M_A determination from the Higgs branching ratios with full parametric uncertainties

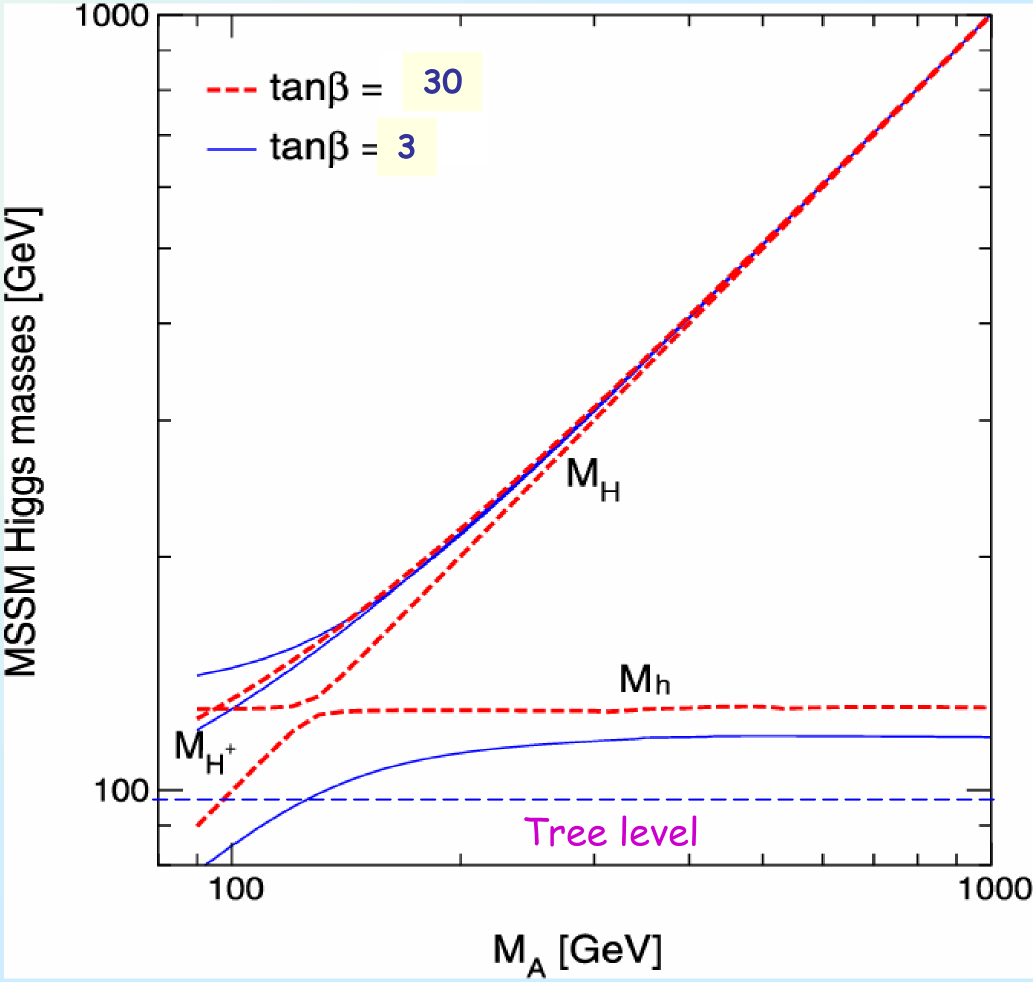
K. Desch, E. Gross, S. Heinemeyer, G. Weiglein, L. Živković

Introduction: MSSM at the Tree Level

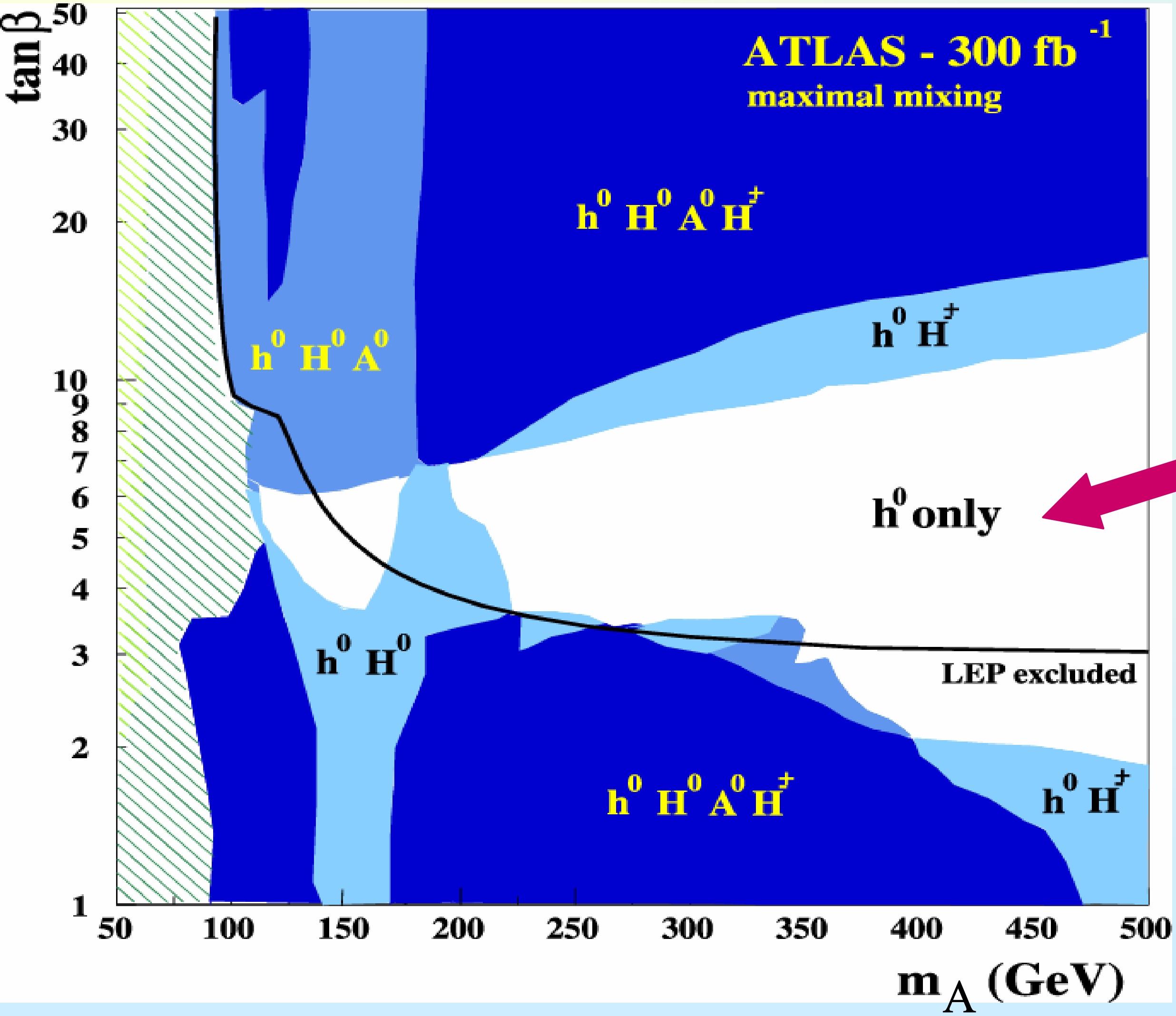
- Two complex scalar doublets in MSSM $\Rightarrow$ five physical states: h, H, A and $H^{\pm}$
- The Higgs sector of the MSSM is fully determined at the lowest order by only two parameters: M_A and $\tan\beta = v_2/v_1$. Both can be determined if the heavy Higgs bosons are observed
- The decoupling limit corresponds to $M_A \gg M_Z \Rightarrow$ the properties of the light CP-even Higgs boson approach those of SM Higgs boson
- The phenomenology of the light CP-even Higgs boson can be predicted if experimental results on the heavy Higgs are available

Introduction - Cont.

- The tree-level upper bound on the mass of the lightest Higgs boson is $m_h < m_Z$
- In real life we need to take into account large radiative corrections in particular from top/stop sector (sbottom for large tanβ also) that can push mass of the light Higgs boson up by about 50%
- Observed deviations in the Higgs sector can no longer be attributed to a single parameter



Is it a SM or an MSSM Higgs Boson?



- After LHC we may find several Higgs bosons…
- or we may find just one
- If we find one can we say if it is SM or MSSM?
- If yes, can we constraint M_A?
- If we see several, what can we say about a specific MSSM model?

SM vs MSSM Higgs Couplings

- Already at the tree-level couplings of the Higgs boson are changed compared to the SM Higgs $g_{MSSM} = g_{SM} \cdot f(\alpha, \beta)$

$f(\alpha,\beta)$	Down type fermions	Up type fermions	Gauge bosons
h	$-\sin\alpha/\cos\beta$	$\cos\alpha/\sin\beta$	$\sin(\beta-\alpha)$
H	$\cos\alpha/\cos\beta$	$\sin\alpha/\sin\beta$	$\cos(\beta-\alpha)$
A	$-i\gamma_5\tan\beta$	$-i\gamma_5\cot\beta$	0

- Radiative corrections to the CP-even Higgs mixing angle α can have significant effect on Higgs boson couplings

Tree Level

- Simple approach – tree level:

$$BR(bb) = \frac{\Gamma(h \to \bar{b}b)}{\Gamma_{TOT}}$$

$$BR^{SM}(bb) = \frac{\Gamma^{SM}(h \to \bar{b}b)}{\Gamma^{SM}{}_{TOT}}$$

$$r_b = \frac{\Gamma(h \to \bar{b}b)}{\Gamma_{SM}(h \to \bar{b}b)} = \frac{\sin^2\alpha}{\cos^2\beta};$$

$$BR(WW) = \frac{\Gamma(h \to WW)}{\Gamma_{TOT}}$$

$$BR^{SM}(WW) = \frac{\Gamma^{SM}(h \to WW)}{\Gamma^{SM}{}_{TOT}}$$

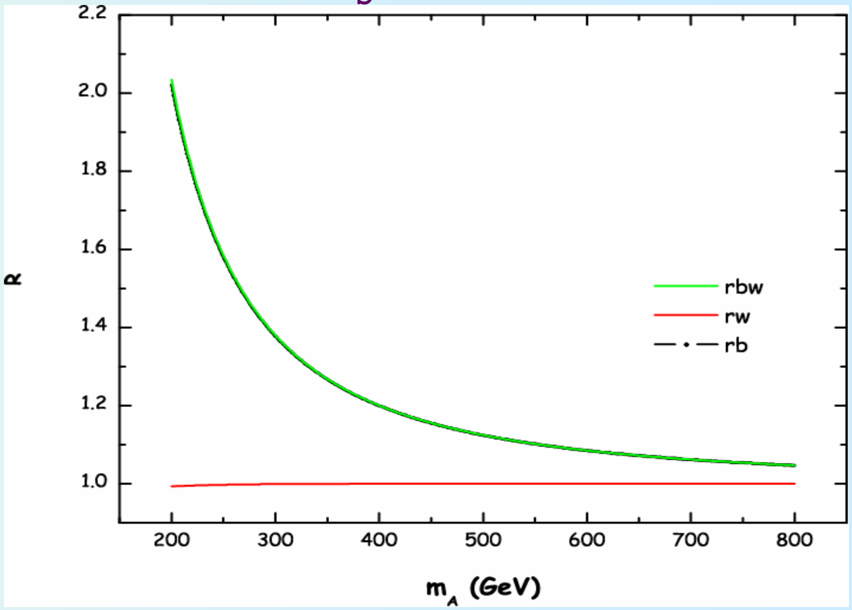
$$r_W = \frac{\Gamma(h \to \overline{W}W)}{\Gamma_{SM}(h \to \overline{W}W)} = \sin^2(\beta - \alpha)$$

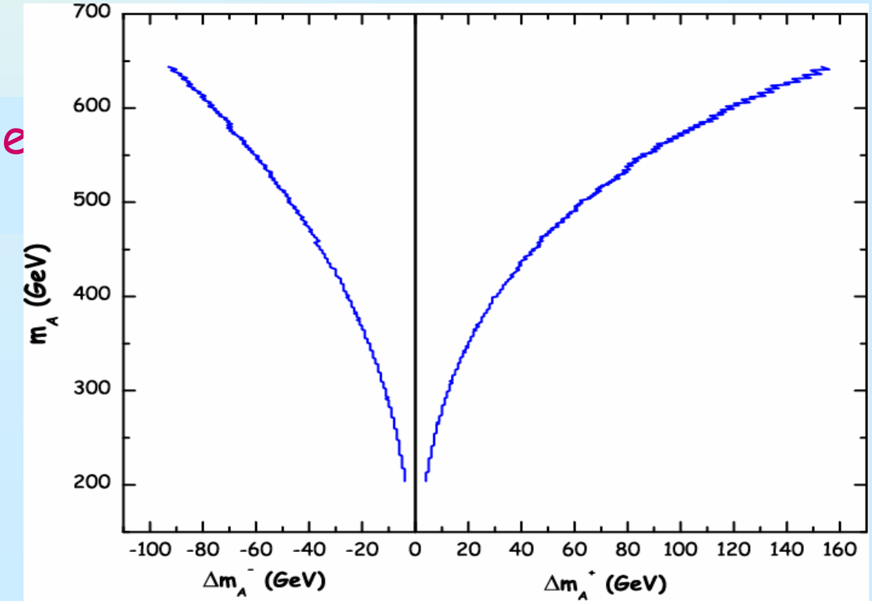
$$r = \frac{r_b}{r_W} = \frac{BR(bb)/BR^{SM}(bb)}{BR(WW)/BR^{SM}(WW)} = \frac{\Gamma_{bb}/\Gamma_{bb}^{SM}}{\Gamma_{WW}/\Gamma_{WW}^{SM}} = \frac{g_{bb}^2/g_{bb}^{2\ SM}}{g_{WW}^2/g_{WW}^{2\ SM}} = \frac{\sin^2\alpha/\cos^2\beta}{\sin^2(\alpha-\beta)}$$

$$\Delta m_A \sim \frac{1}{|\partial r/\partial m_A|}\Delta r$$

Derivative will determine the precision of the M_A

Decoupling limit: $\sin(\beta-\alpha) \to 1 \Rightarrow r_W \to 1$ and $r \approx r_b$





E. Gross;

http://eilam.weizmann.ac.il/mada/Talks/Orsay.pdf

http://eilam.weizmann.ac.il/mada/Talks/Krakow.ppt

A Toy 1-loop Model

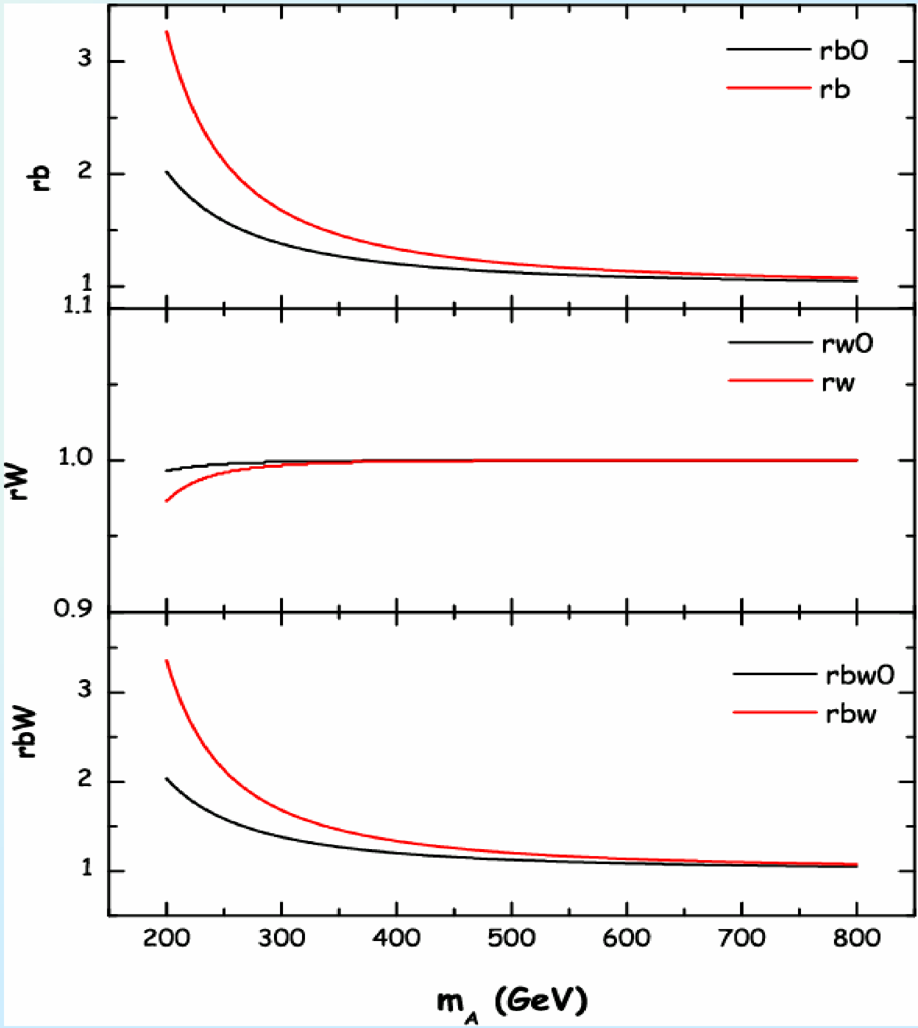
- Simple approach – with ε-radiative corrections:

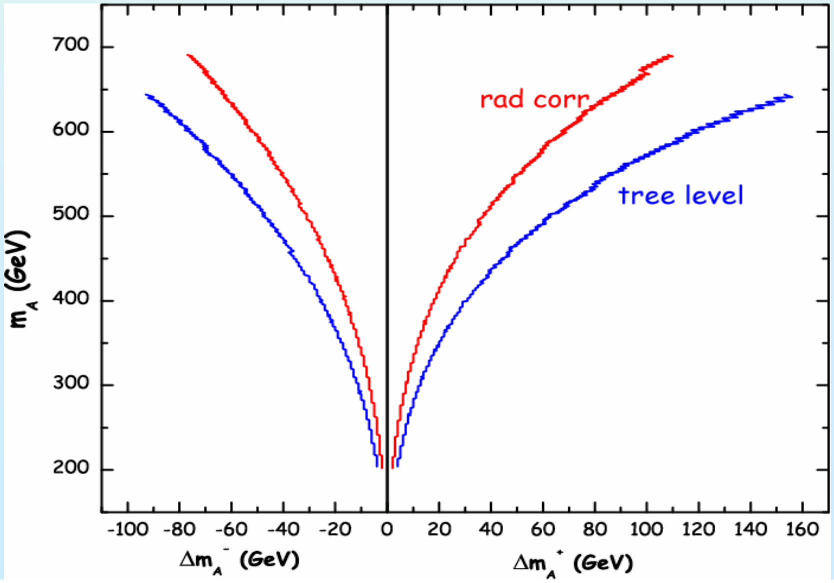
$$\varepsilon = \frac{3G_F}{\sqrt{2}\pi^2}\frac{m_t^{\ 4}}{sin^2\ \beta}Log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^{\ 2}}\right)$$

$M_A \gg M_Z \Rightarrow \beta\text{-}\alpha \to \pi/2 - \eta$, with small η:

$$\eta = \frac{m_Z^{\ 2}\,|\cos 2\beta| + \varepsilon/2}{m_A^{\ 2} - \varepsilon/|\cos 2\beta|}\sin 2\beta$$

then $$\frac{\sin^2\alpha}{\cos^2\beta} \to 1 - 2\eta\tan\beta;\quad \sin^2(\beta-\alpha) \to 1-\eta^2$$





L. Živković

No mixing; $\tan\beta = 5$; $m_h = 120$ GeV;
error = 2.5%

SPS 1 Scenario

- Consider:

  a) SPS 1a scenario:

$M_A \geq 400$ GeV;

Just h can be observed!

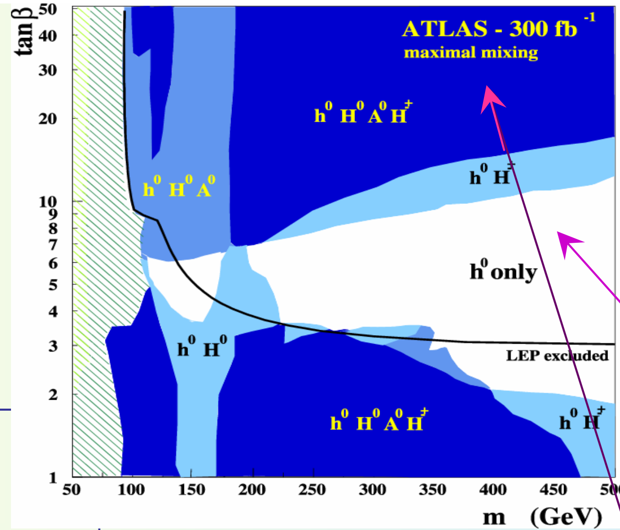
m_0	$m_{1/2}$	A_0	tanβ	μ
100	250	-100	10	+

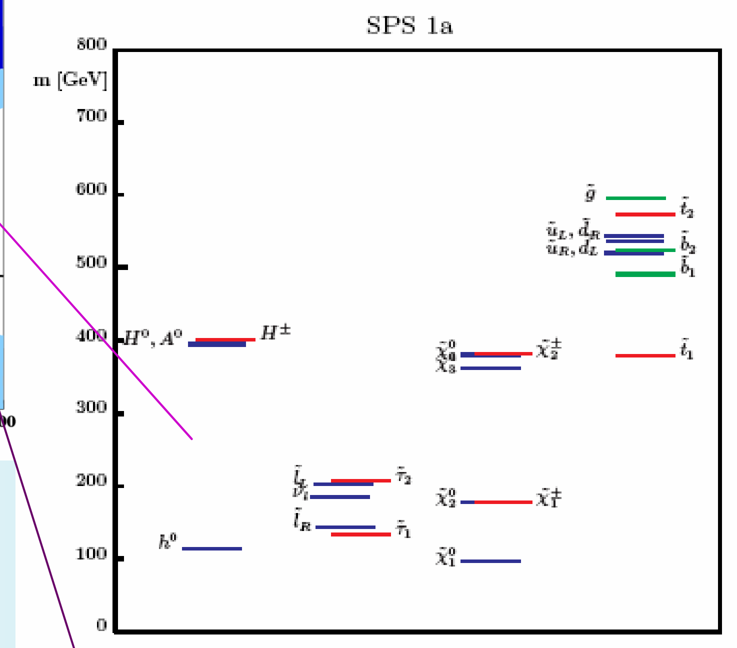
b) SPS 1b scenario:

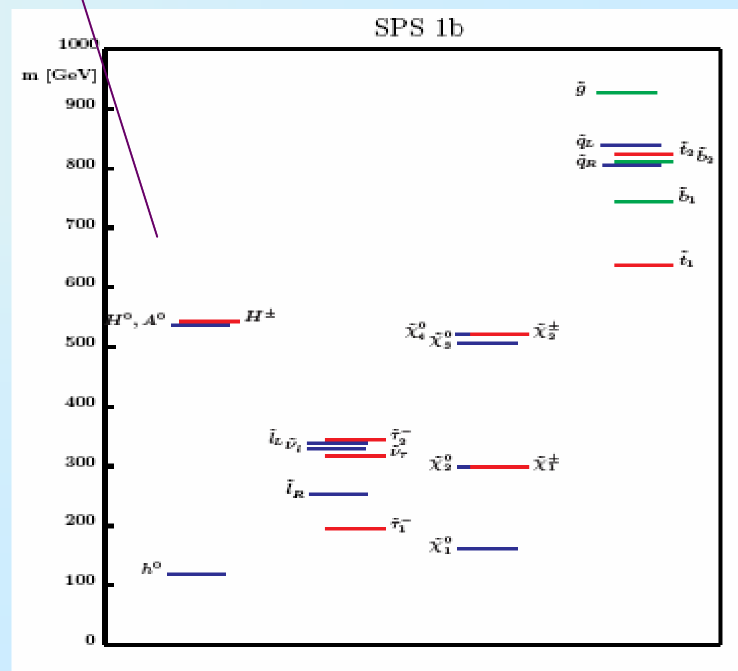
m_0	$m_{1/2}$	A_0	tanβ	μ
200	400	0	30	+

Large value of tanβ; $M_A \approx 550$ GeV; stop and sbottom 600-800 GeV

Both h and A can be observed!







Indirect constrains on M_A

- Several analyses have been performed:
  - D. Asner et al., Eur. Phys. Jour. **C 28** (2003) 27, hep-ex/0111056;
  - J. Guasch, W. Hollik and S. Peñaranda, Phys. Lett. **B 515** (2001) 367, hep-ph/0106027;
  - M. Carena, H. Haber, H. Logan and S. Mrenna, Phys. Rev. **D 65** (2002) 055005, E: *ibid* **D 65** (2002) 099902, arXiv:hep-ph/0106116.

- They all kept fixed all parameters except one under investigation (i.e. M_A) assuming that SUSY parameters enter without any experimental or theoretical uncertainty $\Rightarrow$ here we take into account all experimental and theoretical uncertainties

Indirect constrains on M_A

- Model is SPS1a with following errors assumed:

Δm_{sb1}	Δm_{sb2}	Δm_{gluino}	Δm_{st1}	Δm_h	$\tan\beta$
5.7 GeV	6.2 GeV	6.5 GeV	2 GeV	0.5 GeV	10%

From LC for $\tan\beta = 10$

We assume that we can measure lighter stop at LC, m ~ 400 GeV

Precise measurement of m_h with an error from theory included

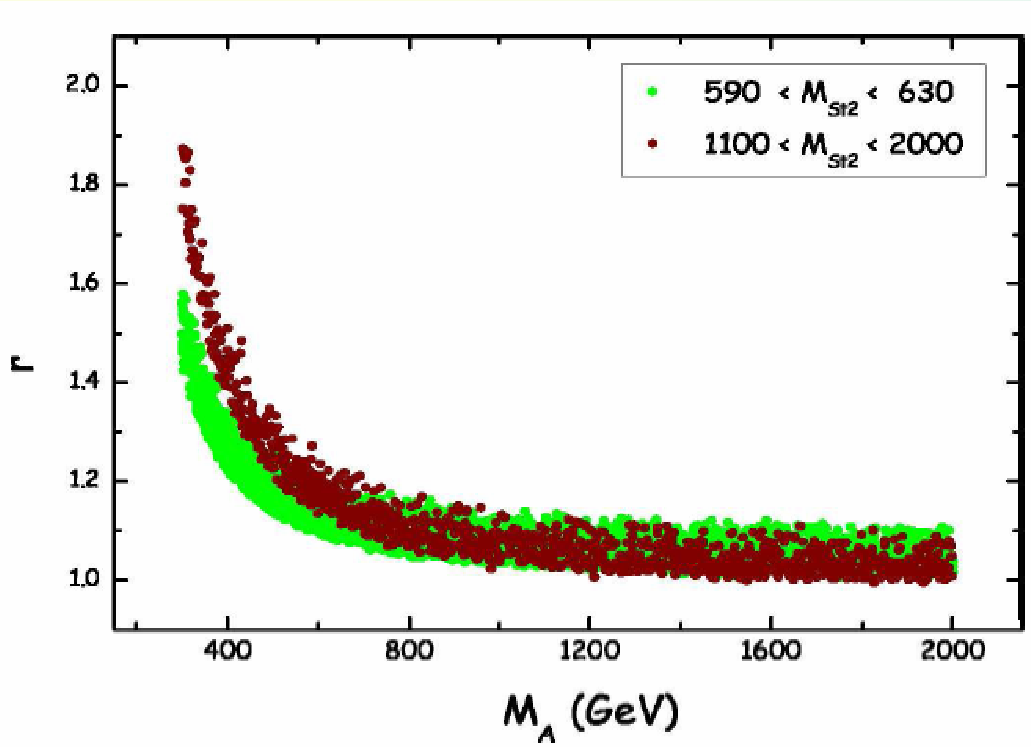
- We compare theoretical prediction of

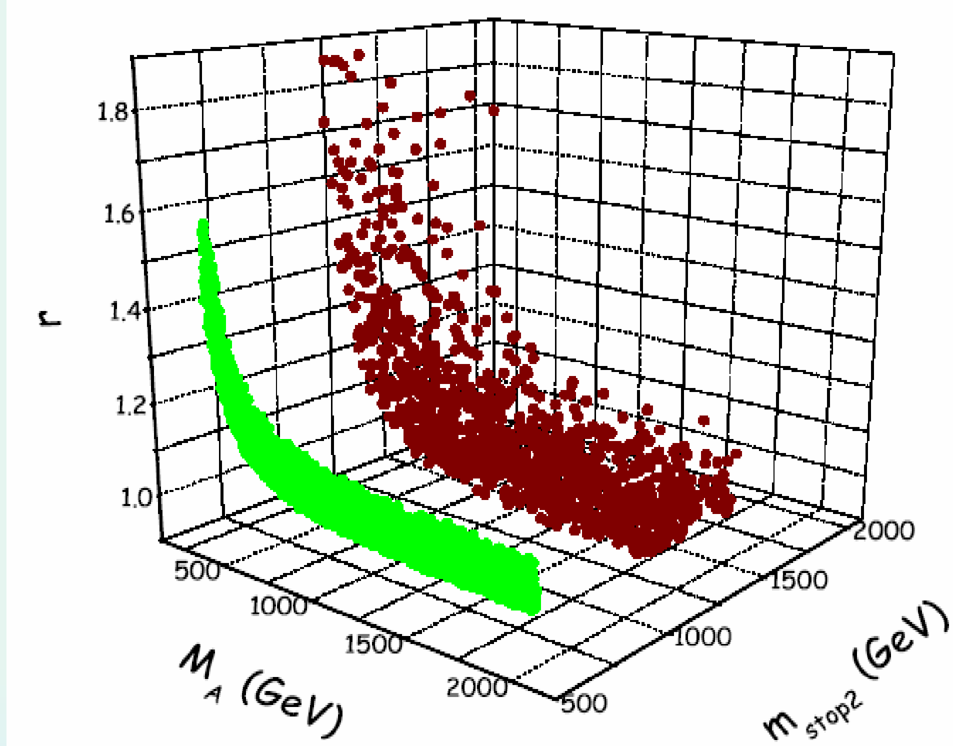
$$r \equiv \frac{[BR(h \to b\bar{b})/BR(h \to WW^*)]_{MSSM}}{[BR(h \to b\bar{b})/BR(h \to WW^*)]_{SM}}$$

with its prospective experimental measurements

- Even though the experimental error of the two BR's is larger than that of the individual ones, it has stronger sensitivity

Theoretical prediction for r as a function of M_A





All relevant SUSY parameters are varied within the 3σ ranges of their experimental errors

If we assume different stop masses we would get different values of r for lower M_A

590 < M_{st2} < 630 – SPS1a

1100 < M_{st2} < 2000 – unconstrained MSSM

Indirect constrains on M_A

- Lighter stop is accessible $\Rightarrow$ we can expect that we can determine mixing angle θ_{st} with sufficient accuracy so we might be able to predict the mass of the heavier stop, distinguishing between the two bands

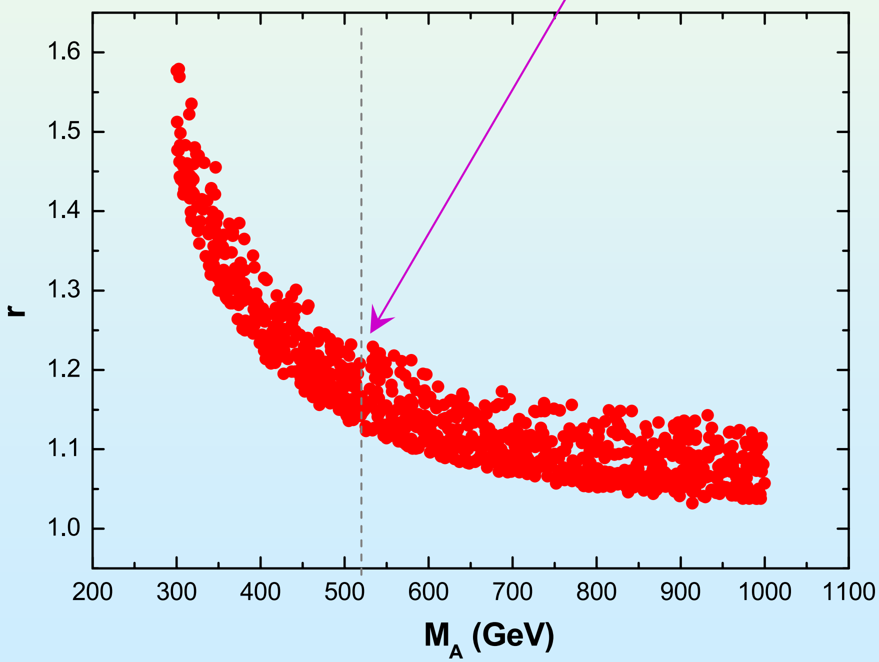
- For the experimental accuracy of r we consider:
  - 4% - from the first phase of LC@$\sqrt{s}$ = 500 GeV
  - 1.5% - from the LC@$\sqrt{s}$ = 1 TeV

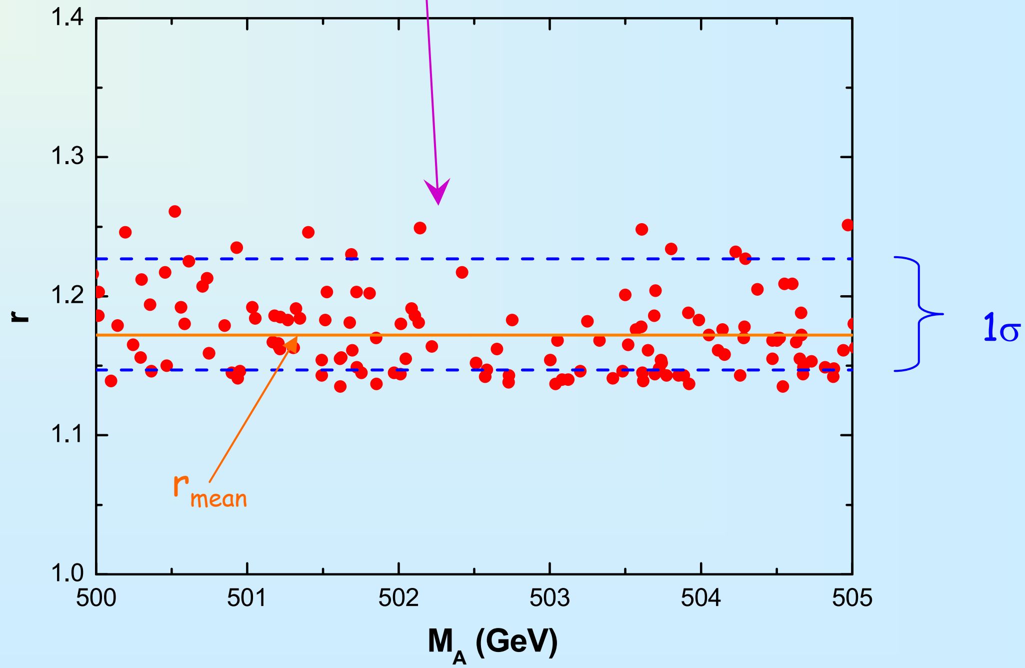
Indirect constrains on M_A

- Divide the mass spectrum into 5 GeV slices.
- Calculate the r_{mean}.
- Calculate the standard deviation from the mean value.

Mass point m_A = 502.5 GeV is a set of points $m_A \in [500,505)$

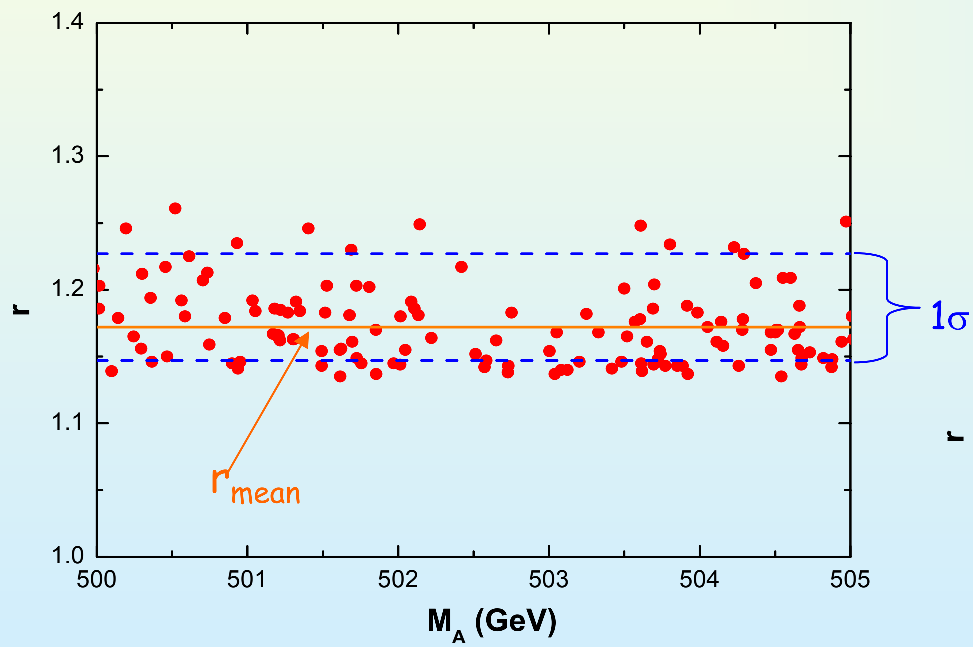
It contains 132 points.

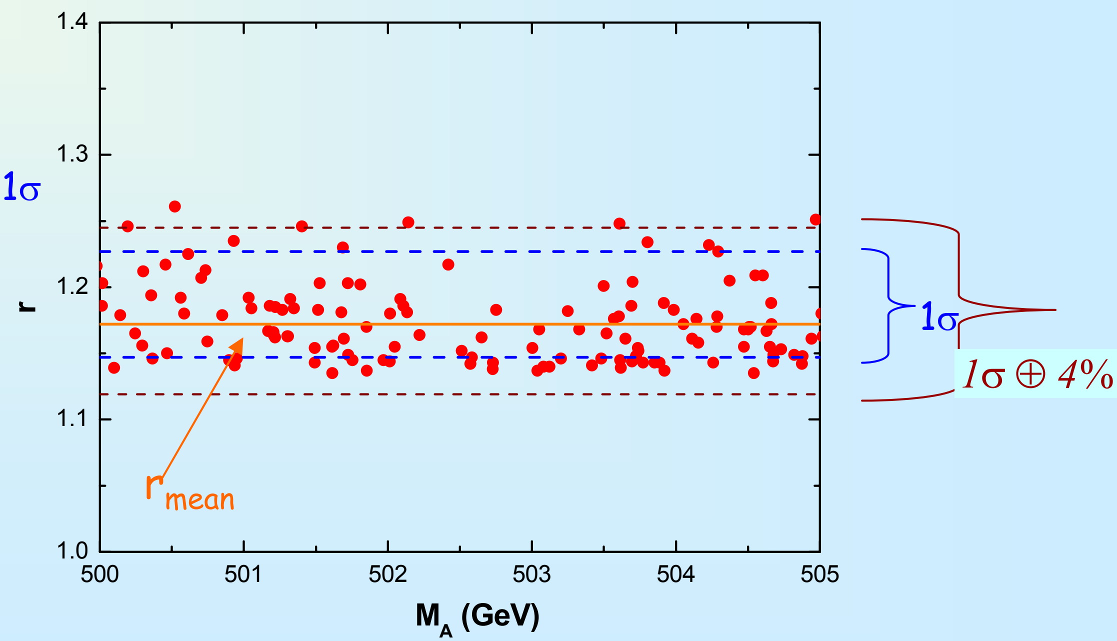




Indirect constrains on M_A

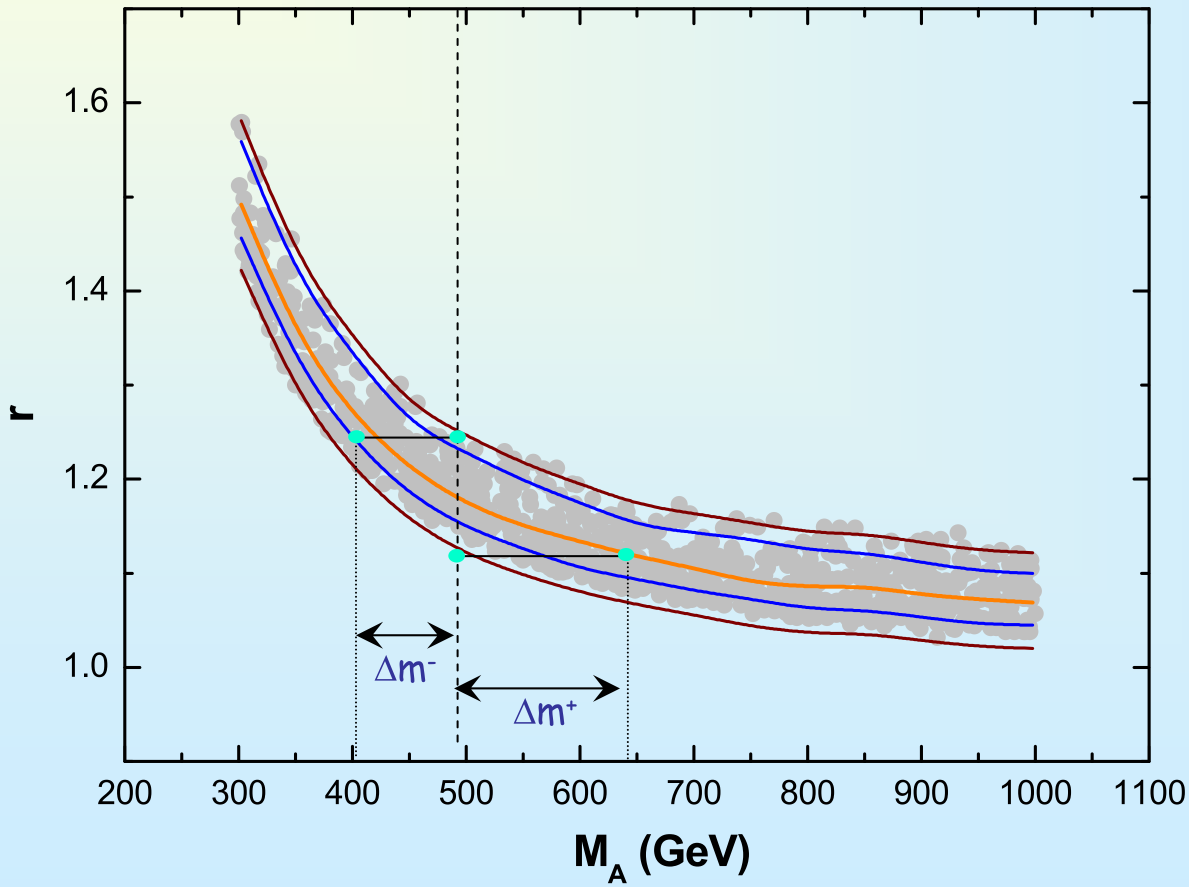
- Add to in quadrature the error in the measurement of r, i.e. 4%.





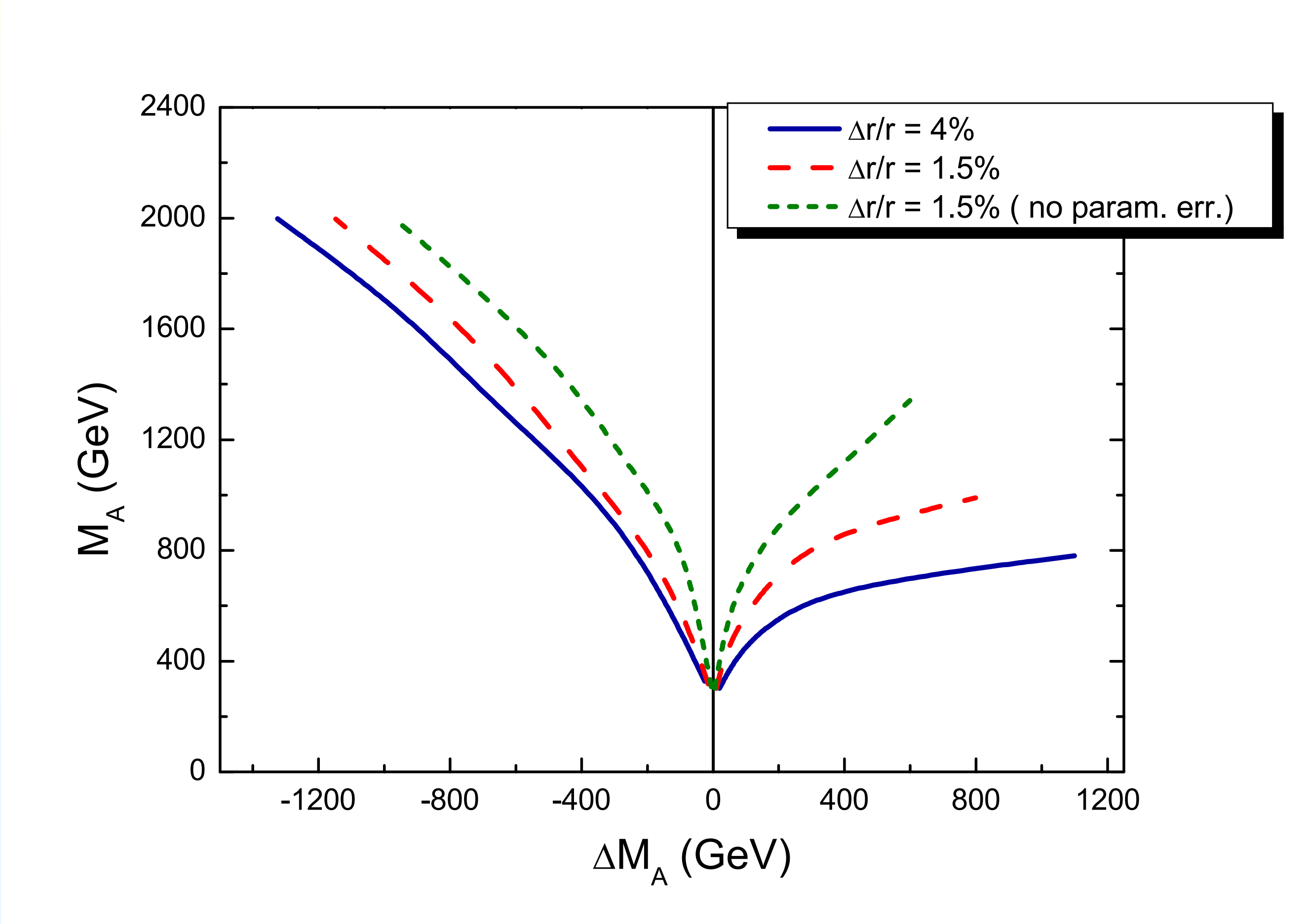
Indirect constrains on M_A

- The resulting bands of 1σ and $1\sigma \oplus 4\%$
- Pick the mass point. Go up and down in r till you hit the band boundary. Then find the mass errors (vertical right and left). Those will be Δm^+ and Δm^-



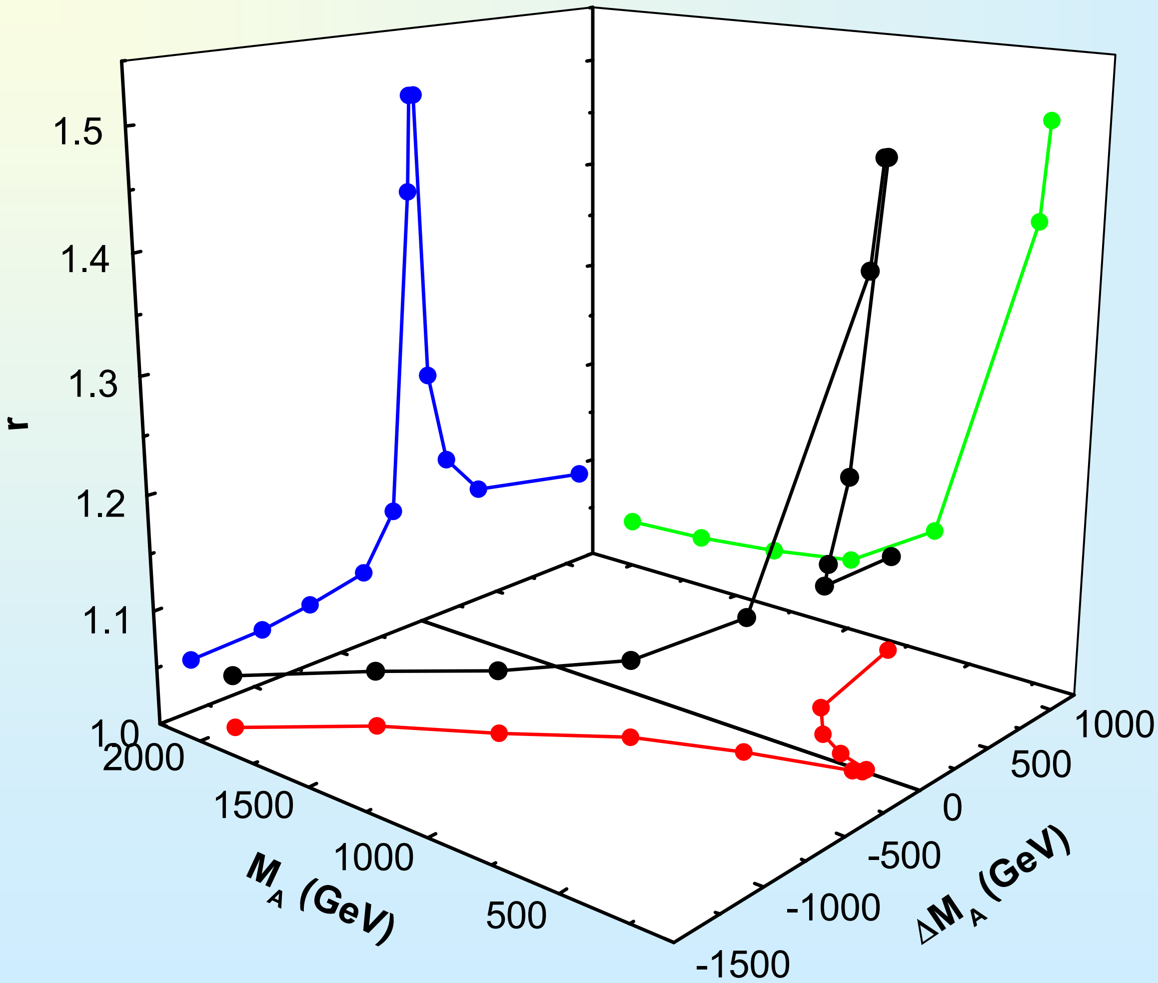
Indirect constrains on M_A

- We can measure M_A with a precision 20% (30%) up to a M_A = 600 (800) GeV with an accuracy of 1.5% on r!



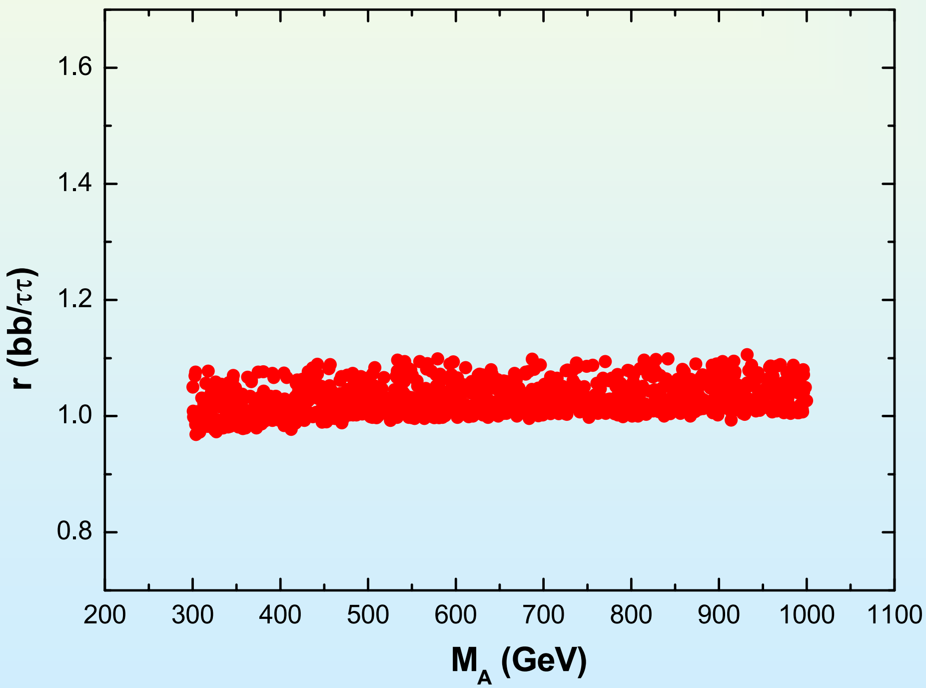
Indirect constrains on M_A

From here, we can read everything ☺

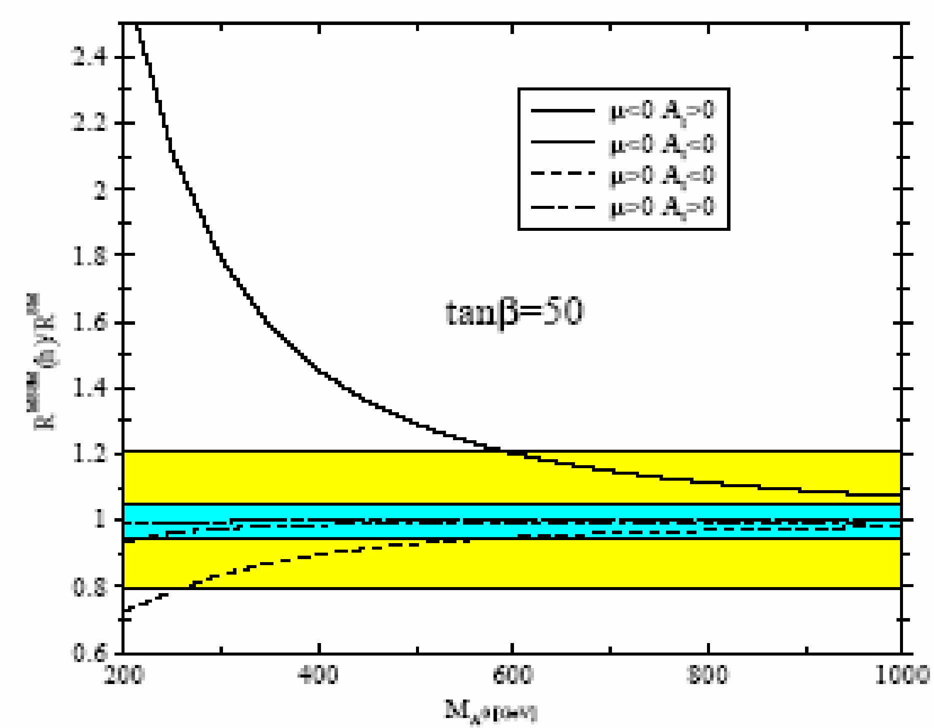


Why not bb/ττ?

No sensitivity in this scenario



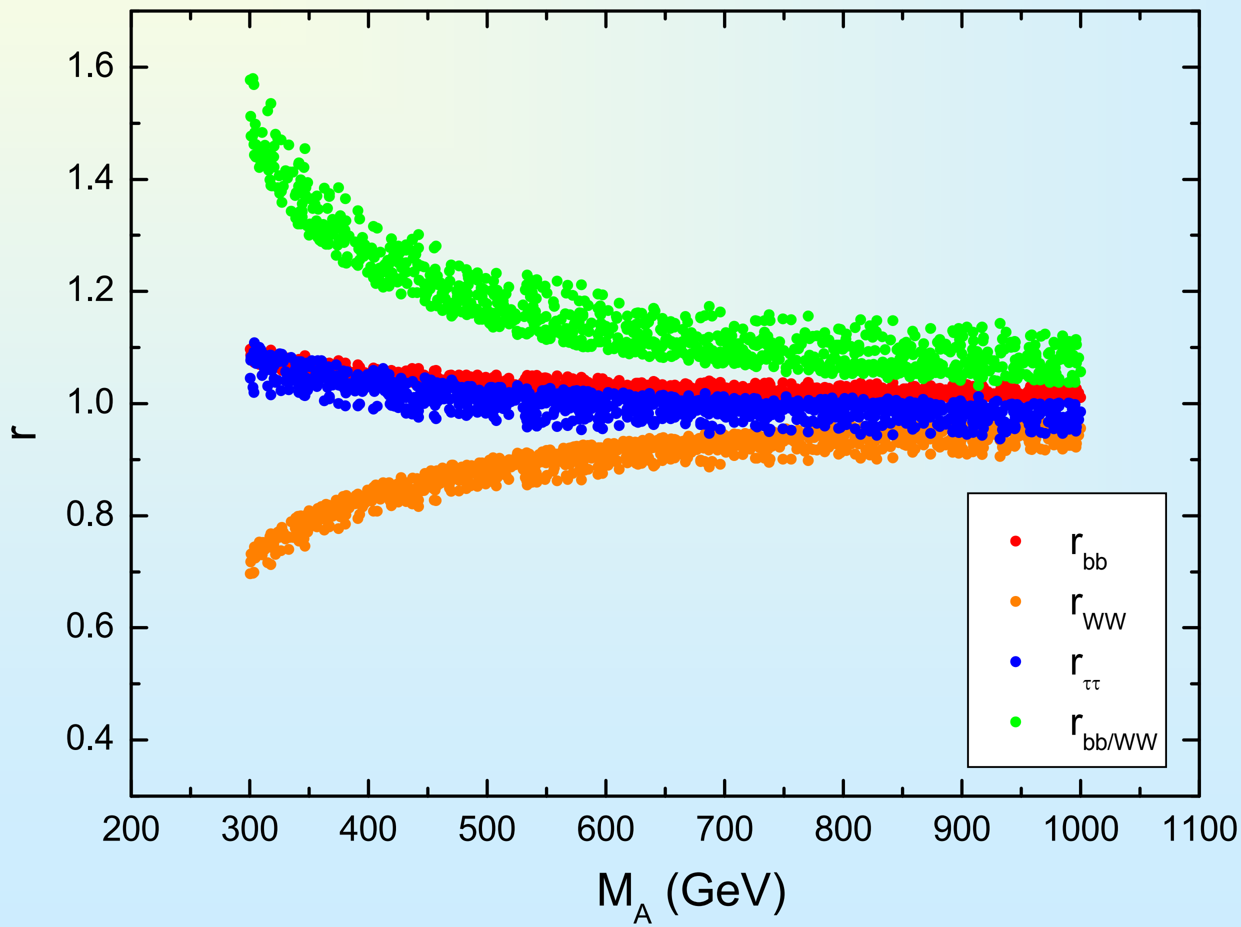
Another Scenario



Distinguishing Higgs models in H→bb/H→ττ; Guasch, Hollik, Peñaranda; hep-ph/0106027

What about bb, WW or ττ alone?

- Again, we can get the best sensitivity with the ratio



Determination of A_t if A is observed

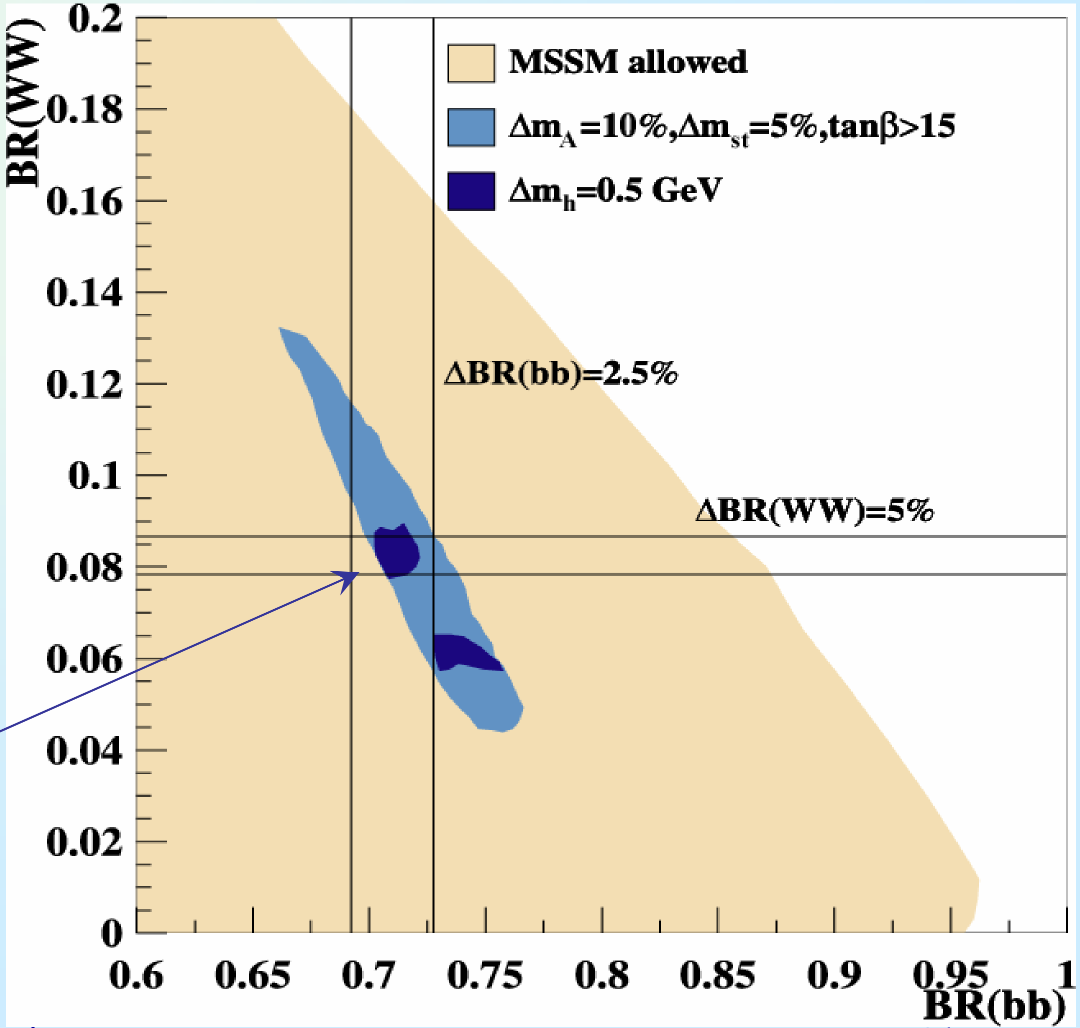
- We assume SPS1b scenario and following experimental information from LHC:
  - ΔM_A = 10% (M_A ~ 550 GeV)
  - $\tan\beta$ > 15
    - Determination of $\tan\beta$ from the comparison of the measured cross-section (bbH/A, H/A $\rightarrow \tau\tau, \mu\mu$) with the theoretical prediction; large errors from QCD uncertainties and experimental errors on SUSY parameters.
  - Δm_{stop}, $\Delta m_{sbottom}$ = 5%
    - Measured at LHC, but outside of the kinematic limit of the LC
  - Δm_h = 0.5 GeV
    - At the LC the mass of the light Higgs can be measured with an accuracy of 50 MeV, but we assumed 0.5 GeV in order to account theoretical uncertaities

Determination of A_t if A is observed

- The experimental information from the heavy Higgs and scalar quark sectors ⇒ prediction on the branching ratios of the light Higgs ⇒ consistency test of the MSSM

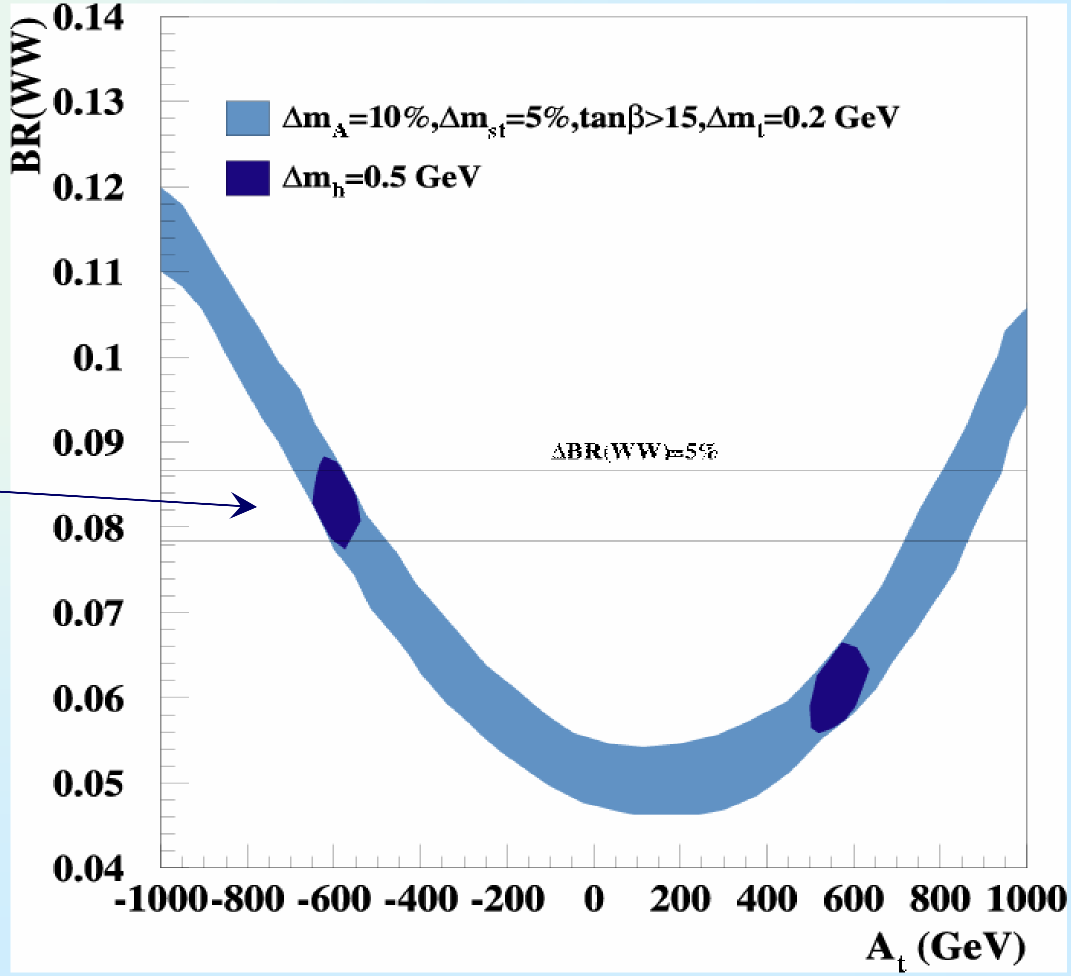
- Yellow full parameter space of the MSSM allowed
- Light blue – $\Delta M_A = 10\%$, $\Delta m_{st} = 5\%$, $\tan\beta > 15$
- Dark blue – additional $\Delta m_h = 0.5$ GeV

- Predictions compared with the prospective experimental accuracies at the LC



Determination of A_t if A is observed

- We investigate BR(h→WW) as a function of a trilinear coupling A_t
- If we can measure precisely m_h, we can determine the sign of A_t
- Precise measurement of m_t is crucial



Conclusions

- If we find just one Higgs boson at LHC, precision measurement at LC would allow to tell its nature (SM or MSSM)

- We could put constraints on the mass of the CP-odd Higgs boson
  precision would be 20 (30)% for m_A equal to 600 (800) GeV

- If we find several Higgs bosons at LHC, precision measurement at LC would allow us to shed some light on the possible model

Backup slides

Distribution of r is not symmetric