



Analisi di eventi con fotoni  
ed energia mancante e limiti  
combinati in modelli di  
Gauge Mediated SUSY Breaking

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LEP TS

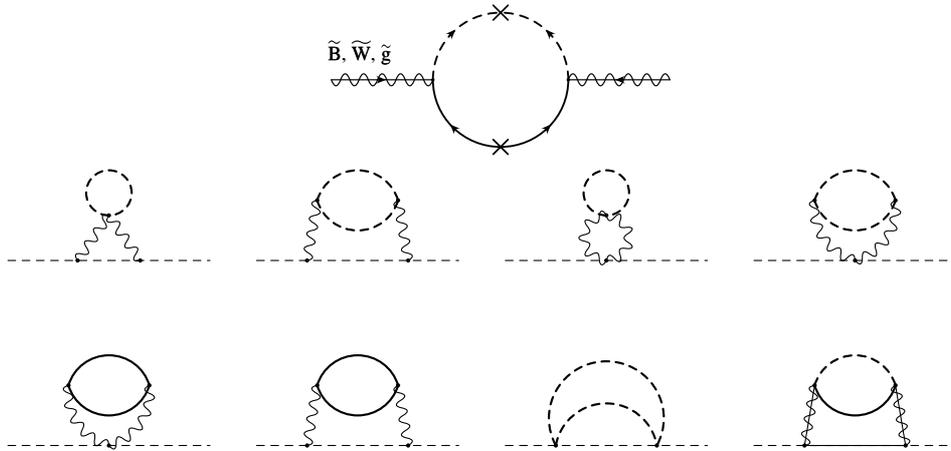


## Sommario:

- fenomenologia dei modelli con GMSB
- ricerca di segnali da GMSB  
con fotoni ed energia mancante al LEP
- interpretazione dei risultati nello spazio dei parametri dei  
modelli GMSB



## Spettro delle masse nei modelli GMSB



$$M_r(t=0) = \frac{\alpha_r(0)}{4\pi} \Lambda_G \quad t = \ln M_m^2/Q^2$$

$$m_{\tilde{f}}^2(t=0) = 2 \sum_{r=1}^3 C_r^{\tilde{f}} \frac{\alpha_r^2(0)}{(4\pi)^2} \Lambda_S^2 \quad r = 1, 2, 3$$

$$\Lambda_G = N \Lambda g(\Lambda/M_m) \quad \Lambda_S^2 = N \Lambda^2 f(\Lambda/M_m)$$

$\Lambda \equiv F_m/M_m$  è la scala universale di massa delle particelle SUSY

- $\mu$  e  $B\mu$  da EWSB,  $A_i = 0$  a  $t = 0$
- parametri:  $\sqrt{F}$ ,  $M_m$ ,  $\Lambda$ ,  $N$ ,  $\tan \beta$ , segno  $\mu$
- a tutti applicate RGE fino a scala MSSM
- masse sfermioni  $\propto \sqrt{N}$ , masse gaugini  $\propto N$
- gerarchia particelle con interazioni forti e/o deboli



## Fenomenologia dei modelli GMSB

particella supersimmetrica più leggera (LSP) :  
gravitino

dipende solo da  $\sqrt{F}$

$$2 \times 10^{-5} \text{ keV} \leq m_{\tilde{G}} \leq 10^7 \text{ keV}$$

dalla cosmologia  $m_{\tilde{G}} \leq 100 \text{ keV}$  meglio ancora se  
 $m_{\tilde{G}} \leq 1 \text{ keV}$

$R$ -parità conservata  $\Rightarrow \tilde{G}$  stabile

\* \* \*

### La NLSP (*next to LSP*)

4 casi:

neutralino più leggero  $\tilde{\chi}_1^0$  alle energie del LEP  
unico decadimento aperto:  $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$



probabilità che  $\tilde{\chi}_1^0$  decada dopo  $x$ :  $P(x) = 1 - e^{-x/L}$  dove

$$L = \gamma\beta c\tau = 9.9 \times 10^{-7} \frac{1}{k_{1\gamma}} \left( \frac{m_{\tilde{\chi}_1^0}}{100 \text{ GeV}} \right)^{-5} \left( \frac{\sqrt{F}}{10 \text{ TeV}} \right)^4 \left( \frac{E_{\tilde{\chi}_1^0}^2}{m_{\tilde{\chi}_1^0}^2} - 1 \right)^{1/2} \text{ cm}$$

stau NLSP:  $\tilde{\tau}_1 \rightarrow \tau \tilde{G}$

sleptoni co-NLSP:  $\tilde{\ell}_R \rightarrow \ell \tilde{G}$

- **Neutralino NLSP**

$$m_{\tilde{\chi}_1^0} < m_{\tilde{\tau}_1} - m_\tau$$

- **Stau NLSP**

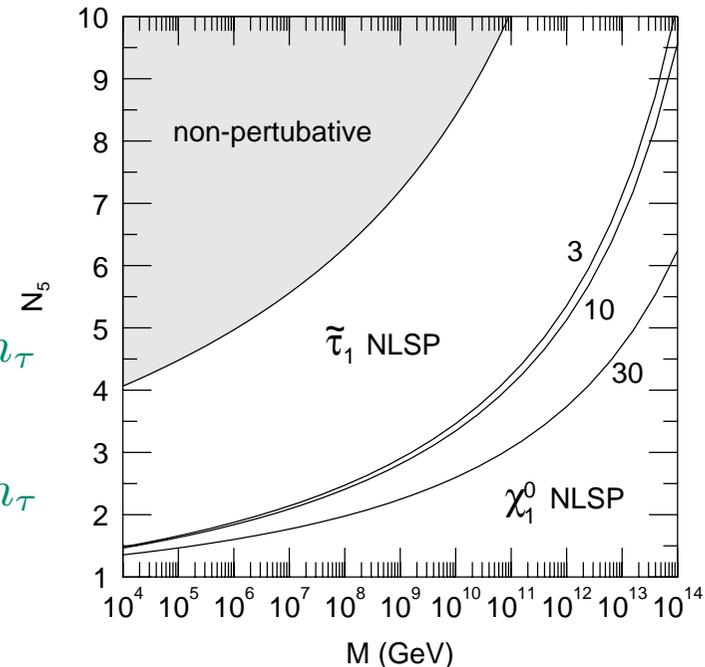
$$m_{\tilde{\chi}_1^0} - m_{\tilde{\tau}_1} > m_\tau \quad m_{\tilde{\ell}_R} - m_{\tilde{\tau}_1} > m_\ell + m_\tau$$

- **Sleptoni co-NLSP**

$$m_{\tilde{\chi}_1^0} - m_{\tilde{\ell}_R} > m_\ell \quad m_{\tilde{\ell}_R} - m_{\tilde{\tau}_1} < m_\ell + m_\tau$$

- **Neutralino-Stau co-NLSP**

$$\left| m_{\tilde{\chi}_1^0} - m_{\tilde{\tau}_1} \right| < m_\tau \quad m_{\tilde{\chi}_1^0} - m_{\tilde{\ell}_R} < -m_\ell$$



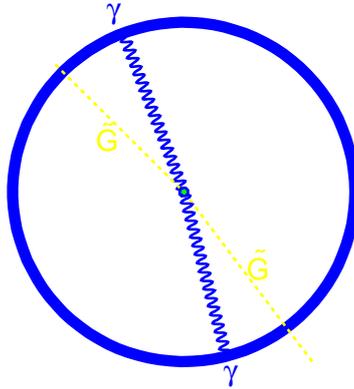


## Luminosità integrate di Aleph, Delphi, L3, Opal

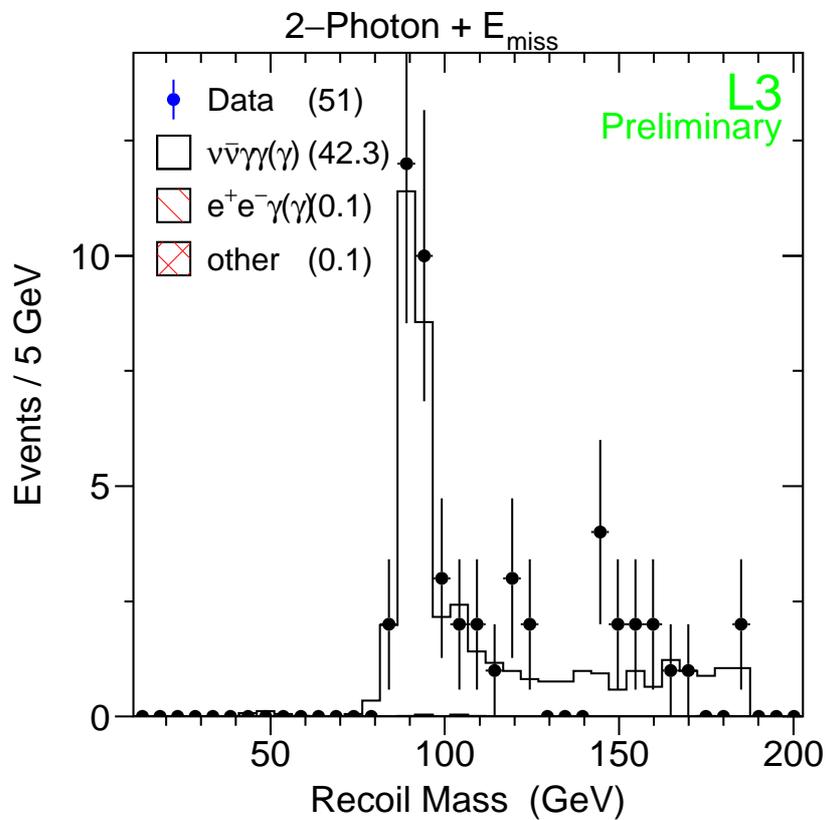
$\sqrt{s}$ GeV	ALEPH ( $pb^{-1}$ )	DELPHI ( $pb^{-1}$ )	L3 ( $pb^{-1}$ )	OPAL ( $pb^{-1}$ )
192	28.9	25.9	29.7	28.9
196	79.9	76.9	83.7	72.4
200	86.3	84.3	82.8	69.6
202	41.9	41.1	37.0	23.1
tot	237.0	228.2	233.2	193.9



## Neutralino a breve vita media (A,D,L,O)



- fondi: QED  $e^+e^- \rightarrow \gamma\gamma(\gamma)$ ,  $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma(\gamma)$
- M.C. di  $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma(\gamma)$  KORALZ (A,D,L,O)  
NUNUGPV (A,L,O) e GRACE (A,L) accordo al 5%

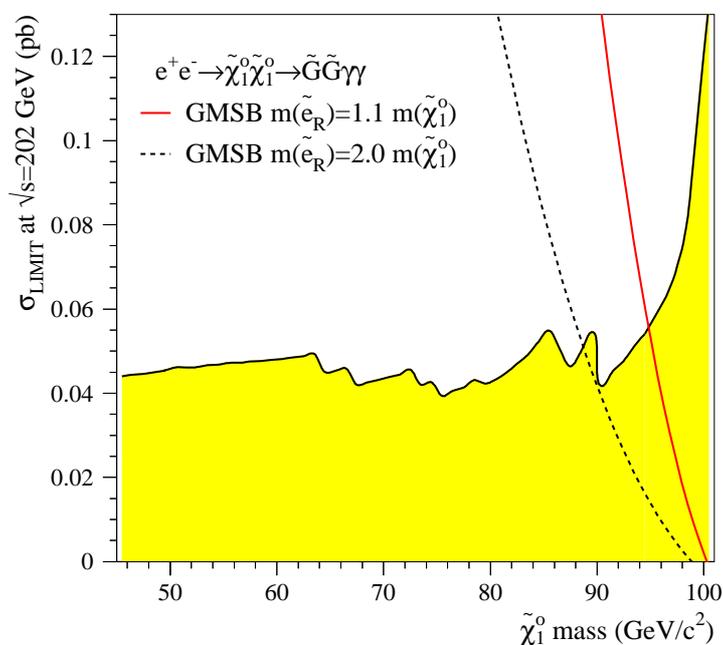




## Delphi

$\sqrt{s}$	Observed events	Expected events
Sample 1 (preselection):		
192 GeV	3	$2.7 \pm 0.2$
196 GeV	7	$7.0 \pm 0.3$
200 GeV	9	$6.5 \pm 0.4$
202 GeV	4	$3.3 \pm 0.3$
130-202 GeV	50	$44.8 \pm 1.2$
Sample 2 (search for $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{G}\tilde{G}\gamma\gamma$ ):		
192 GeV	1	$0.9 \pm 0.1$
196 GeV	3	$2.4 \pm 0.2$
200 GeV	5	$2.2 \pm 0.2$
202 GeV	0	$1.0 \pm 0.1$
130-202 GeV	16	$13.6 \pm 0.6$

- sample 1 significa  $e^+e^- \rightarrow \nu\bar{\nu}\gamma\gamma(\gamma)$



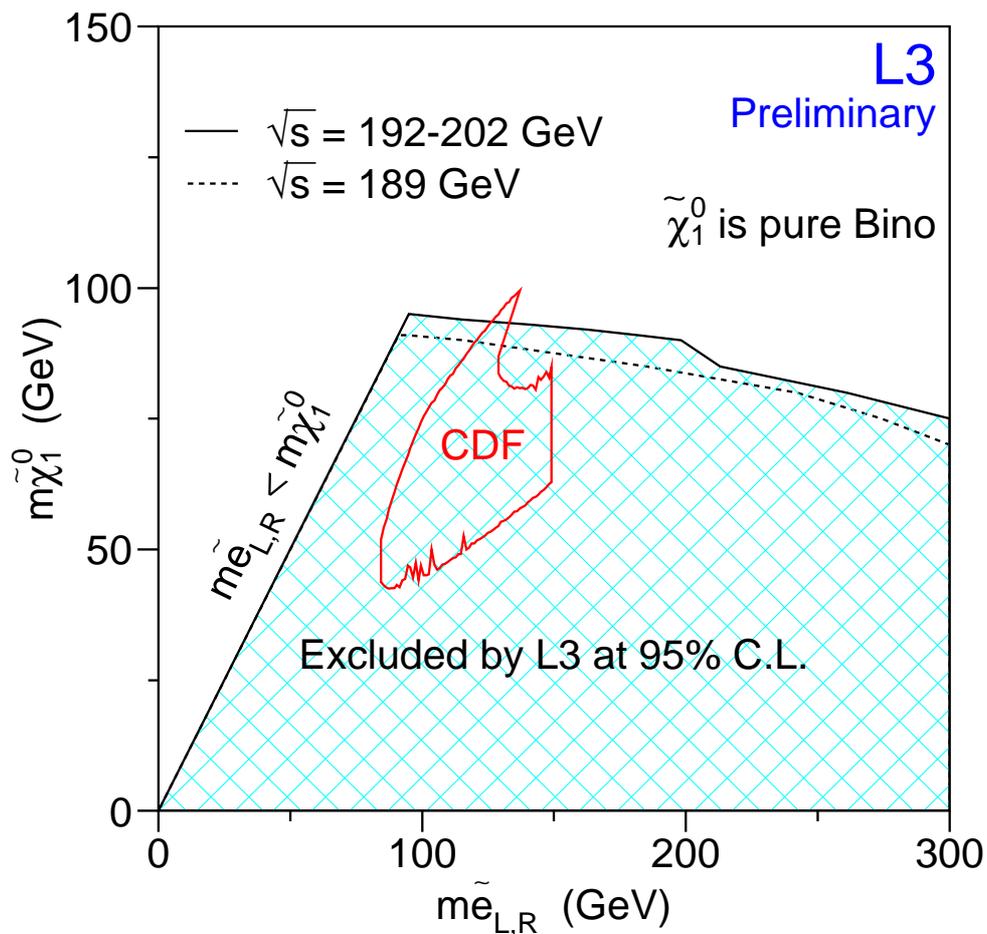
upper limits al 95% C.L.



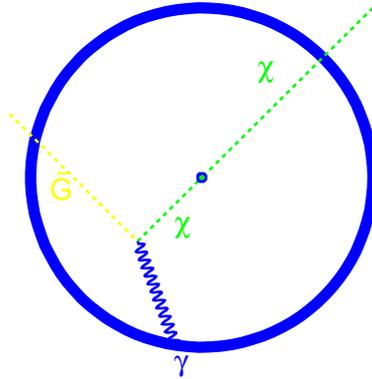
## Evento CDF

dall'interpretazione delle analisi con due fotoni  
ed energia mancante

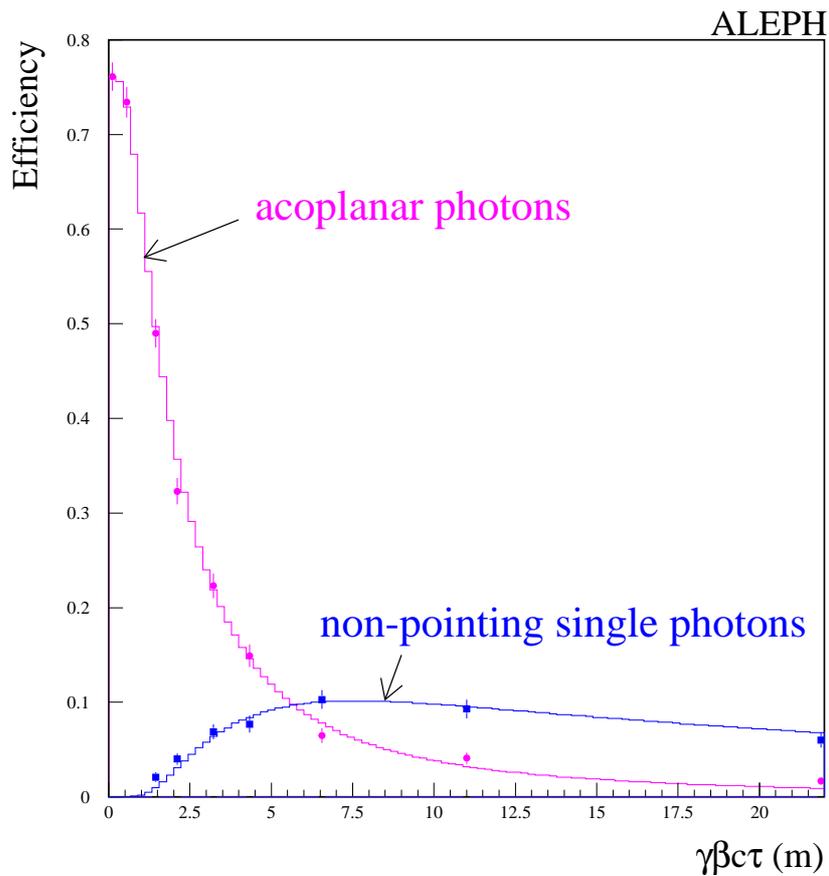
$$q\bar{q} \rightarrow \tilde{e}_R \tilde{e}_R \rightarrow ee \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow ee \tilde{G} \tilde{G} \gamma \gamma$$



## Neutralino a vita media più lunga (A,O)



- fondi:  $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$ , cosmici, Bhabha
- permette di estendere efficienza analisi anche se 1 solo  $\gamma$  decade nel rivelatore



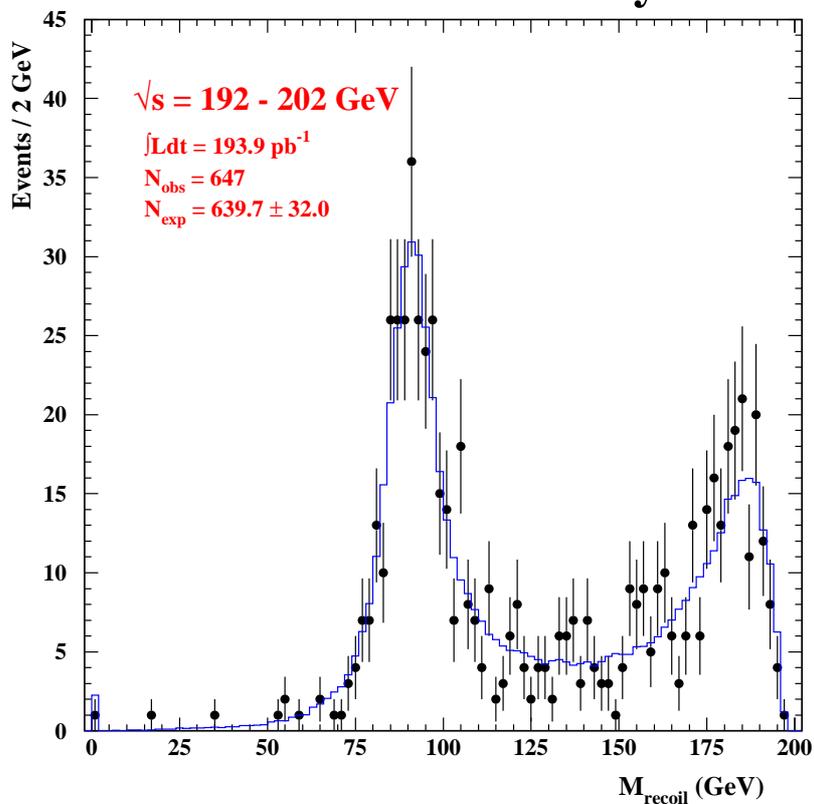


## Opal

Selection	$\sqrt{s}$ (GeV)	$N_{\text{data}}$	$N_{\text{exp}}$	$N_{\text{bkg}}$
$\gamma(\gamma)+\cancel{E}_T$	192	91	$101.8 \pm 5.1$	$0.8 \pm 0.3$
$\gamma(\gamma)+\cancel{E}_T$	196	248	$239.9 \pm 12.0$	$2.0 \pm 0.7$
$\gamma(\gamma)+\cancel{E}_T$	200	238	$223.9 \pm 11.2$	$1.7 \pm 0.6$
$\gamma(\gamma)+\cancel{E}_T$	202	70	$74.1 \pm 3.7$	$0.7 \pm 0.3$
$\gamma\gamma(\gamma)+\cancel{E}_T$	192	3	$3.9 \pm 0.3$	$0.02 \pm 0.01$
$\gamma\gamma(\gamma)+\cancel{E}_T$	196	5	$8.6 \pm 0.5$	$0.06 \pm 0.02$
$\gamma\gamma(\gamma)+\cancel{E}_T$	200	13	$8.3 \pm 0.5$	$0.05 \pm 0.02$
$\gamma\gamma(\gamma)+\cancel{E}_T$	202	6	$2.7 \pm 0.3$	$0.02 \pm 0.01$

- $N_{\text{BKG}} \rightarrow$  fondo non derivante da  $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$

### OPAL Preliminary

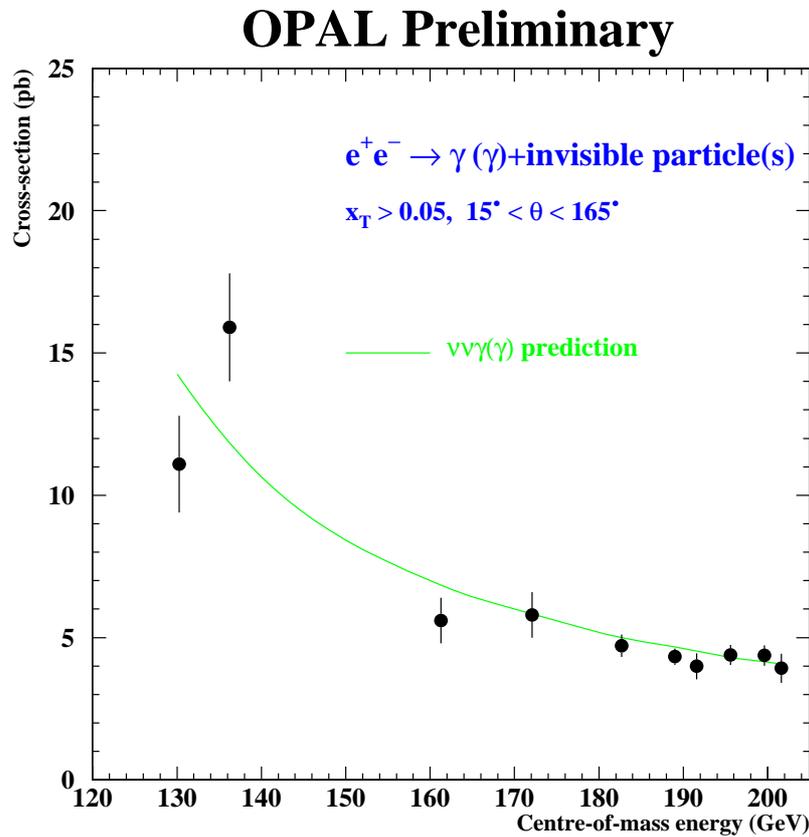




### La sezione d'urto

$\sqrt{s}$ (GeV)	$\sigma_{\text{measured}}$ (pb)	$\sigma_{\text{exp}}$ (pb)
192	$3.99 \pm 0.42 \pm 0.20$	4.50
196	$4.39 \pm 0.28 \pm 0.22$	4.28
200	$4.37 \pm 0.29 \pm 0.22$	4.13
202	$3.92 \pm 0.47 \pm 0.20$	4.05

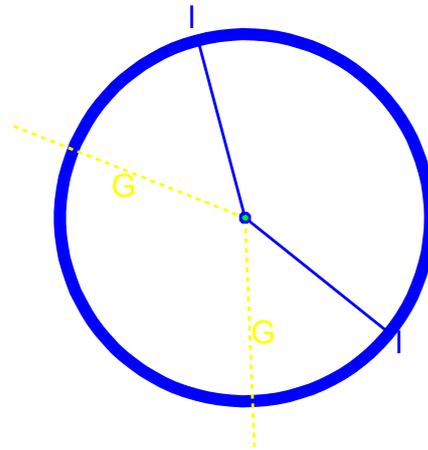
- primo errore statistico, secondo sistematico



- $x_T$  energia trasversa fotone scalata dall'energia fascio

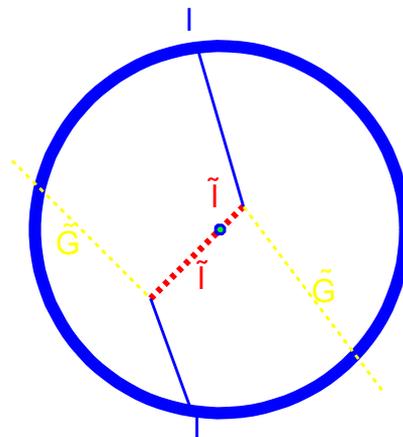


### Sleptoni a breve vita media



- stessa segnatura dei *gravity-mediated*  
( $\tilde{G} \rightarrow \tilde{\chi}_1^0$ )  $\Rightarrow$  nessuna nuova analisi necessaria

### Sleptoni a medio $c\tau_{\tilde{\ell}_R}$



- fondo:  $\gamma\gamma$ , Bhabha,  $2\ell$ ,  $\mu$  cosmici



### Cascade decays fino a $\sqrt{s} = 202$ GeV (Delphi)

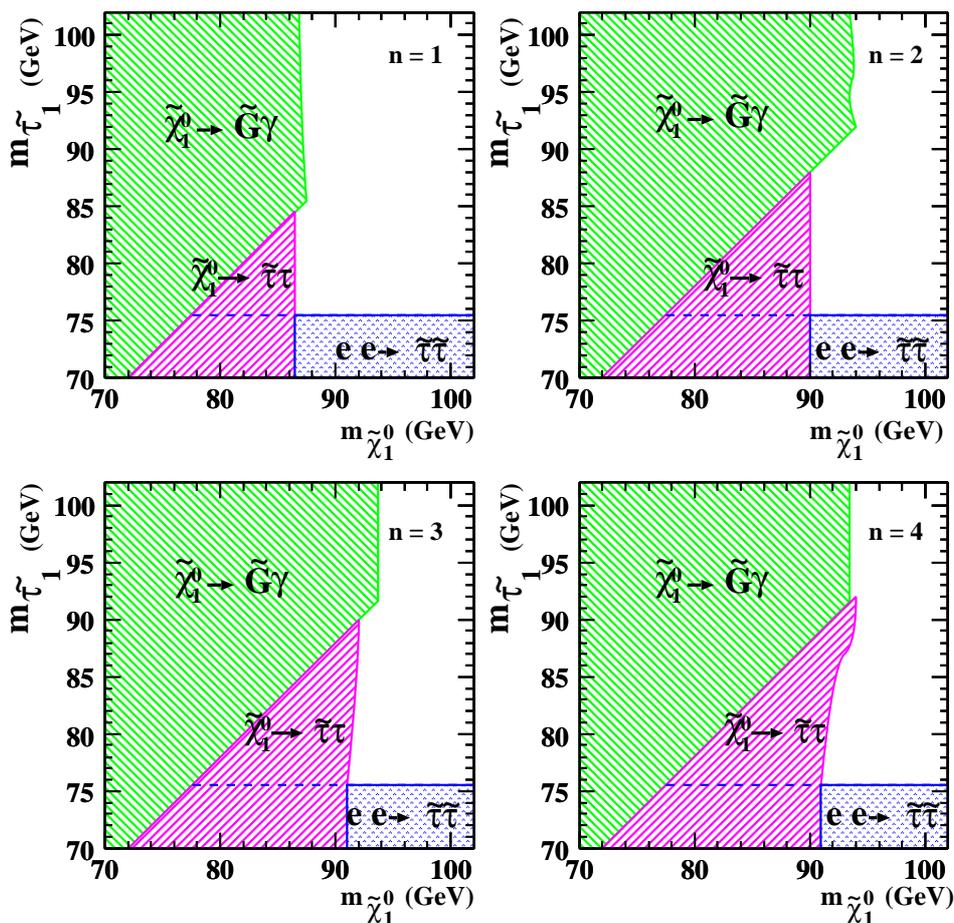
- $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{\ell}_R \tilde{\ell}_R \rightarrow ll \tilde{G} ll \tilde{G} (\tilde{\ell}_R$   
Co-NLSP) e  $\text{Br}(\tilde{\chi}_1^0 \rightarrow \tilde{\ell}_R \ell) = 1/3 \quad \forall$  flavour
- $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \tilde{\tau}_1 \tau \tilde{\tau}_1 \tau \rightarrow \tau \tau \tilde{G} \tau \tau \tilde{G}$   
( $\tilde{\tau}_1$  NLSP)

assieme alle analisi di MSUGRA e 2 fotoni ed energia mancante

scan nello spazio parametri  $n = 1, 2, 3, 4,$   
 $5 \text{ TeV} \leq \Lambda \leq 90 \text{ TeV}, 1.1 \leq M/\Lambda \leq 10^9,$   
 $1.1 \leq \tan \beta \leq 50, \text{sign} \mu = \pm 1$

**DELPHI PRELIMINARY**

$s^{1/2} = 161 - 202$  GeV



LEP TS

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## Le topologie sperimentali

- utilizzati tutti i dati fino a  $\sqrt{s} = 188.6 \text{ GeV}$
- $L = 173, 6 \text{ pb}^{-1}$  raccolti nel 1998
- tutte le particelle cercate fino a  $\sqrt{s}/2$  limite cinematico

NLSP	Produzione	Decadimento	Vita media	Topologia attesa
$\tilde{\chi}_1^0$	$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$	$c\tau \ll L_{\text{detector}}$	$2\gamma$ acoplanari
	$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$	$c\tau \sim L_{\text{detector}}$	$1\gamma$ non pointing
	$e^+e^- \rightarrow \tilde{\ell}_R \tilde{\ell}_R$	$\tilde{\ell}_R \rightarrow \ell \tilde{\chi}_1^0$	$c\tau \gg L_{\text{detector}}$	$2\ell$ acoplanari
	$e^+e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$	$\tilde{\chi}_1^\pm \rightarrow f' \bar{f} \tilde{\chi}_1^0$	$c\tau \gg L_{\text{detector}}$	$f$ acoplanari
$\tilde{\ell}_R$	$e^+e^- \rightarrow \tilde{\ell}_R \tilde{\ell}_R$	$\tilde{\ell}_R \rightarrow \ell \tilde{G}$	$c\tau \ll L_{\text{detector}}$	$2\ell$ acoplanari
	$e^+e^- \rightarrow \tilde{\ell}_R \tilde{\ell}_R$	$\tilde{\ell}_R \rightarrow \ell \tilde{G}$	$c\tau \sim L_{\text{detector}}$	Kinks e grandi $d_0$
	$e^+e^- \rightarrow \tilde{\ell}_R \tilde{\ell}_R$		$c\tau \gg L_{\text{detector}}$	HSCP
	$e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \rightarrow \tilde{\ell}_R \ell \rightarrow \ell \ell \tilde{G}$	$c\tau \ll L_{\text{detector}}$	$4\ell$ (2 soft, 2 hard)



## Lo scan nello spazio dei parametri

- scelto GMSB minimale  $SU(5)$  (5+1) parametri

Parametro	Valore minimo	Valore massimo	Numero di passi
$M_m$	$10^4 \text{ GeV}/c^2$	$10^{12} \text{ GeV}/c^2$	5
$m_{\tilde{G}}$	$10^{-10} \text{ GeV}/c^2$	$10^{-4} \text{ GeV}/c^2$	50
$\Lambda$	$10^3 \text{ GeV}/c^2$	$\min(\sqrt{F}, M_m)$	200
$\tan \beta$	1.3	38	14
N5	1	5	5
segno $\mu$	-1	+1	2

- $M_m < 10^{12} \text{ GeV}/c^2 \Rightarrow$  nucleosintesi primordiale
- $m_{\tilde{G}}$  limiti da sensibilità rivelatore  
 $100\mu m < L, L > 100m$
- $\tan \beta > 40$  costante, limite inferiore  $\Rightarrow$  perturbatività
- N5 fino a 5 (prova fino a 6 ed  $M_m = 10^{14} \text{ GeV}/c^2$ )

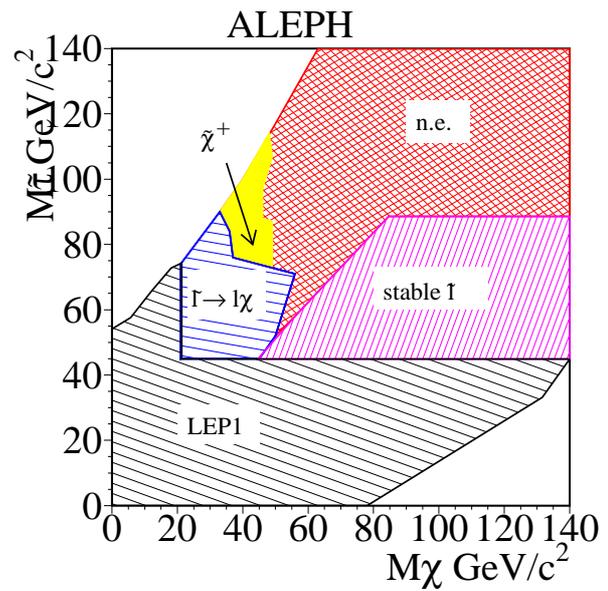
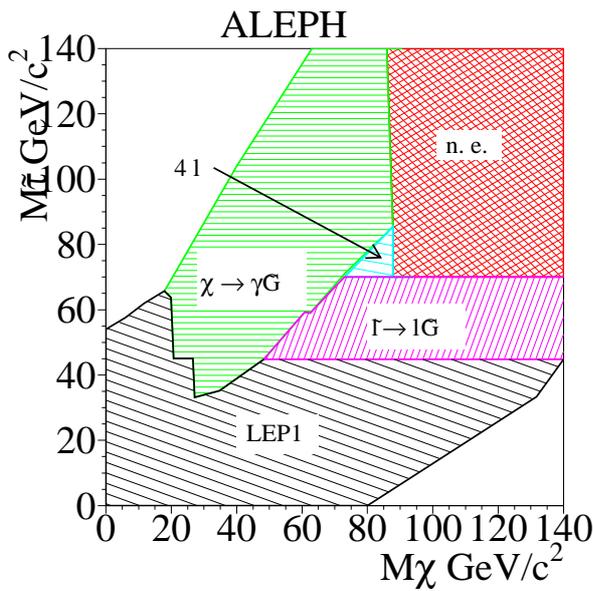
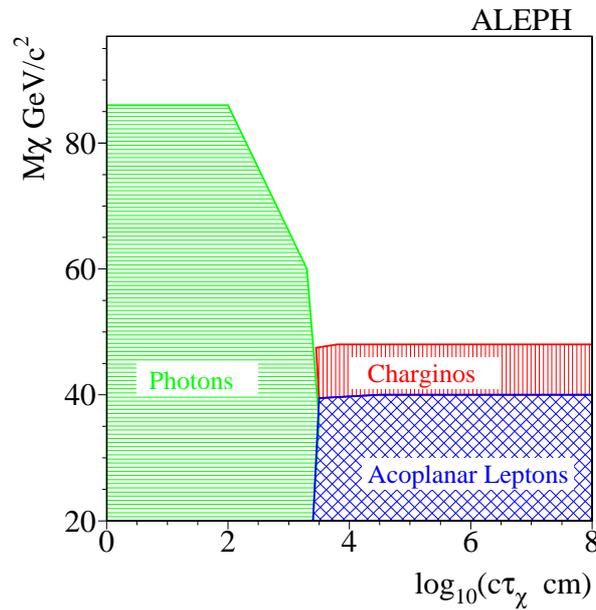


## La procedura di esclusione

- $\Gamma_Z = 2.4944 \pm 0.0024 \text{ GeV}$  (LEP1)  $\Rightarrow$  esclusi tutti i punti fuori di  $1.96\sigma$   
 $\Rightarrow$  esclusi al 95% C.L. se  $\delta\Gamma_Z > 4.5 \text{ MeV}$
- alto  $\tan\beta \Rightarrow \tilde{\tau}_1$  NLSP, con i dati di LEP1 su HSCP e  $\tau$  acoplanari e leptoni acoplanari  $\Rightarrow$  escluse tutte le  $m_{\tilde{\ell}_R} < m_Z/2$
- se  $\tilde{\chi}_1^0$  NLSP e lunga vita media nel caso di  $\tilde{\ell}_R \rightarrow \tilde{\chi}_1^0 \ell$  anche qui LEP1  
 $\Rightarrow$  escluse  $m_{\tilde{\ell}_R} < m_Z/2$
- esclusi tutti i punti per cui  $\sigma_{teoria} > \sigma_{95}$



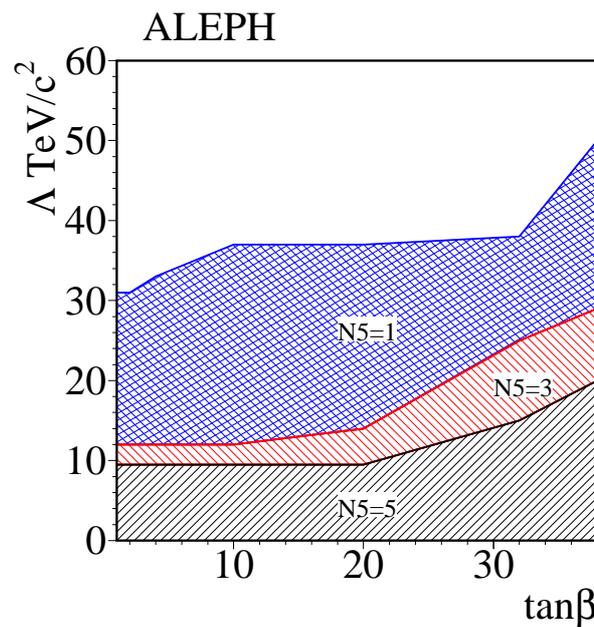
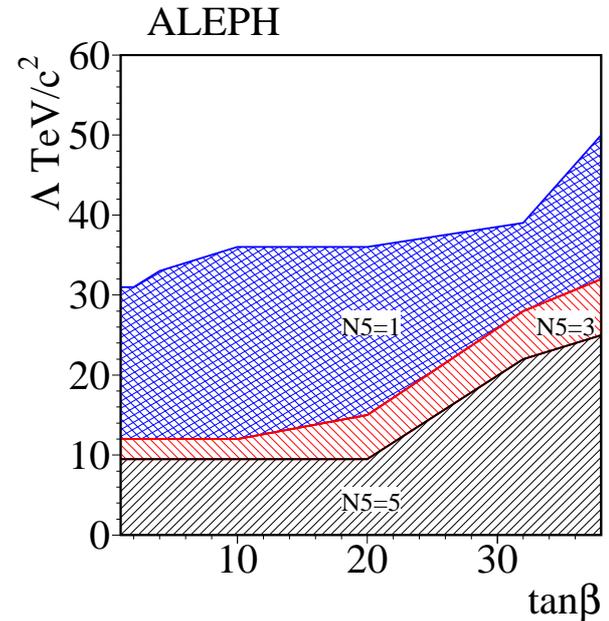
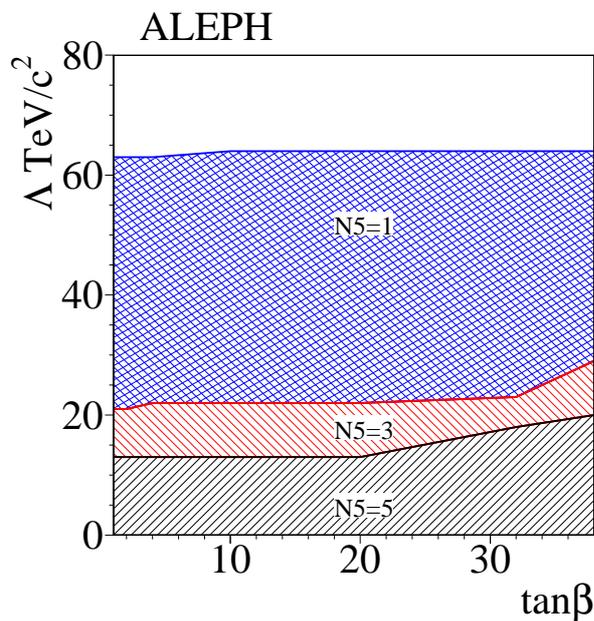
## Il limite inferiore sulla massa della NLSP



- $m_{\tilde{\tau}_1} > 67 \text{ GeV}/c^2$  al 95% C.L.
- $m_{\tilde{\chi}_1^0} > 45 \text{ GeV}/c^2$  al 95% C.L.



## Il limite inferiore su $\Lambda$



- $\Lambda > 9 \text{ TeV}/c^2$  al 95% C.L. quando  $N5 = 5$
- non usate le ricerche dell'Higgs del MSSM (piccolo  $\tan\beta$ )



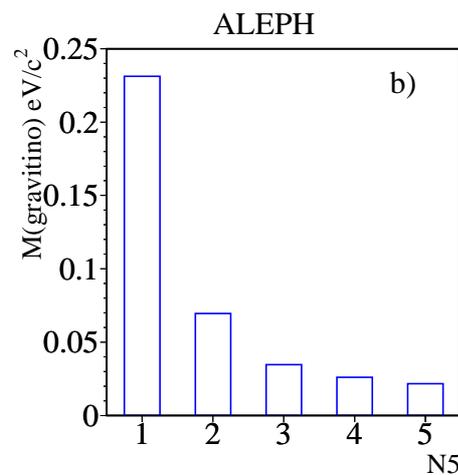
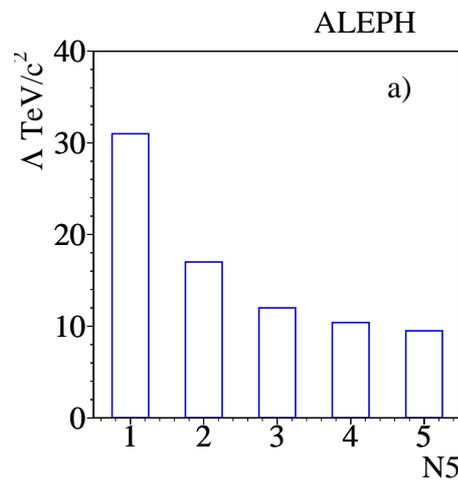
## Il limite inferiore su $m_{\tilde{G}}$

$\Lambda < \sqrt{F} \Rightarrow$  **limiti su  $\Lambda$**   $9 \text{ TeV}/c^2 < \Lambda < \sqrt{F}$  **ma**

$$m_{\tilde{G}} = 2.37 \times 10^{-2} \left( \frac{\sqrt{F}}{10 \text{ TeV}} \right)^2 \text{ eV}/c^2$$

**quindi**

$m_{\tilde{G}} > 2 \times 10^{-2} \text{ eV}/c^2$  al 95% di C.L.





## Conclusioni

- nessuna evidenza sperimentale
- ricerca segnali da GMSB al LEP con particolare attenzione alle analisi di topologie con fotoni e leptoni
- *scan* nello spazio dei parametri GMSB (Aleph e Delphi)
- ancora un anno per sperare...ma comunque...



“...che la vadi ben, che la vadi mal, sempre  
alegri mai pasion viva l’A e po’ bon!”

canzone popolare triestina