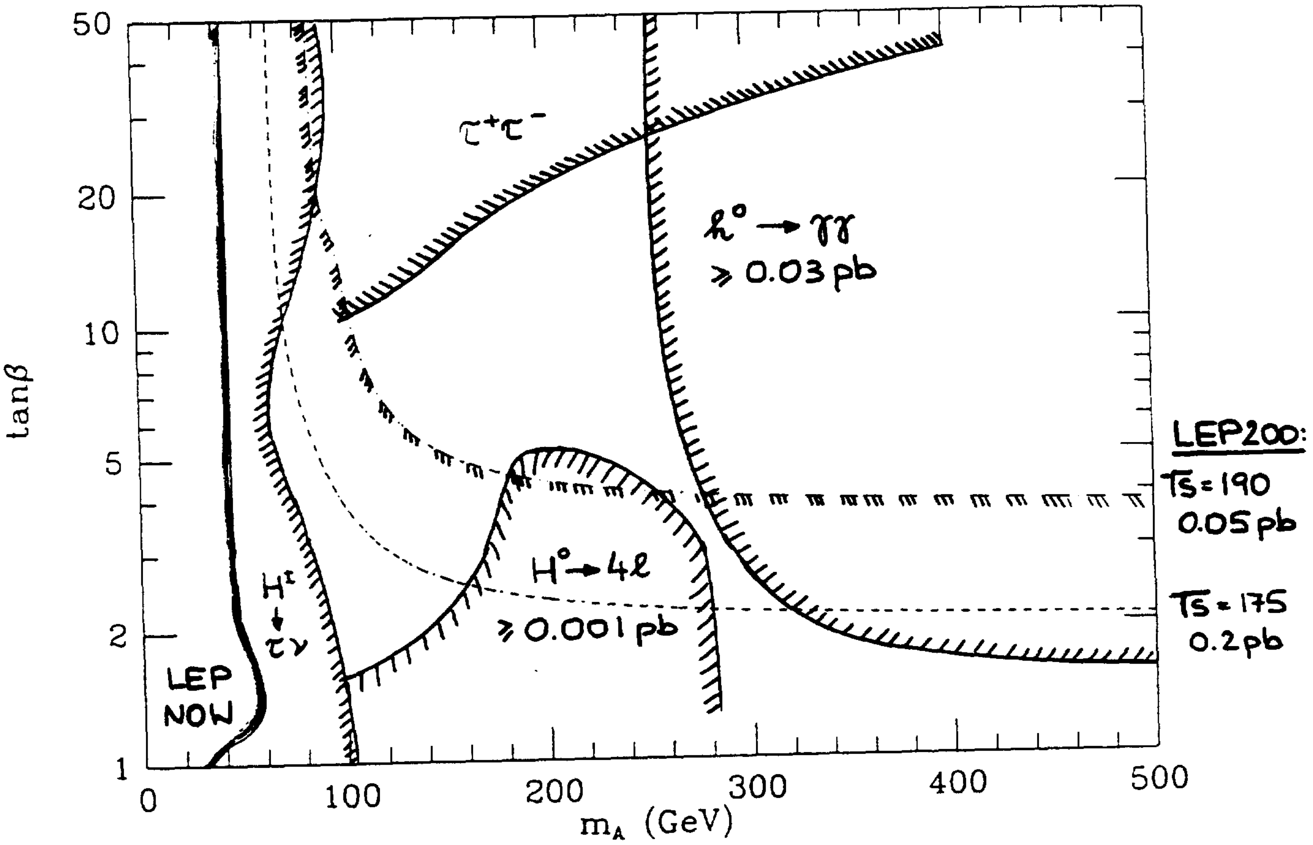
MEASUREMENT OF τ - POLARIZATION COULD HELP FOR SIGNAL / BGD : BEST IN $\mu\tau$ CHANNEL WITH $\tau \xrightarrow{11\%} \pi\nu$

EXPECT: $W^- \to \tau_L^- \nu$, $H^- \to \tau_R^- \nu$ AND

$$\langle p_{\pi^-}^T \rangle_{H^-} \simeq 2 \langle p_{\pi^-}^T \rangle_{W^-}$$

SUSY HIGGS : OPTIMISTIC SUMMARY

$m_t = 140$ GeV, $m_{\tilde{q}} = 1$TeV

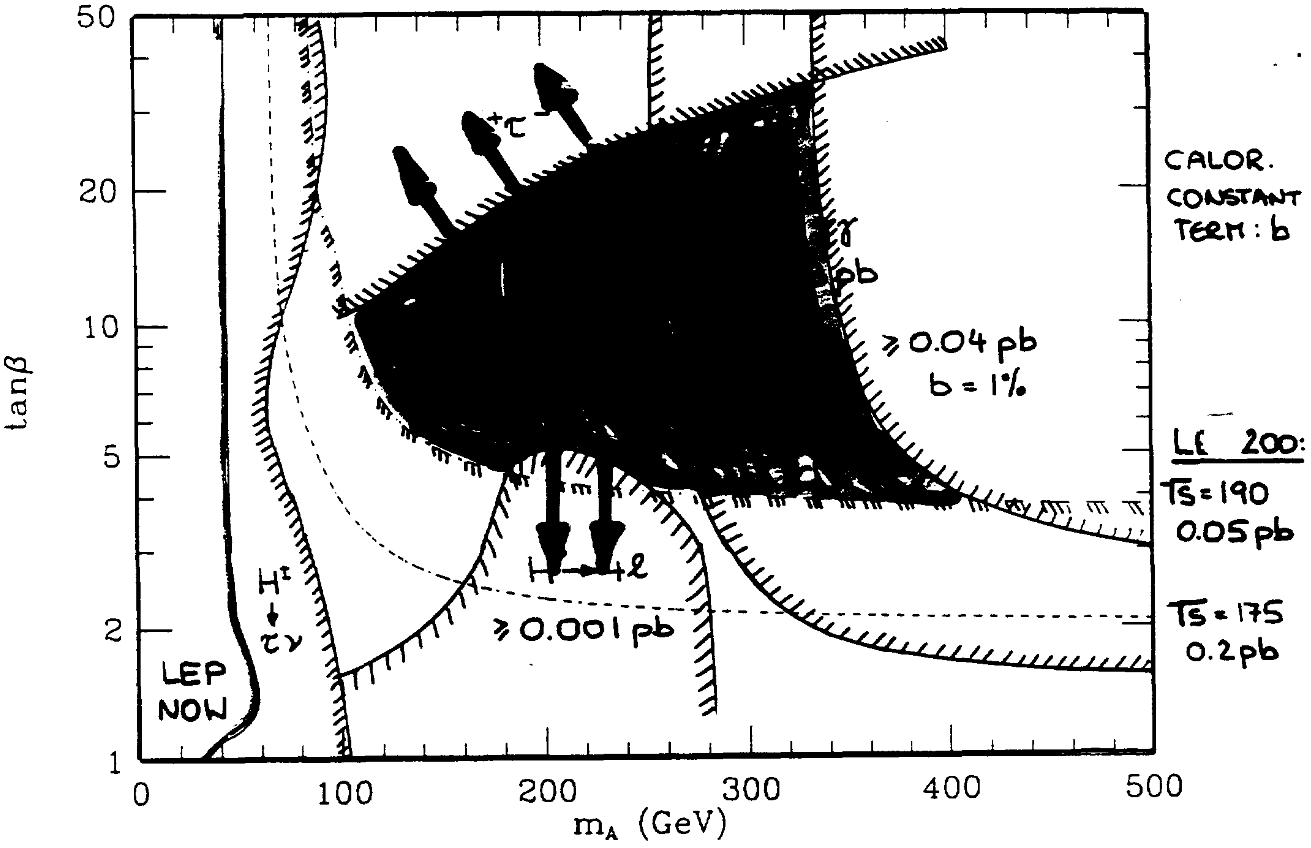


→ IF NO SUSY HIGGS FOUND AT THE LHC WILL NOT BE ABLE TO COMPLETELY EXCLUDE THE MSSM VIA THE HIGGS SECTOR

→ IF A HIGGS → 4 LEPTONS IS FOUND AND CONSISTENT WITH SM σ×BR
→ CANNOT BE SUSY

SUSY HIGGS : OPTIMISTIC SUMMARY

$m_t = 140$ GeV, $m_{\tilde{q}} = 1$ TeV



- ➡ IF NO SUSY HIGGS FOUND AT THE LHC WILL NOT BE ABLE TO COMPLETELY EXCLUDE THE MSSM VIA THE HIGGS SECTOR

- ➡ IF A HIGGS → 4 LEPTONS IS FOUND AND CONSISTENT WITH SM σ×BR
  → CANNOT BE SUSY