International Journal of Modern Physics A,

OPAL SEARCHES FOR PROMPT LIGHT GRAVITINO PRODUCTION AT LEP

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Results of searches for the signatures of promptly decaying light gravitinos are presented, based on data collected using the OPAL detector at LEP. This paper focuses primarily on updates to the results of published analyses of approximately 182 pb^{-1} taken at $\sqrt{s} = 189$ GeV in 1998. These updates are based on analysis of data collected in the energy range of $\sqrt{s} = 200 - 209$ GeV in the year 2000. All results from this data sample are preliminary.

1. Introduction

A number of SUSY models share the feature of an almost massless gravitino ($\tilde{\mathrm{G}}$) as the lightest supersymmetric particle or LSP. The phenomenology of such models is dictated by the identity of the next-to-lightest supersymmetric particle or NLSP, which decays into its Standard Model (SM) partner and an undetectable gravitino. In models with no-scale supergravity, the NLSP is always the lightest neutralino, $\tilde{\chi}^0_1$. Models with gauge-mediated supersymmetry breaking (GMSB) display a richer phenomenology since there are a variety of possibilities for the NLSP. An important feature of light-gravitino models is that the lifetime of the NLSP is essentially arbitrary, with possible mean decay lengths varying from microns to kilometers. Intermediate and long-lifetime scenarios can result in rather unusual signatures. This talk, however, will focus on the case in which the NLSP decays promptly.

In GMSB models, the two candidates for the NLSP are the lightest neutralino, $\tilde{\chi}^0_1$, and the right-handed slepton, $\tilde{\ell}_R$ (which may preferentially be a $\tilde{\tau}_R$ due to slepton mixing effects). Supersymmetric decay sequences all end with either $\tilde{\chi}^0_1 \rightarrow \tilde{\mathrm{G}}\,\gamma$ or $\tilde{\ell}_R \rightarrow \ell\tilde{\mathrm{G}}$, and thus events may contain additional high-energy photons or leptons beyond the signals expected in traditional (gravity-mediated) SUSY models. The simplest final states come from NLSP pair-production, leading to a $\gamma\gamma + \not{E}_{\mathrm{T}}$ ($\ell^+\ell^- + \not{E}_{\mathrm{T}}$) final state in the case of a $\tilde{\chi}^0_1$ ($\tilde{\ell}$) NLSP. Other production mechanisms lead to more complex signatures. OPAL has published papers on searches for $\gamma\gamma + \not{E}_{\mathrm{T}}$ and $\ell^+\ell^- + \not{E}_{\mathrm{T}}$ final states[1,2] as well as on dedicated searches for other relevant final states[3], in a data sample consisting of about 182 pb^{-1} at $\sqrt{s} = 188.7$ GeV. This talk will focus on updates to these analyses, using the higher-energy data samples taken at $\sqrt{s} = 200 - 209$ GeV in the year 2000. This corresponds to to about 84 pb^{-1} taken at an average centre-of-mass energy of 205.5 GeV.

*Representing the OPAL Collaboration

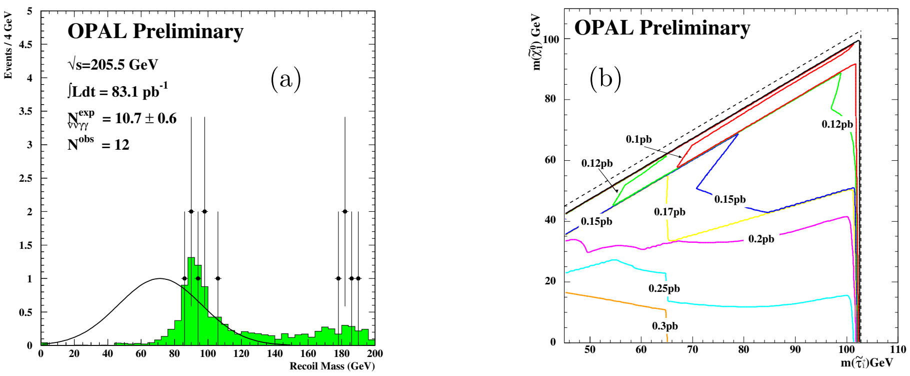

Fig. 1. (a) Results of the OPAL acoplanar photons selection applied to the 2000 data sample. Also shown are the expected SM background contribution (histogram) and the expected signal contribution from neutralino pair production with $\mathrm{M}(\tilde{\chi}^0_1) = 100$ GeV (curve, with arbitrary normalization). (b) shows the results of a search for $\tau\tau\gamma\gamma$ final states which could arise from $\tilde{\tau}$ pair production in the $\tilde{\chi}^0_1$ NLSP scenario. Shown are the 95% CL upper limits on the $\sigma \times$ BR in the plane of $\mathrm{M}(\tilde{\chi}^0_1)$ vs. $\mathrm{M}(\tilde{\tau})$, from the OPAL 2000 data.

2. Neutralino NLSP Scenario

The simplest final states in light-gravitino models arise from pair production of the NLSP. For a neutralino NLSP this results in a final state consisting of two photons and large missing transverse energy, $\not{E}_{\mathrm{T}}$. This final state has an irreducible SM background from the process $\mathrm{e}^+\mathrm{e}^- \rightarrow \nu\bar{\nu}\gamma\gamma$ which, however, might be differentiated from signal processes based on the distribution of the mass recoiling against the two photon system, especially for $\tilde{\chi}^0_1$ masses near the kinematic limit. For the OPAL selection of $\gamma\gamma + \not{E}_{\mathrm{T}}$ final states all other sources of background are negligible. The results of this selection applied to data taken at 189 GeV were consistent with the prediction of the SM[1]. The results of this selection, applied to the 2000 data sample, are shown in Figure 1a. Overlaid as a histogram and a line, respectively, are the expected contributions from $\mathrm{e}^+\mathrm{e}^- \rightarrow \nu\bar{\nu}\gamma\gamma$ and from $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow \tilde{\mathrm{G}}\gamma\tilde{\mathrm{G}}\gamma$ with $\mathrm{M}(\tilde{\chi}^0_1) = 100$ GeV. The signal distribution dominantly populates the region of low recoil mass where the SM background is rather small. The numbers of events selected from the data and expected from the SM are also shown. These agree well as does the overall shape of the recoil-mass distribution.

Other production processes investigated in the $\tilde{\chi}^0_1$ NLSP scenario are:

- $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow (\ell^+\tilde{\chi}^0_1)(\ell^-\tilde{\chi}^0_1) \rightarrow \ell\ell\gamma\gamma + \not{E}_{\mathrm{T}}$
- $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}^+_1\tilde{\chi}^-_1 \rightarrow (\mathrm{W}^{(*)+}\tilde{\chi}^0_1)(\mathrm{W}^{(*)-}\tilde{\chi}^0_1) \rightarrow$ leptons/jets $+ \gamma\gamma + \not{E}_{\mathrm{T}}$
- $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}^0_2\tilde{\chi}^0_1 \rightarrow \mathrm{Z}^{(*)}\tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow$ leptons or jets $+\gamma\gamma + \not{E}_{\mathrm{T}}$

For the first of these channels, the analysis is done separately for $\tilde{\mathrm{e}}$, $\tilde{\mu}$ and $\tilde{\tau}$ pair production. For the latter two, separate selections are applied to high and low multiplicity final states, depending on the decays of the $W^{(*)}$ and $Z^{(*)}$. Results from these searches applied to the 189 GeV data sample are published[3]. Limits on the production cross-section times branching fractions are obtained in the $(M(\tilde{\chi}_1^0), M(X))$ plane where X is the particle which is pair produced (or produced in association with a $\tilde{\chi}_1^0$). These selections have been applied to the 2000 data. The numbers of events selected are generally consistent with the expectations from the SM. The largest discrepancy is observed in the $e^+e^- \to \tilde{\ell}^+\tilde{\ell}^-$ channel, for the case of a large mass difference between the slepton and the neutralino $(M(\tilde{\ell}) - M(\tilde{\chi}_1^0) > M(\tilde{\ell})/2)$, where 4 events are observed for 1.3 ± 0.3 expected from the SM. The background in this kinematic region is dominantly from $e^+e^- \to \tau\tau\gamma\gamma$. Figure 1b shows the limits on $\tilde{\tau}$ pair production, obtained from the selection of $\tau\tau\gamma\gamma + \not{E}_T$ final states.

3. Slepton NLSP Scenario

In the case of a slepton NLSP the situation is complicated by the possibility of stau-mixing. If this mixing is large, the mass of the $\tilde{\tau}_1$ is lowered relative to the first and second generation sleptons and it alone acts as the NLSP. If the mixing is not large, a situation can arise where the three right-handed sleptons act as co-NLSPs. Both scenarios are discussed below.

In the case of a slepton NLSP, the possibility of an intermediate or long lifetime can lead to rather spectacular signatures with negligible SM backgrounds, such as kinked charged tracks or long-lived heavy charged particles. However, if the NLSP is assumed to decay promptly, the experimental signature for slepton pair production is a $\ell^+\ell^- + \not{E}_T$ final state which has a large irreducible SM background, primarily from $e^+e^- \to W^+W^-$ where both W bosons decay semileptonically. OPAL has previously published[2] results on the search for these acoplanar lepton final states using data recorded at $\sqrt{s} = 183 - 189$ GeV. In each case, events passing a general selection for $\ell^+\ell^- + \not{E}_T$ final states are classified as being consistent with the hypothesis of slepton pair production using a likelihood technique. The numbers and distributions of selected events are found to be consistent with the predictions of the Standard Model. The results of these searches, applied to the 2000 data, are summarized in Table 1. Consistency with the SM remains good in all cases.

In the slepton NLSP scenario, pair production of SUSY particles other than the NLSP can lead to final states with 4 or 6 leptons, depending on whether the stau NLSP or slepton co-NLSP scenario applies. The channels considered by OPAL are:

Table 1. Slepton pair production search results from analysis of the 2000 data sample. $M(\tilde{\ell})$ is the slepton mass, N is the number of selected data events, N_{SM} is the number of events expected from SM processes and CL is the confidence level for agreement with the predictions of the SM.

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$M(\tilde{\ell})$ (GeV)	N	N_{SM}	CL(%)	N	N_{SM}	CL(%)	N	N_{SM}	CL(%)
50	15	16.51 ± 0.25	47.6	2	3.68 ± 0.09	89.9	10	11.99 ± 0.23	34.5
70	20	20.45 ± 0.25	41.8	1	4.37 ± 0.13	74.3	8	14.16 ± 0.27	56.5
90	11	11.22 ± 0.17	65.8	2	3.11 ± 0.09	61.3	8	14.25 ± 0.26	77.7
101	1	2.63 ± 0.08	82.9	0	1.17 ± 0.05	46.8	8	13.68 ± 0.24	71.7

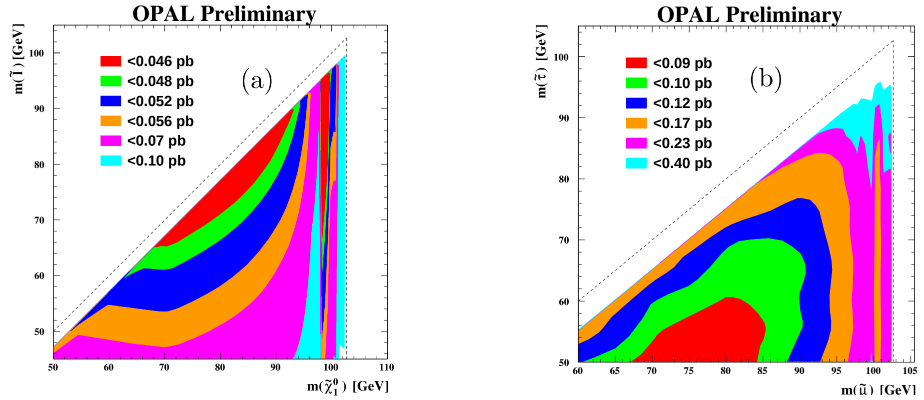

Fig. 2. Results of searches for (a) $\ell\ell\ell'\ell' + \not{E}_{\mathrm{T}}$ and (b) $\mu\mu\tau\tau\tau\tau + \not{E}_{\mathrm{T}}$ final states which might arise from $\tilde{\chi}^0_1$ pair production in the slepton co-NLSP scenario and from $\tilde{\mu}$ pair production in the $\tilde{\tau}$-NLSP scenario, respectively. Shown are the 95% CL upper limits on the $\sigma \times$ BR in the plane of M(NLSP) vs. M(X), where X is the pair produced particle. These results are from analysis of the OPAL 2000 data.

- $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow (\tilde{\ell}^\pm\ell^\mp)(\tilde{\ell}'^\pm\ell'^\mp) \rightarrow \ell\ell\ell'\ell' + \not{E}_{\mathrm{T}}$ ($\tilde{\ell}$ co-NLSP scenario)
- $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow (\tilde{\tau}^\pm\tau^\mp)(\tilde{\tau}^\pm\tau^\mp) \rightarrow \tau\tau\tau\tau + \not{E}_{\mathrm{T}}$ ($\tilde{\tau}$ NLSP scenario)
- $\mathrm{e}^+\mathrm{e}^- \rightarrow \tilde{\ell}^+\tilde{\ell}^- \rightarrow (\ell^+\tilde{\tau}\tau)(\ell^-\tilde{\tau}\tau) \rightarrow \ell\ell\tau\tau\tau\tau + \not{E}_{\mathrm{T}}$ ($\tilde{\tau}$ NLSP scenario)

Searches applied to the 189 GeV data samples selected numbers of events consistent with the SM expectation. Corresponding limits on the production cross-section times branching fractions were obtained in the plane of the mass of the NLSP and the mass of the pair produced particle[3]. These selections have been updated using the 2000 data and the consistency with the SM remains good. The most significant excess is observed in the $\tilde{\ell}$ pair production channel in the stau NLSP scenario, for which 6 events are selected where 2.1 ± 0.2 are expected from the SM. Figure 2 shows production cross-section limits for two of the scenarios described above.

4. Scan of GMSB Parameter Space

The results of OPAL searches for final states expected in models with GMSB have been used to perform a scan of the GMSB parameter space, for the case of a promptly decaying NLSP. Results from the analysis of the 189 GeV data sample are published[3]. Updates using higher energy data samples are not yet available.

References

1. OPAL Collab.,K.Ackerstaff *et al.*,CERN-EP-2000-050. Accepted by *Eur. Phys. J.* **C**
2. OPAL Collab.,K.Ackerstaff *et al.*,CERN-EP/99-122. Accepted by *Eur. Phys. J.* **C**
3. OPAL Collab.,K.Ackerstaff *et al.*,CERN-EP-2000-078. Submitted to *Phys. Lett.* **B**