LoopFest III
April 1-3, 2004, UC Santa Barbara

Higgs Physics at the LC

Experimental Potential and Theory Issues

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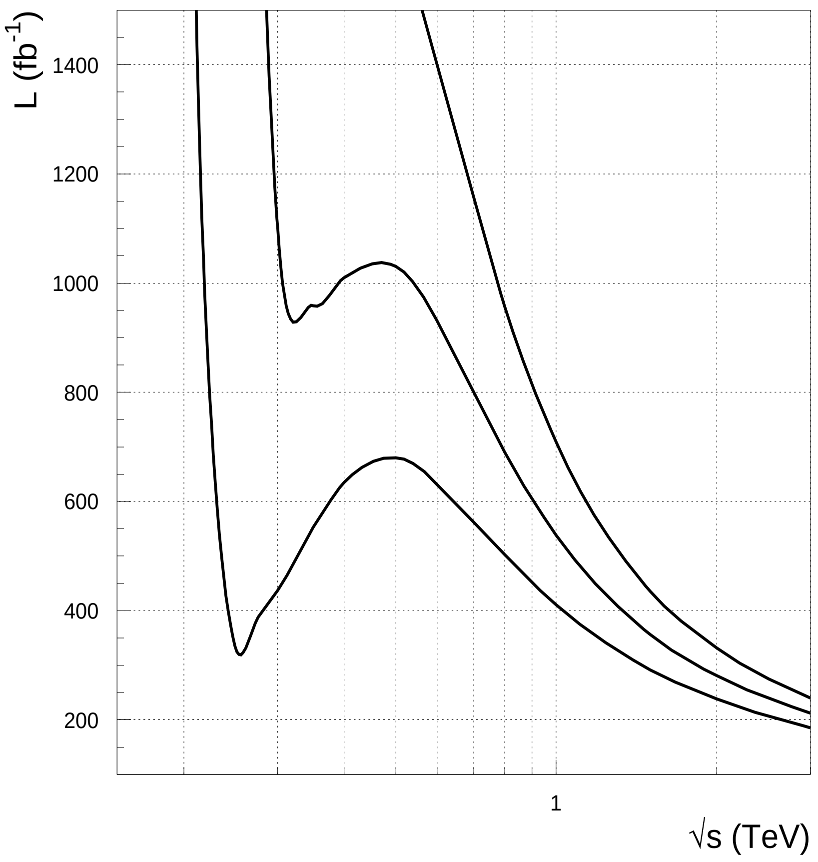
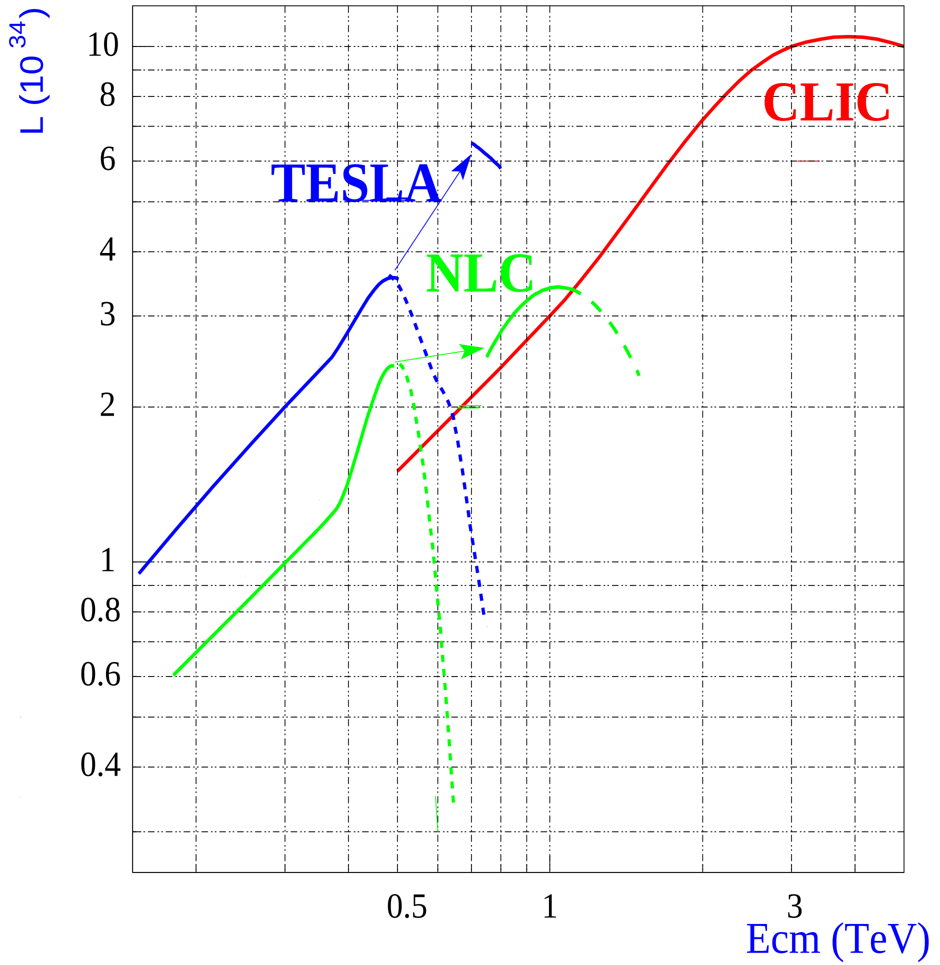
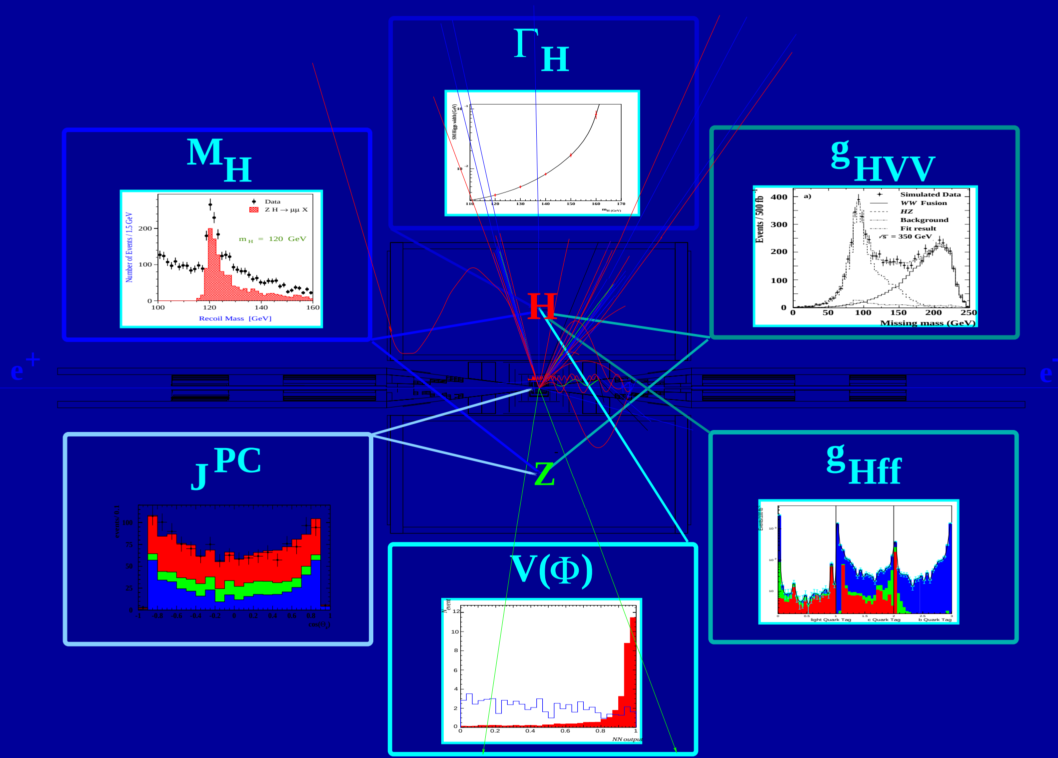
$\int \mathcal{L}$ vs. $\sqrt{s}$ to produce 10^5 H bosons with 120, 180 and 240 GeV Mass



$\mathcal{L}$ vs. $\sqrt{s}$ Scaling for LC Projects



The Higgs Boson Profile



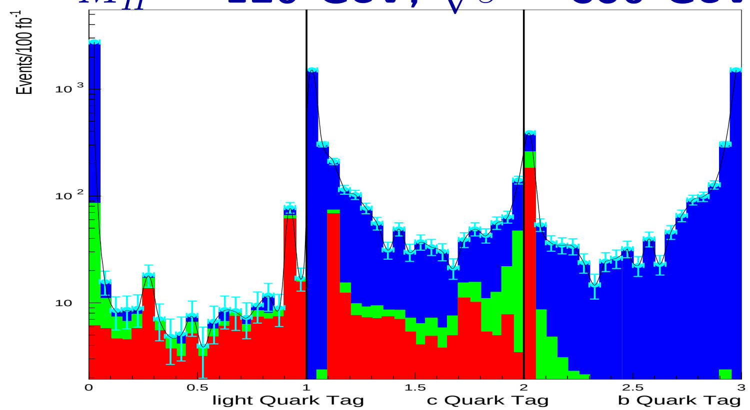
The Generation of Mass
The Quark Sector

$\sqrt{s}$ = 350 - 500 GeV

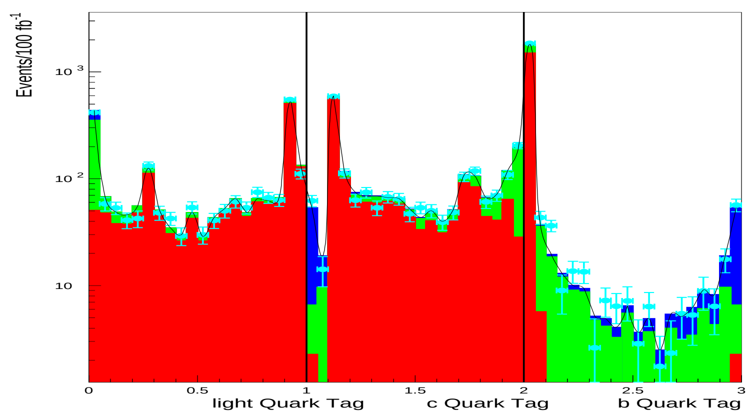
- Compute $u\bar{u} + d\bar{d} + s\bar{s}$, $c\bar{c}$ and $b\bar{b}$ di-jet flavour tagging probs
- Fit hadronic branching fractions:
  - BR($H \to b\bar{b}$)/BR($H \to$ hadrons),
  - BR($H \to c\bar{c}$)/BR($H \to$ hadrons)
  - [BR($H \to gg$)/BR($H \to$had.)]
  - [BR($H \to WW$)/BR($H \to$had.)]
- binned likelihood fit to bkg subtracted di-jet probs:

BR($H(120) \to X$)	δBR/BR TDR	δBR/BR ECFA03
$b\bar{b}$	0.024	0.025
$c\bar{c}$	0.085	0.120
gg	0.055	0.085

M_H = 120 GeV, $\sqrt{s}$ = 350 GeV



M_H = 160 GeV, $\sqrt{s}$ = 350 GeV

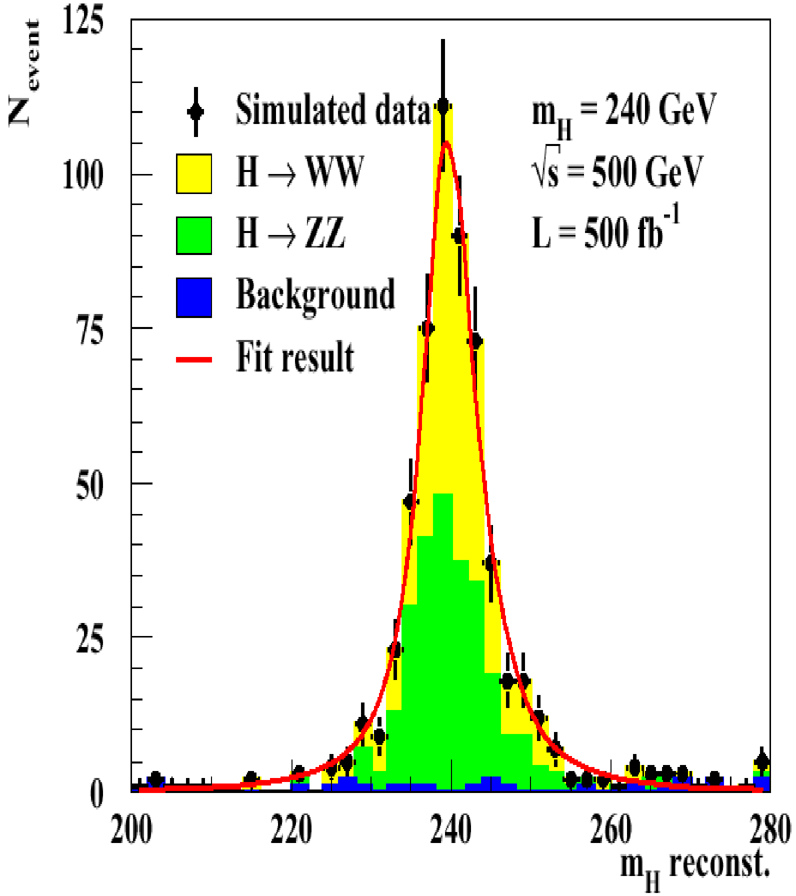


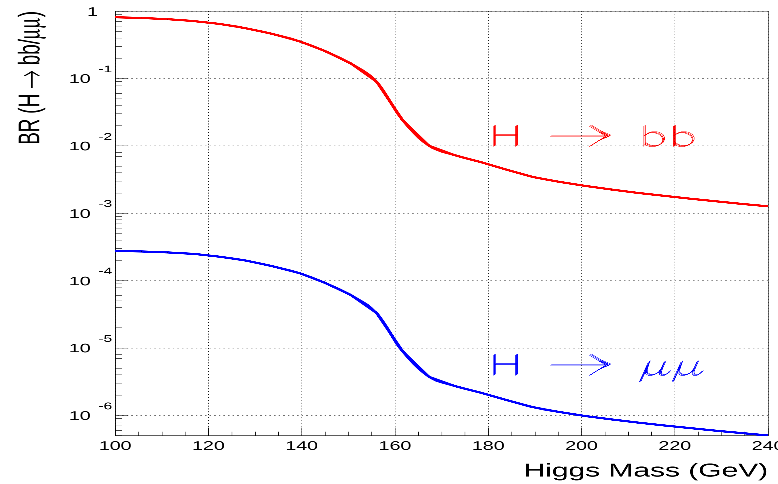
M B hep-ph/9910271
JC Brient, LC-PHSM-2002-003
T. Kuhl, LC Note

What if the Higgs is heavier ?

✧ Analyse $HZ \rightarrow \ell^+\ell^-, q\bar{q}$ recoil mass at 500 GeV and $H\nu\bar{\nu}$ at 800 GeV;

✧ Extract M_H, Γ_H and σ from fit to recoil mass, $H \rightarrow WW$ and ZZ branching fractions from fit to jet-jet mass in HZ and $H \rightarrow b\bar{b}$ in $H\nu\bar{\nu}$:





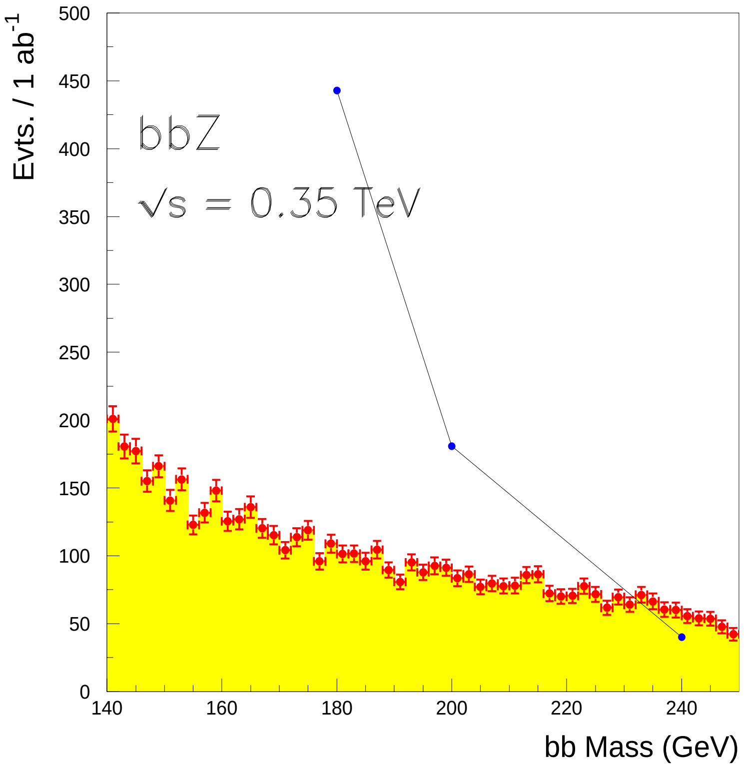
	M_H GeV	$\delta X/X$ LC-500/800
M_H	240	9×10^{-4}
Γ_H	240	0.12
$\sigma(e^+e^- \rightarrow HZ)$	240	0.04
BR($H \rightarrow ZZ$)	240	0.10
BR($H \rightarrow WW$)	240	0.07

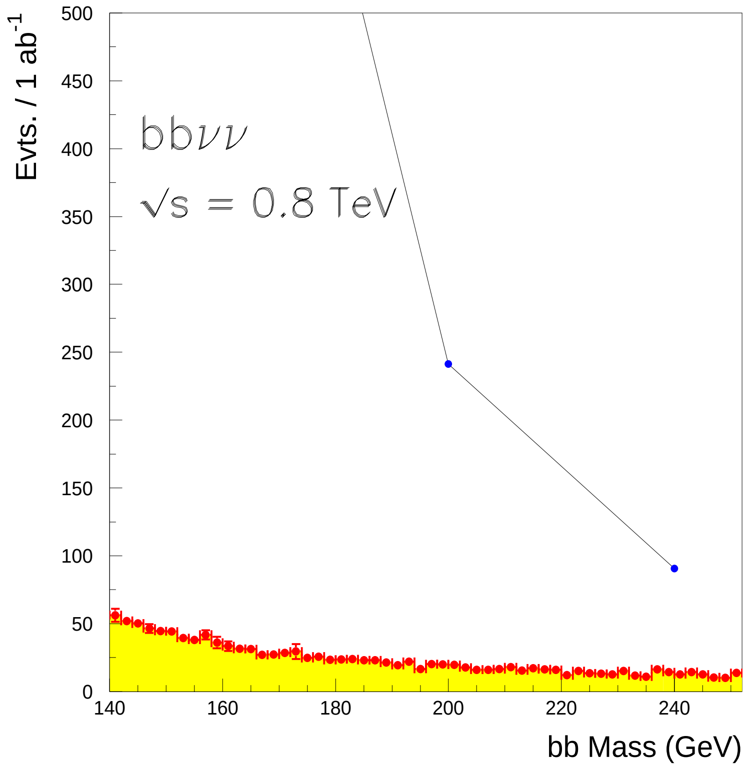
N.Meyer, K.Desch, M.B.

Fermion Couplings

A comparison of $e^+e^- \to HZ$ and $H\nu\bar{\nu}$ Processes

Estimated Bkg and Nb$(H \to b\bar{b})$ for $\int \mathcal{L} = 1$ ab^{-1}





✦ $e^+e^- \to \nu\bar{\nu}H \to b\bar{b}$ at $\sqrt{s} = \mathcal{O}(1$ TeV) promising for probing g_{Hff} for intermediate-mass Higgs boson.

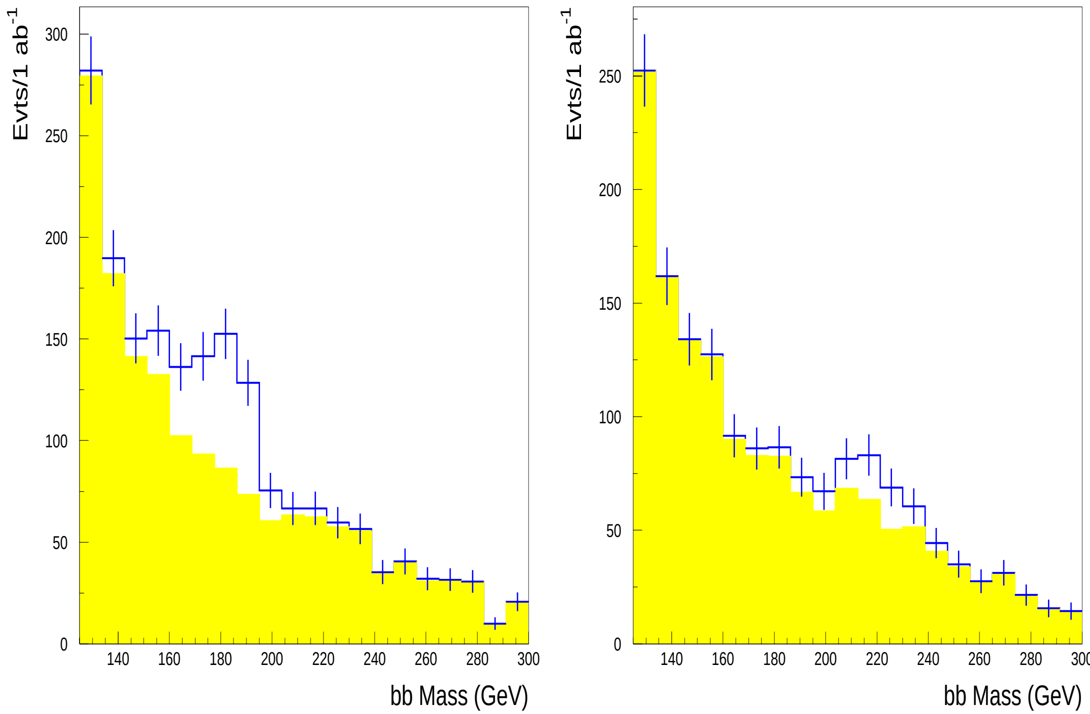
$\sqrt{s}$ = 0.8 TeV
with Unpolarised Beams

$H^0 \to b\bar{b}$ for $\sqrt{s} = 0.8$ TeV
and $\int \mathcal{L} = 1$ ab^{-1}

M_H (GeV)	$S/\sqrt{B}$	δ BR / BR
180	10.5	0.115
200	7.5	0.165
220	4.1	0.275

$e^+e^- \to \nu\bar{\nu}H^0$ at 0.8 TeV

$M_H = 180$ GeV $\qquad M_H = 220$ GeV

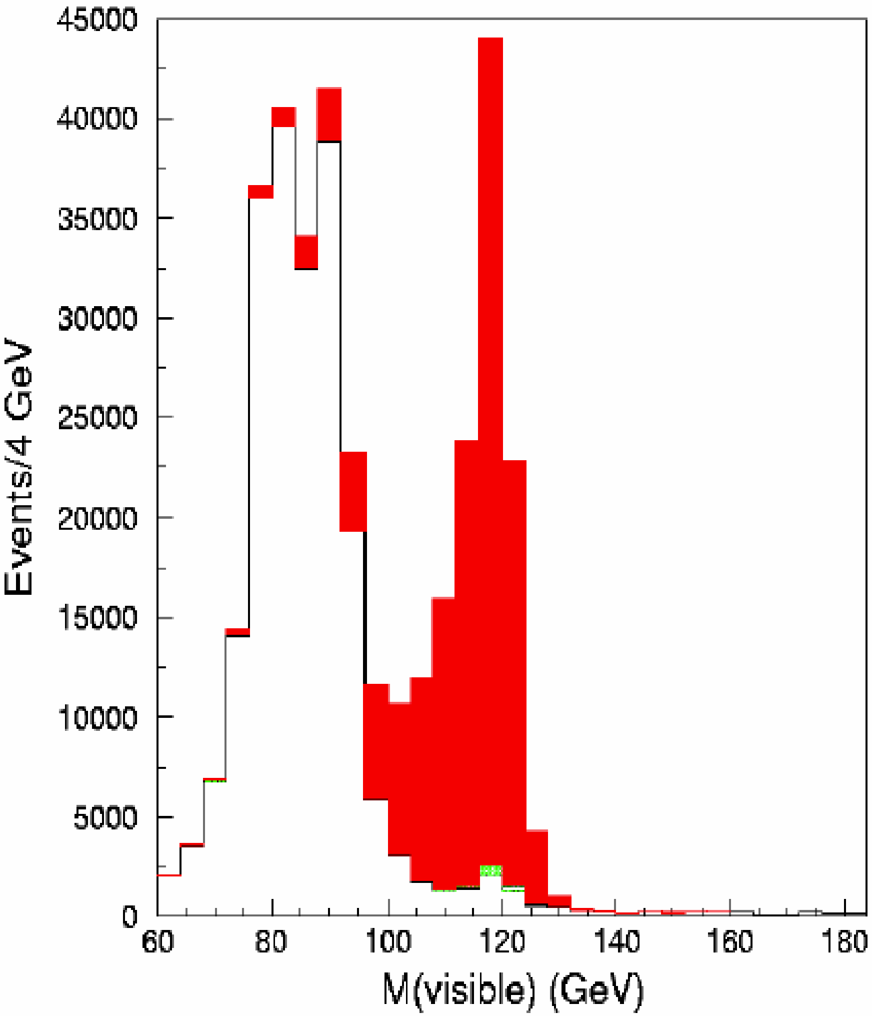


$\sqrt{s}$ = 1.0 TeV with Polarised Beams

✧ Analysis at large $\sqrt{s}$=1 TeV with polarised beams profits of larger cross section and enhanced tagging performances
✧ Since 1 ab^{-1} = 570 k $H(120)$ evts., rare modes become measurable;
✧ Analysis includes full 2, 4, 6, 8 fermion background generated with WHIZARD.

Channel	120	140	160	200
$H^0 \to b\bar{b}$	0.016	0.016	0.020	0.090
$H^0 \to gg$	0.023	0.035	0.146	-
$H^0 \to WW$	0.020	0.018	0.010	0.025

$e^+e^- \to \nu\bar{\nu}H^0 \to b\bar{b}$



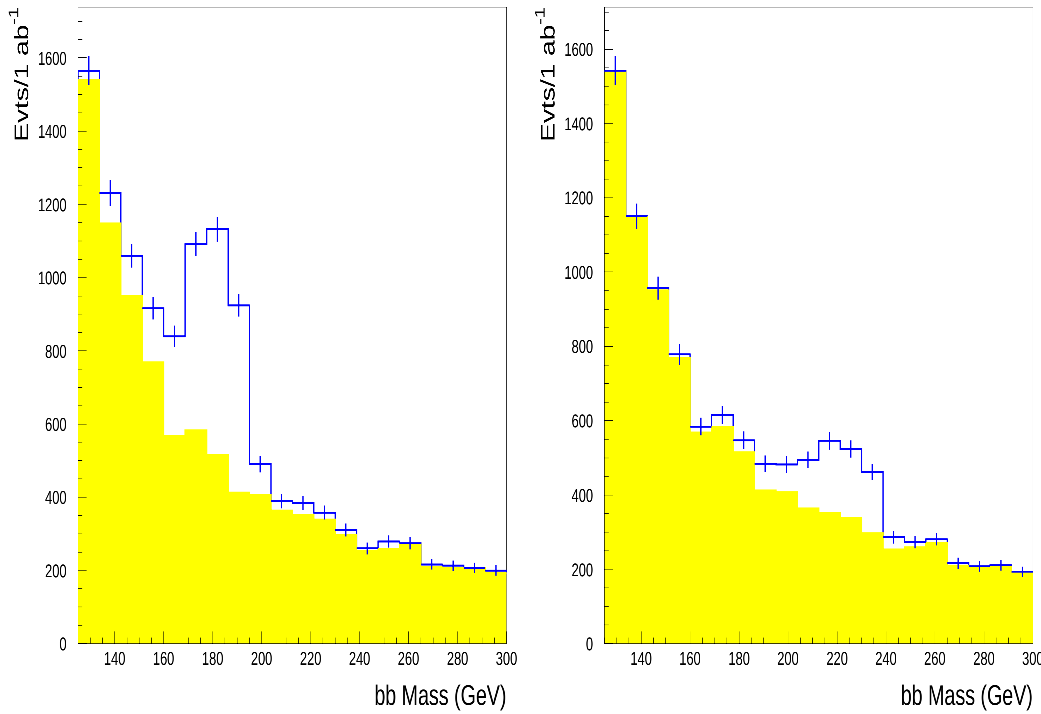
T. Barklow

$\sqrt{s}$ **= 3.0 TeV**
with Unpolarised Beams

$H^0 \to b\bar{b}$ FOR $\sqrt{s} = 3.0$ TEV
AND $\int \mathcal{L} = 3$ AB^{-1}

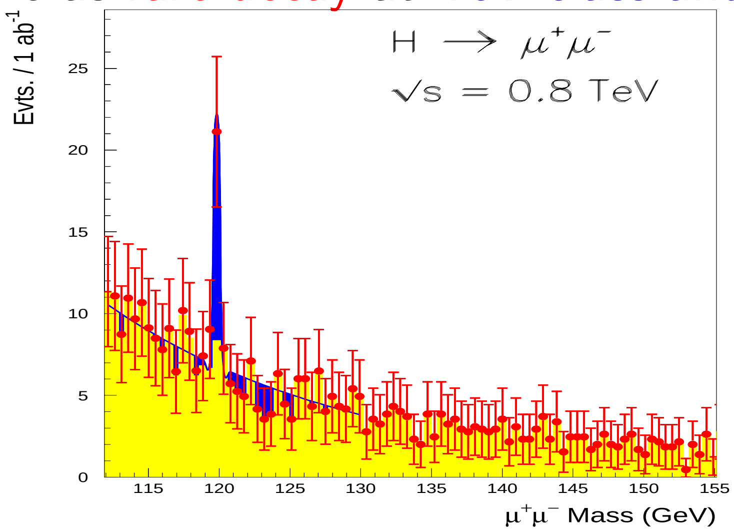
M_H (GeV)	$S/\sqrt{B}$	δ BR / BR
180	40.5	0.033
200	25.0	0.051
220	18.0	0.069

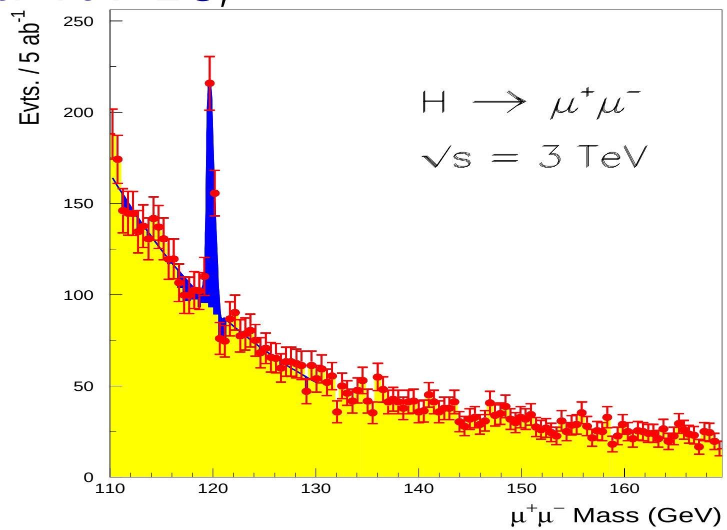
$e^+e^- \to \nu\bar{\nu}H^0$ AT 3.0 TEV
$M_H = 180$ GeV $M_H = 220$ GeV



The Generation of Mass
The Lepton Sector

✧ BR($H \to \tau^+\tau^-$) with τ-id based on multiplicity and kinematics; BR($H \to \mu\mu$) observable as rare decay at TeV-class and multi-TeV LC;





M_H	120 GeV	140 GeV	150 GeV
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (at 0.5 TeV)	0.027	0.050	
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (at 0.8 TeV)	0.150	-	-
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (at 3.0 TeV)	0.035	0.060	0.105

M B, hep-ph/9910271 and JC Brient, LC Note   M B and A De Roeck, hep-ph/0111307

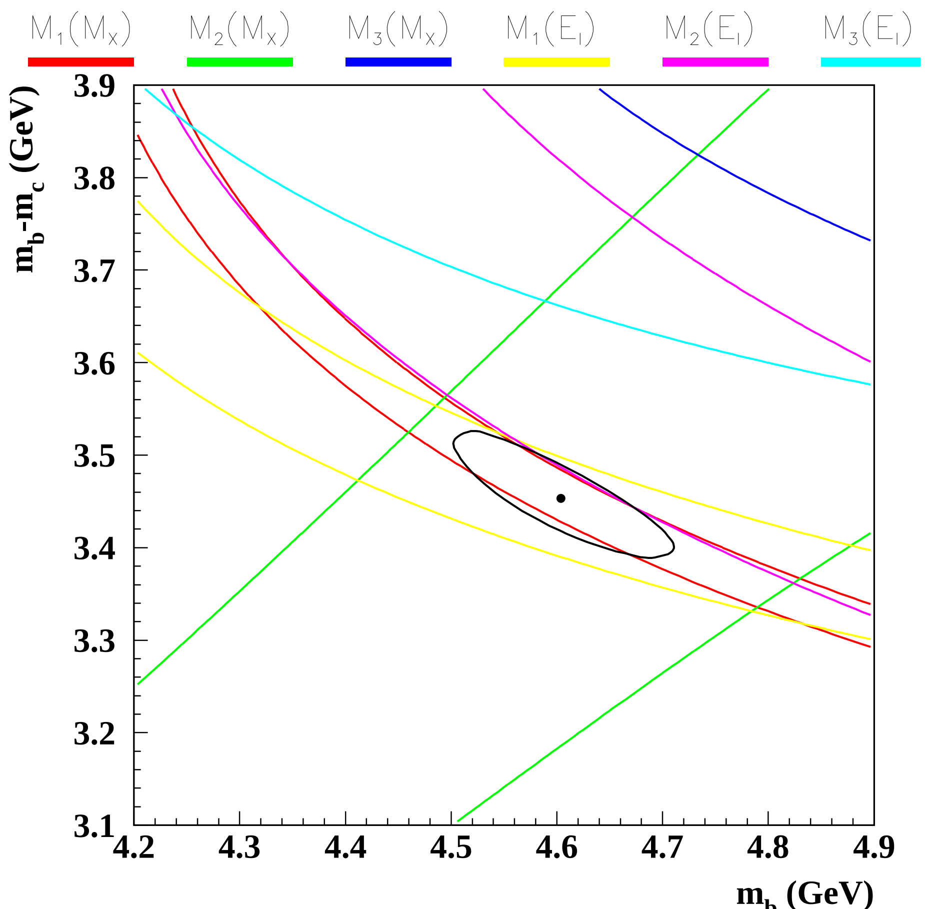
✧ Test $g_{H\mu\mu}/g_{H\tau\tau}$ coupling ratio to **0.05-0.08** accuracy at multi-TeV LC, compared to **0.03-0.04** at FMC for $120 < M_H < 140$ GeV.

The Quark Masses

✦ Recent progress in determination of heavy quark masses using moments of spectral distribution in s.l. b decays will make possible a significant reduction in m_Q uncertainties from B-factory and CDF data;

	$\delta m_Q/m_Q$
m_b	90 $\rightarrow$ 50 MeV
m_c	150 $\rightarrow$ 100 MeV
$m_b - m_c$	60 $\rightarrow$ 40 MeV

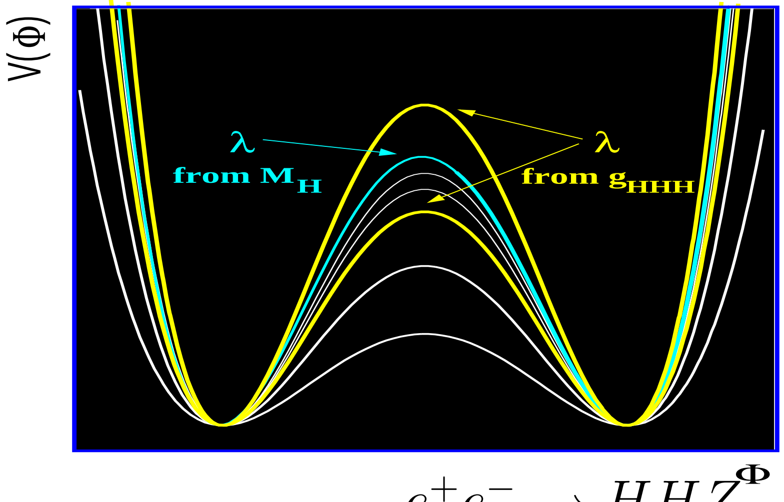
BR	δ BR/BR
$H^0 \rightarrow b\bar{b}$	1.7 $\rightarrow$ 1.0 %
$H^0 \rightarrow c\bar{c}$	21. $\rightarrow$ 9.5 %



M.B. et al, PLB556

Reconstruction of the Higgs Potential

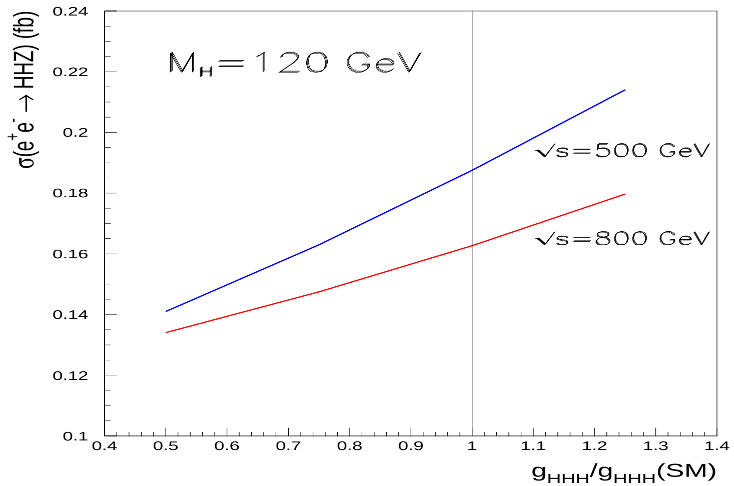
✦ Fundamental test of shape of Higgs potential through independent determination of g_{HHH} in double Higgs production (HHZ and $HH\nu\nu$):



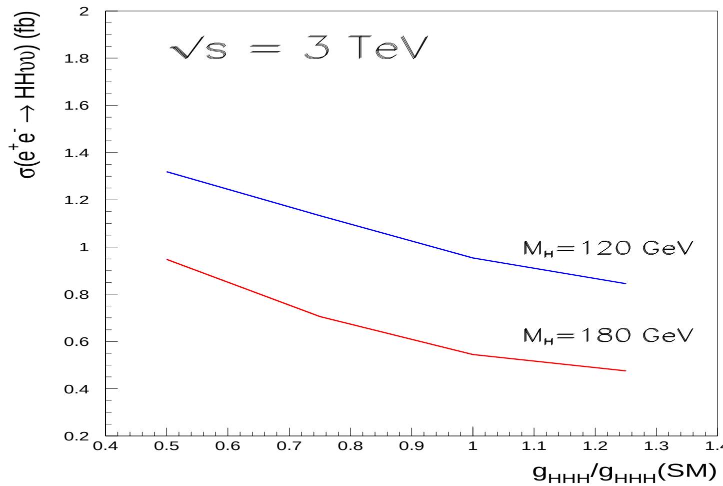
$$V(\Phi^*\Phi) = \lambda(\Phi^*\Phi - \frac{1}{2}v^2)^2$$

$$g_{HHH} = \frac{3}{2}\frac{M_H^2}{v}$$

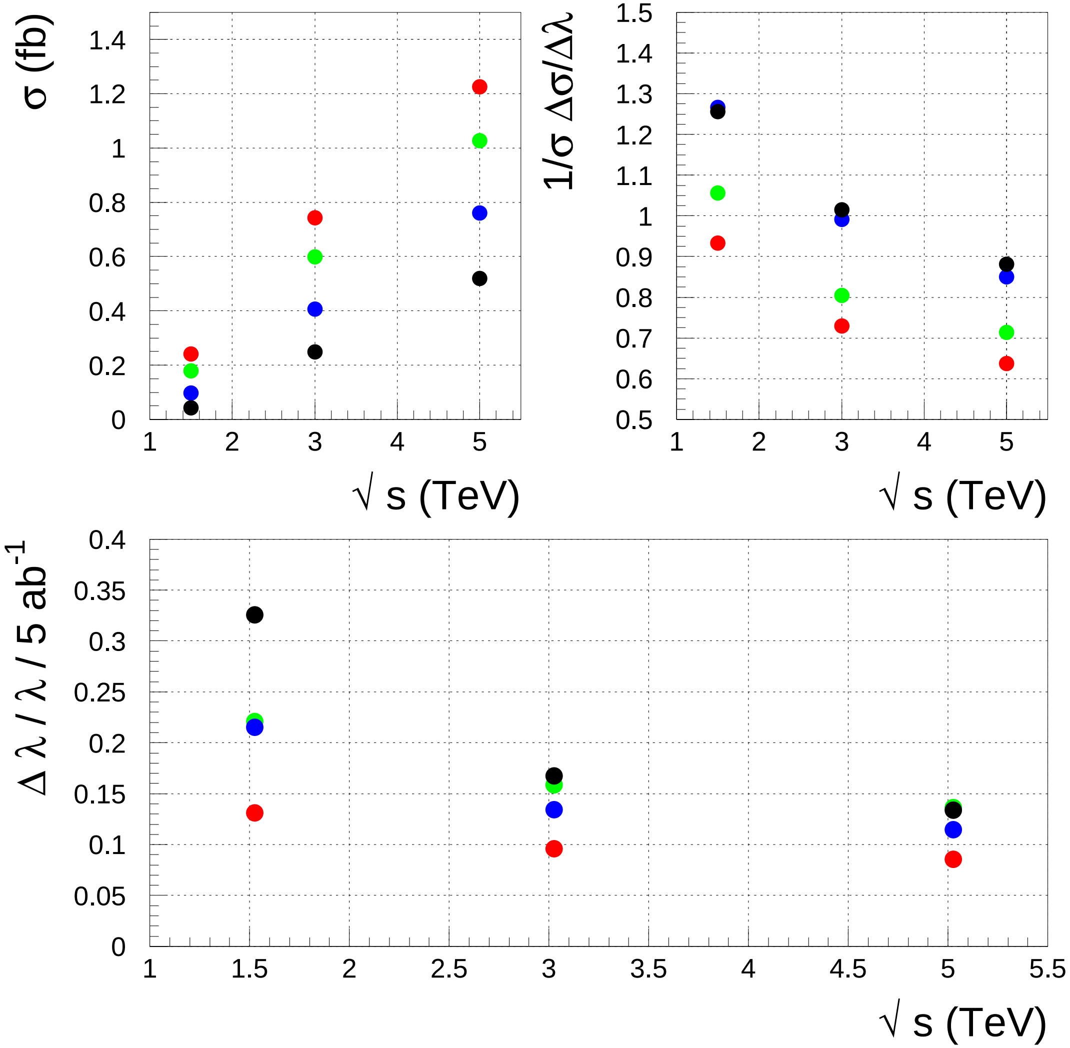
$e^+e^- \to HHZ$



$e^+e^- \to HH\nu\nu$



SCALING OF $e^+e^- \to \nu\bar{\nu}HH$ SENSITIVITY



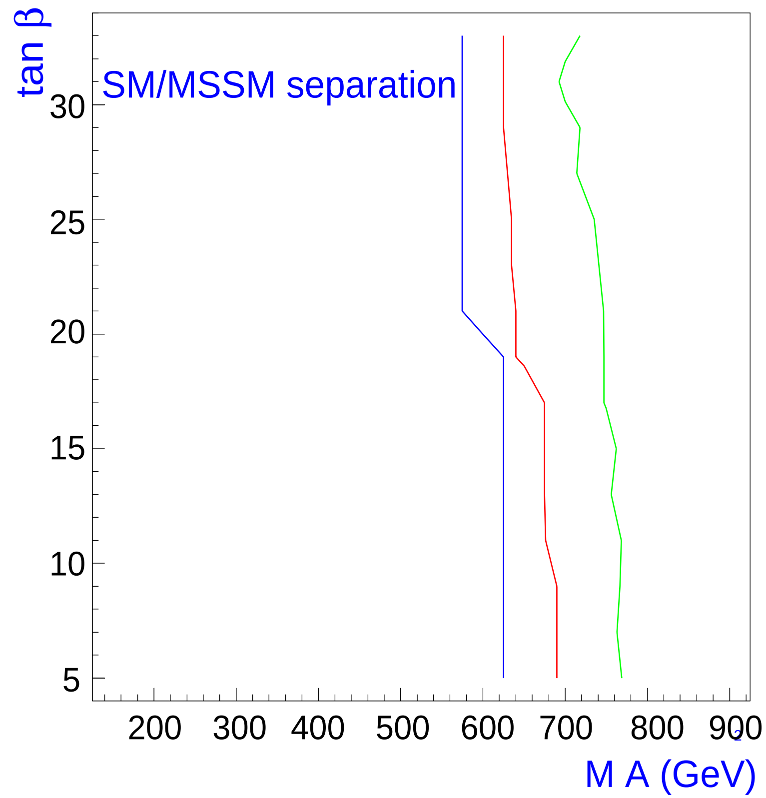
Telling a SUSY Higgs from the SM H^0

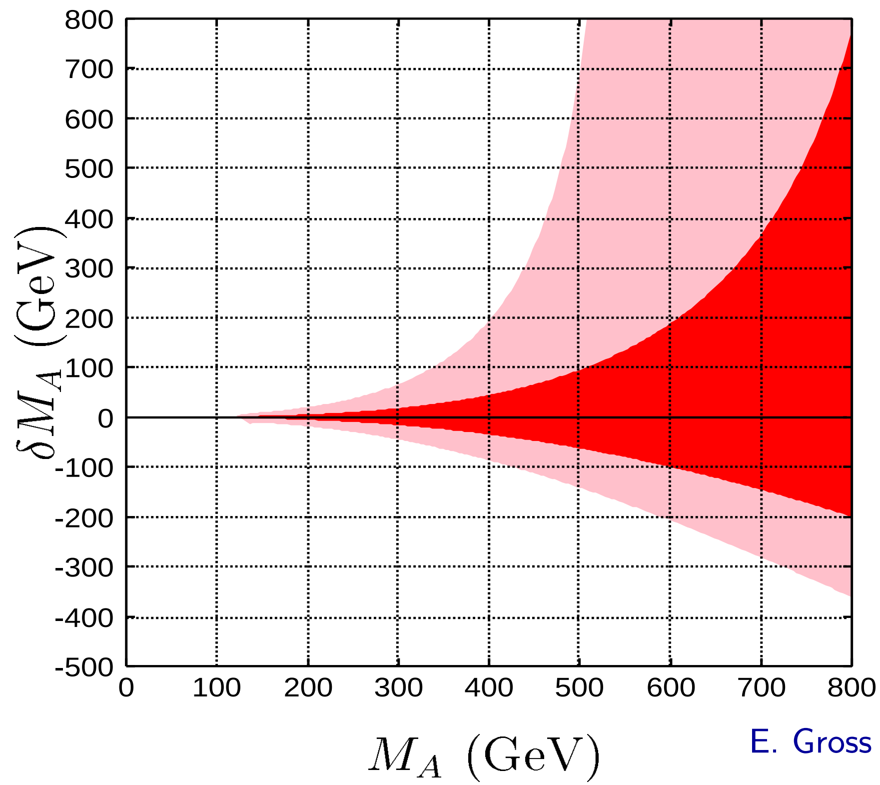
✧ Higgs couplings to fermions may reveal its SM or SUSY nature:

$$\text{SM:} \quad \frac{g_{Hf\bar{f}}}{g_{Hf'\bar{f}'}} \propto \frac{m_f}{m_{f'}}$$

✧ in SUSY couplings to up-like and down-like fermions shifted w.r.t. their SM predictions:

$$\text{MSSM:} \quad \frac{BR(h \to f_u \bar{f}_u)}{BR(h \to f_d \bar{f}_d)} \propto \frac{1}{tan^2\alpha \tan^2\beta} \simeq \frac{(M_h^2 - M_A^2)^2}{(M_Z^2 + M_A^2)^2}$$



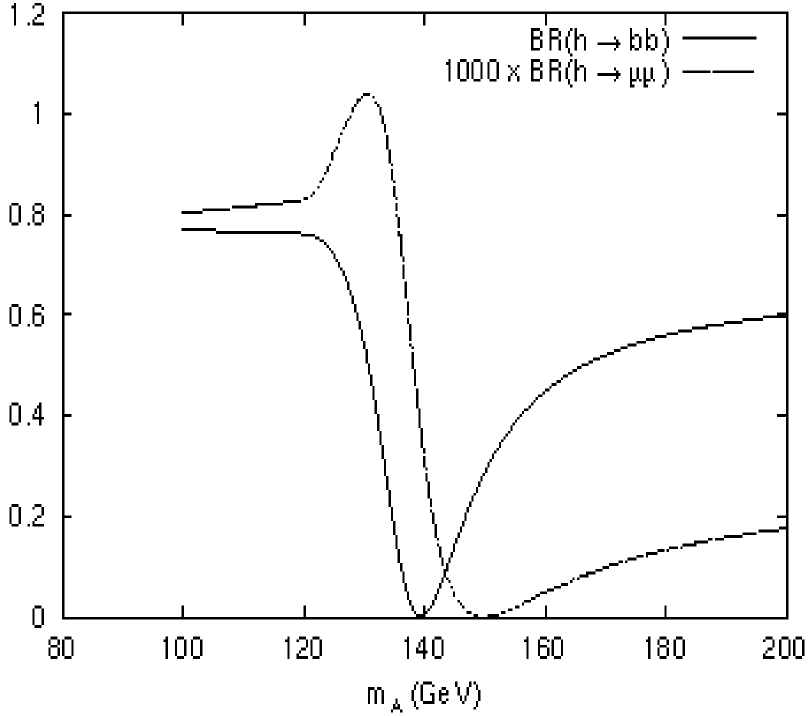


E. Gross

✧ SUSY sbottom-gluino and stop-higgsino loops induce a shift of the effective b-quark mass in the hbb couplings:

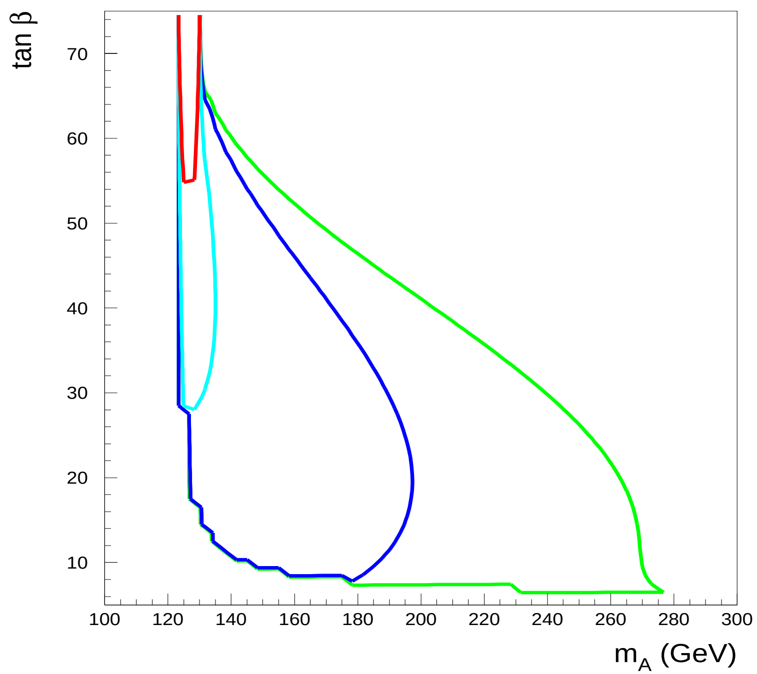
$$\Delta m_b \propto \mu\ M_{\tilde{g}}\ \tan\beta\ f(M_{\tilde{b}_1}, M_{\tilde{b}_2}, M_{\tilde{g}})$$

BR($h \to b\bar{b}$, $\mu\mu$) vs. M_A



M.Carena

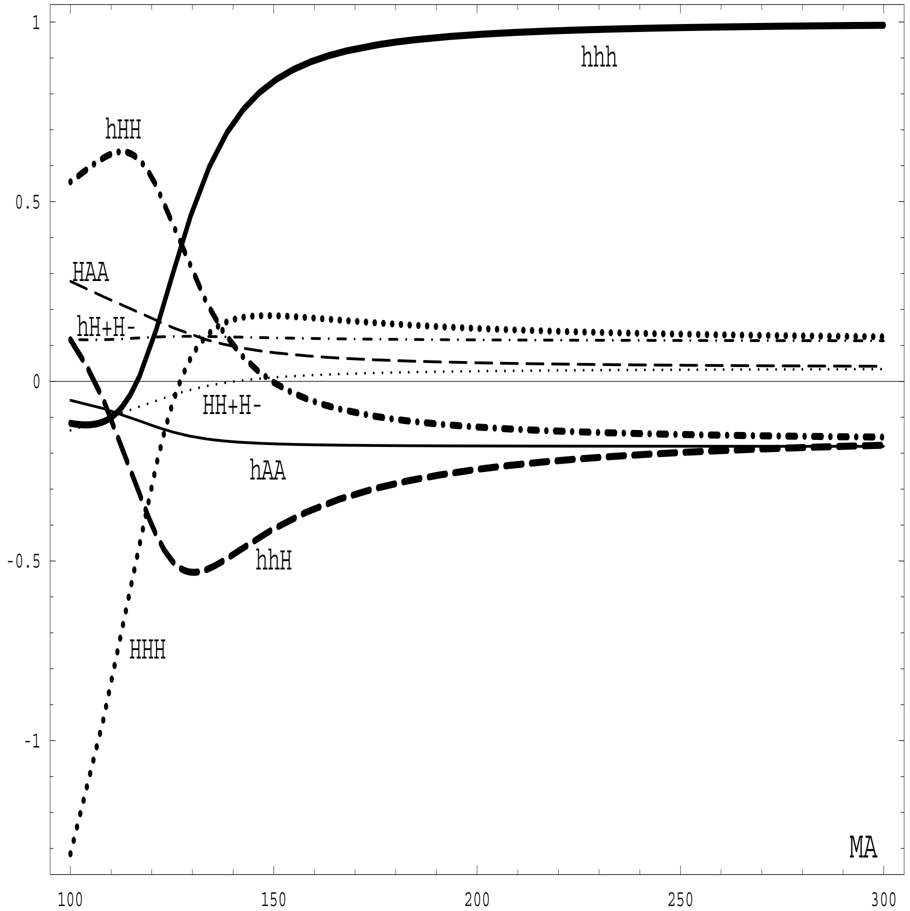
$BR(h \to \mu\mu)$/BR$_{SM}$



M.B., M.Spira

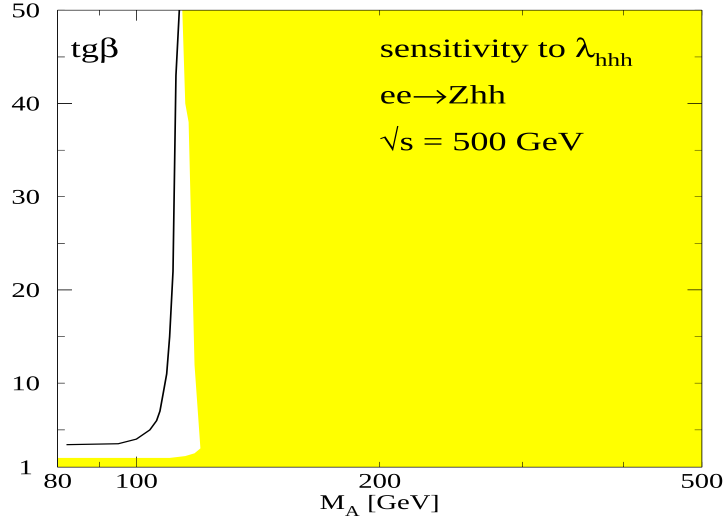
SUSY Higgs Self-Couplings

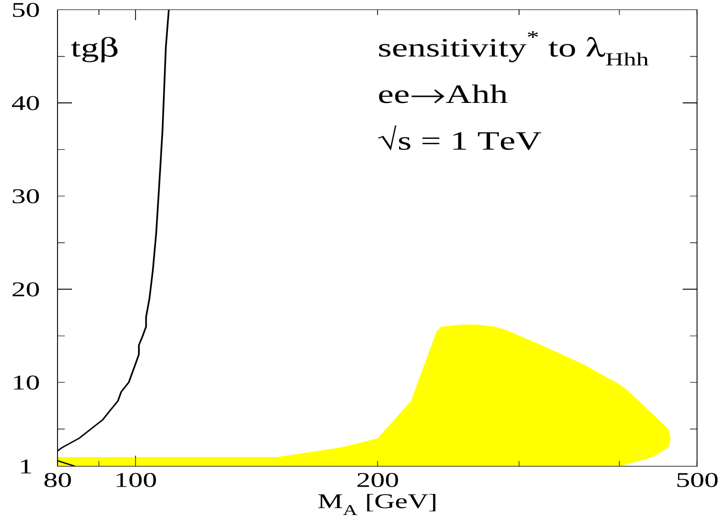
MSSM Higgs Self Couplings Normalized to SM g_{HHH}



F.Boudjema, A.Semenov hep-ph/0201219

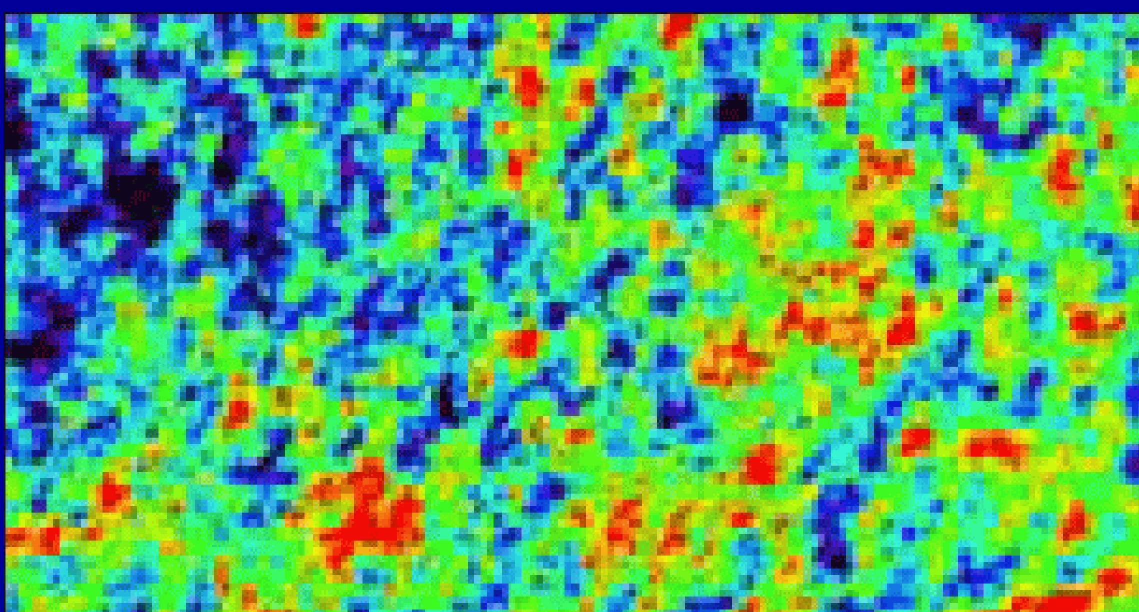
Regions of LC Sensitivity





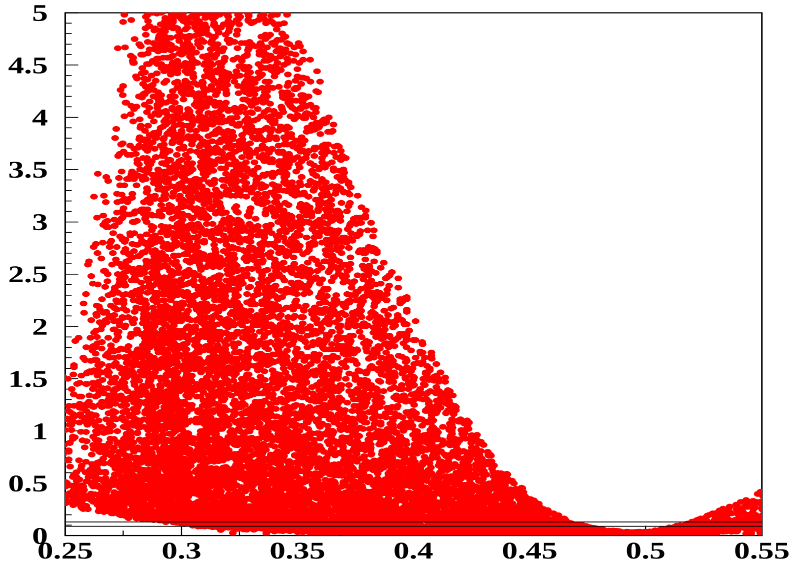
A.Djouadi *et al.* hep-ph/0001169

Heavy SUSY Higgs Bosons and Cosmology

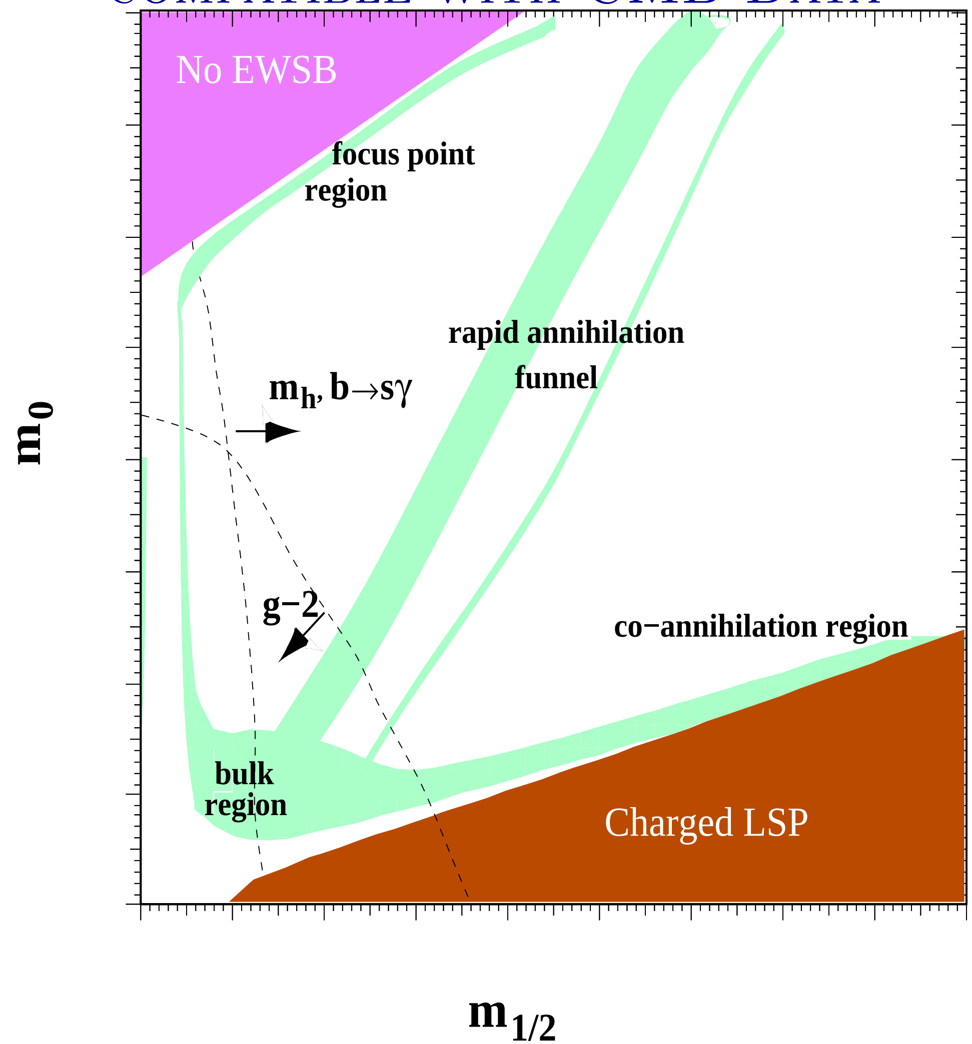


✦ Retaining the LSP as dark matter candidate in presence of the LEP-2 search limits requires to investigate specific $\chi\chi$ annihilation mechanism to restore agreement with WMAP data;

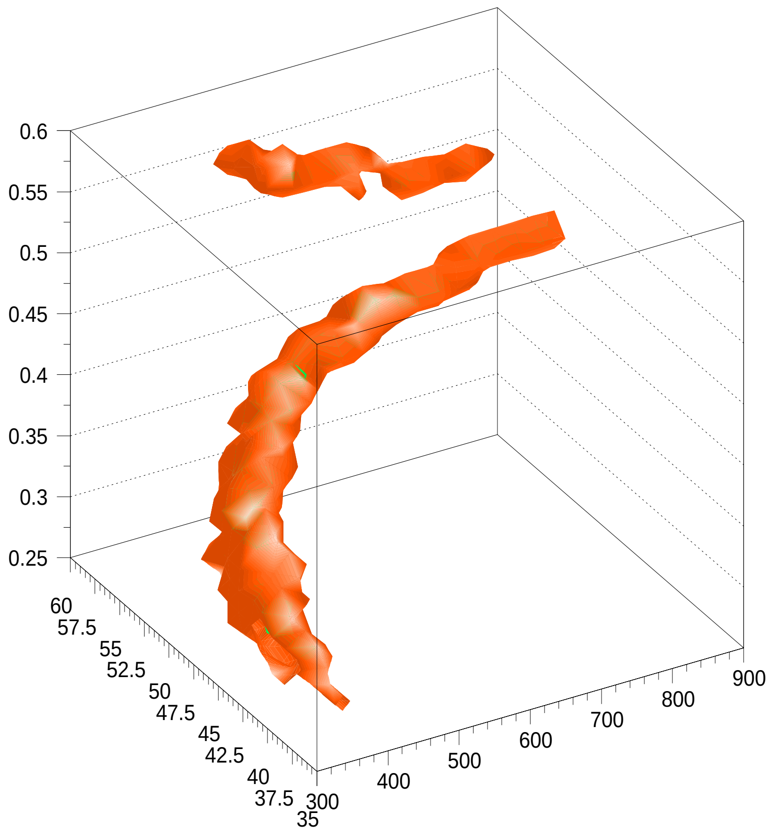
✦ the process $\chi\chi \to A^0$ at large $\tan\beta$ offers a possible solution and will require accurate determinations of the χ_1^0 and A^0 masses and of $\tan\beta$ to verify consistency with Cosmology data;

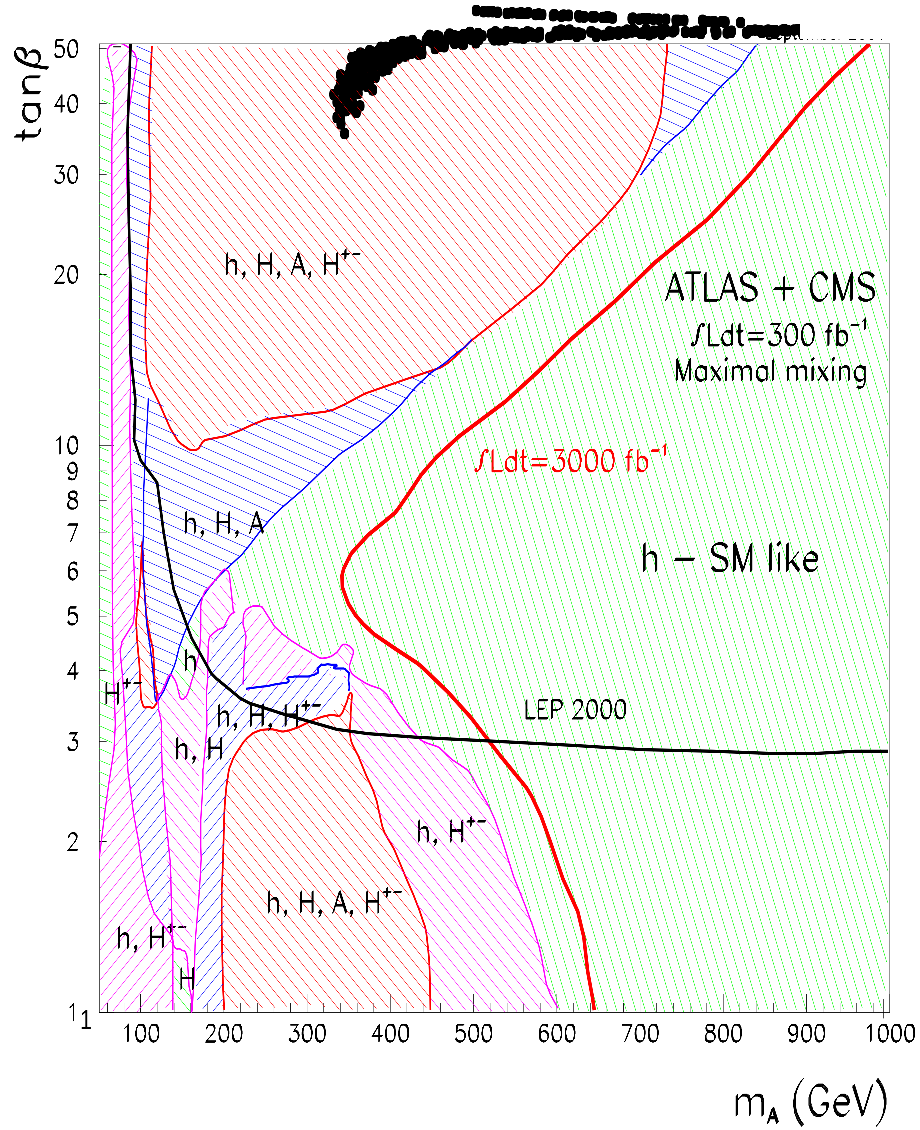


Generic cMSSM Regions compatible with CMB Data



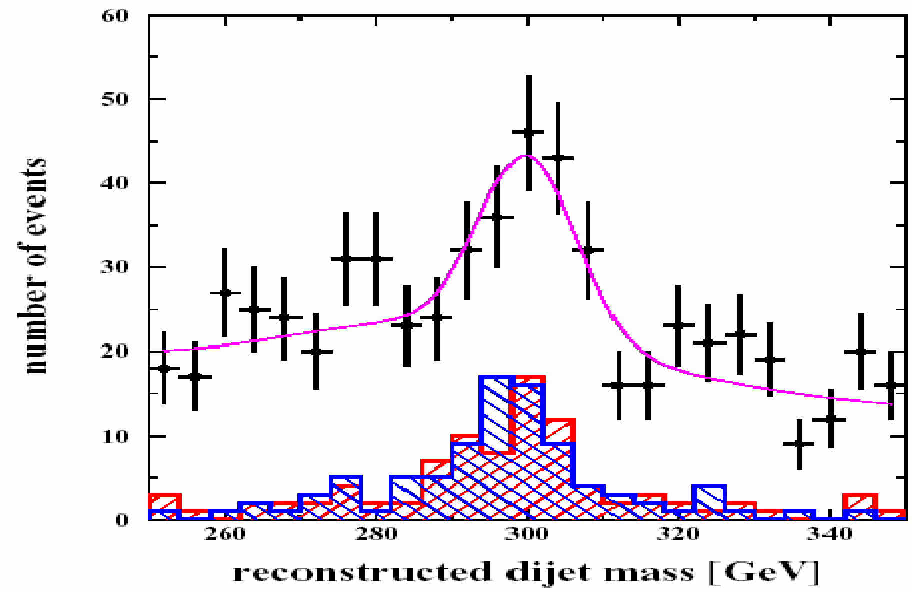
$\tan\beta$ vs. m_0 vs. $m_{1/2}$
WMAP Parameter Region
for A=0 and $\mu > 0$



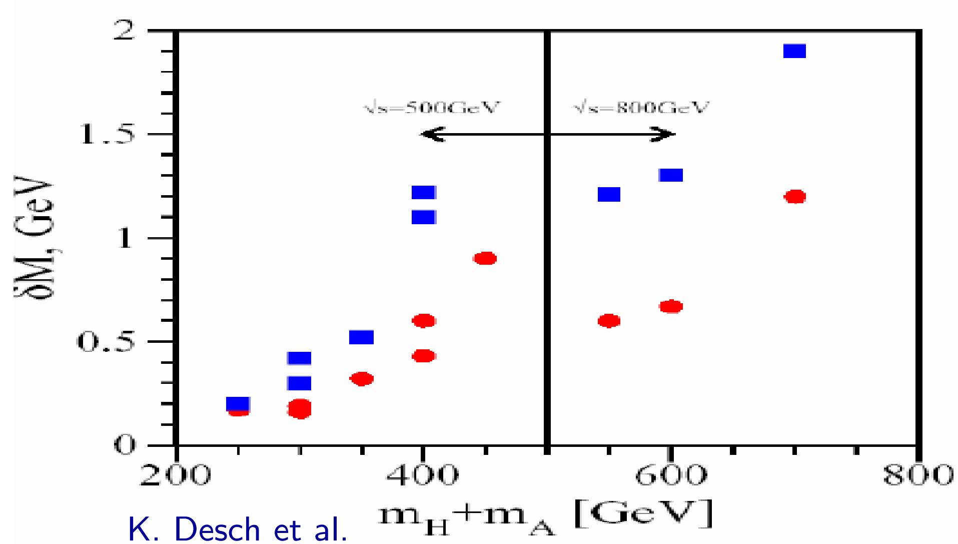


✦ With $\mathcal{O}$ (2000 evts) ab^{-1} the LC should measure masses of heavy Higgs bosons to few MeV and $\sigma\times$ BR to 5-10%, when kinematically accessible;

✧ Decay $A^0 \rightarrow \chi\chi$ can be investigated and the H^0, A^0 total width estimated for large $\tan\beta$, branching fractions in $b\bar{b}$ and $\tau^+\tau^-$ can also be measured.



Precision on mass:



K. Desch et al.

Higgs Bosons in Extra-Dimensions

Higgs-Radion Mixing

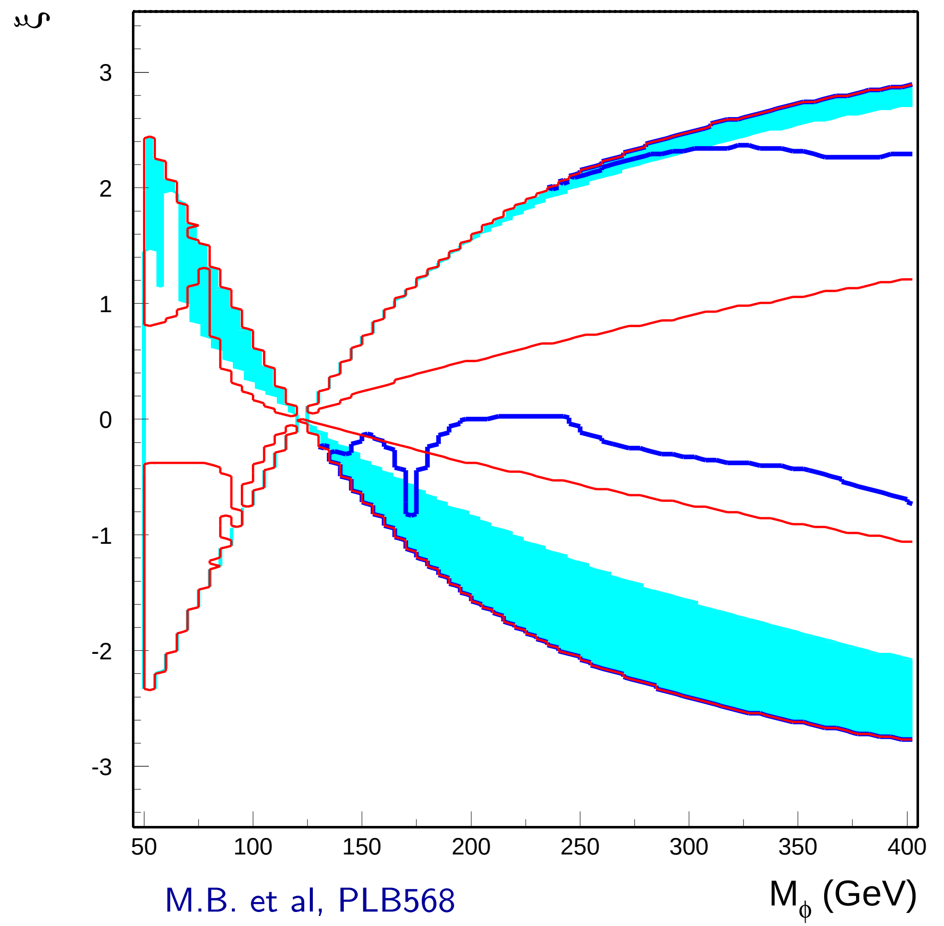
✦ Randall-Sundrum models with 3+1 branes separated in a fifth dimension, predict the existence of a radion graviscalar, ϕ;

✦ through its mixing with the Higgs field the radion modifies the Higgs phenomenology and opens interesting scenarios for direct and indirect detection at LHC and LC;

✦ LC should guarantee observation of both the h and the ϕ even in most of the regions within which detection of either at the LHC might be difficult;

✦ At LC there would be enough measurements and sufficient accuracy to detect Higgs-radion mixing for moderate to large ξ values.

INDIRECT RADION DETECTABILITY (LHC, LC)

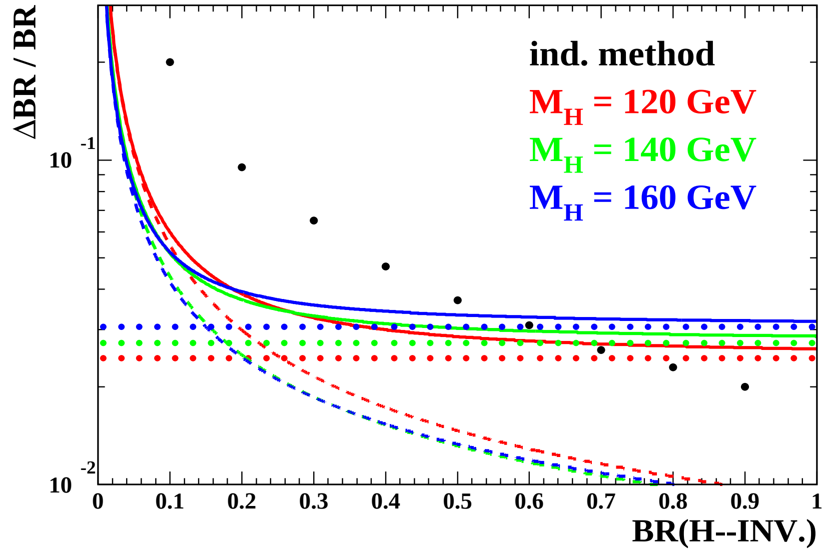


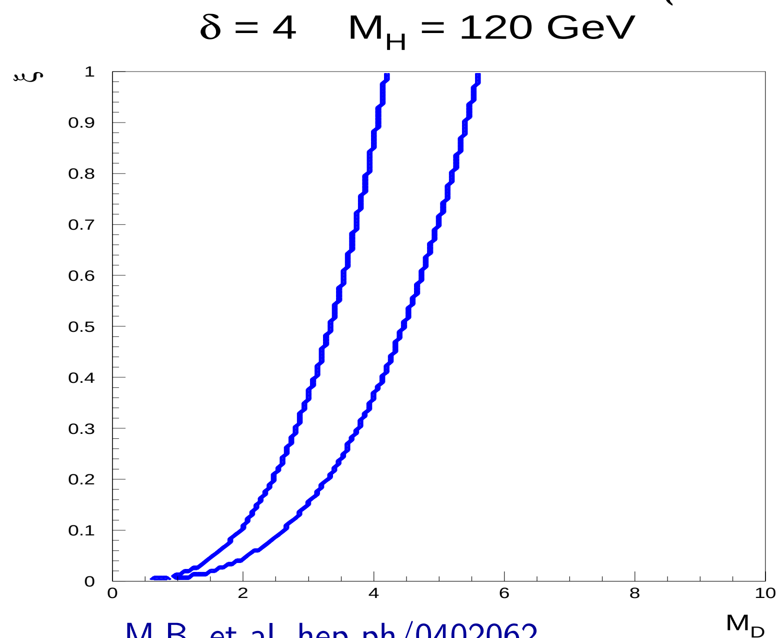
Invisible Higgs Decay

✦ In the ADD model, the mixing width $\Gamma_{h\to graviscalar} \sim G(M_H^2)/M_H$ corresponds to an invisible decay width, thus perturbing the SM branching fractions;

✦ the LHC should be able to detect the invisible deacy signal for a large portion of the Higgs-graviscalar mixing (ξ) and effective Planck mass (M_D) parameter space where channels relying on visible Higgs decays fail to achieve a $5\ \sigma$ signal;

✦ at the LC, the accuracy in determining the invisible decay width would establish an independent constraint on the M_D, ξ and δ parameters.





M.B. et al, hep-ph/0402062