Hyperon physics with light sgoldstino

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Abstract

We study sensitivity of hyperon experiments to the scale of supersymmetry breaking $\sqrt{F}$ in models with light sgoldstinos — superpartners of goldstino. It is found that searches for two-body hyperon decays into nucleon and light pseudoscalar sgoldstino can probe the supersymmetry breaking scale $\sqrt{F}$ in the 100 TeV range and above, provided MSSM flavor violating parameters are close to their experimental bounds.

1 Introduction

Superpartners of goldstino — longitudinal component of gravitino — may be fairly light. In a variety of models with low energy supersymmetry they are lighter than a few GeV. Such pattern emerges in a number of non-minimal supergravity models [1, 2] and also in gauge mediation models if supersymmetry is broken via non-trivial superpotential (see, e.g., Ref. [3] and references therein). To understand that superpartners of goldstino may be light, it suffices to recall that in globally supersymmetric theories with canonical Kähler potential and in the absence of anomalous abelian gauge factors, the sum of scalar squared masses is equal to the sum of fermion squared masses in each separate sector of the spectrum. Since goldstino is massless, its spinless superpartners (scalar and pseudoscalar particles, S and P, hereafter, *sgoldstinos*) are massless too; they are associated with a non-compact flat direction of the scalar potential. Higher order terms from the Kähler potential contribute to sgoldstino masses. Provided these terms are sufficiently suppressed, sgoldstinos remain light. Of course, these arguments in no way guarantee that sgoldstinos are always light, but they do indicate

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that small sgoldstino masses are rather generic. The theoretical discussion of sgoldstino masses is contained, e.g., in Ref. [4]; here we merely assume that sgoldstino masses are light, so that the hyperon decays into baryon and sgoldstino are kinematically allowed.

Sgoldstinos couple to MSSM fields in the same way as goldstino [5, 6] with corresponding coupling constants being proportional to the ratios of soft terms (squark and gaugino masses, trilinear coupling constants) and the supersymmetry breaking parameter F (the scale of the supersymmetry breaking in the underlying theory is of the order of $\sqrt{F}$). Thus constraints on sgoldstino couplings may be translated into the limits on $\sqrt{F}$. The most sensitive probes of sgoldstinos are flavor violating processes, provided that flavor is violated in squark and/or slepton sector.

There are several papers devoted to astrophysical [7, 8], cosmological [9] and collider [10, 11, 12, 13] constraints on models with light sgoldstinos. The role of light sgoldstinos in low-energy laboratory measurements has been studied in detail in Ref. [8]. In particular, it was found that in models where sgoldstino couplings violate flavor, the sensitivity of searches for rare kaon decays $K^+ \to \pi^+ S$ to $\sqrt{F}$ is in the range up to $10^3 - 10^4$ TeV, provided that the scalar sgoldstino mass is smaller than $(m_K - m_\pi)$ (see Ref. [8] for details). Similar analysis applies to $K_L^0 \to \pi^0 S$ decay, and searches for rare neutral kaon decays have sensitivity to $\sqrt{F}$ of the same order.

A special class of supersymmetric extensions of the Standard Model in which interactions of sgoldstinos with quarks and gluons conserve parity but do not conserve quark flavor, has been considered in Ref. [14]. Parity conservation in sgoldstino interactions with quarks and gluons (as well as with leptons and photons) may not be accidental. As an example, it is natural in theories with spontaneously broken left-right symmetry (see Ref. [14] for details). We note in this regard that left-right symmetric extensions of MSSM not only are aesthetically appealing but also provide a solution [15] to the strong CP-problem, which is a viable alternative to the Peccei–Quinn mechanism. It is likely that sgoldstino interactions will conserve parity in supersymmetric versions of other models (see, e.g., Ref. [16]) designed to solve the strong CP-problem without introducing light axion. It was found [14] that if the pseudoscalar sgoldstino P is light, $m_P < (m_K - 2m_\pi)$, and the scalar sgoldstino is heavier, $m_S > (m_K - m_\pi)$, an interesting place for experimental searches is the poorly explored area of three-body decays of kaons, $K_{S,L}^0 \to \pi^+\pi^- P$, $K_{S,L}^0 \to \pi^0\pi^0 P$ and $K^+ \to \pi^+\pi^0 P$, with P subsequently decaying into $\gamma\gamma$, possibly e^+e^-, or flying away from the detector.

In this talk we show, that if sgoldstino is sufficiently light, the hyperon decays into baryon and sgoldstino are kinematically allowed and searches for these decays are very sensitive to sgoldstino couplings in models with light pseudoscalar sgoldstino and parity conservation. These searches for light pseudoscalar sgoldstino would be sensitive to the supersymmetry breaking scale $\sqrt{F}$ in the 100 TeV range and above, provided MSSM flavor violating parameters are close to their experimental bounds. In particular, these models may be tested by the HyperCP experiment [17] (E871 in FNAL), where collected statistics of Σ^+ and Λ hyperons allows to probe the scale of supersymmetry breaking as large as $10^3 - 10^4$ TeV. In models with light scalar sgoldstino and/or parity violating sgoldstino couplings the hyperon decays into baryon and sgoldstino are strongly constrained by searches for two-body kaon decays $K^+ \to \pi^+ S(P)$, $K_L^0 \to \pi^0 S(P)$.

2 Sgoldstino decays

For the sgoldstino masses $M_{P(S)}$ of order 200 MeV and smaller, which could be relevant for hyperon physics, the sgoldstino decay rate is saturated by decay into two photons or into $\mu^+\mu^-$. From the formulae of Ref. [8] one estimates the sgoldstino life-time as

$$\tau \simeq 10^{-12} \left(\frac{\sqrt{F}}{1 \text{ TeV}} \right)^4 \left(\frac{100 \text{ GeV}}{M_{soft}} \right)^2 \text{ s} , \qquad (1)$$

where $\sqrt{F}$ denotes the scale of supersymmetry breaking and M_{soft} corresponds to the scale of MSSM soft mass terms. Note, that the unitarity provides the constraint $M_{soft} \lesssim \sqrt{F}$. The relevant sgoldstino branching ratios are presented in Figs. 1, 2 for two sets of soft supersymmetry breaking parameters of MSSM and (pseudoscalar) sgoldstino mass within the interval $M_P < m_\Sigma - m_p$, where m_Σ and m_p are Σ^+-hyperon and proton masses, respectively.

3 $\Sigma^+ \to pP(S)$

The relevant interaction between *sgoldstino* (S, P), *down-* and *strange-quarks* is parameterized as [14]

$$\mathcal{L}_{q,S(P)} = -S \cdot \left(h_{12}^{(D)} \cdot \bar{d}s + h.c. \right) - P \cdot \left(h_{12}^{(D)} \cdot \bar{d} i \gamma^5 s + h.c. \right) \ . \qquad (2)$$

To estimate the interaction between hyperon, proton and sgoldstino one has to evaluate the matrix elements $\langle p | \bar{s} d | \Sigma^+ \rangle$ and $\langle p | \bar{s} \gamma_5 d | \Sigma^+ \rangle$ (In what

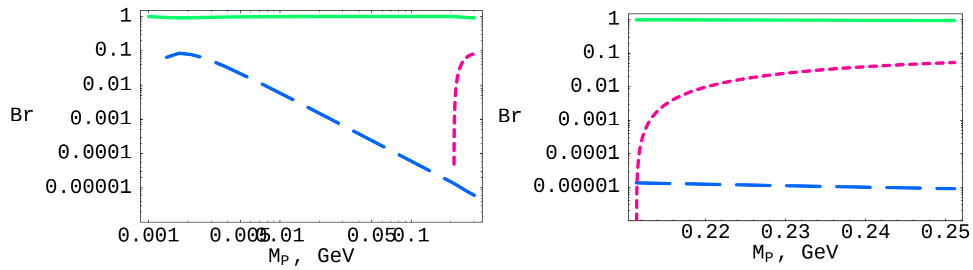

Figure 1: Branching ratio of sgoldstino decay into two photons (green solid line), e^+e^- (blue long-dashed line) and $\mu^+\mu^-$ (red short-dashed line) for $m_P < m_\Sigma - m_p$, and $A = 100$ GeV, $M_{\gamma\gamma} = 100$ GeV (see Ref. [8] for details).

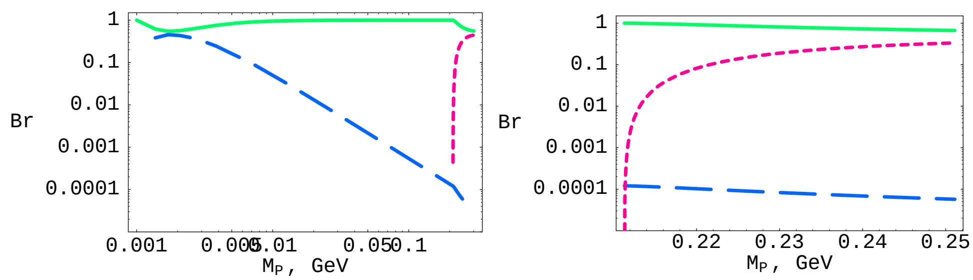

Figure 2: Branching ratio of sgoldstino decay into two photons (green solid line), e^+e^- (blue long-dashed line) and $\mu^+\mu^-$ (red short-dashed line) for $m_P < m_\Sigma - m_p$, and $A = 300$ GeV, $M_{\gamma\gamma} = 100$ GeV (see Ref. [8] for details).

follows we will consider only $\Sigma^+ \to pP(S)$ decays, though the interaction (2) is responsible for the decays $\Lambda \to nP(S)$ as well, and the latter branching ratio can be estimated along the same ways, as for the Σ^+ decays.). To this end one can consider the same matrix elements but for the vector and axial-vector currents, respectively, and define the form factors A and B as follows,

$$\langle p|\bar{s}\gamma^\mu d|\Sigma^+\rangle = A \cdot \bar{u}_p \gamma^\mu u_\Sigma \ , \quad \langle p|\bar{s}\gamma^\mu\gamma_5 d|\Sigma^+\rangle = B \cdot \bar{u}_p \gamma^\mu \gamma_5 u_\Sigma \ .$$

Actually, these form factors depend on the external momentum (i.e. on sgoldstino mass), but let us treat them as constants, since the deviations are expected to be small. $SU(3)$ symmetry implies that these constants are exactly the same as ones describing $\Sigma^- \to ne^-\nu$ decay, hence, $A = 1$,

$B = 0.34$ [18]. Then

$$\langle p|\bar{s}d|\Sigma^+\rangle = A\frac{m_\Sigma - m_p}{m_s}\cdot\bar{u}_p u_\Sigma\ ,\ \ \langle p|\bar{s}\gamma_5 d|\Sigma^+\rangle = -B\frac{m_\Sigma + m_p}{m_s}\cdot\bar{u}_p\gamma_5 u_\Sigma\ , \quad (3)$$

where m_s, m_Σ and m_p are masses of s-quark, Σ-hyperon and proton, respectively.

Finally one obtains the hyperon decay rates

$$\Gamma_{\Sigma^+\to pS} = \frac{|h_{12}^{(D)}|^2|A|^2}{8\pi}\frac{(m_\Sigma - m_p)^2}{m_s^2}\left(\left(1+\frac{m_p}{m_\Sigma}\right)^2 - \frac{m_S^2}{m_\Sigma^2}\right)\cdot q_S\ , \quad (4)$$

$$\Gamma_{\Sigma^+\to pP} = \frac{|h_{12}^{(D)}|^2|B|^2}{8\pi}\frac{(m_\Sigma + m_p)^2}{m_s^2}\left(\left(1-\frac{m_p}{m_\Sigma}\right)^2 - \frac{m_P^2}{m_\Sigma^2}\right)\cdot q_P\ , \quad (5)$$

where m_S and m_P are masses of scalar and pseudoscalar sgoldstino, respectively, and

$$q_X = \frac{1}{2m_\Sigma}\sqrt{\left((m_\Sigma + m_X)^2 - m_p^2\right)\left((m_\Sigma - m_X)^2 - m_p^2\right)}\ , \quad X = S,\ P\ .$$

In models where scalar sgoldstino S is light, or parity is violated in sgoldstino-quark interactions, the strongest limit on the $h_{12}^{(D)}$ comes from the searches for two-body kaon decays (see Ref. [8] for details),

$$|h_{12}^{(D)}|^2\mathrm{Br}(S\to\mu^+\mu^-) < 5\cdot 10^{-23}\ ,$$

that results in the limits

$$Br(\Sigma\to pS)\cdot\mathrm{Br}(S\to\mu^+\mu^-) < 3\cdot 10^{-10}\ , \quad (6)$$

$$Br(\Sigma\to pP)\cdot\mathrm{Br}(P\to\mu^+\mu^-) < 8\cdot 10^{-12}\ . \quad (7)$$

For other sgoldstino decay modes the corresponding limits are roughly of the same order of magnitude, as the limit for sgoldstino decay into muon-antimuon pair. Thus hyperon decay into proton and sgoldstino is highly suppressed in these models.

If scalar sgoldstino is heavy and parity is conserved in sgoldstino-quark interactions, the experimental constraints on the flavor-violating sgoldstino couplings come from the measurements of the parameters of $K^0-\bar{K}^0$ system and read [14]

$$|h_{12}^{(D)}|^2 < 5\cdot 10^{-15}\quad \text{for}\quad \mathrm{Im}[h_{12}^{(D)}]\gg(\ll)\mathrm{Re}[h_{12}^{(D)}]\ , \quad (8)$$

$$(\mathrm{Im}[h_{12}^{(D)}])^2 < 1.5\cdot 10^{-17}\quad \text{for}\quad \mathrm{Im}[h_{12}^{(D)}]\simeq\mathrm{Re}[h_{12}^{(D)}]\ , \quad (9)$$

and from the limits on $K^+ \to P\pi^+\pi^0$ decays [14, 19].

These limits imply that hyperon decay to sgoldstino and proton is allowed at the level of $10^{-3} - 10^{-4}$, depending on sgoldstino mass and pattern of MSSM soft terms. The corresponding branching ratios as a function of sgoldstino mass are presented in Figs. 3, 4. Taking into account the sgold-

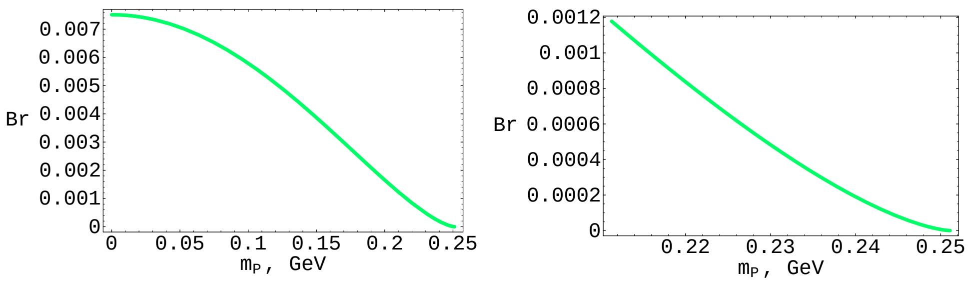

Figure 3: Upper bound on the branching ratio of hyperon decay into proton and light pseudoscalar sgoldstino for $m_P < m_\Sigma - m_p$ in models with $\mathrm{Im}[h_{12}^{(D)}] \gg (\ll) \mathrm{Re}[h_{12}^{(D)}]$.

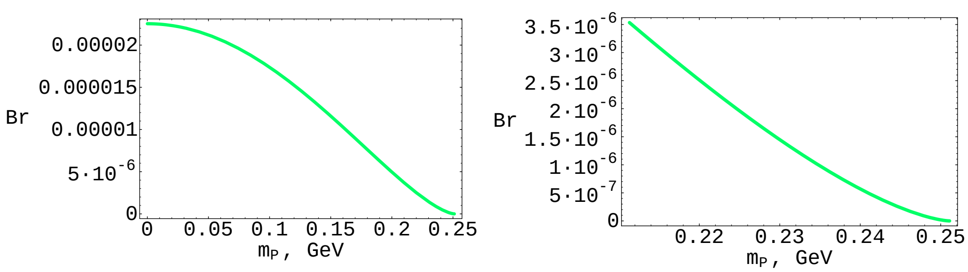

Figure 4: Upper bound on the branching ratio of hyperon decay into proton and light pseudoscalar sgoldstino for $m_P < m_\Sigma - m_p$ in models with $\mathrm{Im}[h_{12}^{(D)}] \simeq \mathrm{Re}[h_{12}^{(D)}]$.

stino branching ratios one can expect to strengthen the bound on $h_{12}^{(D)}$ by one-three orders of magnitude. One can show, that $\Lambda \to nP$ decay exhibits the similar sensitivity to the same sgoldstino coupling constants.

4 Conclusions

We estimated hyperon decay widths into baryon and sgoldstino. The experimental limits on the sgoldstino couplings imply that Σ^+-hyperon decay to sgoldstino and proton and Λ-hyperon decay to sgoldstino and neutron are allowed at the level of $10^{-3} - 10^{-4}$ in models with light pseudoscalar sgoldstino and parity conserving sgoldstino couplings. In models with lights scalar sgoldstino and/or parity violating sgoldstino couplings the hyperon decays into baryon and sgoldstino are strongly constrained by searches for two-body kaon decays $K^+ \to \pi^+ S(P)$, $K_L^0 \to \pi^0 S(P)$.

The large statistics of hyperon decays ($\sim 10^{10}$ for Σ^+ and 10^8 for Λ) collected in HyperCP experiment (E871) gives an opportunity to probe the scale of supersymmetry breaking as large as $\sqrt{F} \sim 10^3 - 10^4$ TeV, provided MSSM flavor violating parameters are close to their experimental bounds.

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