Search for SUSY in Gauge Mediated and Anomaly Mediated SB Models

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- GMSB searches at LEP/OPAL
- GMSB searches at Tevatron/DØ and prospects for Run II
- AMSB searches at LEP/Delphi

Gauge Mediated SUSY Breaking

- Alternative to gravity mediated SUSY breaking: Gauge interactions with messenger fields at a scale $M_{mess} << M_{Planck}$ are responsible for SUSY breaking.
- Gauge interactions are flavour blind, thus no FCNC (as in SUGRA models)

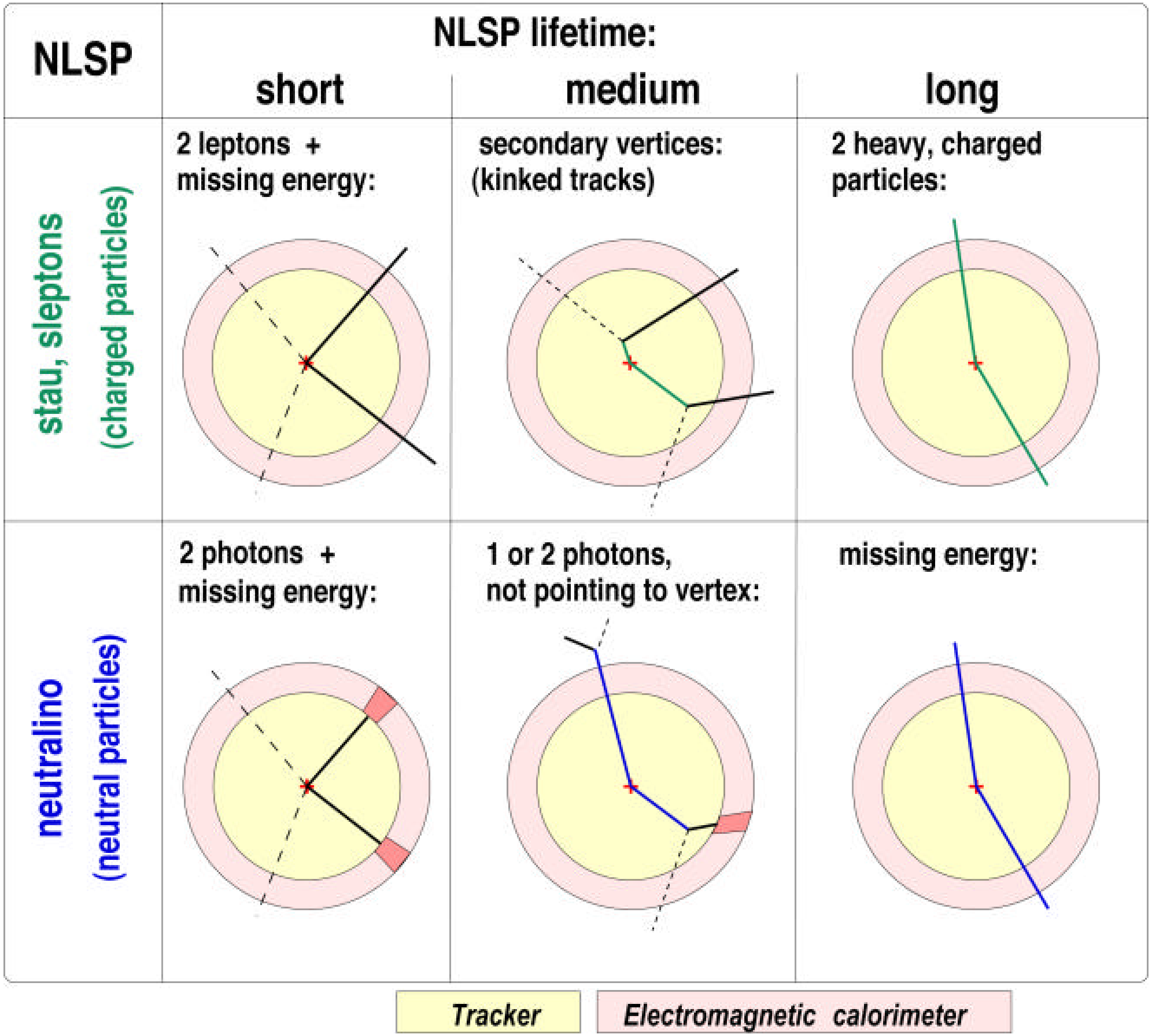
- The LSP is a Goldstone Fermion: Gravitino $\tilde{G}: M(\tilde{G}) \leq 1\,\mathrm{keV}$
- The NLSP (next-to-lightest SUSY particle) is either the lightest neutralino (bino) or a charged slepton (mostly stau)

$$\tilde{c}_1^0 \rightarrow g\,\tilde{G}$$
$$\tilde{l} \rightarrow l\,\tilde{G}$$

- The NLSP lifetime can range from 0 to ∞
  - $\Rightarrow$ many different topologies

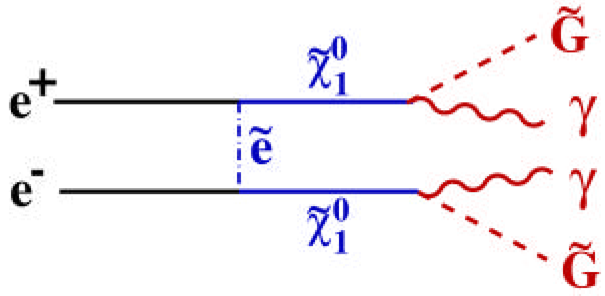
- Minimal set of parameters:
  - Λ : scale of SUSY masses
  - M_{mess} : messenger mass scale
  - N_{mess} : number of mess. fields
  - $\tan\beta$: ratio of Higgs v.e.v.
  - $|\mu|$: sign of higgs mass term

GMSB Topologies

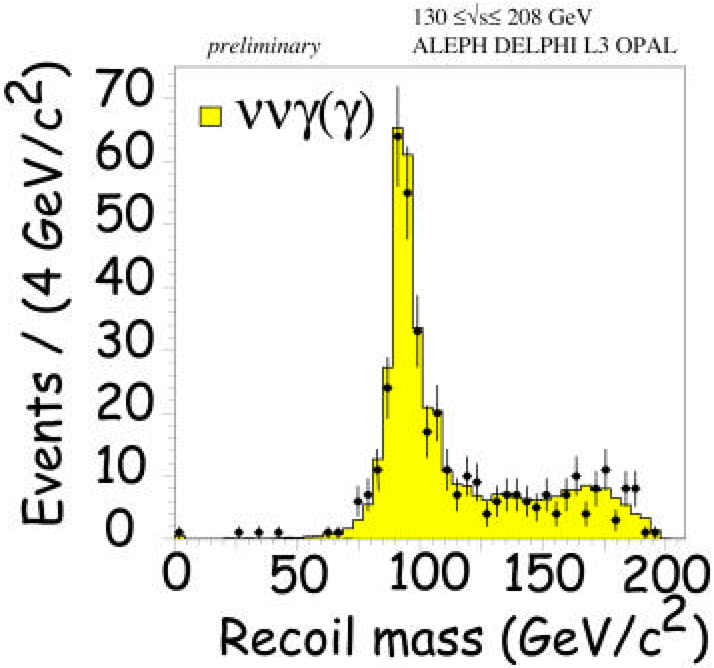


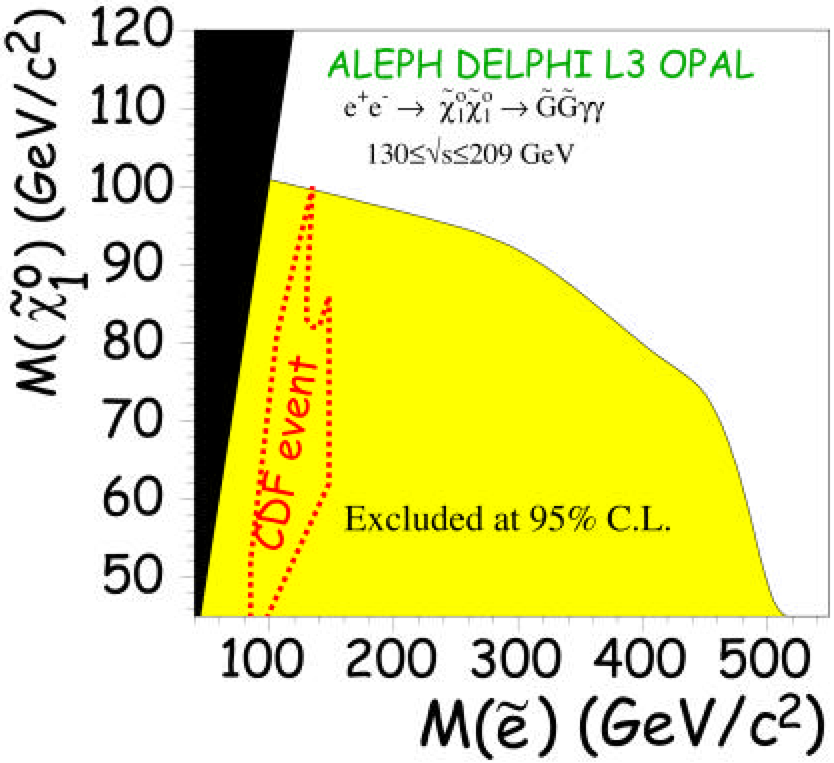
Neutralino NLSP: gg Production

Signal: Pair prod. of acoplanar γγ:



Expected SM production:





- GMSB interpretation of CDF $ee\gamma\gamma \not{E}_T$ event excluded
- Within GMSB Snowmass Slope parameter set (used by DØ):

$$M(\tilde{c}_1^0) > 100\,\mathrm{GeV},\ \ M(\tilde{e}) > 130\,\mathrm{GeV}$$

Stau NLSP

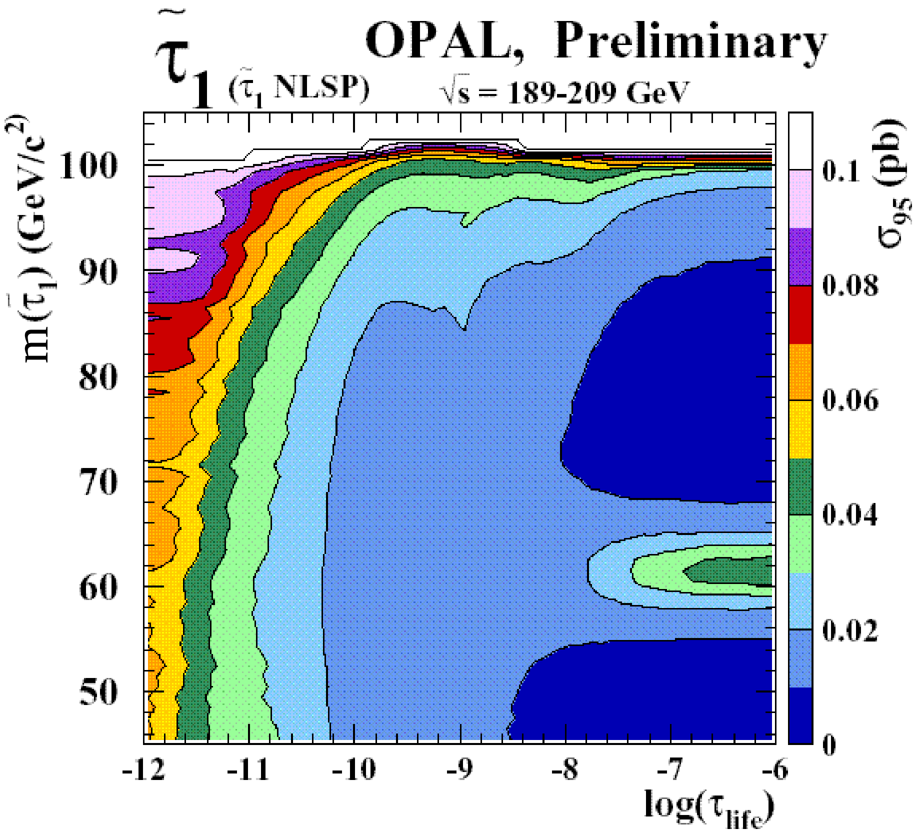
- Combination of four different analysis, sensitive to various stau life times

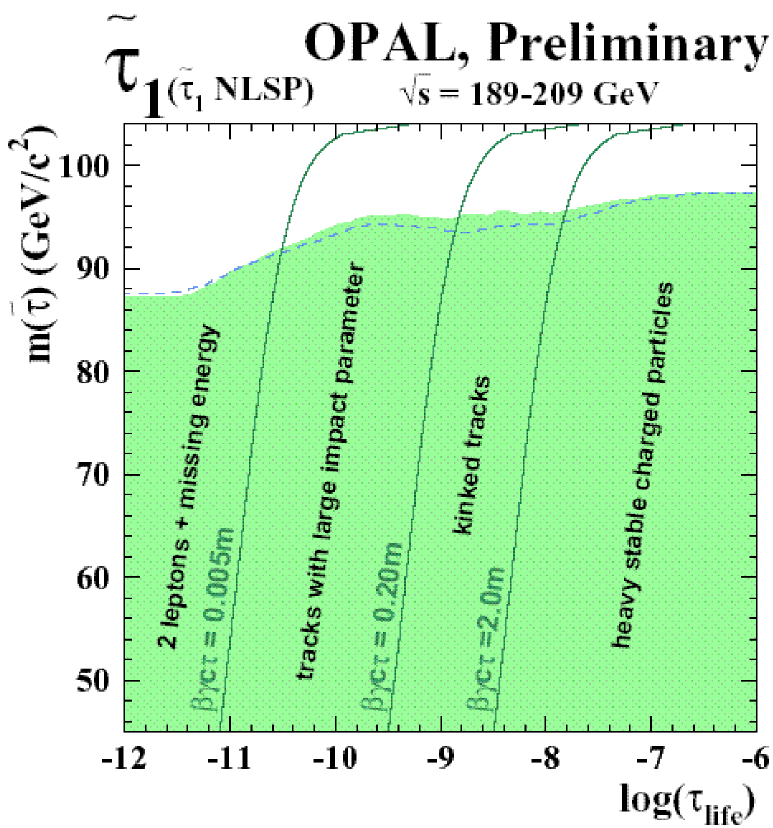
- Measurement: upper limit of the production cross section in the plane

$M(\tilde{t}_1) - t_{\text{life}}$

- Lower stau mass limits obtained by comparison to theoretical predictions of cross section

$M(\tilde{t}_1) > 87.6\,\text{GeV}$





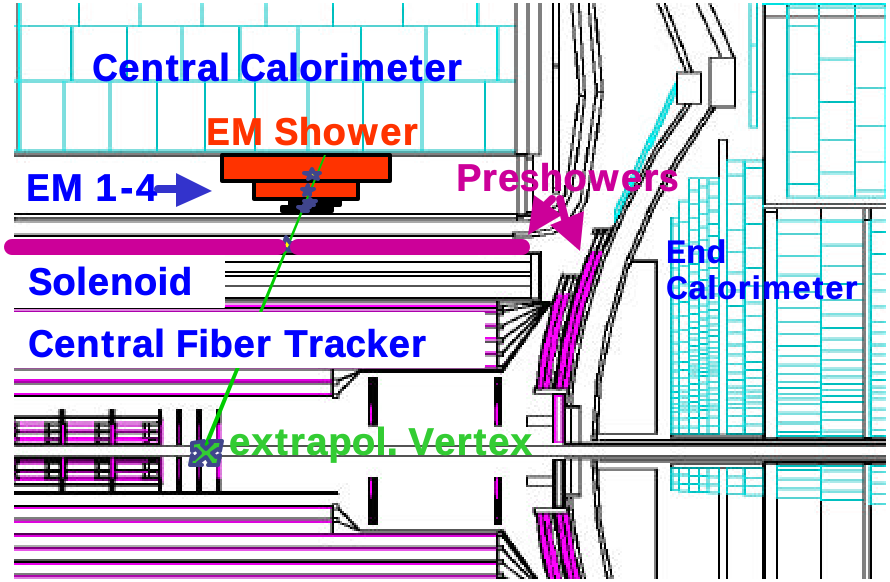
Inclusive Search for $\gamma\gamma$ Missing E_T ($\not{E}_T$)

- Dominating production channels at Tevatron: $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$
- In case of Neutralino NLSP:

$$\text{gauginos} \rightarrow$$

$$\tilde{\chi}_1^0\tilde{\chi}_1^0 + W, Z, g \rightarrow \gamma\gamma + \tilde{G}\tilde{G} + X$$

- Analysis assumes short NLSP life time $\Rightarrow$ prompt decay
- 2 γ's in central calorimeter ($|\eta| \leq 1.1$)
  - w. transverse energy $E_T > 20$GeV
  - γ–consistent shower shape
  - isolation requirement based on energy deposition
  - $e^{\pm}$ veto: no matched tracks
- Measurement of missing E_T distribution of di-photon events



- γ pointing using highly segmented LAr calorimeter and Preshower strips
- γ vertex resolution (beam direction):
  - Calorimeter only: $\sigma_z \approx 15$ cm
    - used in this analysis
  - Central Preshower: $\sigma_z \approx 2.2$ cm
    - not fully comissioned yet, but good prospects for future analyses

Background Estimation

- Background without true missing E_T:
  - Dominating: QCD with direct photons or jets mis-identified as γ's (due to leading π^0)
    - Contribution estimated using fake $\gamma\gamma$ sample: at least one γ candidate fails shower shape requirement, normalized at low $\not{E}_T < 20$ GeV
  - Drell-Yan, electrons mis-identified as γ's due to track reconstruction inefficiency
- Background with true missing E_T (from ν):
  - Dominating: $W\gamma \rightarrow e\nu\gamma$ (missed tracks)
    $W+jet \rightarrow e\nu+jet$ (jet faking γ)
    - Constribution estimated using $e\gamma$ sample and $e \rightarrow \gamma$ mis-identification probability derived from data

	$\not{E}_t > 25$ GeV	$\not{E}_t > 30$ GeV	$\not{E}_t > 35$ GeV
gg events	**3**	**1**	**0**
QCD (w. wrong $\not{E}_t$) $e+\nu+\gamma/j$	6.0 ± 0.8 0.6 ± 0.4	2.5 ± 0.5 0.2 ± 0.2	1.6 ± 0.4 0.0 ± 0.2

Search for Excess in $\not{E}_T$ Spectrum

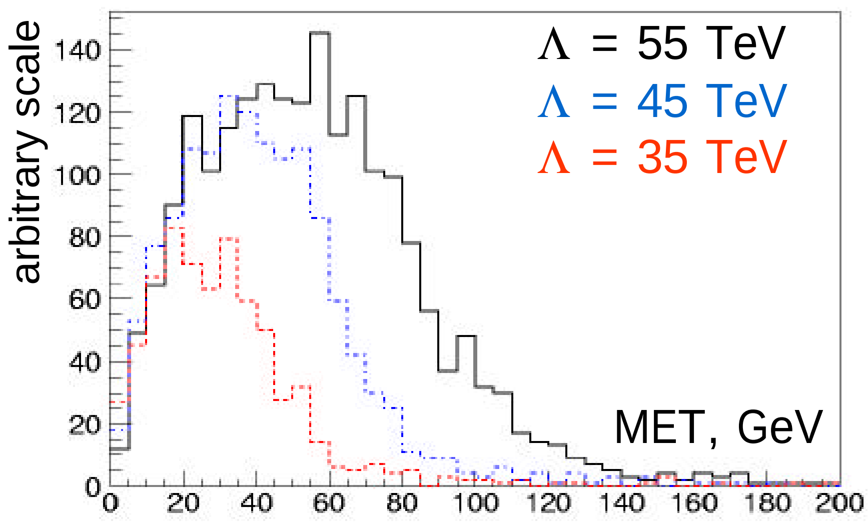
- No excess seen in missing E_T distribution
- Signal efficiencies derived using Snowmass Slope for GMSB:

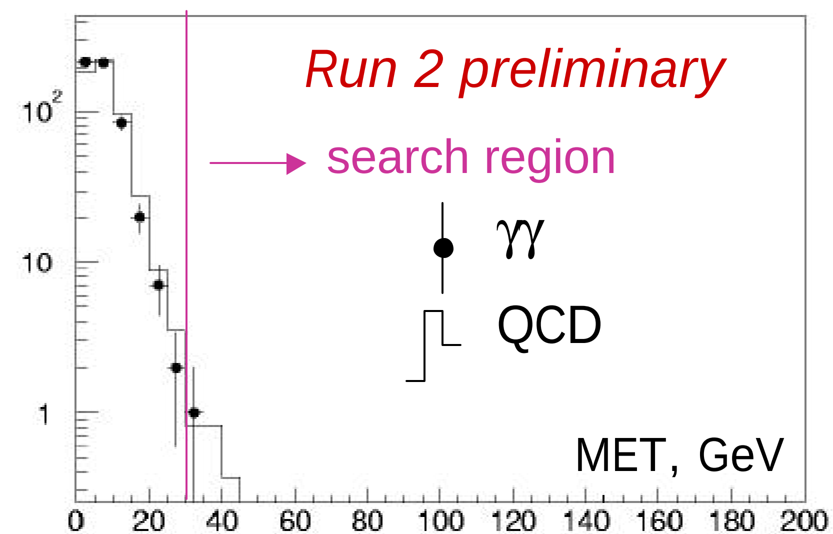
$$M_{mess} = 2\Lambda, \quad N_{mess} = 1,$$
$$\tan b = 15, \quad m > 0$$

  - combined efficiency (also incl. trigger and reconstruction) for $\not{E}_T > 30$ GeV and $45 < \Lambda < 55$ TeV: ~ (7-10) %

- Upper limits on cross sections are calculated using bayesian approach with cut: $\not{E}_T > 30$ GeV

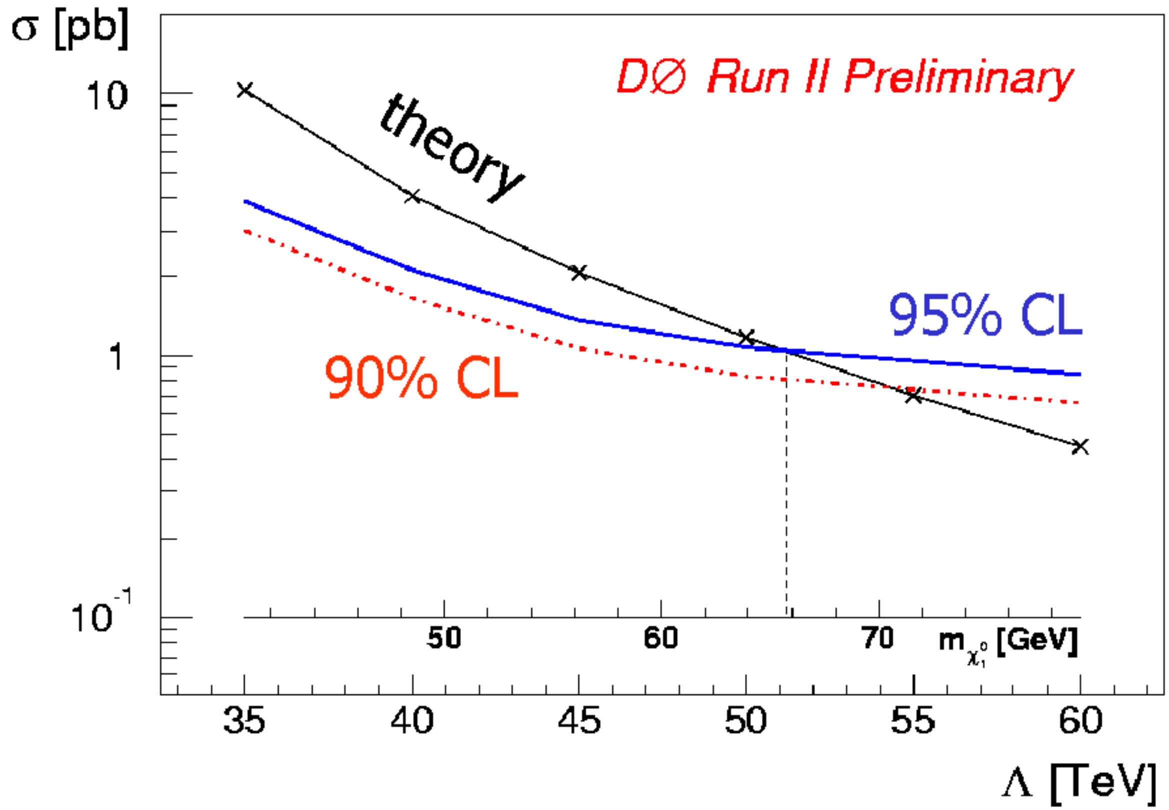
Simulated Signal





Limit for GMSB Model

- Comparing cross section limits with theoretical predictions:



95% C.L. Limits

$\Lambda > 51\,\mathrm{TeV}$

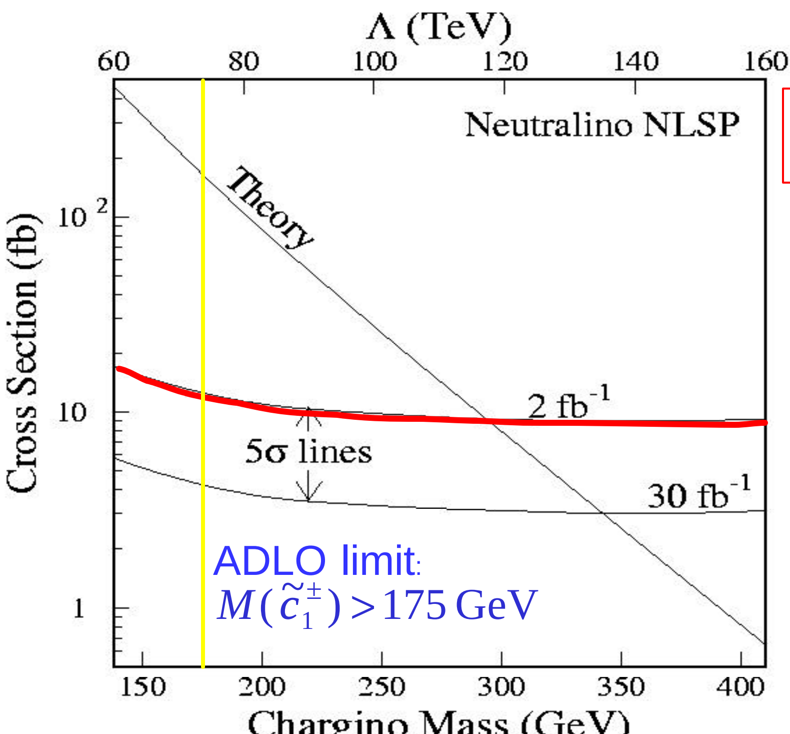
$M(\tilde{c}_1^0) > 66\,\mathrm{GeV}$

$M(\tilde{c}_1^\pm) > 116\,\mathrm{GeV}$

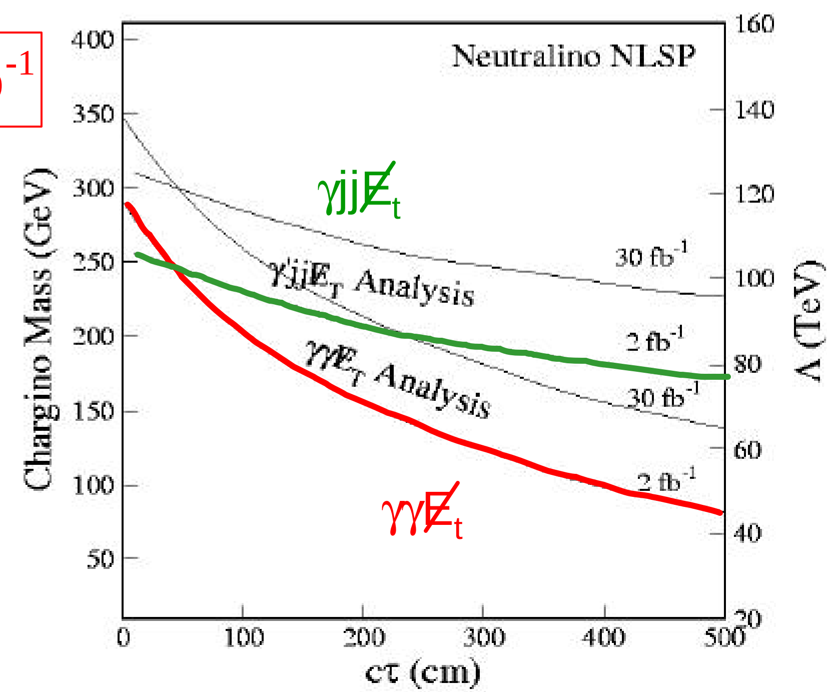
- Measurement is based on luminosity L = 41 pb^{-1}
- Results are approching limits from Run I analyses based on ~100 pb^{-1} (similar models)
  - DØ: $M(\tilde{c}_1^0) > 77$ GeV
  - CDF: $M(\tilde{c}_1^0) > 65$ GeV

Prospects for Tevatron RunII

- Prompt neutralino decays;
  - With L = 2 fb^{-1} discovery up to
    $M(\tilde{c}_1^0) \approx 165$ GeV, $M(\tilde{c}_1^\pm) \approx 300$ GeV
    (J. Qian, hep-ph/9903548 v2, similar model, but tan β = 2.5))
  - LEP limit (from acoplanar $\gamma\gamma$ search):
    $M(\tilde{c}_1^0) > 100$ GeV, $M(\tilde{c}_1^\pm) > 175$ GeV
- Intermediate neutralino life-time
  - Sensitivity drops as NLSP decays outside detector
  - Larger sensitivity in photon+jets+$\not\!E_T$ channel
- Opal: for any NLSP life-time
  $M(\tilde{c}_1^\pm) > 100$ GeV



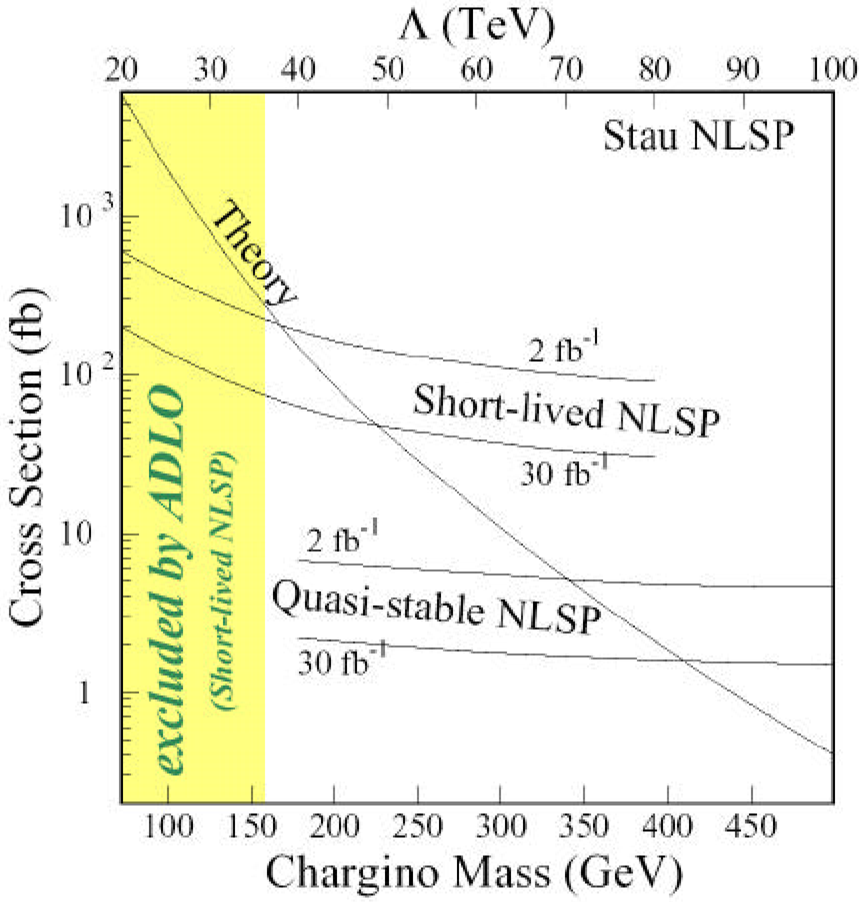
$L = 2$ fb^{-1}



Prospects for Stau NLSP Scenario

- High mass reach also in stau NLSP scenario
- Short-lived stau
  - Prompt decay
  - Standard SUSY searches: Tri-lepton or like-sign di-lepton signature
- Quasi-stable stau
  - Stau escapes detector
  - 2 μ-like objects with large dE/dx

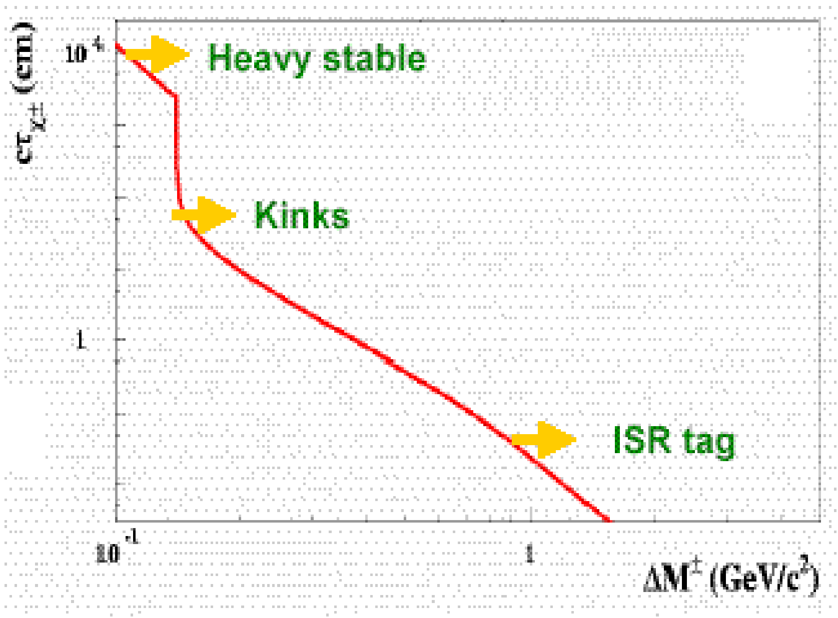
J. Qian: hep-ph/9903548 v2



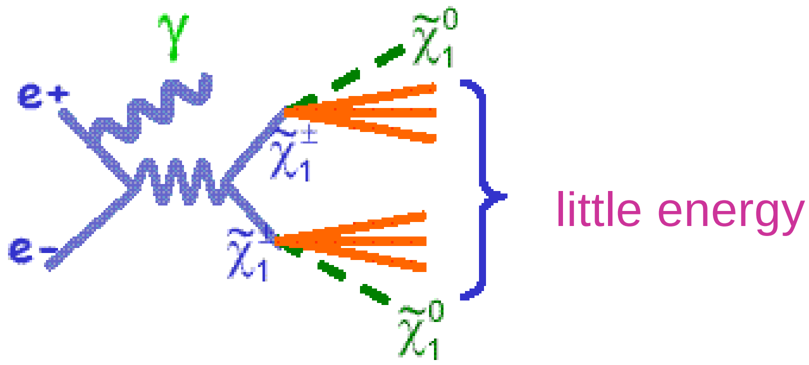
AMSB Phenomenology

- SUSY breaking is mediated by anomalies in the supergravity lagrangian
  - Provides soft mass parameters in visible spectrum
  - No need for messenger sector
  - Flavour blind ⇒ FCNC automatically suppressed
  - But: need additional non-anomaly contribution to avoid tachyonic sleptons
- AMSB model is very predictive
  - Defined by $m_{3/2}$, m_0, tan β and sign(μ)
- LSP: $\tilde{c}_1^0, \tilde{n}, \tilde{t}$
- Neutralino and chargino are gaugino-like and nearly mass degenerate

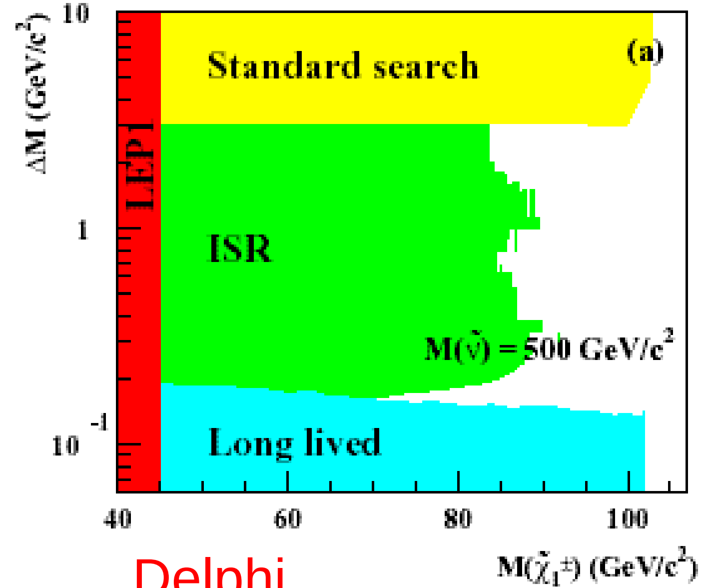
$$\Delta M = M(\tilde{c}_1^{\pm}) - M(\tilde{c}_1^0) < O(10\ \mathrm{GeV})$$



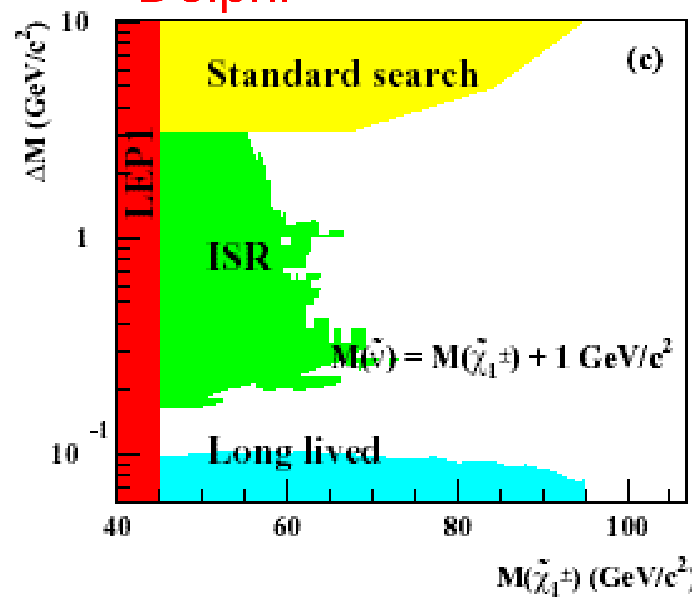
Small DM Chargino Search



- Problem: small ΔM means little visible energy .
- ⇒ large background from γγ-scattering
- Require ISR tag!
- Exclusion region depends on sneutrino mass.
  - Leptonic decay mode $\tilde{c}_1^{\pm} \rightarrow \tilde{n}^{*} l^{\pm} \rightarrow \tilde{c}_1^{0} n\, l^{\pm}$ important for small sneutrino masses



Delphi



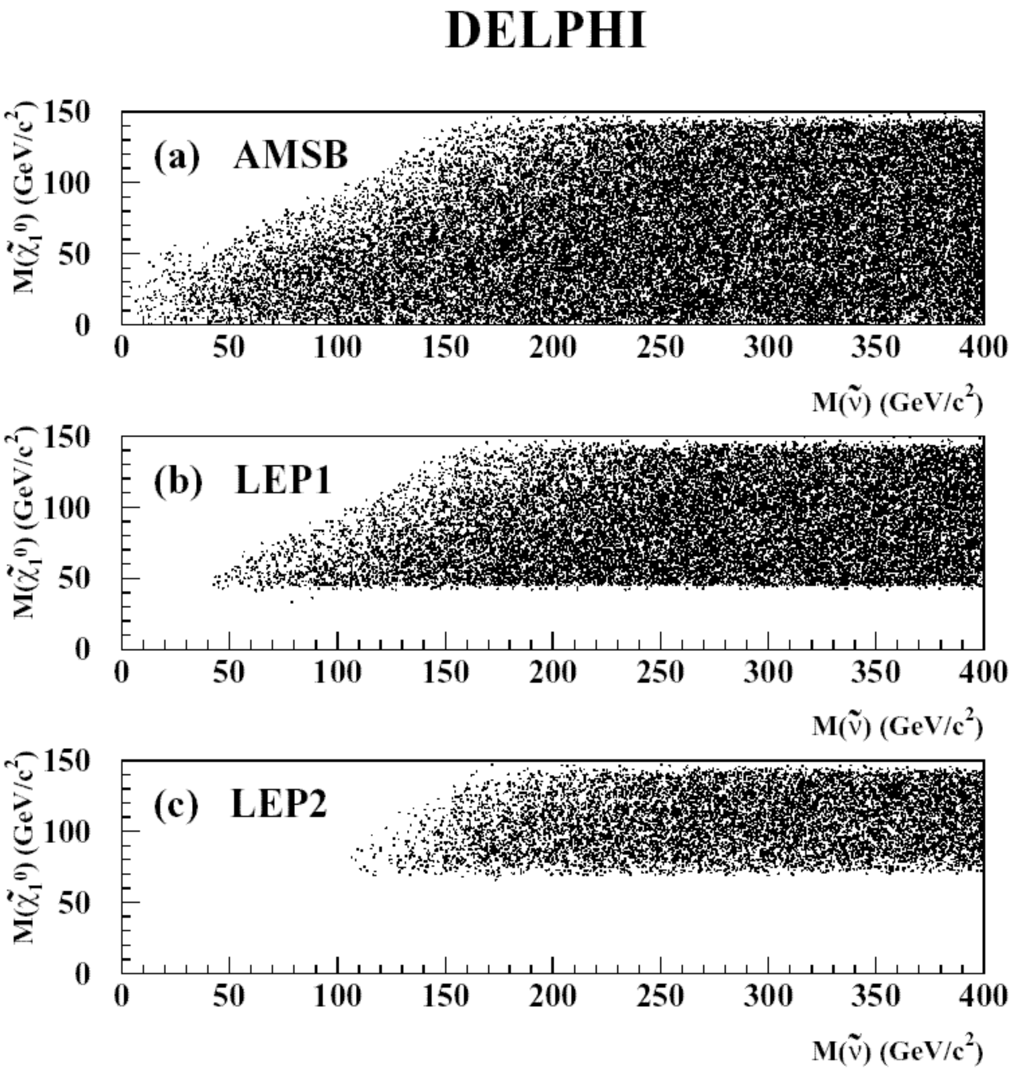
Constraints on AMSB Parameter Region

- Combination of various analyses to constrain AMSB parameter space
  - LEP1 constrain (Z width)
  - SM Higgs search
  - Invisible Higgs search
  - Small ΔM chargino search
  - Search for $\tilde{c}_1^{\pm} \rightarrow \tilde{n}\, l^{\pm}$
- Parameter scan using Isajet:

$$M(\tilde{c}) > 68\,\mathrm{GeV}$$

$$M(\tilde{n}) > 98\,\mathrm{GeV}$$

$$M(\tilde{l}) > 72\,\mathrm{GeV}$$



Summary and Outlook

- Many different topologies have been studied by the LEP experiments.
  - Combination of results is used to set limits for all NLSP lifetimes and to cover most of the kinematically accessible parameter space for the GMSB and AMSB scenarios.
- First results from Tevatron are approaching Run I limits with much smaller statistics.
- For GMSB models Tevatron has the potential to significantly improve lower limits on SUSY particle masses.

Many thanks to Christoph Rembser for the valuable discussion on the LEP results!