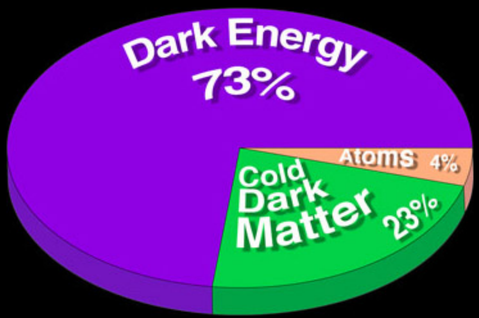
Stau Scenarios at ILC

SUSY Co-annihilation Signal as Possible Benchmark Physics

SiD Benchmarking Meeting
November 6, 2007



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Outline

SUSY and Cosmology

ILC ($\sqrt{s}$ = 500 and 800 GeV) reach of the mSUGRA parameter space via $\tilde{\tau}_1^+\tilde{\tau}_1^-$ and $\tilde{\chi}_1^0\tilde{\chi}_2^0$

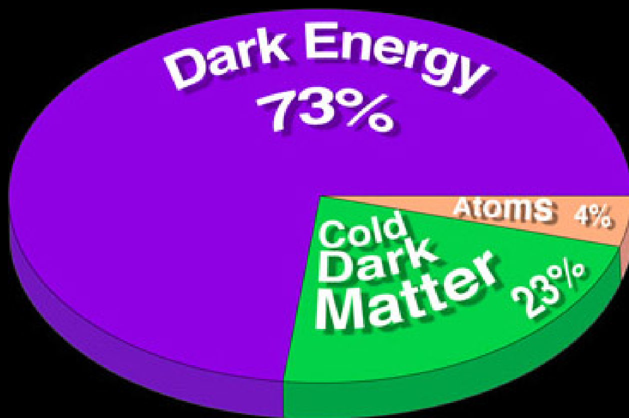
[Ref. V. Khotilovich et al., Phys Lett. B 618 (2005) 182]

Key Detector Design:
- Forward Calorimeter
- Tracking
- PFA

Summary

SUSY and Cosmology

Astrophysics



$$\underbrace{\Omega_{\tilde{\chi}_1^0}}_{0.23} h^2 \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$$

$$\underbrace{\langle \sigma_{\text{ann}} v \rangle}_{0.9\ \text{pb}} = \frac{\pi \alpha^2}{8M^2}$$

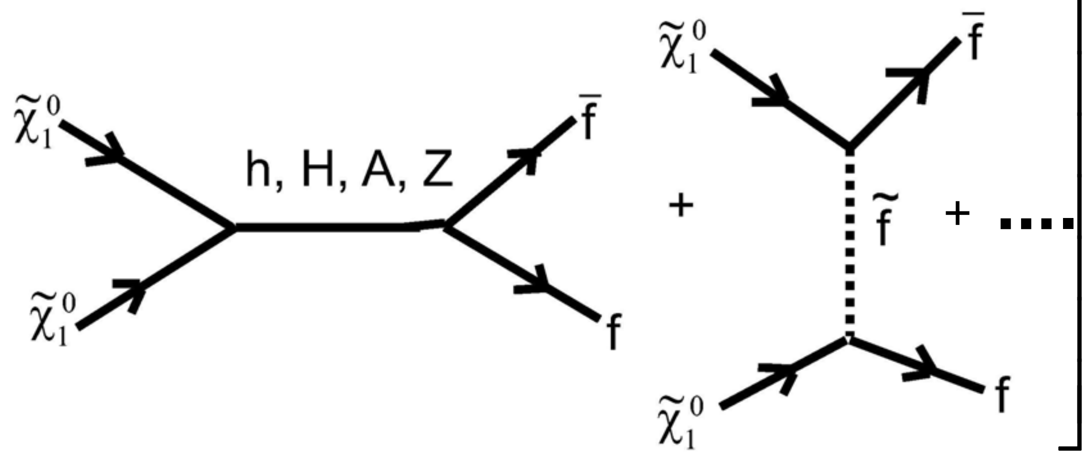
CDM = Neutralino ($\tilde{\chi}_1^0$)

SUSY

SUSY is an interesting class of models to provide a weakly interacting massive neutral particle (M ~ 100 GeV).

Anatomy of σ_{CDM}

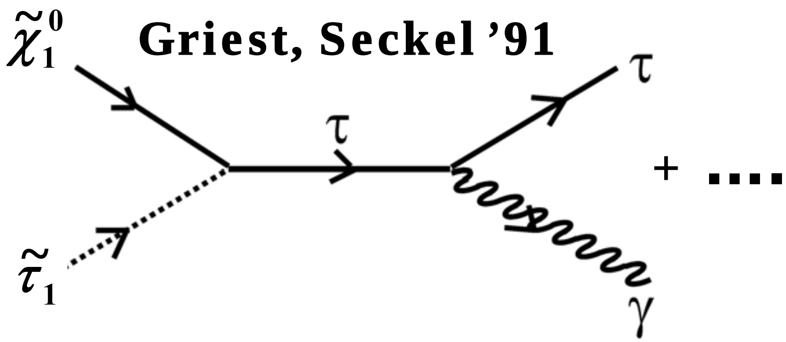
$$(\Omega_{CDM})^{-1} \propto \left[\quad \right]^2$$



$$+ \left[\quad \right]^2$$

Co-annihilation Process

Griest, Seckel '91

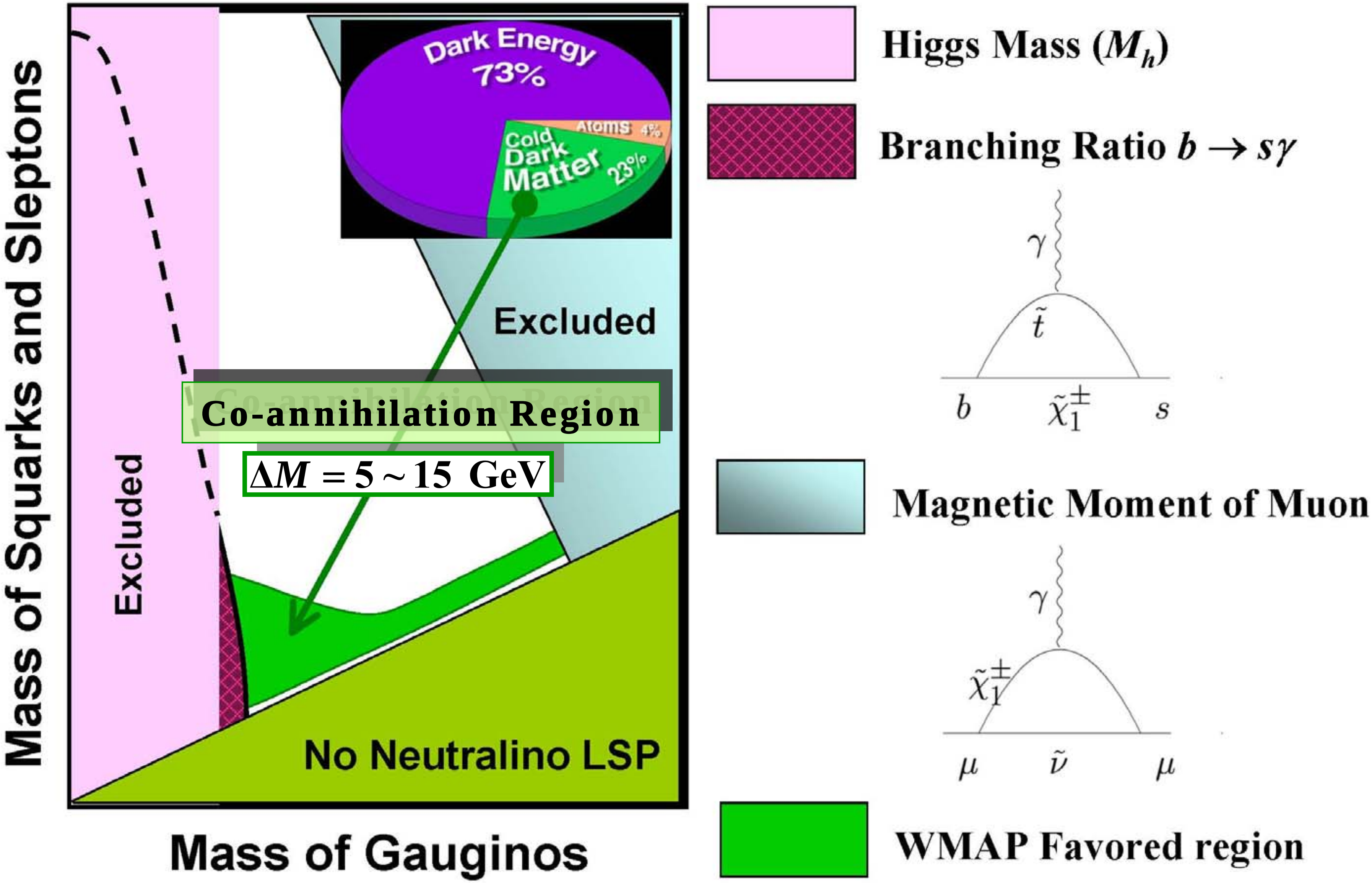


$$e^{-\Delta M / 20}$$

$$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0}$$

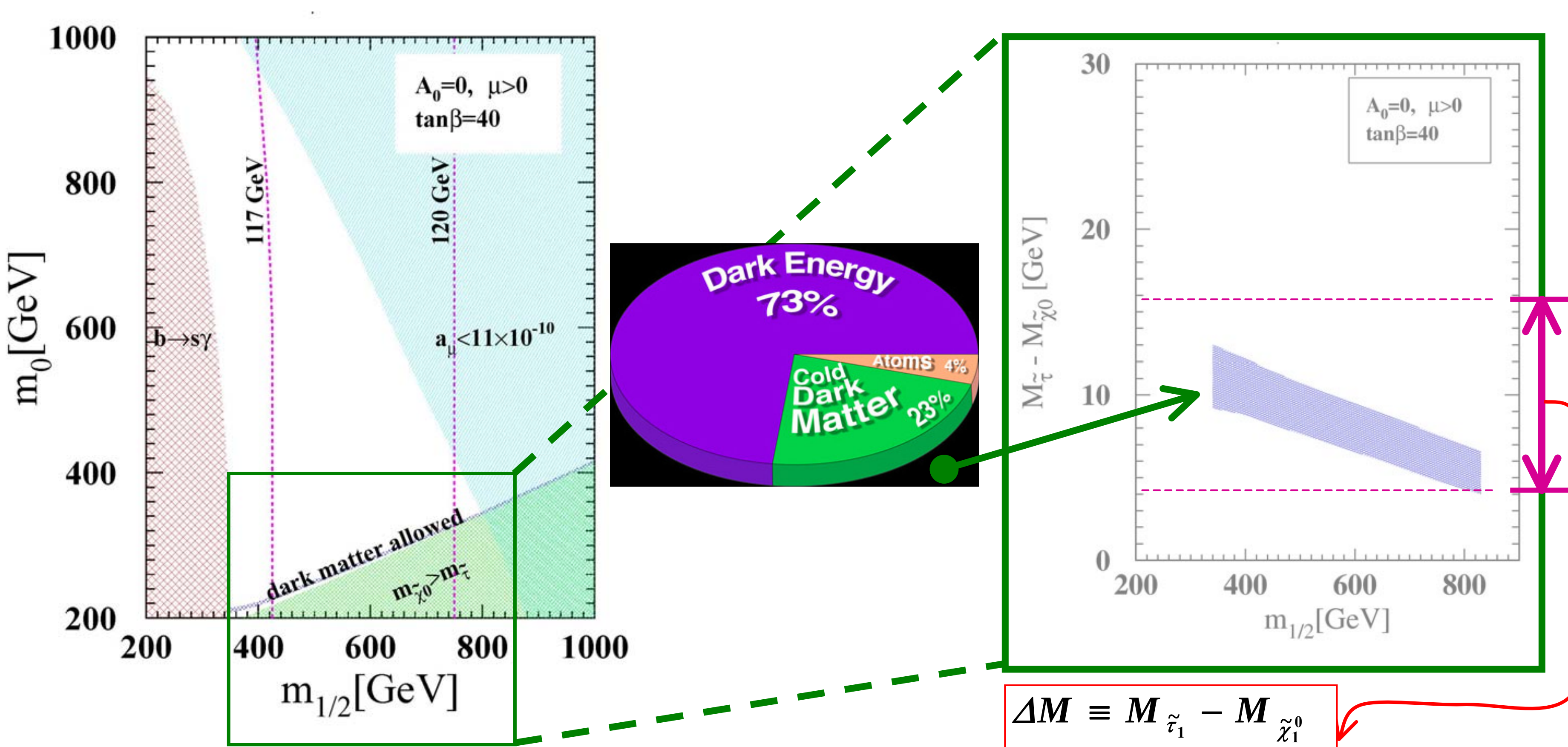
An accidental near degeneracy occurs naturally for light stau in mSUGRA.

Dark Matter Allowed Region



CDM Allowed Region

m_0 vs. $m_{1/2}$ ($\tan\beta = 40$, $A_0 = 0$, $\mu > 0$)

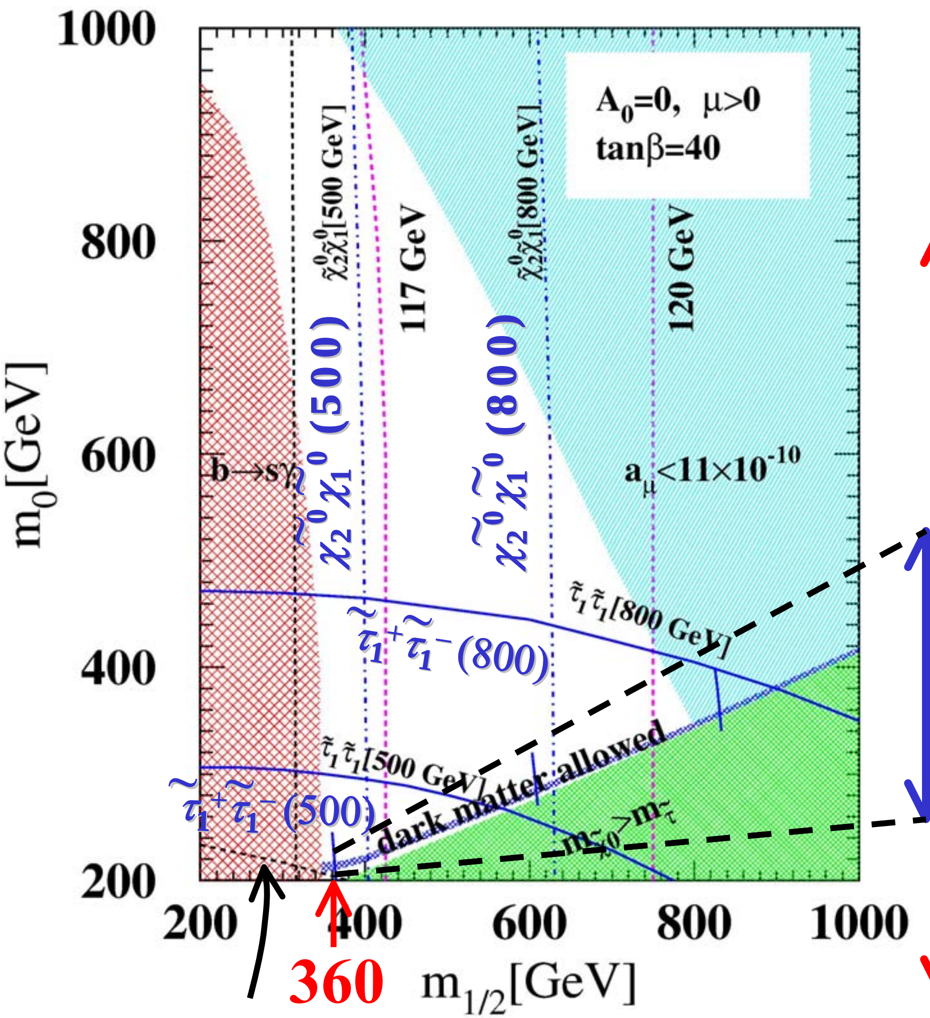


$$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} = 5 \sim 15\ \text{GeV}$$

Can we measure ΔM at colliders?

CDM Allowed Region (LC Version)

m_0 vs. $m_{1/2}$ ($\tan\beta = 40$, $A_0 = 0$)



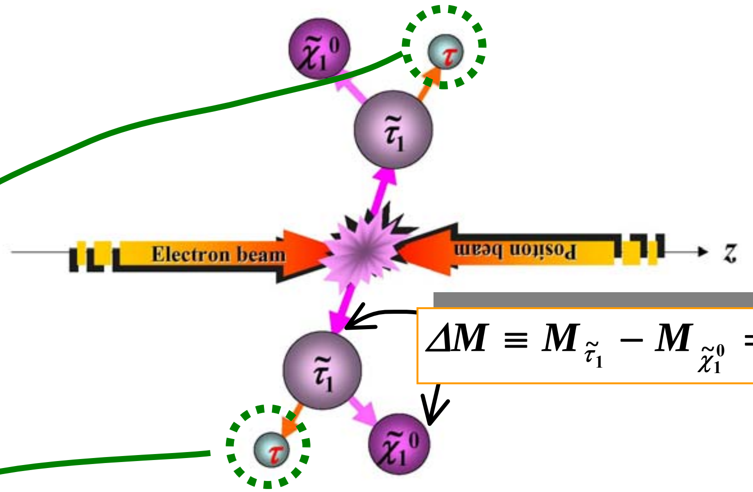
ISAJET v7.69 mSUGRA					
$A_0 = 0$, $\mu > 0$, $\tan\beta = 40$					
$m_{1/2}$ (GeV)	m_0 (GeV)	$M(\tau_1)$ (GeV/c^2)	$M(\chi_1^0)$ (GeV/c^2)	$M(\chi_2^0)$ (GeV/c^2)	ΔM(true) = $M(\tau_1)$-$M(\chi_1^0)$
360	203	145.14	142.47	274.21	2.67
360	204	146.29	142.47	274.17	3.82
360	205	147.24	142.48	274.18	4.76
360	206	148.20	142.48	274.18	5.72
360	207	149.16	142.49	274.19	6.67
360	208	150.12	142.50	274.21	7.62
360	209	151.08	142.50	274.22	8.58
360	210	152.04	142.51	274.22	9.53
360	211	153.00	142.51	274.23	10.49
360	212	153.95	142.52	274.25	11.43
360	213	154.90	142.53	274.26	12.37
360	214	155.86	142.53	274.26	13.33
360	215	156.81	142.54	274.27	14.27
360	216	157.76	142.54	274.28	15.22
360	217	158.70	142.55	274.29	16.15
360	218	159.65	142.56	274.30	17.09
360	219	160.59	142.56	274.31	18.03
360	220	161.55	142.57	274.33	18.98

$m_{\tilde{e}} = 250$ GeV

Small ΔM

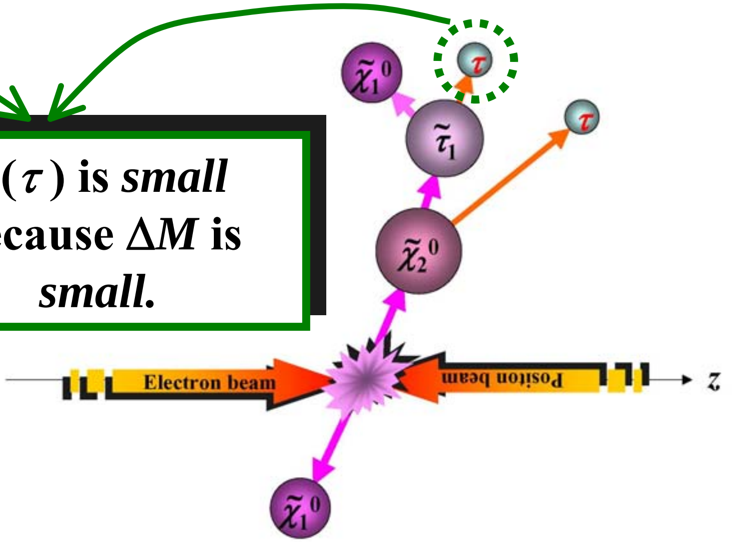
SUSY Signals at LC

- **Stau-pair production** $\tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$



$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} = 5 \sim 15\ \text{GeV}$

- **Neutralino-pair production** $\tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$

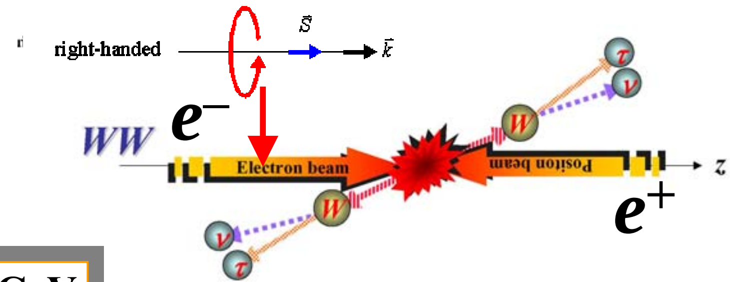


E*(τ) is *small* because Δ*M* is *small.

SM Backgrounds at LC

- **4-fermion *WW*, *ZZ*, *Zνν* production**

e.g., $e^+e^- \to W^+W^- \to \tau^+\nu\,\tau^-\bar{\nu}$

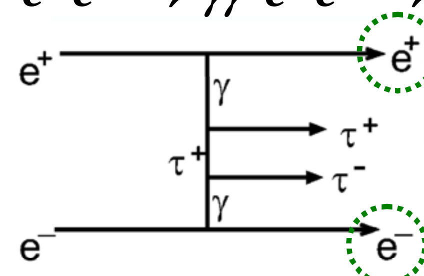


Suppressed by RH polarized electron beams

N_{4f}(500 fb^{-1}) ≈ 10k @ 90% RH

- **Two-photon (γγ) process**

$e^+e^- \to \gamma\gamma\, e^+e^- \to \tau^+\tau^-e^+e^-$



Lower energy τ's

$N_{2\gamma}$(500 fb^{-1}) ≈ 13M events*!*

We need to detect e⁻ and e⁺ going very close to the beam direction (down to 2° or 1°).

Monte Carlo

Event Generator plus Beam Bremsstruhlung

SUSY: ISAJET v7.69

$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^0 \rightarrow \tilde{\tau}_1\tau + \tilde{\chi}_1^0 \rightarrow \tau\tau + E^{miss}$

$e^+e^- \rightarrow \tilde{\tau}_1^+\tilde{\tau}_1^- \rightarrow \tau\tau + E^{miss}$

SM : WPHACT v2.02pol

(all 4 fermion final states (SM4f) and $\gamma\gamma$ process with e^+/e^- polarization)

$e^+e^- \rightarrow \nu_e\nu_e\tau\tau,\ \nu_\mu\nu_\mu\tau\tau,\ \nu_\tau\nu_\tau\tau\tau$; $ee\tau\tau$, $eeqq$ ($\gamma\gamma$ process)

Ref: E. Accomando and A. Ballestrero, Comput. Phys. Commun. 99, 270 (1997)
E. Accomando, A. Ballestrero, and E. Maina, Comput. Phys. Commun. 150, 166 (2003)

Tau Decay: TAUOLA v2.6

Detector Simulation & Event Analysis:

Package LCD Root v3.5

FAST MC using LD Mar01 detector parameterization, Jet Finder, …

mSUGRA Points

ISAJET 7.69 $\mu > 0$, $\tan\beta = 40$, $A_0 = 0$

MCPt	m_0	$m_{1/2}$	$M\tilde{\tau}_1$	$M\tilde{\chi}_1^0$	$M\tilde{\chi}_2^0$	$M\tilde{\tau}_1 - M\tilde{\chi}_1^0$	$M\tilde{\chi}_1^0 + M\tilde{\chi}_2^0$
	Mass (GeV)						
P1	205	360	147.2	142.5	274.2	4.75	390
P2	210	360	152.0	142.5	274.2	9.53	390
P3	220	360	161.6	142.6	274.3	19.0	390

$\sigma \times Br(\tau \rightarrow \tau_h)^2$ [fb]

ISAJET 7.69 $\sqrt{s} = 500$ GeV

	$Pol(e^-) = -0.9$		$Pol(e^-) = 0$		$Pol(e^-) = +0.9$	
SM4f	7.84		48.9		89.8	
SUSY	$\tilde{\chi}_1^0\tilde{\chi}_2^0$	$\tilde{\tau}_1\tilde{\tau}_1$	$\tilde{\chi}_1^0\tilde{\chi}_2^0$	$\tilde{\tau}_1\tilde{\tau}_1$	$\tilde{\chi}_1^0\tilde{\chi}_2^0$	$\tilde{\tau}_1\tilde{\tau}_1$
P1	0.41	28.3	3.39	19.6	6.09	13.2
P2	0.40	26.6	3.31	18.4	6.00	12.4
P3	0.38	23.0	3.15	15.8	5.68	10.6

Event Selection Cuts

$\tilde{\chi}_1^0\tilde{\chi}_2^0$ at $Pol = +0.9$(LH)	$\tilde{\tau}_1^+\tilde{\tau}_1^-$ at $Pol = -0.9$(RH)
$N_{jet} \geq 2$ ($E_{jet} > 3$ GeV; JADE $Y \geq 0.0025$)	
τ_h ID (N_{track}=1, 3; $q=\pm1$; $M_{track} < 1.8$ GeV)	
$-q \times \cos\theta_{jet} < 0.7$	$\lvert \cos\theta_{jet} \rvert < 0.65$
Missing $P_T > 5$ GeV	
$-0.8 < \cos\theta(j_2, P_{vis}) < 0.7$	$-0.6 < \cos\theta(j_2, P_{vis}) < 0.6$
Acoplanarity > 40°	
No EM clusters in 5.8° < θ < 25.8° with $E > 2$ GeV	
No electrons in θ > 25.8° with $P_T > 1.5$ GeV	
Beam mask: 2°(1°) - 5.8° No EM clusters with $E > 100$ GeV	

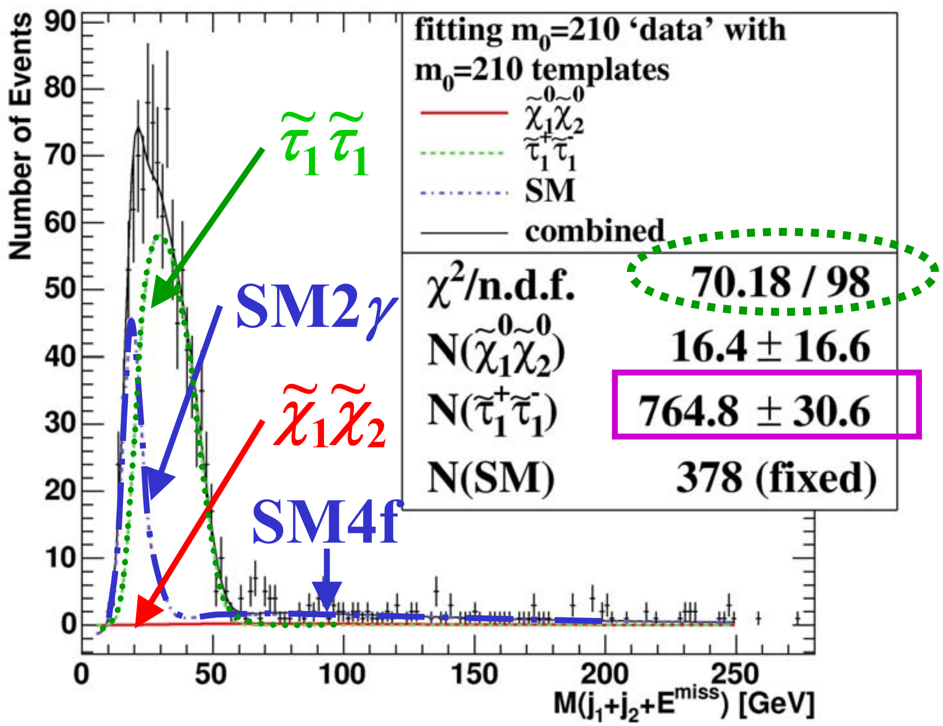
Note: cos(25.8°)=0.9, cos(5.8°)=0.995

$M(j_1,j_2,E^{miss})$

- Choose an effective mass of j_1, j_2 and E^{miss}, $M(j_1,j_2,E^{miss})$, as a discriminator.
- Prepare three templates of the distribution of the effective mass for $\tilde{\chi}_1^0\tilde{\chi}_2^0$, $\tilde{\tau}_1\tilde{\tau}_1$ and SM.
- Fit a MC sample of 500 fb^{-1} with the three templates to extract each contribution.
- χ^2 to find the best SUSY template.

"Experimental Data" (500 fb^{-1})
m_0 = 210 (ΔM = 9.53 GeV)

2° Mask

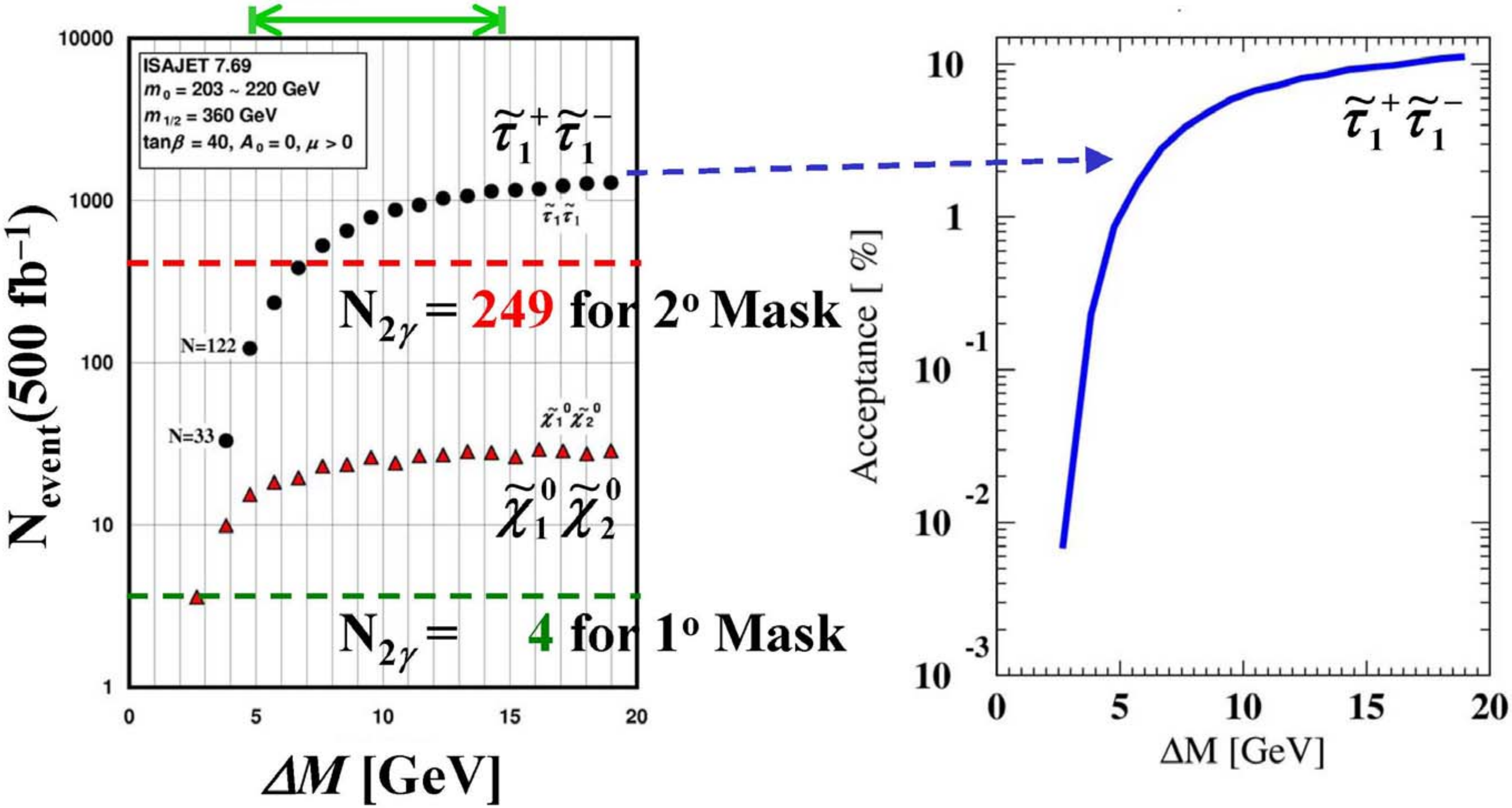


Note: 1° mask deduces SM2γ and enables us to probe smaller ΔM.

500 GeV ILC Performance

	(500 fb^{-1})	ΔM("500 fb^{-1} experiment")	
m_0 (ΔM)	$N_{\tilde{\tau}_1\tilde{\tau}_1}$	2° Mask	1° Mask
205 (4.76 GeV)	122	Not determined	$4.74^{+0.97}_{-1.03}$ GeV
210 (9.53 GeV)	787	$9.5^{+1.1}_{-1.0}$ GeV	$9.5^{+1.0}_{-1.0}$ GeV
213 (12.37 GeV)	1027	$12.5^{+1.4}_{-1.4}$ GeV	$12.5^{+1.1}_{-1.4}$ GeV
215 (14.27 GeV)	1138	$14.5^{+1.1}_{-1.4}$ GeV	$14.5^{+1.1}_{-1.4}$ GeV

1° Mask



- We need 1° to access to small *ΔM* at 500 GeV ILC!

Looking Back at a Slide

Event Selection Cuts

$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ at $Pol = +0.9$(LH) | $\tilde{\tau}_1^+ \tilde{\tau}_1^-$ at $Pol = -0.9$(RH)

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Note: cos(25.8°)=0.9, cos(5.8°)=0.995

SUSY Co-annihilation Region at ILC (LCWS 2005)

Tracks, π^0
PFA

BeamCal

Summary

[1] Stau-Neutralino co-annihilation region is one of the cold dark matter allowed parameter space. The signals should be one of the benchmark physics processes.

[2] The SUSY mass reaches are maximized via the $\tilde{\tau}_1\tilde{\tau}_1$ and $\tilde{\chi}_1^0\tilde{\chi}_2^0$ production at 500 GeV. The detector should be designed to detect E^{miss} + two low-energy τ's events.

[3] The importance of 1° "active mask" to detect very forward electron/positron to suppress $\gamma\gamma$ events especially for small ΔM.

[4] $\delta(\Delta M)/\Delta M \sim 10\%$ with

→Shape analysis using $M(j_1,j_2,E^{miss})$

→1° active beam mask for 500 GeV ILC.

→500 fb^{-1} with RH polarization for e^-

[5] 0.5° for 800 GeV?