

## High-Energy Frontier

- what will be interesting after LHC (LC)?
- how does MC compare with high-energy LC (CLIC)?

Relevant considerations:

Effective mass reach

CLIC and MC need  $E_{cm} \geq 2\text{TeV}$ : assume  $4\text{TeV}$  \*

Special features

CLIC: cleanliness, polarization

MC:  $H\mu^+\mu^-$  coupling, precise  $E$ , small spread

\* Strong limitation by neutrino radiation

$\mu\mu$  collides?

## Test Points:

	$m_0$	$m_{1/2}$	$A_0$	$\tan\beta$	$m_g$	$m_{\tilde{u}_R}$	$m_{\tilde{\chi}^\pm}$	$m_{\tilde{e}_R}$	$m_h$
1	400	400	0	$2^+$	1004	925	325	430	111
2	400	400	0	$10^+$	1008	933	321	431	125
3	200	100	0	$2^-$	298	313	96	207	68
4	800	200	0	$10^+$	582	910	147	805	117
5	100	300	300	$2.1^+$	767	664	232	157	104

Proposed for Snowmass, LHC experiments committee

6 200 200 0  $45^-$  540

"difficult" point: many  $\tau$  in decays

# The LHC as "Bevatrino"

sparticles detectable at each point

	$h$	$H/A$	$\chi_2^0$	$\chi_3^0$	$\chi_4^0$	$\chi_1^\pm$	$\chi_2^\pm$	$\tilde{q}$	$\tilde{u}$	$\tilde{t}$	$\tilde{g}$	$\tilde{\tau}$
1	✓	✓	✓			✓		✓	✓	✓	✓	
2	✓	✓	✓			✓		✓	✓	✓	✓	
3	✓	✓	✓			✓		✓	✓	✓	✓	✓
4	✓		✓	✓		✓	✓	✓			✓	
5	✓	✓	✓					✓	✓	✓	✓	✓

(<http://www.cern.ch/Committees/LHCC/SUSY96.html>)

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1	✓	✓	✓			✓		✓	✓	✓	✓	
2	✓	✓	✓			✓		✓	✓	✓	✓	
3	✓	✓	✓			✓		✓	✓	✓	✓	✓
4	✓	✓	✓	✓		✓	✓	✓			✓	
5	✓	✓	✓					✓	✓	✓	✓	✓

(<http://www.cern.ch/Committees/LHCC/SUSY96.html>)

Physics Topic	LHC	CLIC	HEMC
Strong E.W. Symmetry X	$\leq 1\text{TeV}$ —	$\approx 2\text{TeV}$ ✓	$\approx 2\text{TeV}$ ✓✓ ( $\Delta m$ )
extra dimensions	heavy $g^*, q^*$ large $E_T$	✓ ✓	✓✓ ( $\Delta m$ ) ✓
supersymmetry	Higgses H, A	?	✓✓ ( $\Delta m, H_{pp}$ )
	sfermions	heavy $\tilde{l}$	(H, A) $\tilde{f}\tilde{f}$ ( $\Delta m, H_{pp}$ )
	charginos	heavy $\tilde{q}$	(H, A) $\tilde{\chi}^+\tilde{\chi}^-$ ( $\Delta m, H_{pp}$ )
	R X	decays $\Rightarrow \tilde{f}$	measure $\lambda'_{2ij}$ ( $\Delta m$ )
susy X	some	more ✓	accurate ✓✓ ( $\Delta m$ )

# Allowed Radiation Levels

## Classification of controlled areas Classification des zones contrôlées

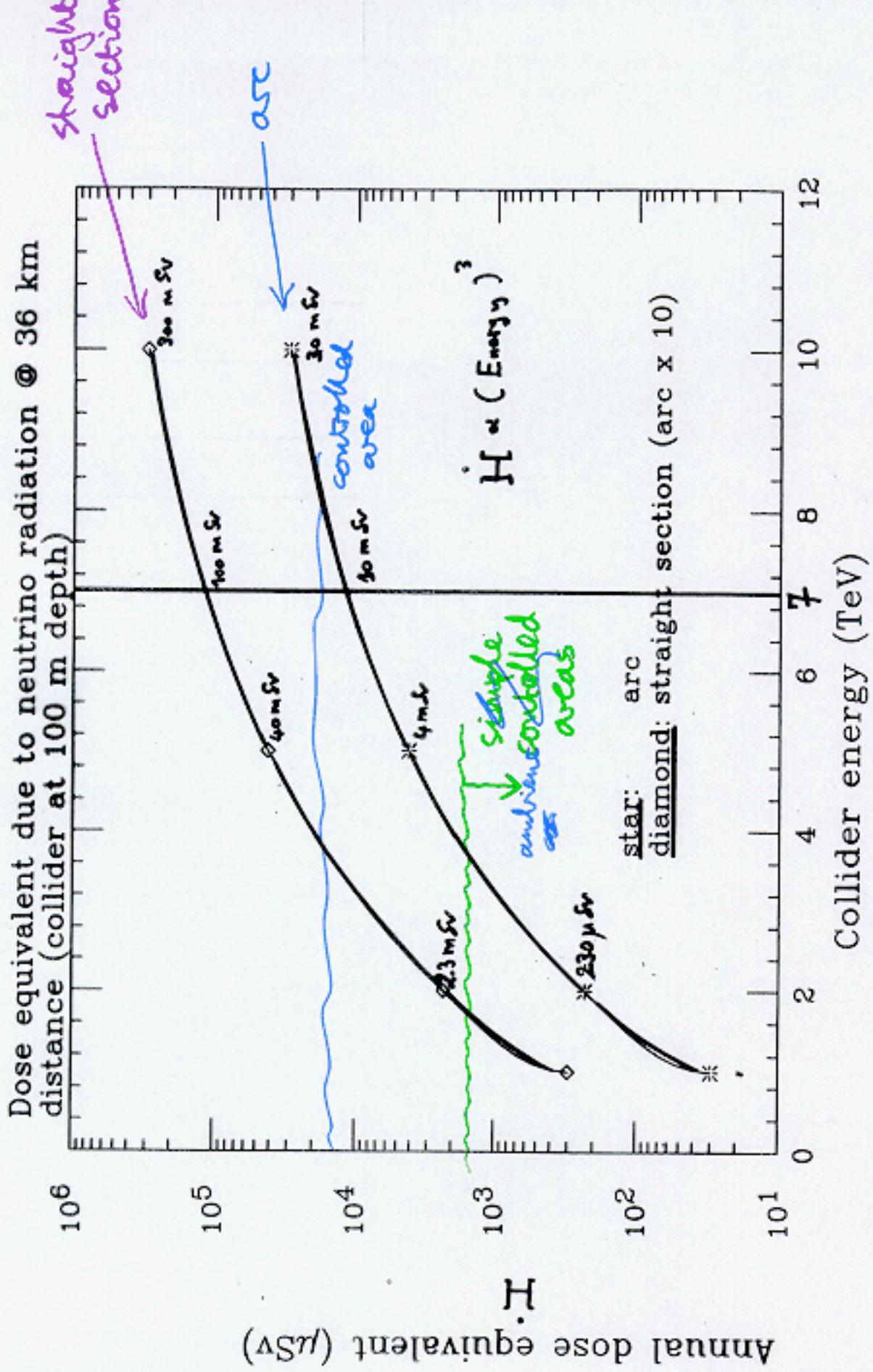
Simple controlled areas  
Zones contrôlées simples → < 15 mSv/year

Limited stay areas  
Zones de séjour limité → < 2 mSv/hour

High radiation areas  
Zones à haute radioactivité → > 2 mSv/hour

Prohibited areas  
Zones interdites → > 100 mSv/h

# Neutrino Radiation Hazard



I.2.4

Bunches of  $N^{\circ} = 2 \times 10^{12} \mu$ , rep. rate 15 Hz, 100 days operation

(C. Johnson + M. Silari)

## Strongly-Coupled Higgs Sector?

### possibility of direct-channel resonances

The production rate at the peak obtained by convoluting the Breit-Wigner with a Gaussian distribution of width  $\sigma_{\sqrt{s}}$  is

$$\bar{\sigma} \approx \frac{3\pi\sqrt{2\pi}\Gamma(V \rightarrow \mu^+\mu^-)}{M_V^2\sigma_{\sqrt{s}}} \left(1 + \frac{\pi}{8} \left[\frac{\Gamma_V}{\sigma_{\sqrt{s}}}\right]\right)^{-1/2}$$

In the limits

$$\sigma_{\sqrt{s}} \ll \Gamma_V, \quad \bar{\sigma} \rightarrow \sigma^{\text{peak}}$$

$$\sigma_{\sqrt{s}} \gg \Gamma_V, \quad \bar{\sigma} \rightarrow 0.6 \left(\frac{\Gamma_V}{\sigma_{\sqrt{s}}}\right) \sigma^{\text{peak}}$$

In our case

$$\sigma_{L_3}^{\text{peak}} \approx 6 \times 10^5 \left(\frac{1 \text{ TeV}}{M_V}\right)^2 \text{ fb}$$

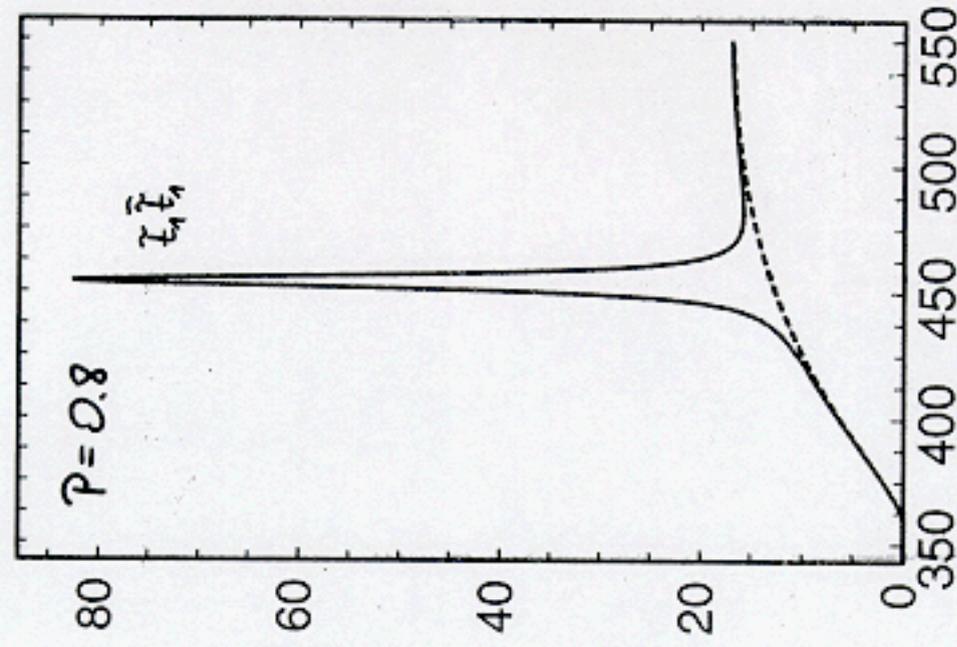
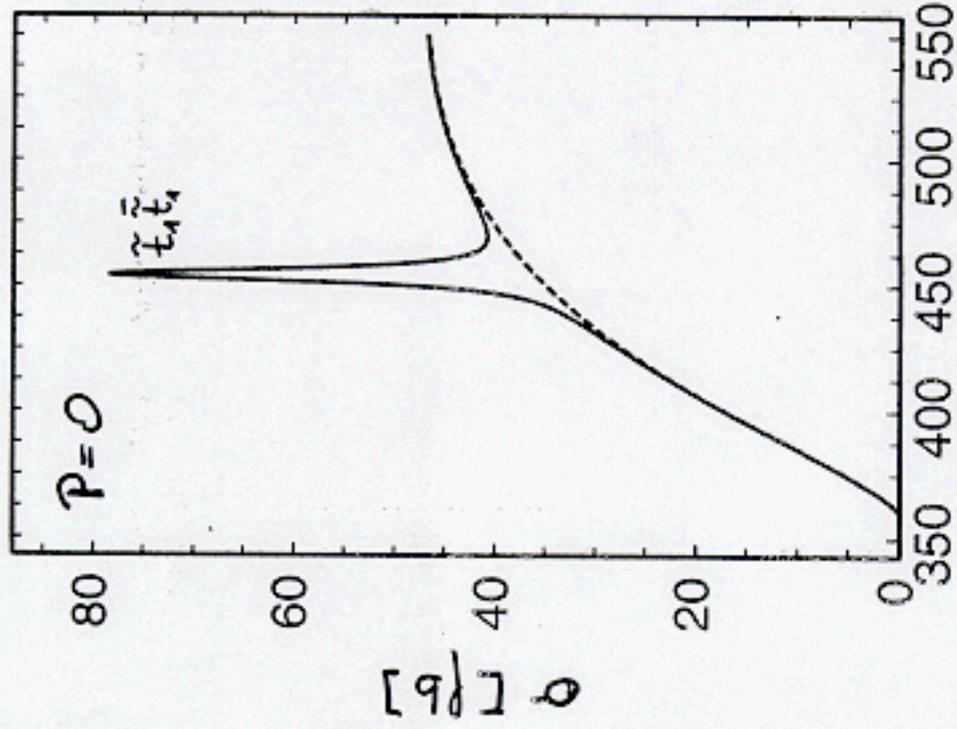
$$\sigma_{R_3}^{\text{peak}} \approx 1.8 \times 10^6 \left(\frac{1 \text{ TeV}}{M_V}\right)^2 \text{ fb}$$

The main advantage of a muon collider over NLC would be the possibility of studying the shape of these resonances.

(Casalbruoni + ...)

# $\tilde{t}_1 \tilde{t}_2$ PRODUCTION

effects of direct-channel MSSM Higgs poles:  $H, A \rightarrow \tilde{t}_1 \tilde{t}_2$



- $m_{\tilde{t}_1} = 180 \text{ GeV}$
- $m_{\tilde{t}_2} = 260 \text{ GeV}$
- $\cos \theta_{\tilde{t}} = -0.556$
- $m_A = 450 \text{ GeV}$
- $m_{H^+} = 454 \text{ GeV}$

- $M_2 = 120 \text{ GeV}$
- $\mu = 300 \text{ GeV}$
- $\tan \beta = 3$
- $m_{\tilde{b}_1} = 175 \text{ GeV}$
- $m_{\tilde{b}_2} = 195 \text{ GeV}$
- $\cos \theta_{\tilde{b}} = 0.9$
- $M_{\tilde{t}} = 170 \text{ GeV}$
- $M_{\tilde{E}} = 150 \text{ GeV}$
- $A_{\tilde{t}} = 300 \text{ GeV}$

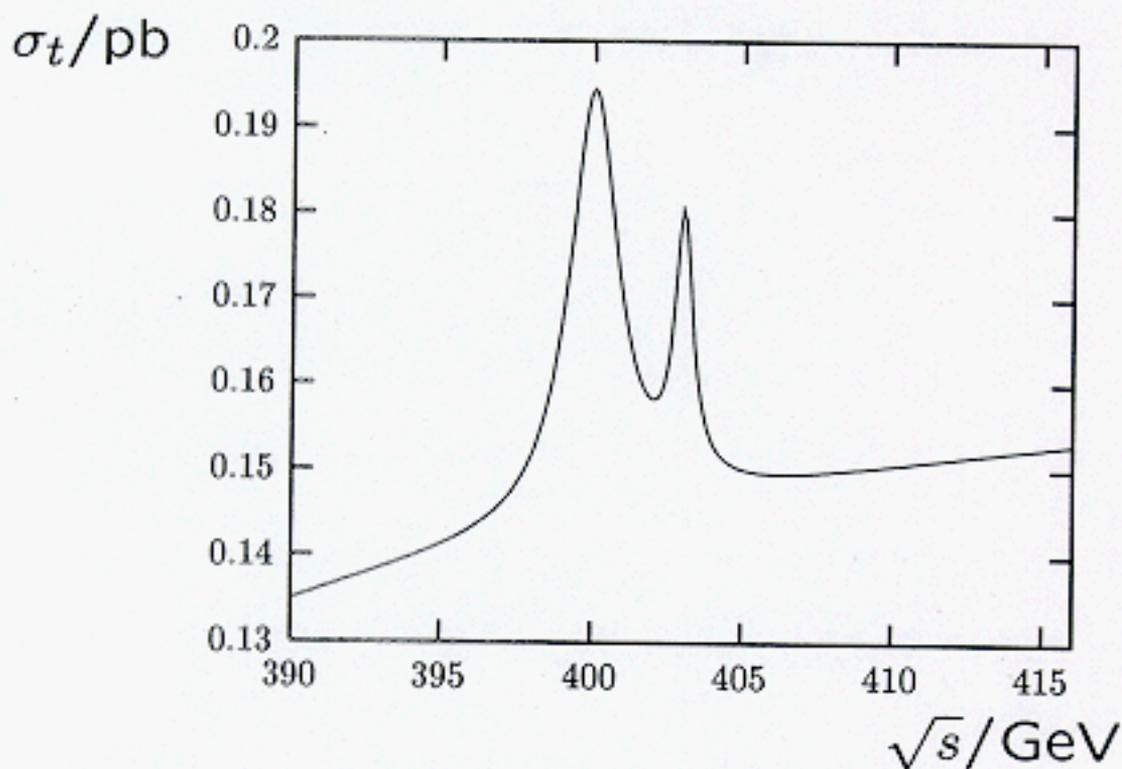
(Kraml + ...)

## Chargino production ( $\tan\beta = 3$ )

Heavy Higgs resonances: *in direct channel*

Sc 1: gaugino-like

$m_A = 400, \Gamma_A = 1.95^\dagger, \Gamma_H = 0.72$ [GeV]						
$M'$	$M$	$\mu$	$m_0$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_1^0}$	$\Gamma_{\tilde{\chi}_1^\pm}^\ddagger$
95	200	405	200	180	90	0.003



→ discrimination of A- and H-channel

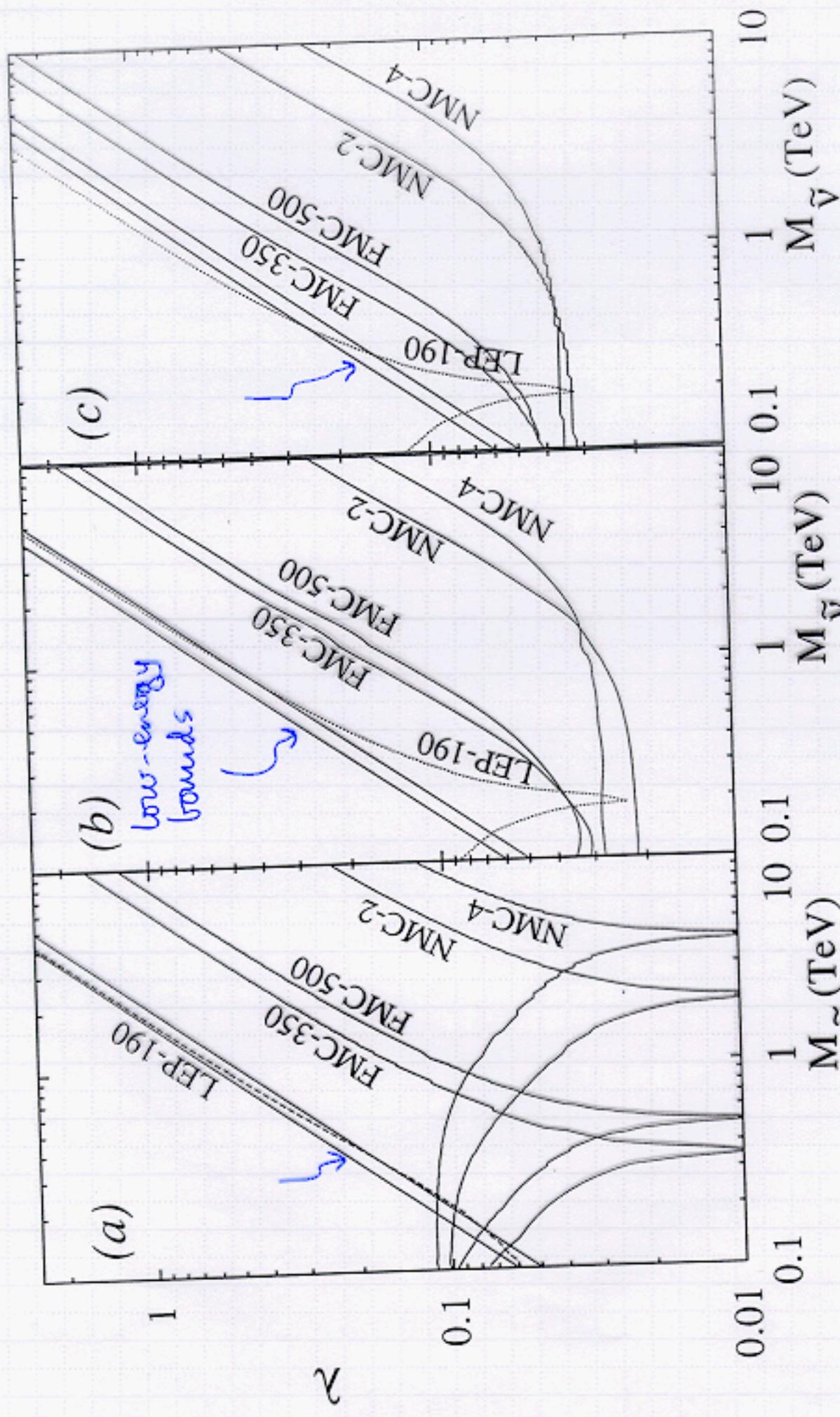
<sup>†</sup>  $\Gamma_A, \Gamma_H$  provided by H. Eberl

<sup>‡</sup> all  $\Gamma_{\tilde{\chi}_1^\pm}$  provided by S. Hesselbach

*measure  $H, A \rightarrow \chi^+ \chi^-$*

R Violation at  $\mu^+\mu^-$  Colliders

LL $\bar{E}$  case



$\mu^+\mu^- \rightarrow \mu^+\mu^-$

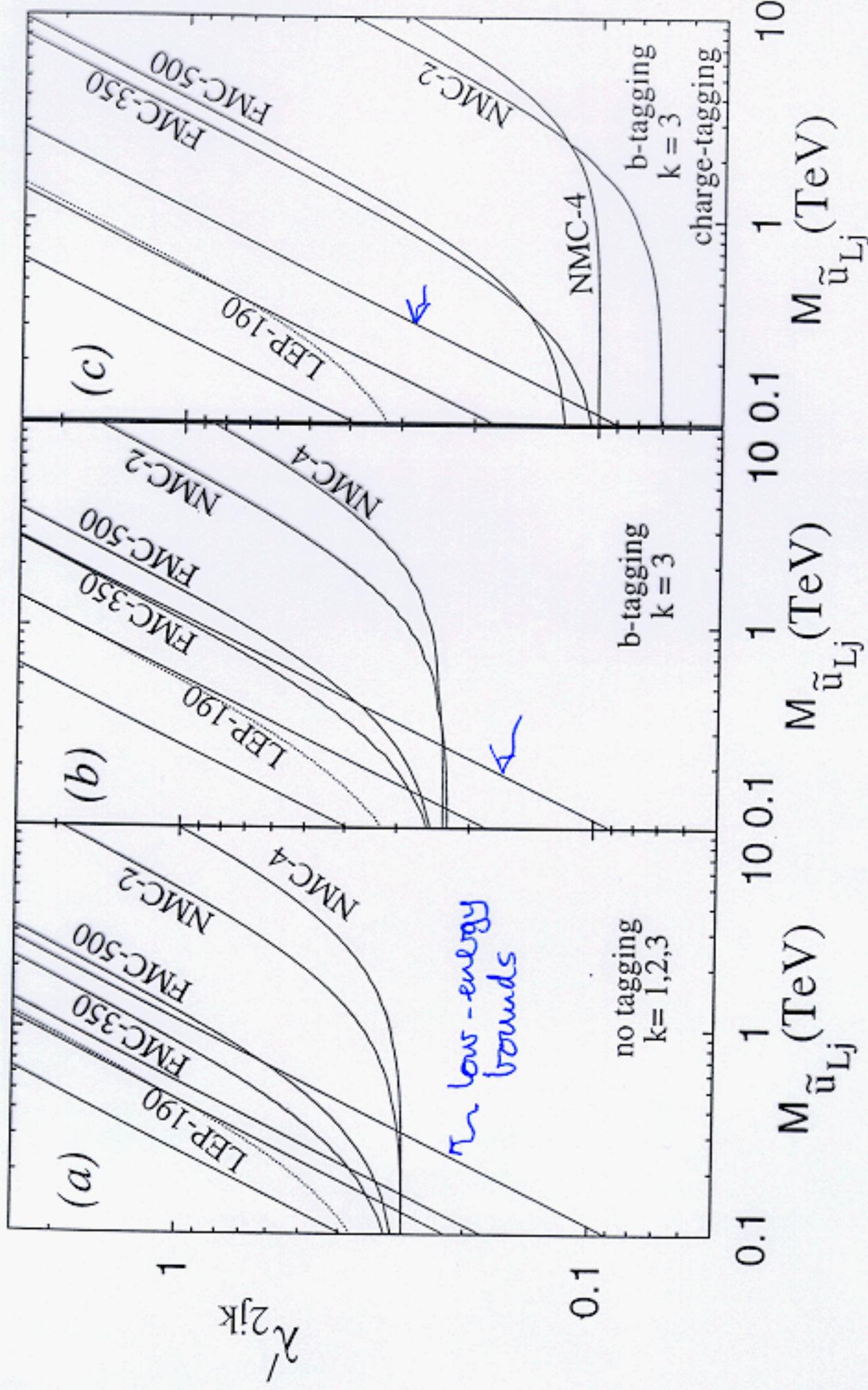
$\frac{d\sigma}{d\cos\theta}(\mu^+\mu^- \rightarrow \tau^+\tau^-)$

$\sigma(\mu^+\mu^- \rightarrow e^+e^-)$

(Choudhury + Raychaudhuri)

R Violation at  $p^+p^-$  Colliders

LQD case



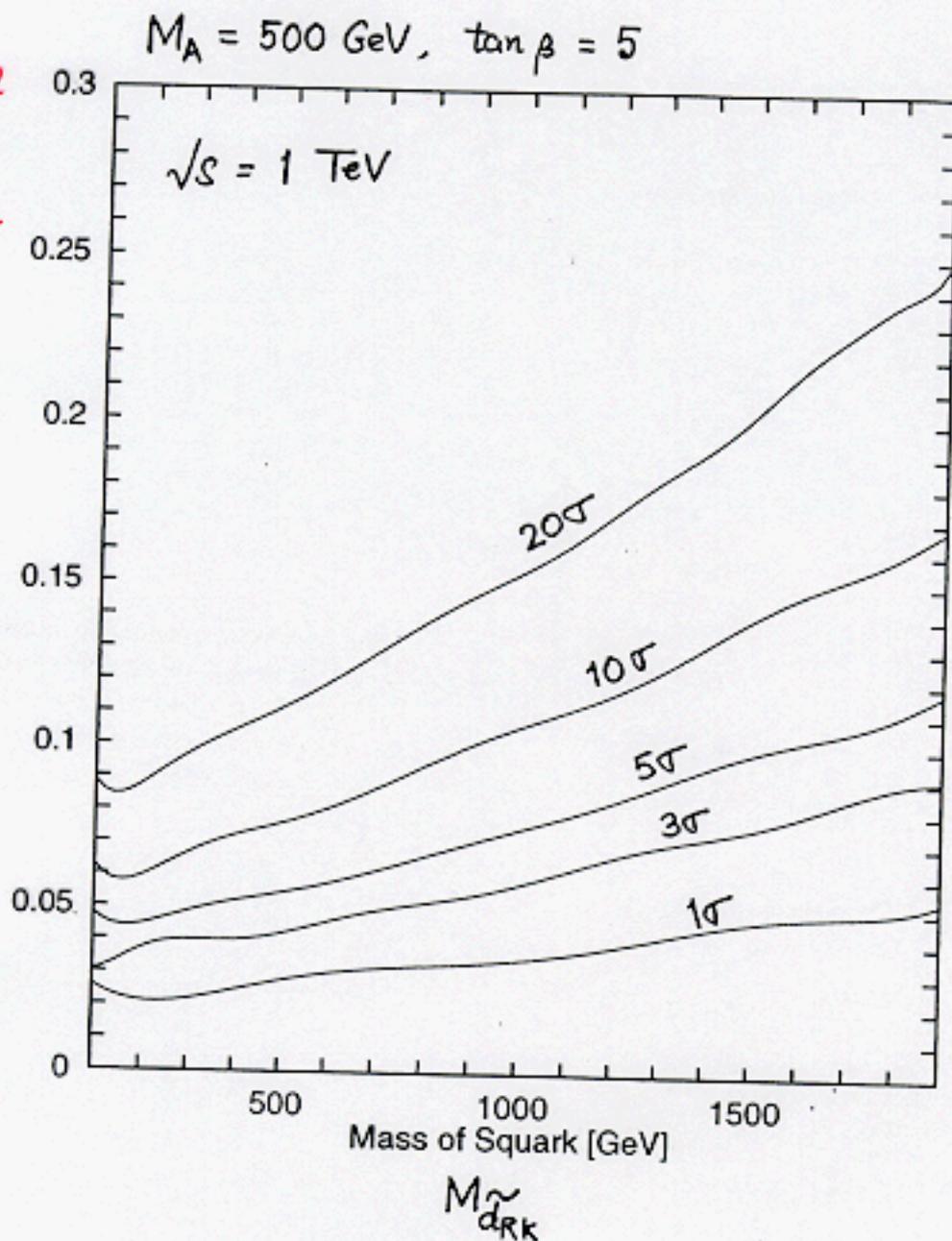
(Choudhury + Raychaudhuri)

# Sensitivity to R Violation in $\mu\mu \rightarrow \bar{t}t$

present limit

unique  
for  
 $\mu\mu$   
collides

Coupling  $\lambda_{23k}$



(Raychaudhuri + ...)

# Mass Measurements to Distinguish Models of Supersymmetry Breaking (3)

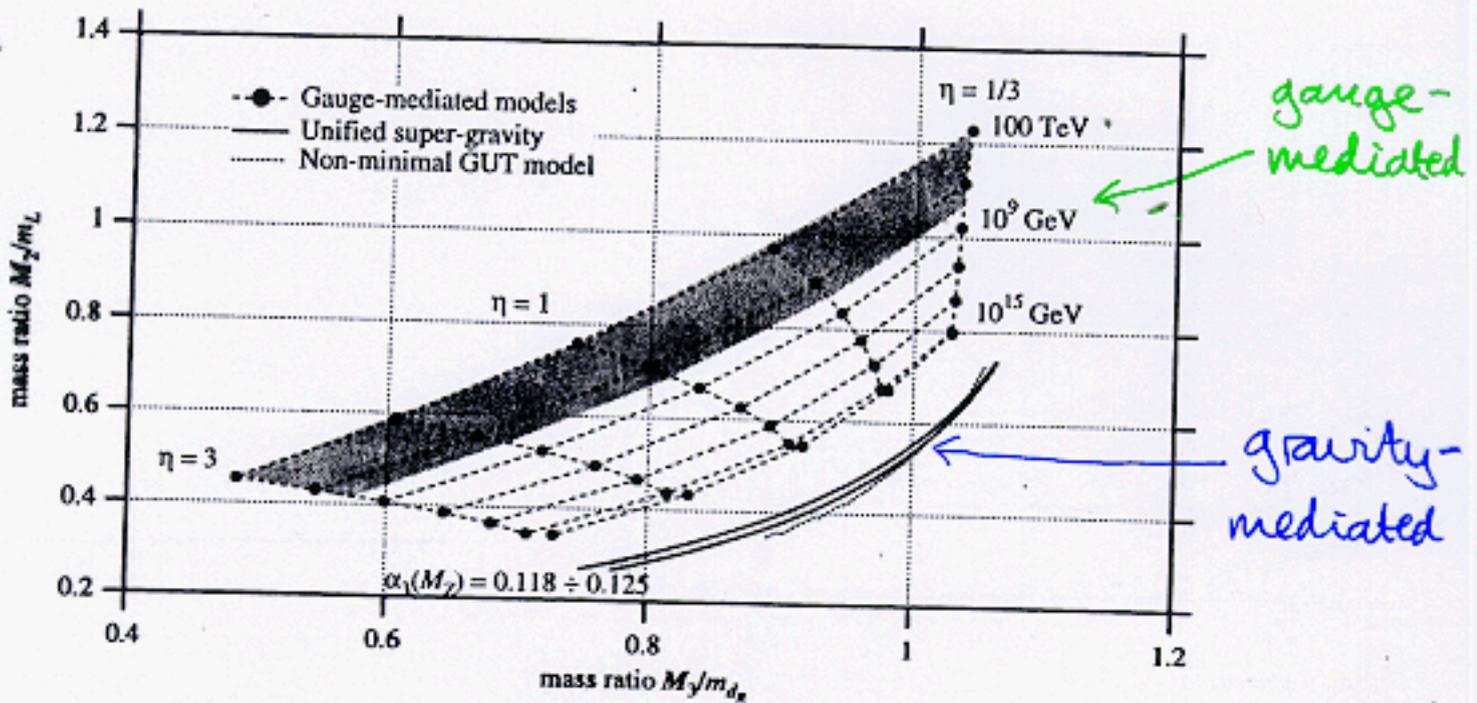


Figure 1: Correlations  $(M_3/m_{\tilde{d}_R}, M_2/m_L)$  as predicted by unified supergravity (continuous line) and gauge-mediation (dashed lines) for different values of the messenger scale and of the parameter  $\eta$ , defined in (2). We have employed  $\alpha_3(M_2) = 0.118$ . The supergravity and gauge-mediation predictions with  $M_M = 10^{15} \text{ GeV}$  are also shown for  $\alpha_3(M_2) = 0.125$  (lower lines). In the shaded area it is possible to observe the clean signature of LSP decay. The dotted line refers to a non minimal unification model, as discussed in the text.

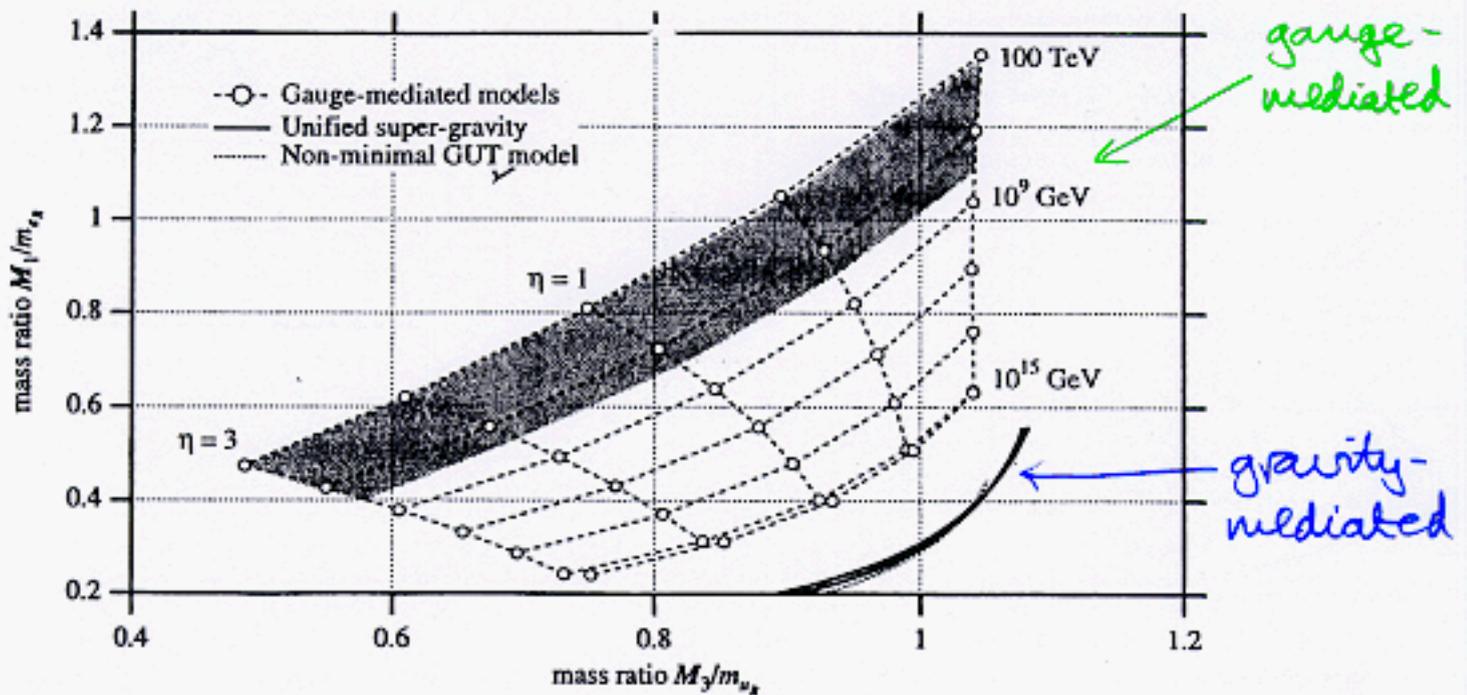


Figure 2: As in fig. 1, except that we plot the correlations  $(M_3/m_{\tilde{u}_R}, M_2/m_{\tilde{e}_R})$  involving masses of sparticles unified in a 10 of SU(5).

(indice + ...)

# Testing Supersymmetric GUT Mass Predictions at $e^+e^-$ LC

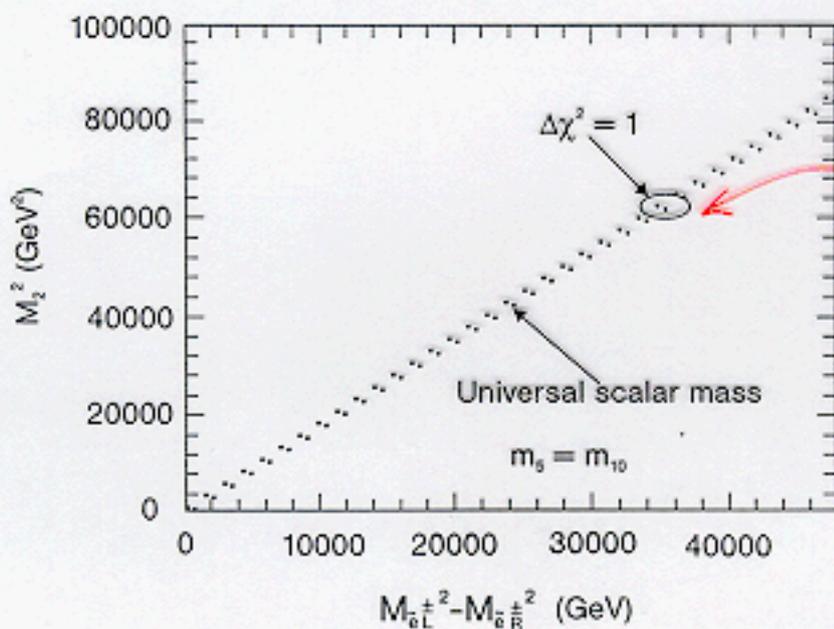
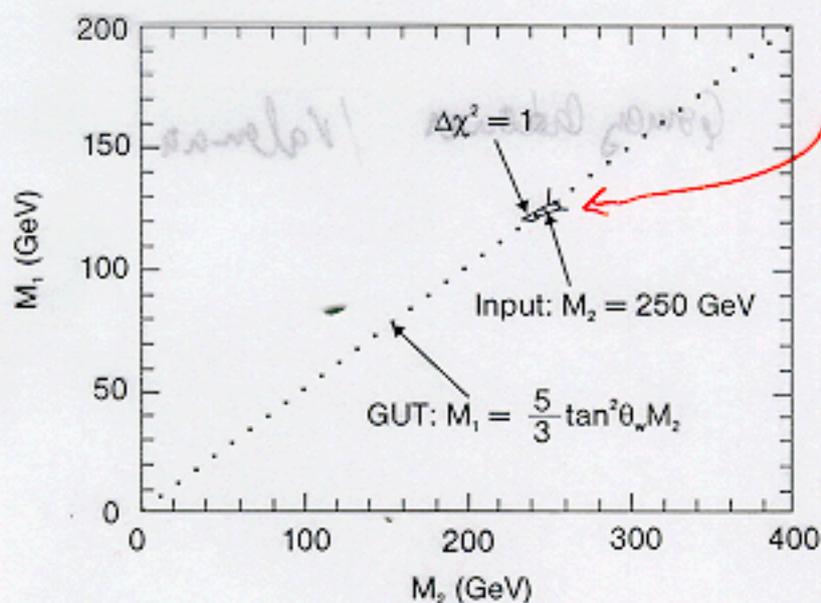


Figure 42: Testing mass relations at  $e^+e^-$  colliders between gauginos, and between selectrons (lower part), as predicted in minimal supergravity; Refs.[152, 153].

(DESY-ECFA)