LSP dark matter and LHC

MSSM (minimal SUSY SM)

- gauge coupling unification
- sparticles (collider)
- LSP dark matter (dark matter search
  ($\tilde{\chi}^0_1$ or gravitino)

collider – no signal yet LHC (2005~)

dark matter search

may be next year! CDMS II

= dark matter exist =

$\Omega_\chi = 0.35 \pm 0.1$ (Turner)

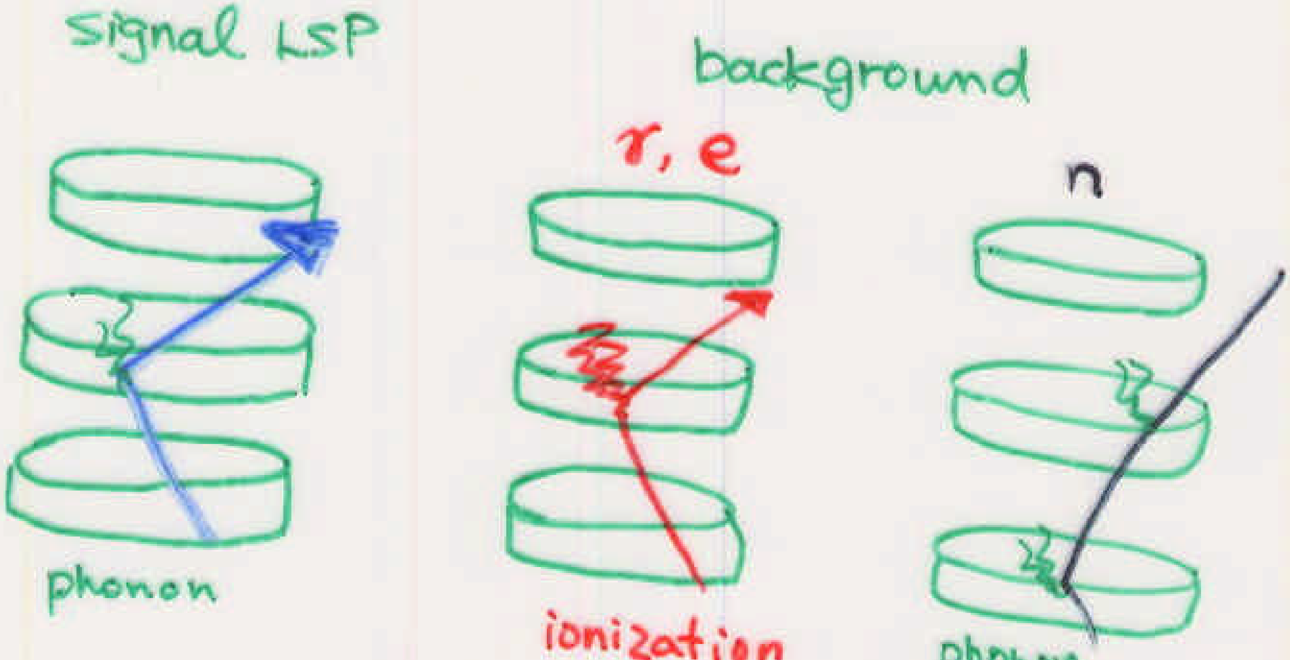
$h^2_{65}\Omega_B \simeq < 0.05$

(we need "New Physics")

CDMS & CDMS SUDAN

CDMS ('99)

- prototype experiment operating at 16 mwE → 2/(keV kg d)
- Small detector (total 1.6 kg·d)
- phonon / ionization measurement



- surface electron event removed by phonon rise time
- neutron multiple scattering
- roughly same reach to DAMA (NAI)

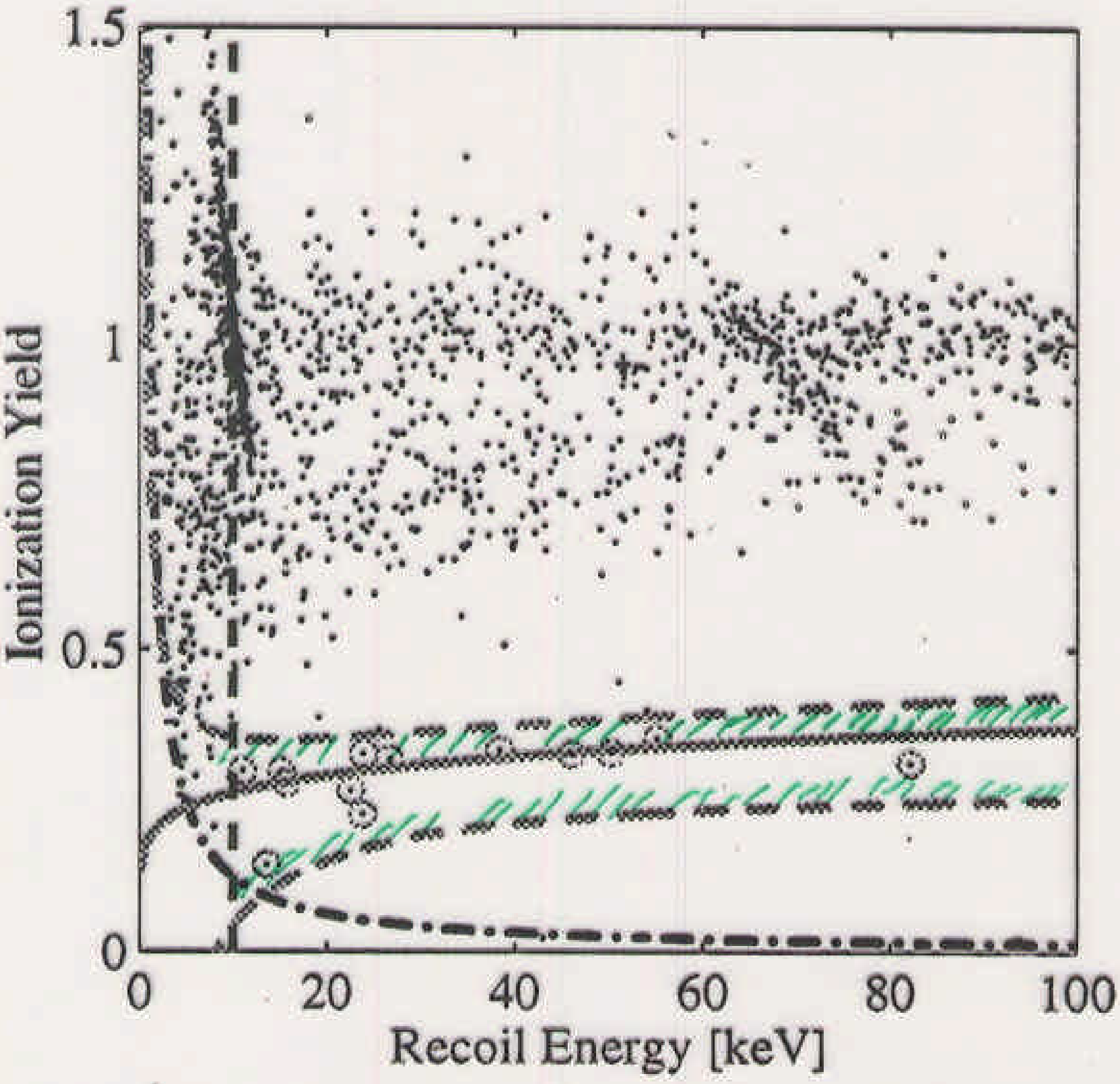
NO SIGNAL

→ will operate 7kg detector at SUDAN (2090 mwe)

expected background

3×10^{-4} /kg keV day

FIGURES

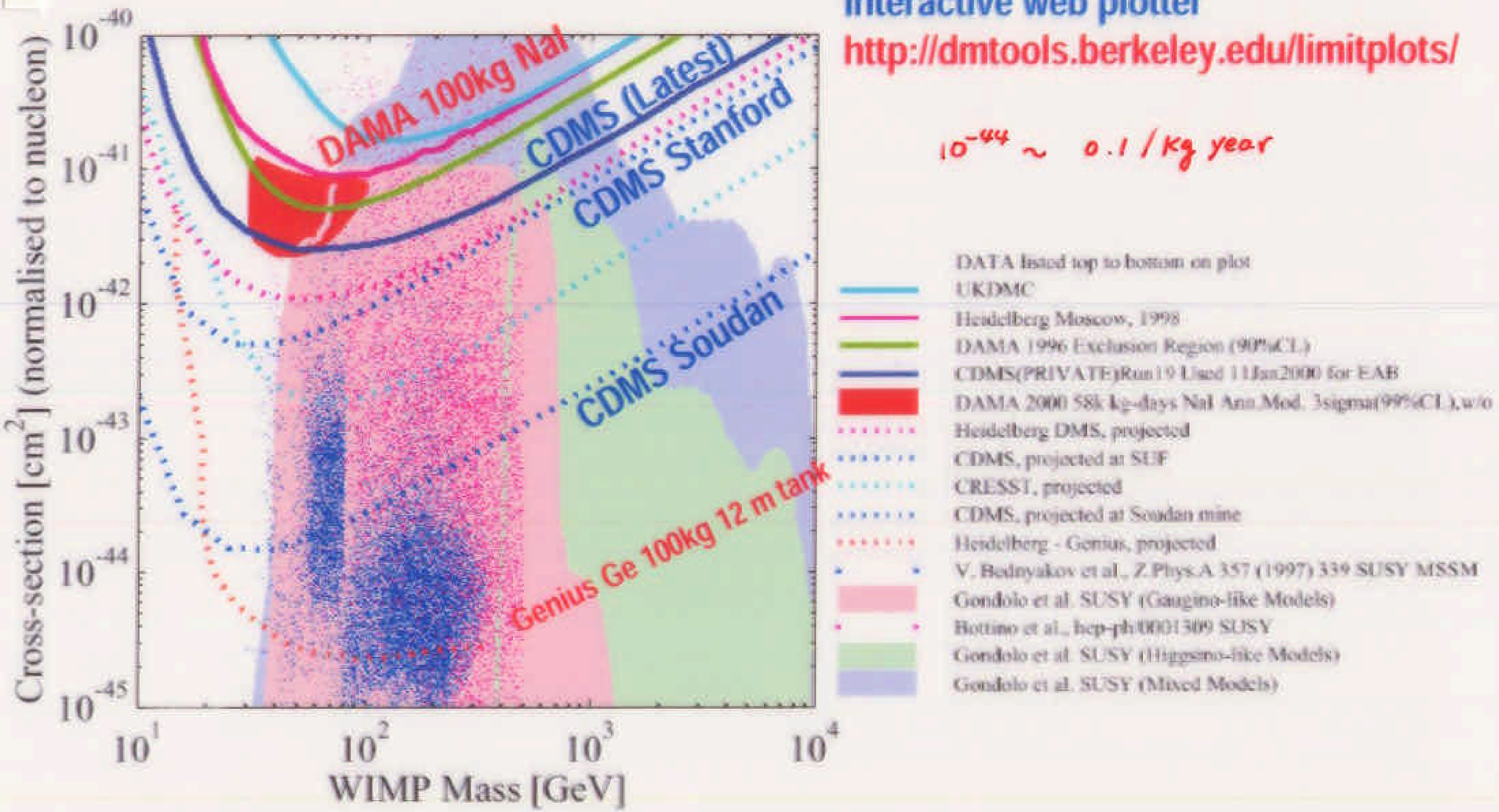


:ation yield (Y) vs. recoil energy for veto-anticoincident single
:trodes of the 3 uncontaminated Ge detectors. Solid curve:
s. Dashed curves: nominal 90% nuclear-recoil acceptance re
:hreshold. Dashed-dotted curve: threshold for separation of ioı
Circled points: nuclear recoils. The presence of 3 events just al
:ible with 90% acceptance.

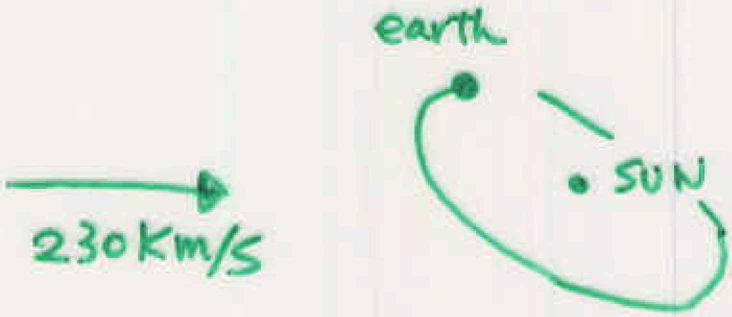
Interactive web plotter

http://dmtools.berkeley.edu/limitplots/

$10^{-44} \sim 0.1$ / kg year



Very Nervous about making comment on DAMA



background 1/day/kg/keV

modulation 0.02 (at 2-3 keV)

- NaI 1-4 (4 years)
  (NaI 3 does not fit cos curve well ....)
- no neutron background estimation

CDMS (SUDAN) covers this region completely

:. A complete
the following
he energy and
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region of the
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g period of our
/IA/NaI-4) [6].
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n, while flat$_{jk}$
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s made on all
l keV bins (k
energy inter-

disfavours the
giving a prob-
/20). On the
the function
in each of the
= (0.022 ±
(1.00 ± 0.01)
A = (0.023
± 13) days,
χ^2/d.o.f. ≃
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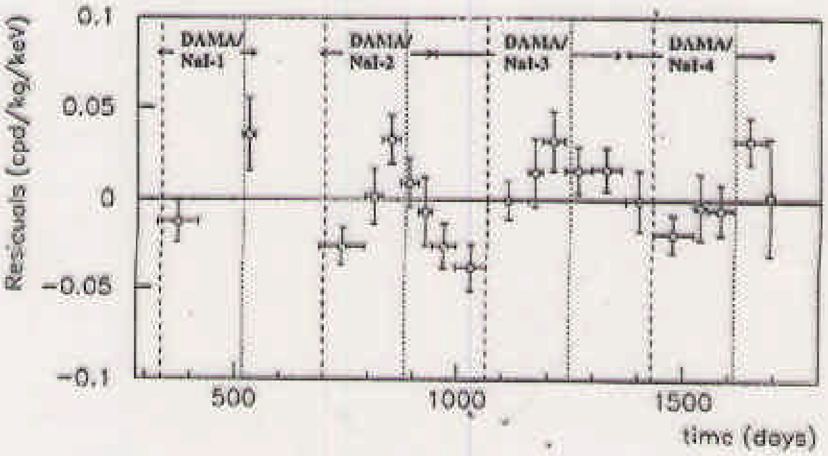


Fig. 2. Model independent residual rate in the particular 2-6 keV cumulative energy interval as a function of the time elapsed since January 1-st of the first year of data taking. The expected behaviour of a WIMP signal is a cosine function with minimum roughly at the dashed vertical lines and with maximum roughly at the dotted ones.

0.013 × 7 × 18 (keV) × 365 ~ O(100) year

further comment on this approach, still using this particular 2–6 keV cumulative interval as an example.

4. Full correlation analysis of the DAMA / NaI-3 and DAMA / NaI-4 data sets

According to Refs. [4,5], a complete time and energy correlation analysis of the data collected between 2 and 20 keV has been performed by using the standard maximum likelihood method. For this purpose the data have been grouped in cells identified by three indices: i for the time interval (1 day), k for the energy bin ($\Delta E = 1$ keV) and j to specify the detector. The maximum likelihood function can be written as a product of Poissonians $\mathbf{L} = \Pi_{ijk} e^{-\mu_{ijk}} \frac{\mu_{ijk}^{N_{ijk}}}{N_{ijk}!}$. Here N_{ijk} is the number of events in each ijk cell which follows a Poissonian distribution with expectation value $\mu_{ijk} = [b_{jk} + S_{0,k} + S_{m,k} \cdot \cos\omega(t_i - t_0)] M_j \Delta t_i \Delta E \epsilon_{jk}$. The unmodulated and modulated parts of the signal are $S_{0,k}$ and

Implication of (Non) Discoverly

Discovery (LSP dark matter)

1st approximation $\Omega_m \sim \Omega_\chi$

Standard mechanizm (thermal prodution)

$$\Omega^{th} \propto \frac{1}{\langle \sigma v \rangle_{\chi\chi \to \ldots}} \Bigg|_{T_f}$$

$\langle \sigma v \rangle$: function of m_χ & interaction)

collider input! from Tevatron LHC ...

case 1 $\Omega^{th} \sim 0.3$ Standard BB up to T_f

2 $\Omega^{th} < 0.3$ inflaton, AD decay or other DM component

3. $\Omega^{th} > 0.3$ entropy production low reheating

4. sofistication

$$\sigma_{\chi N} \times \left(\frac{\Omega^{th}}{\Omega^m} \right) \rho_{halo}\, v$$

collider input

v.s. counting rate

some problem + halo composition

Can $\delta\Omega_\chi \sim 20\%$?

Precision LHC χ_1 study

TU. Munich, YITP, YITP
(Drees, Y.G. Kim, Nojiri
Theory →
→ Toya, Hasuko, Tomio, Kobayashi)
experiment ICHEP. Tokyo

review of "MSUGRA approach"

- "**believe**" universal soft mass @ GUT because we need them to kill FCNC

→ $\mu >> M$

→ $\sigma(\chi\chi\to) \sim \sigma(\chi_{\tilde{B}}\chi_{\tilde{B}} \to \tilde{l}_R\, l_R)$

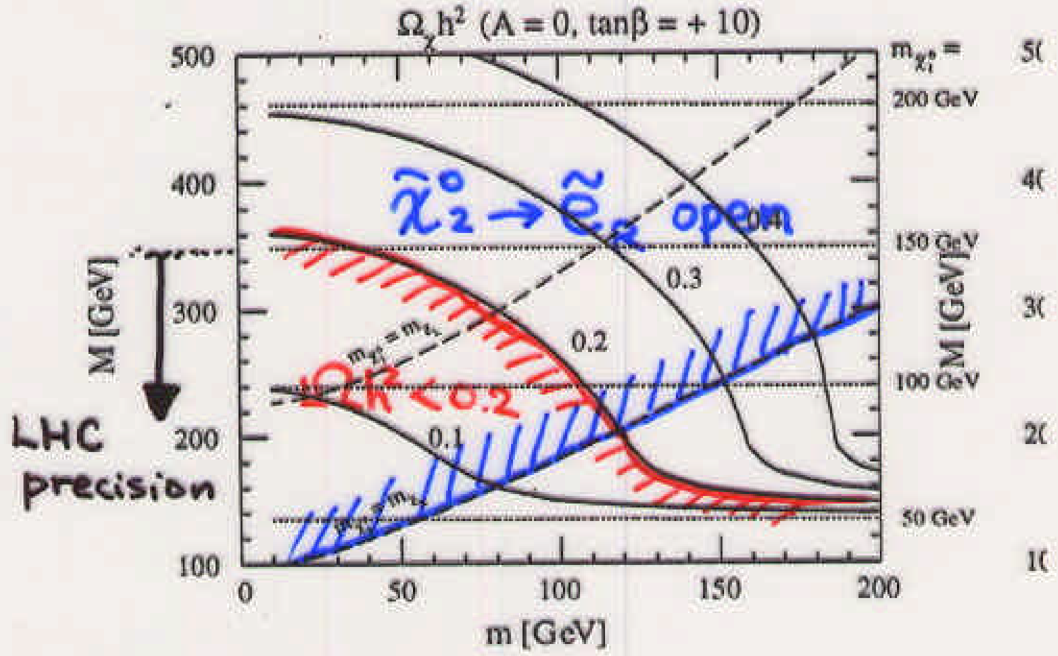
$\Omega_\chi \sim \Omega_{\tilde{B}}$ ()

- at LHC (end point measurement)

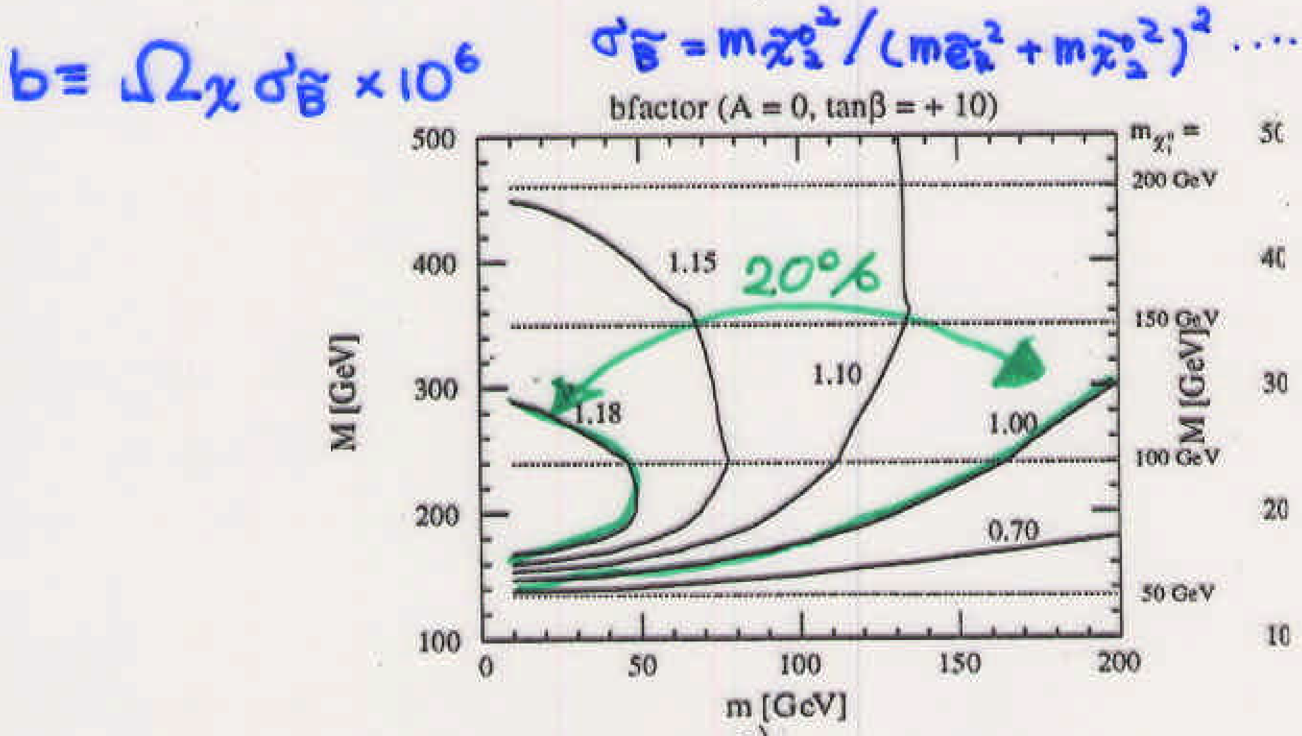
$\tilde{q} \to \tilde{\chi}^0_2\, q$
$\quad \hookrightarrow \tilde{l}\, l$] m_{jl}^{max}
$\quad\quad \hookrightarrow \tilde{\chi}^0_1\, l$] m_{ll}^{max}
] $m_{jll}^{max\ min}$

→ 10% measurement of $m_{\tilde{l}_R}$, $m_{\tilde{\chi}^0_1}$ (for point 5 $M = 300$ GeV) — Hinchliffe & Paige

→ $\delta\sigma_{\tilde{B}\tilde{B}} \sim 20\%$ → $\Omega \sim 20\%$

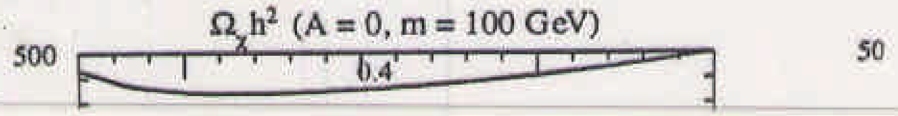


a)



c)

Figure 1: Contours of constant Ωh^2 (Fig 1 a,b) and b
(a,c) and 4 (b,d). We take $\mu > 0$. Contours of consta
$m_{\chi_1^0} = m_{\tilde{e}_L}$ are also shown.

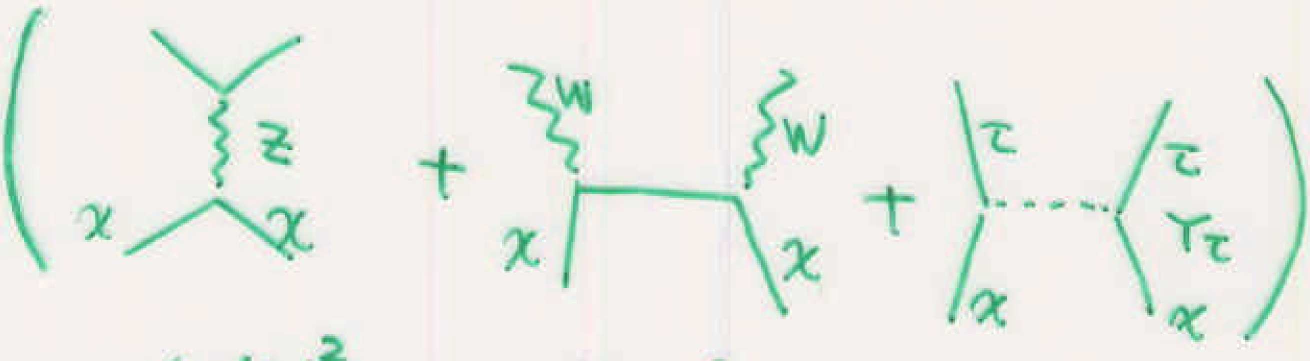


But how we know $\mu \gg M$? 5

$\Omega_{th} \sim \Omega_{\tilde{B}}$ (for $\mu \gtrsim M_2 > M_1$)

$\Omega_{th} \neq \Omega_{\tilde{B}}$ (for $\mu \lesssim M_2$)

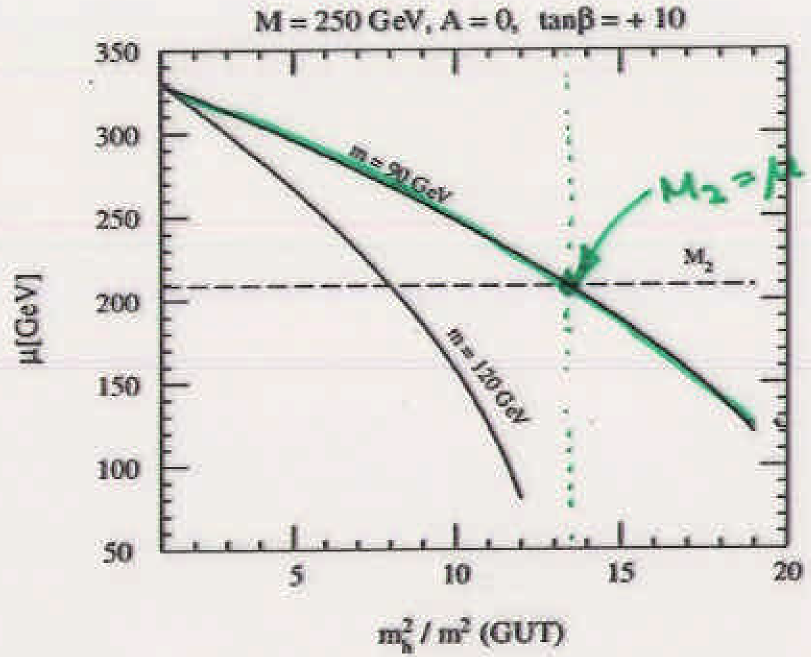
$\sigma_{\chi\chi} v \sim$



$(N\tilde{H})^2$ $\quad$ $(NH)^2$ $\quad$ $N\tilde{H}\tan\beta$

- What is the collider signal?
- if $\delta\mu$, $\delta\tan\beta$ small enough to constrain $\delta\Omega < 20\%$?
- ($\mu \lesssim M_2$ when $m_h|_{GUT} \gg m$)

→ Fig


M = 250 GeV, A = 0, tanβ = + 10
350
300
250
200
150
100
50
μ[GeV]
5
10
15
20
m = 90 GeV
m = 120 GeV
M₂
M₂ = μ
m²_h / m² (GUT)

a)

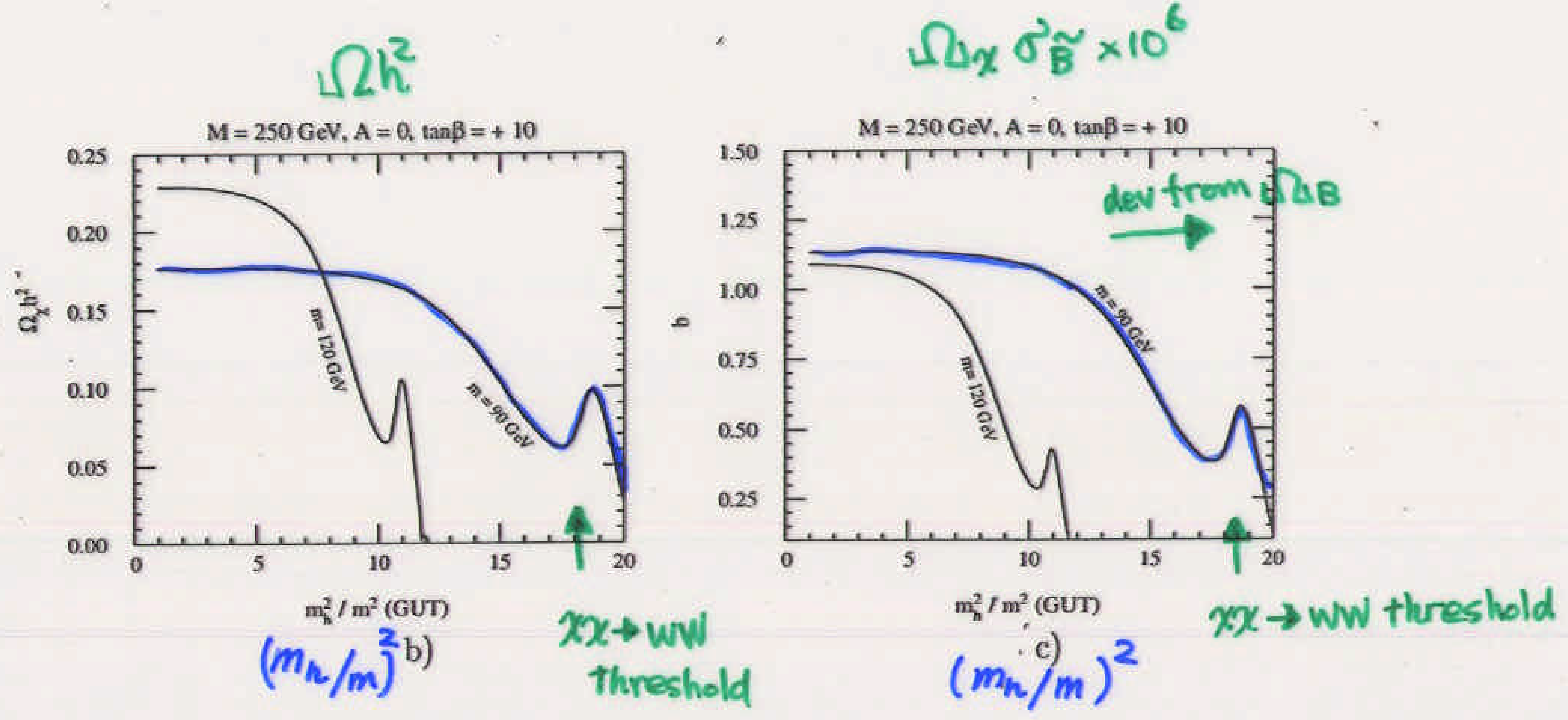


Figure 3: a) μ b) Ω and c) b as function of $(m_h/m)^2$. We fix $M = 250$ GeV, $A = 0$ and $\tan\beta = 10$.

$\mu \sim M$ Case

($m = 90$ GeV $M = 250$ GeV $\tan\beta = 10$
$(M_2, \mu) = (209, 200)$)

- $\tilde{\chi}_2^{\pm}$ $\tilde{\chi}_4^0$ production accesible due to wino comp
- Br($\tilde{q} \to \tilde{\chi}_2^0 \tilde{\chi}_4^0 \cdots$) is large enough
  when $\Omega_{\tilde{\chi}} \neq \Omega_{\tilde{B}}$ Fig
- $\tilde{\chi}_2^{\pm} \to \tilde{\nu}\, l$
  $\hookrightarrow l\, \tilde{\chi}_1^{\pm}$
  $\hookrightarrow \tilde{\tau}\, \tilde{\chi}_1^0$
  $\tilde{\chi}_4^{\pm} \to \tilde{l}_{L,R}\, l$
  $\hookrightarrow \tilde{\chi}_{2,1}^0\, l$

  conventional llj mode from different decay mode
- different m_{ll} signal region Fig

  reconstruction of endpoints using m_{ll} cut

mode	m_{ll} cut	mass from end point
$\tilde{q} \to \tilde{\chi}_2^0 \to \tilde{e}_R \to \tilde{\chi}_1^0$	$m_{ll} < 55$ GeV	$m_{\tilde{q}}$, $m_{\tilde{\chi}_2^0}$, $m_{\tilde{e}_R}$, $m_{\tilde{\chi}_1^0}$
$\tilde{q} \to \tilde{\chi}_2^{\pm} \to \tilde{\nu} \to \tilde{\chi}_1^{\pm}$	55 GeV $< m_{ll} < 125$ GeV	$m_{\tilde{q}}$, $m_{\tilde{\chi}_2^{\pm}}$, $m_{\tilde{\nu}}$, $m_{\tilde{\chi}_1^{\pm}}$

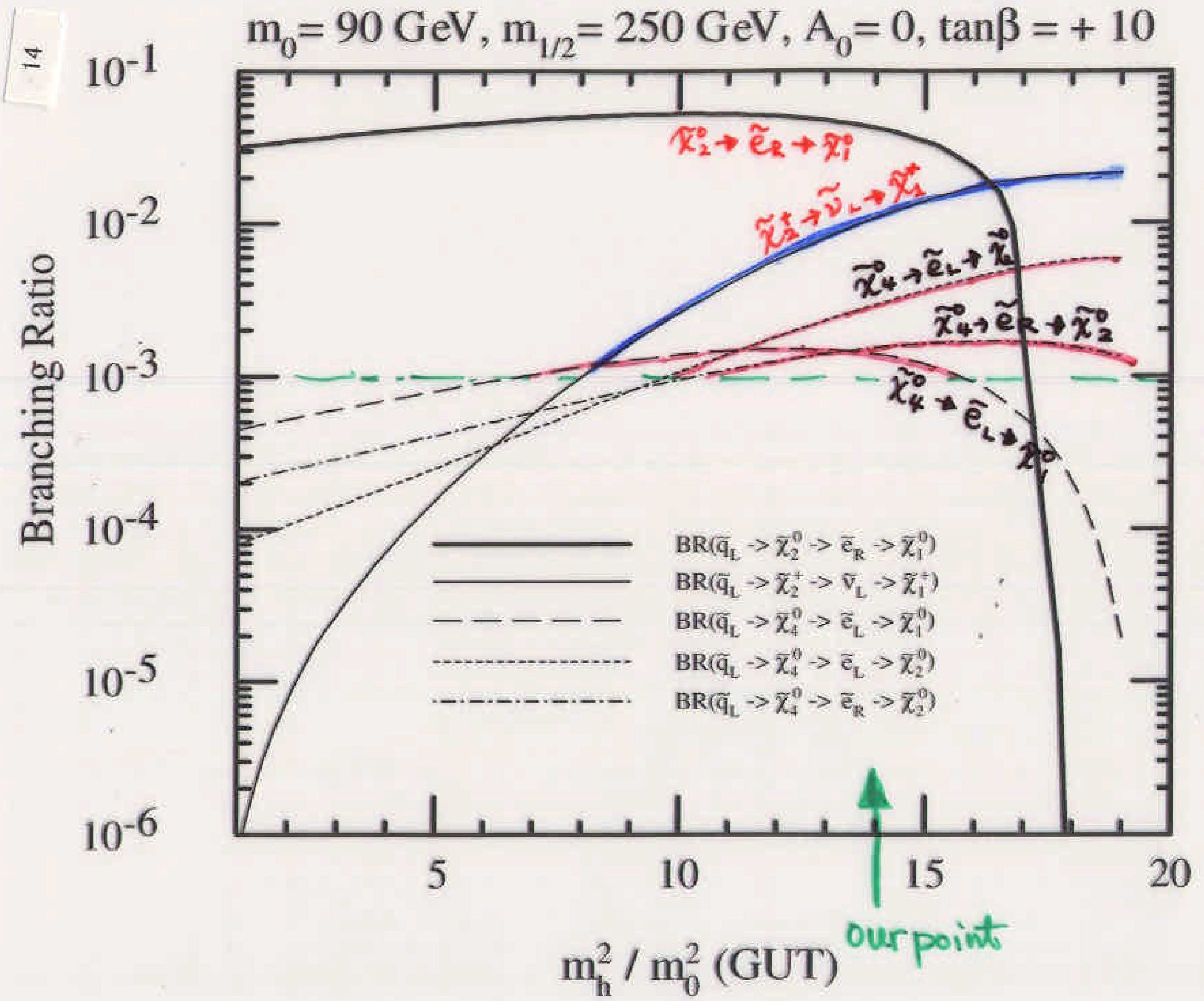
Fig

MSSM parameter ($M_1, M_2, \mu, \tan\beta$, $m_{\tilde{e}_R}$ $m_{\tilde{\nu}}$) $\leftarrow$ Mass measurement ($m_{\tilde{\chi}_2^{\pm}}$, $m_{\tilde{\chi}_1^{\pm}}$, $(m_{\tilde{\chi}_4^0})$, $m_{\tilde{\chi}_2^0}$, $m_{\tilde{\chi}_1^0}$, $m_{\tilde{e}_R}$, $m_{\tilde{e}_L}$, $m_{\tilde{\nu}}$)

ex: $m_{\tilde{\chi}_1^{\pm}} < \mu$, $M_2 < m_{\tilde{\chi}_2^{\pm}}$

- $\tilde{\chi}_2^{\pm}$ mode identified

  $ll + \tau$ from $\tilde{\chi}_1^{\pm}$ decay Fig



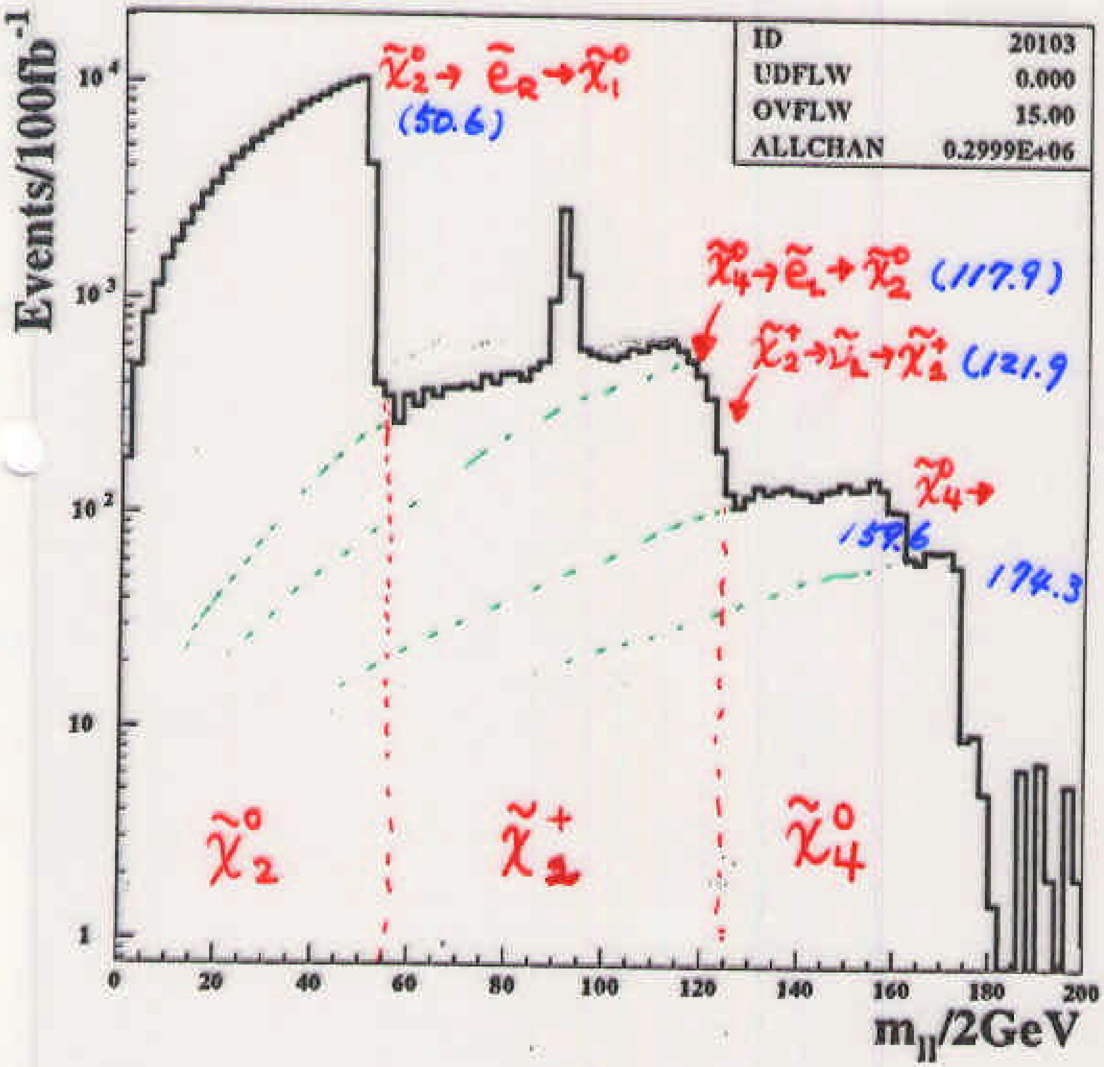
m0= 90 GeV, m1/2= 250 GeV, A0= 0, tanβ = + 10
Branching Ratio
10-1
10-2
10-3
10-4
10-5
10-6
5
10
15
20
m_h^2 / m_0^2 (GUT)
BR(q̃L -> χ̃2^0 -> ẽR -> χ̃1^0)
BR(q̃L -> χ̃2^+ -> ν̃L -> χ̃1^+)
BR(q̃L -> χ̃4^0 -> ẽL -> χ̃1^0)
BR(q̃L -> χ̃4^0 -> ẽL -> χ̃2^0)
BR(q̃L -> χ̃4^0 -> ẽR -> χ̃2^0)
χ̃2^0 → ẽR → χ̃1^0
χ̃2^+ → ν̃L → χ̃1^+
χ̃4^0 → ẽL → χ̃2^0
χ̃4^0 → ẽR → χ̃2^0
χ̃4^0 → ẽL → χ̃1^0
our point

$(M_2, \mu) = (209, 200)$ GeV

$M = 250$ GeV $m = 90$ GeV $\tan\beta = 10$

$m_{\tilde{\chi}^0_2}$	$m_{\tilde{e}_R}$	$m_{\tilde{\chi}^0_1}$
155.13	139.3	93.18

$m_{\tilde{\chi}^\pm_2}$	$m_{\tilde{\nu}}$	$m_{\tilde{\chi}^+_1}$
272.52	188.67	148.44



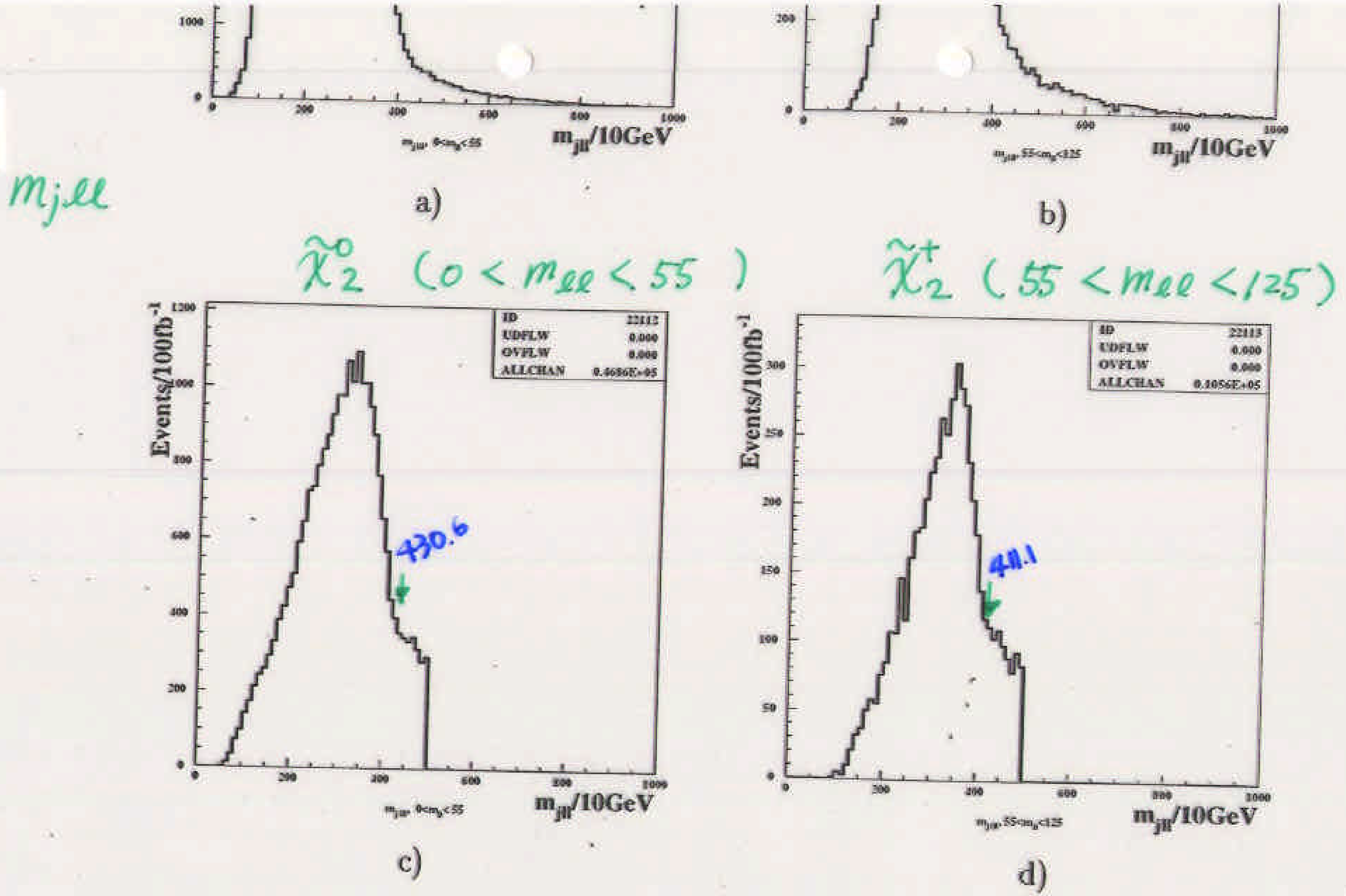


Figure 7: a), b): m_{j_1ll} distributions for a) $m_{ll} < 55$ GeV, b) 55 GeV $< m_{ll} <$ 125 GeV. c), d): The same distributions after requiring $m_{j_1ll} <$ 500 GeV $< m_{j_2ll}$.

$m_{ll\tau}$

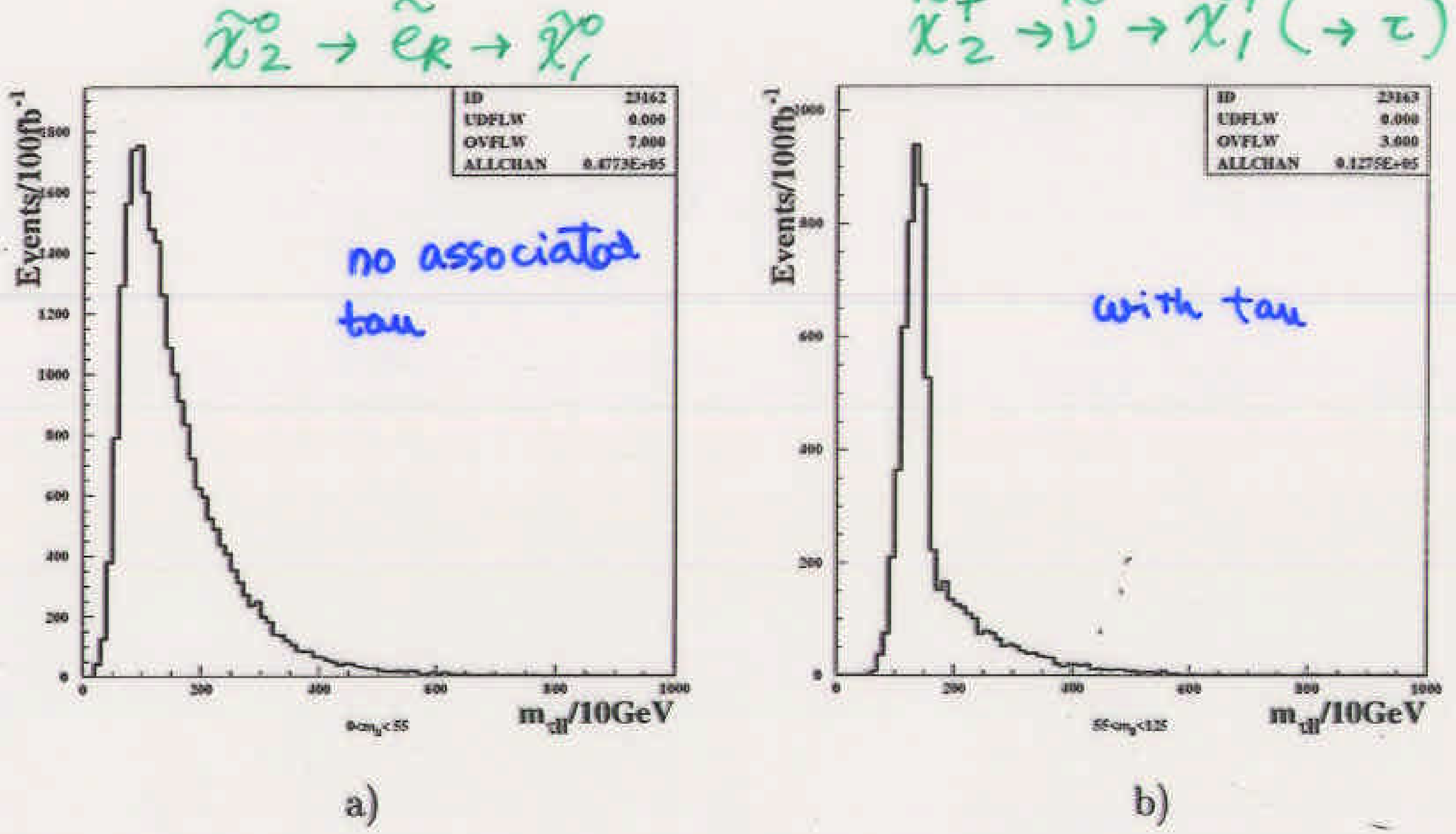
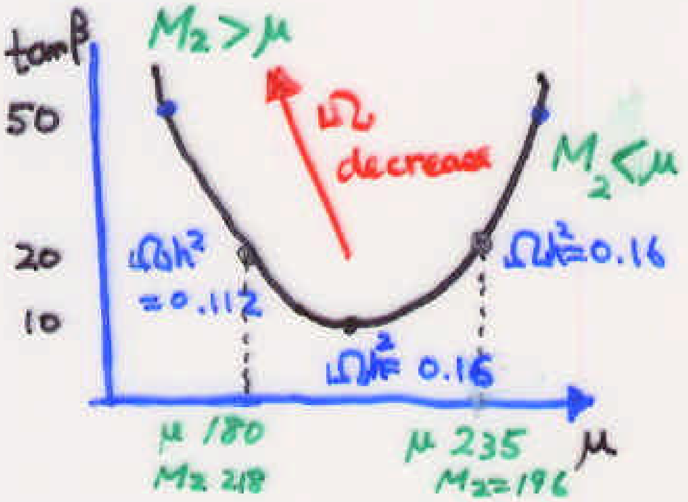


Figure 10: The invariant mass distribution $m_{j_\tau ll}$ for a) $m_{ll} < 55$ GeV and b) for 55 GeV$< m_{ll} < 125$ GeV.

	$m_{\tilde{q}_L}$	M_1	M_2	μ	$\tan\beta$	$m_{\tilde{e}_R}$	$m_{\tilde{\nu}_L}$
μ max	575.381	108.93	198.97	232.55	16.60	147.46	202.04
μ min	556.23	100.96	220.7	180.69	20.	136.4	186.79

$\tilde{\chi}$

Masses are constrained but MSSM parameters (interaction) are NOT



- one dim solution in 7 dim parameter
- tanβ=10 (input) → no upper bound on tanβ

		Ωh^2
$\mu < M_2$	$\tan\beta = 20$	$= 0.12$
$\mu > M_2$	$\tan\beta = 20$	0.16
$\mu > M_2$	$\tan\beta = 30$	0.11

- Mass (end point) measurement is not enough

《Br meaurement》

		$\tilde{\chi}^0_2$	$\tilde{\chi}^+_2$	ratio $\tilde{\chi}^+_2 / \tilde{\chi}^0_2$
$\mu > M_2$ (tanβ 20)	$\tilde{u}_L \to$	0.257	0.113	0.44
$\mu < M_2$ tanβ(20)	$\tilde{u}_L \to$	0.167	0.285	1.71

factor 4

tanβ : $\Gamma(\tilde{\chi}^0_2 \to \tilde{\tau}\tau)$ tanβ dependence

$\tilde{\chi}^0_2 \to \tilde{e}_R$ coupling supression + phase space supression

$\tilde{\chi}^0_2 \to \tilde{\tau}_1$ $\tilde{\tau}_L$ mixing $\propto \mu \tan\beta$, $m_{\tilde{\tau}_1} < m_{\tilde{e}_R}$ > enhanced!

- $Br(\tilde{\chi}^0_2 \to e^+e^- \tilde{\chi}^0_1)$ can change factor 2 from tanβ 10 → 20

LHC $\Omega^{th} h^2$ study

◎ have not check

$\mu \ll M$ (Higgsino

$M_2 < M_1 < \mu$ (Anormaly Med)

$m_{\tilde{\chi}_2^0} < m_{\tilde{\ell}}$ (Hard to do?)

$\tilde{\tau}$ mode (tanβ, $m_{\tilde{\tau}}$, GUT effect)

◎ $\sigma_{N\chi}$ (tanβ, m_A, μ/M)

◎ Dark Matter discovery (Next Year?)

→ LHC LC Tevatron implications..