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PRELIMINARY

Search for charginos nearly mass-degenerate with the lightest neutralino in e^+e^- collisions up to $\sqrt{s} = 209$ GeV

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1 Introduction

This paper reports on the search for chargino ($\tilde{\chi}_1^\pm$) with a mass difference with respect to the lightest neutralino($\tilde{\chi}_1^0$) of less than 5 GeV/c^2. In the Minimal Supersymmetric extension of the Standard Model (MSSM) [1], $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ are nearly mass-degenerate for large $M_{1,2}$ (higgsino region); small values of Δm ($\Delta m = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$) are possible in gaugino region if the gaugino unification relation between M_1 and M_2 is relaxed. Moreover supersymmetric models with anomaly mediated supersymmetric breaking mechanism [2] foresee the degeneration of chargino and neutralino, since $M_1/M_2 >> 1$.

The analysis is based [3] on the reconstruction of an isolated initial state radiation (ISR) photon together with the low-momentum detectable chargino decay products. The ISR photons are required to have high transverse momentum with respect to the beam line to ensure high trigger efficiency.

Data collected by the ALEPH detector [4] at LEP during 1998–2000, at centre-of-mass energies ranging from 189 to 209 GeV, are used. The total data sample corresponds to an integrated luminosity of about 627 pb^{-1}.

Background events expected from Standard Model processes are generated with a statistics corresponding to at least 20 times the collected luminosity used in the analysis.

Signal events are simulated with the Monte Carlo program `SUSYGEN` [5]. Charginos are produced in pairs with masses ranging from 40 GeV/c^2 up to the kinematic limit, for Δm between 0.1 to 5 GeV/c^2, and with decay length, λ, up to 80 cm. Corrections to the efficiency calculations are applied to take into account the spectral functions of the hadronic decay [6], which are based on the Kühn-Santamaria parametrisation [7]. Parameters are tuned to describes correctly the semileptonic τ decays to pions [8]. The ISR is enabled in the Monte Carlo samples [9]. The photon energy spectrum is different in various regions of the MSSM parameter space; it depends on the relative contribution of the s-channel Z exchange, which, in turn, depends on the $Z\tilde{\chi}_1^+\tilde{\chi}_1^-$ coupling; this effect becomes as important as the chargino is far from the kinematic limit. The photon energy and the transverse momentum Monte Carlo spectra are shown in Fig. 1a) and b) respectively.

2 Event selection

The signal topology depends on Δm values Below the threshold of pion production, charginos are long-lived and strongly ionising particles; stable particle analysis [10] selects efficiently this final state. When Δm is larger than 5 GeV/c^2, missing energy chargino analysis [11] are used. In the intermediate range, $m_\pi < \Delta m < 5$ GeV/c^2, the analysis described below is tailored to search for events with few low-momentum particles accompanied by an ISR photon.

Photons are reconstructed by localised energy depositions within groups of neighbouring ECAL towers and by the photon conversion finding [12]. In order to optimise the energy reconstruction of photons, which are not well-contained in ECAL, the sum of the localised energy depositions in ECAL and HCAL is computed inside a cone with half-opening of 11.5°.

Events are selected if at least one photon in the geometrical acceptance ($|\cos\theta_\gamma| < 0.95$) is

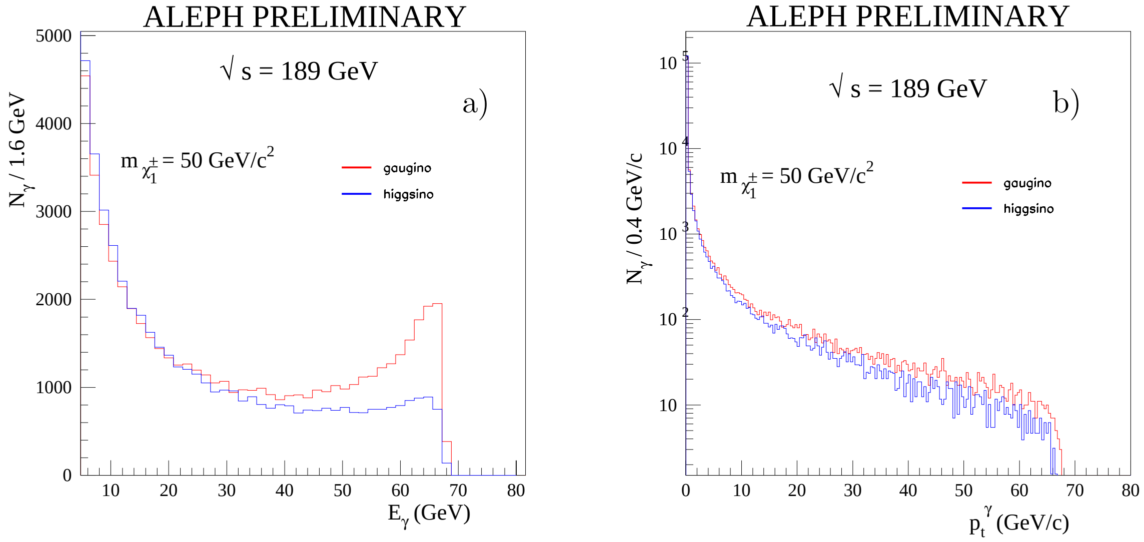

Figure 1: Generated energy (a) and transverse momentum (b) distribution of ISR γ at $\sqrt{s} = 189$ GeV for $m_{\tilde{\chi}_1^\pm} = 50$ GeV$/c^2$; different colours correspond to the histograms in gaugino or higgsino region.

reconstructed with the transverse momentum with respect to the beam axis , p_t, greater than $\sqrt{s}\sin\theta_{min}$, where $\theta_{min} = 35$ mrad is the lowest polar angle covered by the SICAL detector. The energy deposition is then large enough to ensure the trigger.

Two or more charged tracks, reconstructed with at least 4 hits in the ITC or 4 hits in the TPC, are required. Photons have to be isolated from the closest charged track by 30°.

Good tracks are defined requiring the impact parameter in the transverse plane to the beam axis to be less than 4 cm, if no hits in the TPC are used in the reconstruction. The cut is tightened to 2 cm, and the distance from the interaction point along the beam axis is required to be less than 10 cm, if at least 4 TPC hits are used in the track finder. Most of the two and four fermions events are rejected requiring that the number of good tracks is less than or equal ten.

To prevent from $\gamma(\gamma)\nu\bar{\nu}$ events with one non identified photon conversion in the TPC, at least one track has to be reconstructed with a number of ITC hits greater than zero; secondary vertex reconstruction is enforced for each pair of tracks, the momentum of the tracks is computed at the secondary vertex position and the invariant mass is determined assuming electron mass for each track and it is asked to be greater than 0.1 GeV$/c^2$. Events with a recoiling mass to the photon smaller than 100 GeV$/c^2$ are also discarded.

Candidates with a non vanishing value of the visible energy inside a cone of 14° around the beam axis are rejected. The total visible transverse momentum of the event $p_t^{\rm vis}$ is required to be greater than 3.5% $\sqrt{s}$. Both these cuts improve the signal to $\gamma\gamma$ background discrimination.

The total energy not associated to the reconstructed photons, is constrained to the maximum value of the expectation for charginos decaying promptly, at each chargino mass and Δm.

Similarly $p_t^{\rm vis}$ is constrained to the maximum value as determined by the Monte Carlo signal simulations. Finally the photon energy is required to be less than the maximum energy for an ISR photon as computed with the following formula:

$$E_\gamma^{max} = \frac{s - (2m_{\tilde{\chi}_1^\pm})^2}{2\sqrt{s}} \ .$$

The selection criteria have been optimised according to the $\bar{N}_{95}$ [13] prescription over the whole range of Δm.

3 Results

The selection efficiency of pair-produced charginos with an ISR high transverse momentum photon is about 40%. Fig. 2 shows the dependence of the average efficiency on the generated transverse momentum of the photon, p_t^γ. In the range of p_t^γ between 15 and 25 GeV/c, about 20% of the events are lost due to the photon acceptance and reconstruction. Photon isolation criteria reduce the efficiency of about 30%.

The selection efficiency with respect to all chargino pair produced is below 3% and it is mostly due to the small fraction of events with a high p_t^γ photon. The efficiency does not depend on Δm significantly, but on the chargino mass through the ISR photon reconstructed p_t requirements as shown in Fig. 3a).

Inefficiency arises when the chargino gets a sizeable decay length, due to the cut on the additional reconstructed energy in addition to the photon. Signal efficiency is shown in Fig. 3b) as a function of λ with $m_{\tilde{\chi}_1^\pm} = 71$ GeV/c^2, $m_\pi < \Delta m < 0.3$ GeV/c^2 and for 1-π final state.

Additional inefficiency due to beam related background leading to depositions in the very forward detectors is estimated using random trigger events. The applied correction to the efficiency amounts to about (4±1)%. The total systematic uncertainty on the selection efficiency is 15 % and it is dominated by the limited Monte Carlo statistics.

The number of observed events is in good agreement with the expectation from standard model processes as shown in Table 1, for $m_{\tilde{\chi}_1^\pm} > 50,\ 65,\ 85$ GeV/c^2 and $\Delta m < 2,\ 1,\ 0.3$ GeV/c^2 respectively The main background contributions are also reported. The main contributions to the background after the selection come from $\tau^+\tau^-$, $\gamma\gamma \to \tau^+\tau^-$ and $\gamma(\gamma)\nu\bar{\nu}$ events. A candidate event which is contributing up to $m_{\tilde{\chi}_1^\pm} = 84$ GeV/c^2 and any Δm is shown in Fig. 4.

4 Interpretation in the MSSM

The non-observation of any excess of candidate events is interpreted in terms of upper limits on the chargino production cross section in the MSSM framework. The cross section upper limits are in turn translated into 95% confidence level excluded regions in the $(m_{\tilde{\chi}_1^\pm},\ \Delta m)$ plane. No

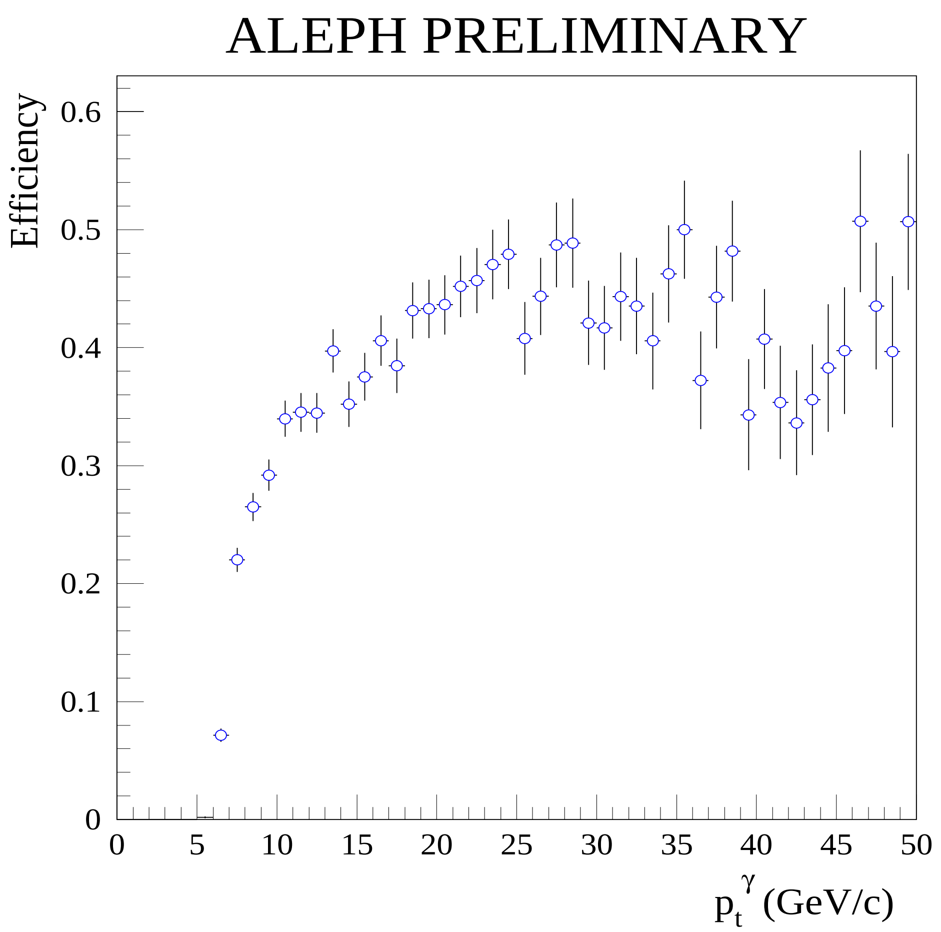

Figure 2: Chargino selection efficiency as a function of generated transverse momentum of the ISR photon for chargino masses from 46 to 91 GeV/c^2 and $\sqrt{s} = 189$ GeV.

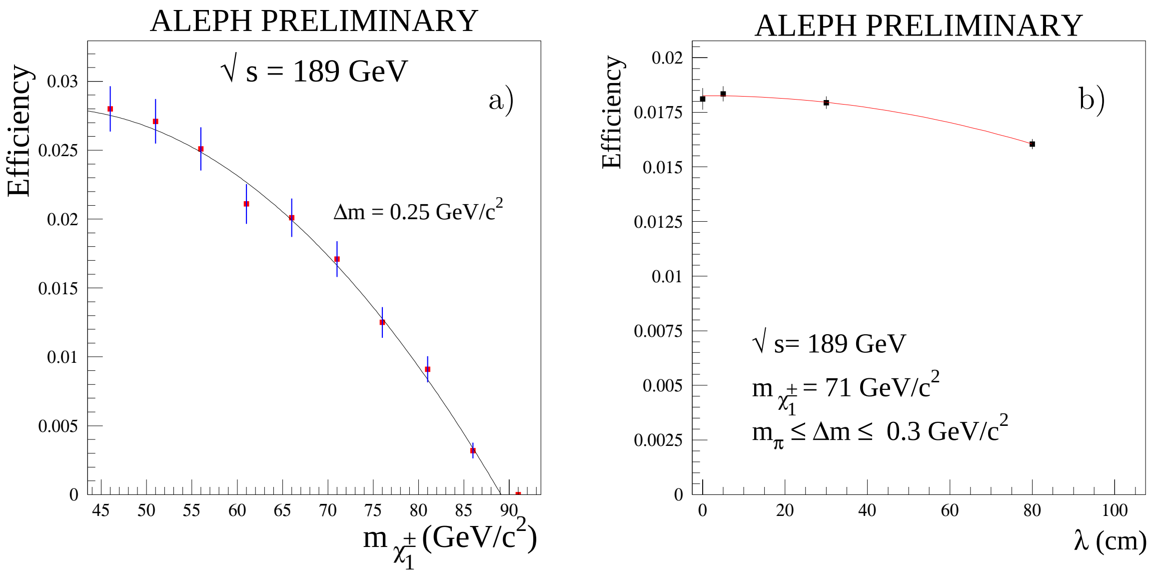

Figure 3: a) Signal efficiency as a function of chargino mass at $\sqrt{s}$ = 189 GeV for Δm = 0.25 GeV/c^2 and λ = 0; b) Signal efficiency as a function of λ for $m_{\tilde{\chi}_1^\pm}$ = 71 GeV/c^2, $m_\pi < \Delta m < 0.3$ GeV/c^2 and for 1-π final state.

$\sqrt{s} = 189 - 209\,GeV$		Data	background					
$m_{\tilde{\chi}_1^\pm}$ (GeV/c^2)	Δm (GeV/c^2)		$\gamma(\gamma)\nu\bar{\nu}$	$\gamma\gamma \to \tau^+\tau^-$	$\gamma\gamma \to$ e$^+$e$^-$	$\tau^+\tau^-$	$4f$	Tot. Exp.
> 50	< 2	13	1.2	2.0	0.3	3.8	1.3	9.0
> 65	< 1	5	0.7	1.8	0.3	1.7	0.6	5.4
> 85	< 0.3	1	0.6	1.4	0	0.5	0	2.9

Table 1: Number of observed events on data and standard model background expected events for $m_{\tilde{\chi}_1^\pm} > 50,\ 65,\ 85$ GeV/c^2 and $\Delta m < 2,\ 1,\ 0.3$ GeV/c^2 respectively.

background subtraction is performed and systematics are taken into account according to Ref. [14].

The excluded regions in gaugino and higgsino scenario are shown in Fig. 5 and 6 and are valid for all $\tan\beta$ and in the hypothesis of high scalar masses. The results of the standard missing energy selection, the ISR analysis and the stable particles search are distinguished. Lower limits on chargino mass of 88 GeV/c^2 and $8x$ GeV/c^2 are set in the gaugino and higgsino region respectively. These results are improved with respect to those obtained by the DELPHI [15] and L3 [16] collaborations using data collected at energies from $\sqrt{s}$= 189 GeV up to $\sqrt{s}$ = 202 GeV.

5 Conclusions

Search for charginos nearly mass degenerate with the lightest neutralino is performed using data collected ALEPH detector at LEP at a centre-of-mass energies from 189 GeV to 209 GeV. No excess on candidate events with respect to standard model background prediction is found.

In the framework of MSSM, in the high scalar masses scenario and for any $\tan\beta$ the following mass limits are set at 95% confidence level:

- in gaugino region: $m_{\tilde{\chi}_1^\pm} > 91$ GeV/c^2;
- in higgsino region: $m_{\tilde{\chi}_1^\pm} > 89$ GeV/c^2.

References

[1] H.E. Haber and G.L. Kane, Phys. Rep. C 117 (1985) 75;
R. Barbieri, Riv. Nuovo Cimento 11 (1988) 1.

[2] G.F.Giudice, M.A. Luty, H. Murayama and R. Rattazzi, J. High Energy Phys. 9812 (1998) 027;
L. Randall and R. Sundrum, Nucl. Phys. B 557 (1999) 79;
T. Gherghetta, G.F. Giudice and J. D. Wells, Nucl. Phys. B 559 (1999) 27.

[3] C.H. Chen, M. Drees and J.F. Gunion, Phys. Rev. Lett. 76 (1996) 2002.

[4] ALEPH Collaboration, *ALEPH: A detector for electron-positron annihilation at LEP.* Nucl. Instrum. and Methods A 294 (1990) 121;
Performance of the ALEPH detector at LEP. Nucl. Instrum. and Methods A 360 (1995) 481.

[5] SUSYGEN version 2.2: S. Katsanevas and P. Morawitz, Comp. Phys. Comm. 122 (1998) 227.

[6] C.H. Chen, M. Drees and J.F. Gunion, Phys. Rev. D55 (1997) 330, erratum Phys. Lett. 82 (1999) 3192.

[7] J.H. Kühn and A. Santamaria, Z. Phys. C 48 (1990) 445.

[8] ALEPH collaboration, *Measurement of the spectral functions of vector current hadronic τ decays*, Z. Phys. C 76 (1997) 15;
Measurement of the spectral functions of axial-vector hadronic τ decays and determination of $\alpha_s(M_{tau}^2)$, Eur. Phys. Journal C 4 (1998) 409.

[9] REMT: F.A. Berends and R. Kleiss, Nucl. Phys. B 260 (1985) 32.

[10] ALEPH Collaboration, *Search for gauge mediated SUSY breaking topologies at $\sqrt{s} \sim$* 189 GeV Eur. Phys. J. C 16 (2000) 1;
Single- and multi-photon production and a search for slepton pair production in GMSB topologies in e^+e^- collisions at a $\sqrt{s}$ up to 208 GeV, ALEPH 2001-010 CONF 2001-007.

[11] ALEPH collaboration, *Search for charginos and neutralinos in* e^+e^- *collisions at centre-of-mass energies near 183 GeV and constraints on the MSSM parameter space*, Eur. Phys. J. C 11 (1999) 193;
Search for charginos and neutralinos in e^+e^- *collisions at* $\sqrt{s}$ *up to 208 GeV and mass limit for the lightest neutralino*, ALEPH 2001-009, CONF 2001-009.

[12] ALEPH collaboration, *Single- and multi-photon production in* e^+e^- *collisions at a centre-of-mass energy of 183 GeV*, Phys. Lett. B 429 (1998) 201.

[13] ALEPH Collaboration, Phys. Lett. B 384 (1996) 427;
J.-F. Grivaz and F. Le Diberder, *Complementary analyses and acceptance optimization in new particle searches.*, LAL 92-37 (1992).

[14] R.D. Cousins and V.L. Highland, Nucl. Instrum. and Methods A 320 (1992) 331.

[15] DELPHI Collaboration, *Search for charginos nearly mass-degenerate with the lightest neutralino* , Eur. Phys. J. C 11 (1999) 1;
Update of the search for charginos nearly mass-degenerate with the lightest neutralino, Phys. Lett. B 485 (2000) 95.

[16] L3 Collaboration, *Search for charginos with a small mass difference to the lightest supersymmetric particle at* $\sqrt{s} = 189$ GeV , Phys. Lett. B482 (2000) 31;
Search for charginos with a small mass difference to the lightest supersymmetric particle at $189 < \sqrt{s} < 202$ GeV , L3 Note 2582, July 3,2000, Contribution to the *XXXth International Conference on High Energy Physics, Osaka, Japan, July 27-August 2, 2000.*

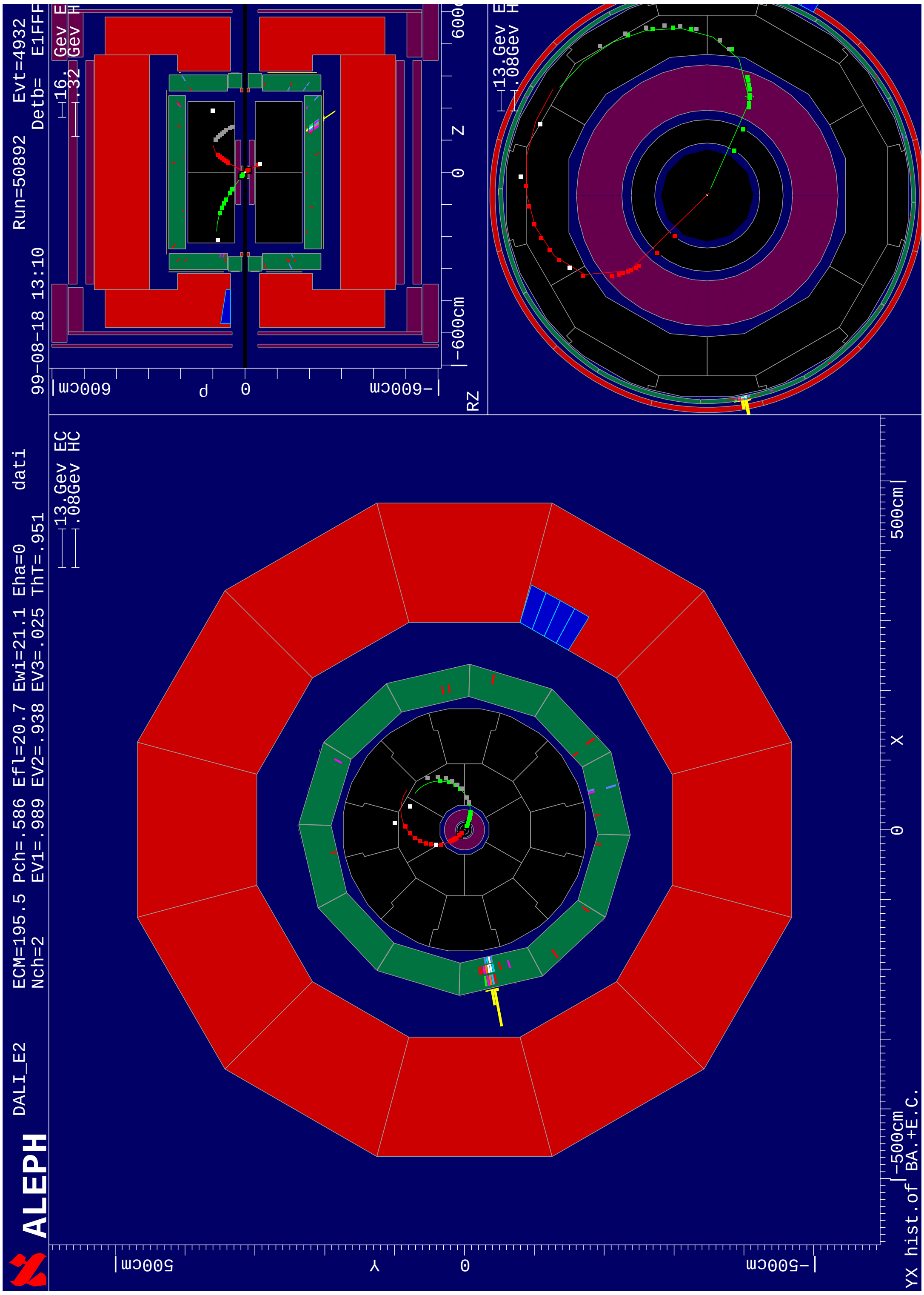

Figure 4: Candidate event at $\sqrt{s} = 195.4$ GeV which contributes to the range $m_{\tilde{\chi}_1^\pm} < 84$ GeV$/c^2$. The reconstructed photon energy is about 21 GeV.

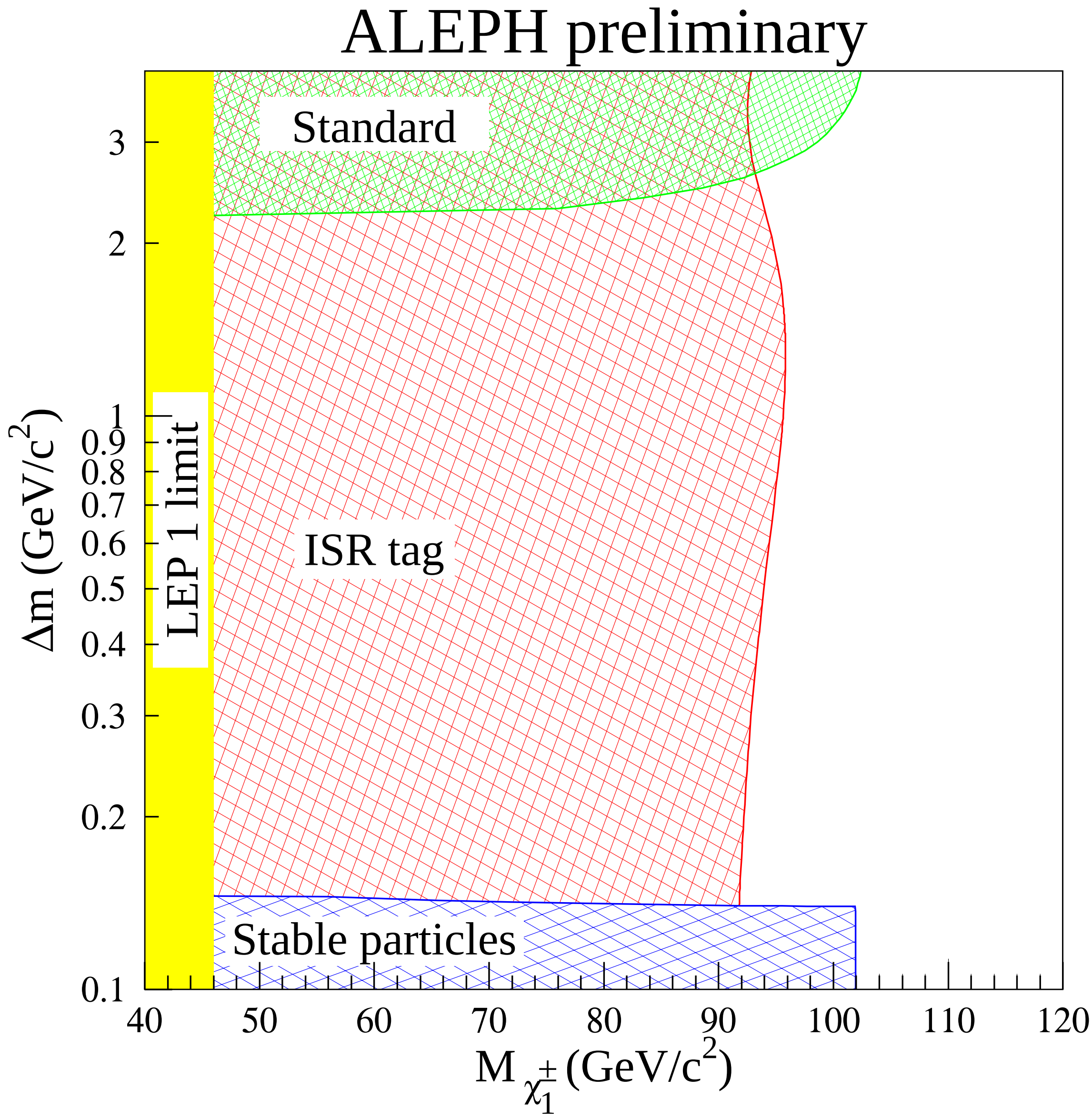

Figure 5: Excluded region in the $(m_{\tilde{\chi}_1^\pm},\ \Delta m)$ plane at 95% confidence level, for $m_0 >$ 500 GeV/c^2 in the gaugino region. The green region is excluded by the standard missing energy chargino selection [11], the red region is the resulting exclusion of the ISR analysis; the blue region is excluded by the the stable particle search [10]. The 95% confidence level lower limit on chargino mass is 91 GeV/c^2.

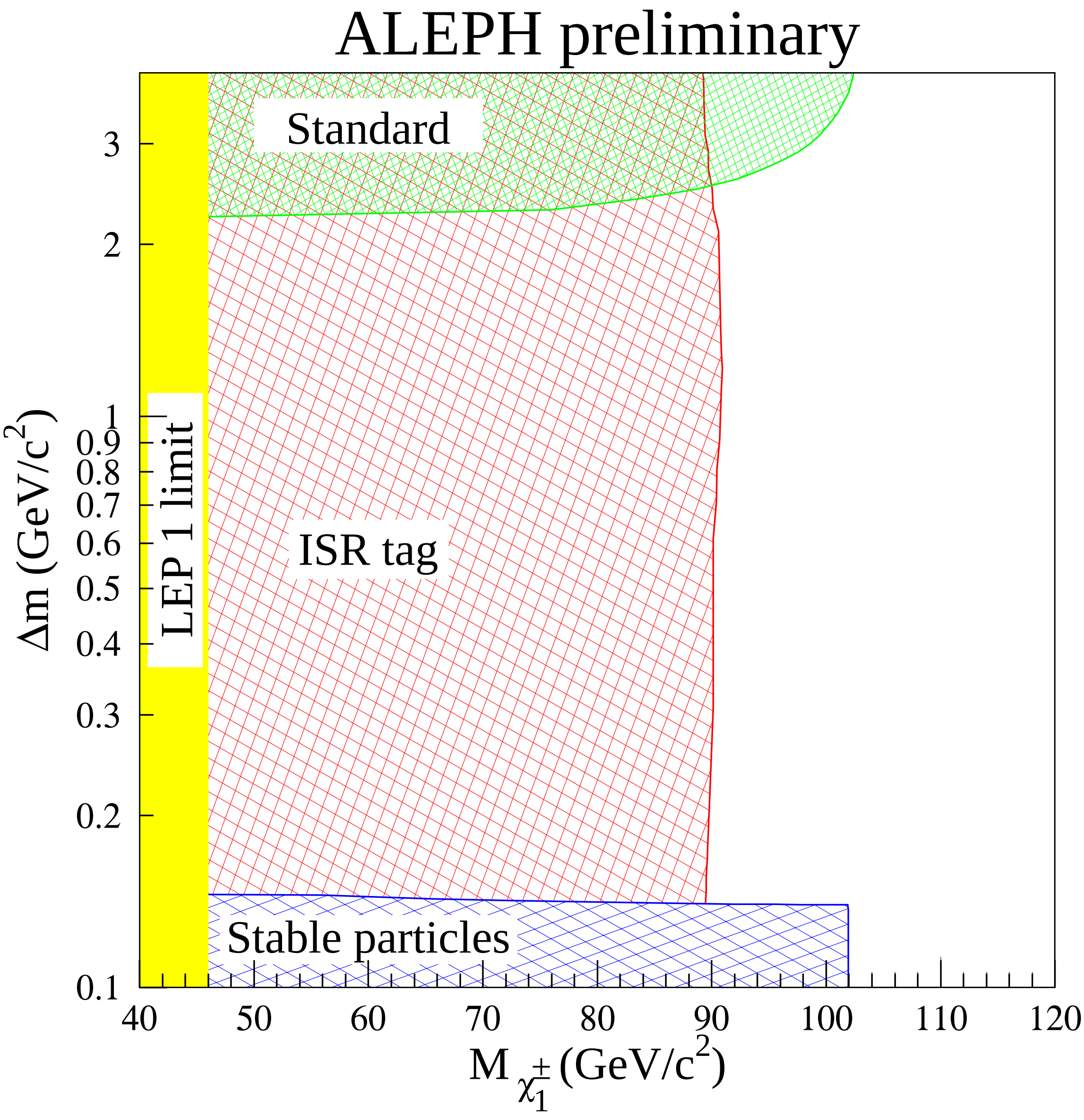

Figure 6: 95% confidence level excluded region for $m_0 > 500$ GeV/c^2 in the higgsino region. The green region is excluded by the results of the standard missing energy chargino results [11], the red region by the ISR analysis; the blue region by the the stable particle search [10]. Chargino masses below 89 GeV/c^2 are excluded at 95% confidence level.