Sgoldstino interpretation of HyperCP events

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Outline

- Σ^+ decay in HyperCP experiment
- Sgoldstino, what is it?
- Decays of D- and B-mesons
- Decays of ρ-, ω- and ϕ-mesons
- Conclusions

HyperCP events

- Three events of $\Sigma^+ \to p\mu^+\mu^-$ (HyperCP, Fermilab, 2005)
- $\mathrm{Br}(\Sigma^+ \to p\mu^+\mu^-) = [3.1^{+2.4}_{-1.9}(\mathrm{stat.}) \pm 1.5(\mathrm{sys.})] \times 10^{-8}$
- $\Sigma \to pX$, where $X \to \mu^+\mu^-$ with $m_X = 214.3 \pm 0.5$ MeV
- X can be pseudoscalar or pseudovector, but not scalar or vector
- X — pseudoscalar sgoldstino

Sgoldstino — what is it?

- SUSY theories
- Superfields: $\hat{S} = \phi + \sqrt{2}\theta\psi + \theta^2\tilde{F}$
- $\langle\tilde{F}\rangle = F$ — SUSY broken spontaneously
  - $\sqrt{F}$ — the scale of SUSY breaking
- Supersymmetric analog of Nambu-Goldstone theorem:
  ψ is massless fermion — goldstino
- Sgoldstino: $\phi = \frac{1}{\sqrt{2}}(S + iP)$:
  S — scalar and P — pseudoscalar

Interactions of sgoldstino

- Couplings to the Standard model fields are related with soft SUSY breaking terms

An example:

SUSY breaking lagrangian

$$\mathscr{L}_{soft} = -m_{H_u}^2 |H_u|^2 - m_{H_d}^2 |H_d|^2 - B\mu H_u H_d$$

can be obtained from

$$\mathscr{L}_{SUSY} = \int d^2\theta d^2\bar{\theta} \left(-\frac{m_{H_u}^2}{F} \hat{S} \hat{H}_u^\dagger \hat{H}_u - \frac{m_{H_d}^2}{F} \hat{S} \hat{H}_d^\dagger \hat{H}_d \right)$$

$$+ \int d^2\theta \left(-\frac{B\mu}{F} \hat{S} \hat{H}_u \hat{H}_d \right)$$

- Masses m_S and m_P are not related with the soft terms

- Sgoldstinos S and P can be light

Sgoldstino in Σ^+ decay

- Lagrangian for $s - d$ transition:

  $$\mathscr{L}_{Pds} = -P \cdot (h_{12}^{(D)} \cdot \bar{d} i \gamma^5 s + \text{h.c.}) \, ,$$

- From measured branching one obtains:

  $$|h_{12}^{(D)}| \cdot \mathrm{Br}^{1/2}(P \to \mu^+ \mu^-) = 3.8 \cdot 10^{-10}$$

- Constraints on sgoldstino lifetime:

  $$1.7 \cdot 10^{-15} \text{ s} \lesssim \tau_P \lesssim 2.5 \cdot 10^{-11} \text{ s}$$

- The energy scale of SUSY breaking is low :

  $$2 \text{ TeV} \lesssim \sqrt{F} \lesssim 65 \text{ TeV}$$

- $m_P = 214.3$ MeV
- Possible decays:

  $P \to \mu^+\mu^-$, $P \to e^+e^-$ and $P \to \gamma\gamma$

$$\frac{\Gamma\left(P \to e^+e^-\right)}{\Gamma\left(P \to \mu^+\mu^-\right)} \sim \frac{m_e^2}{m_\mu^2}, \qquad \frac{\Gamma\left(P \to \gamma\gamma\right)}{\Gamma\left(P \to \mu^+\mu^-\right)} \sim 1 \div 10^4$$

- Predicted branchings of kaon decays with $s-d$ transition:

$$\mathrm{Br}\left(K^+ \to \pi^+\pi^0 P(P \to \mu^+\mu^-)\right) \sim 10^{-12}$$

$$\mathrm{Br}\left(K_L \to \pi^0\pi^0 P(P \to \mu^+\mu^-)\right) \sim 10^{-8}$$

$$\mathrm{Br}\left(K_S \to \pi^0\pi^0 P(P \to \mu^+\mu^-)\right) \sim 10^{-11}$$

Sgoldstino interactions with quarks

- General interaction lagrangian:

$$\mathscr{L}_P = -P \cdot \left(h_{jl}^{(U)} \cdot \bar{u}_j i\gamma^5 u_l + h_{jl}^{(D)} \cdot \bar{d}_j i\gamma^5 d_l + \mathrm{h.c.} \right),$$

- Constants $h_{jl} = \frac{m_{jl}^{(LR)2}}{\sqrt{2}F}$ depend on model
- Three models:
  - I: $h_{jl} \sim h_{12}^{D}$.
  - II: $h_{jl} \sim \frac{A}{F} \max(m_j, m_l)$
  - III: particular left-right SUSY model

Decays of *D*- and *B*-mesons

- Interactions with quarks induce flavor changing neutral transitions
- Possible signature of sgoldstino:

$$P_{B,D} \to \mathscr{V} P \ ,$$

- For decay with $u_l - u_j$ or $d_l - d_j$ transition:

$$\mathscr{M}\left(P_{B,D} \to \mathscr{V} P\right) = h_{jl} \cdot P(q) \cdot \mathscr{O}_{P_{B,D},\mathscr{V}}\left(q^2\right),$$

where q — sgoldstino momentum and

$$\mathscr{O}_{P_{B,D},\mathscr{V}}\left(q^2\right) \equiv \langle \mathscr{V}(p_{\mathscr{V}}, \varepsilon_{\mathscr{V}}) | \bar{q}_j \gamma^5 q_l | P_{B,D}(p) \rangle =$$

$$A_0^{(P_{B,D},\mathscr{V})}(q^2) \cdot \frac{-2im_{\mathscr{V}}}{m_j + m_l}$$

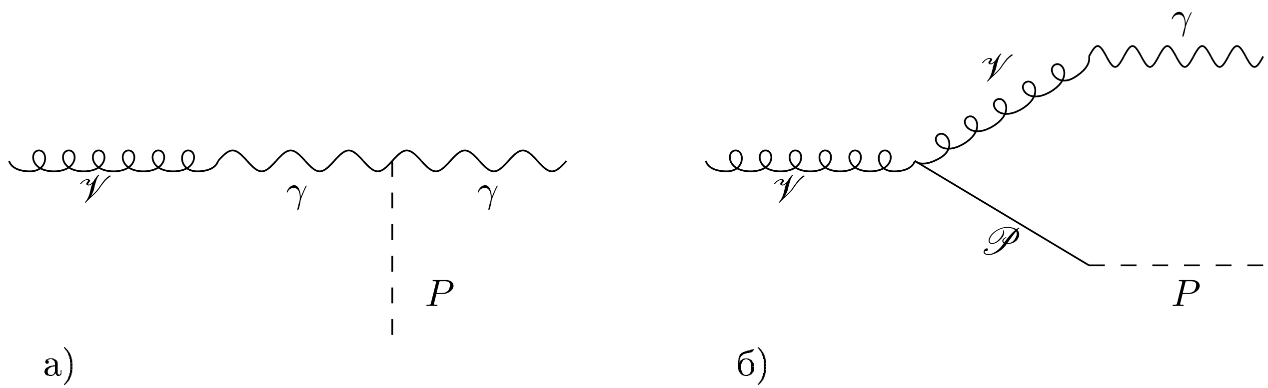
Numerical results

Decay	h_{jl}	$\mathrm{Br}_{(I)}$	$\mathrm{Br}_{(II)}$	$\mathrm{Br}_{(III)}$
$B_s \to \phi P(P \to \mu^+\mu^-)$	$h_{23}^{(D)}$	$6.5 \cdot 10^{-9}$	$8.8 \cdot 10^{-6}$	$8.7 \cdot 10^{-6}$
$B_s \to K^{*0} P(P \to \mu^+\mu^-)$	$h_{13}^{(D)}$	$5.3 \cdot 10^{-9}$	$7.2 \cdot 10^{-6}$	$2.3 \cdot 10^{-7}$
$B_c^+ \to D^{*+} P(P \to \mu^+\mu^-)$	$h_{13}^{(D)}$	$3.2 \cdot 10^{-10}$	$4.4 \cdot 10^{-7}$	$1.4 \cdot 10^{-8}$
$B_c^+ \to D_s^{*+} P(P \to \mu^+\mu^-)$	$h_{23}^{(D)}$	$3.0 \cdot 10^{-10}$	$4.0 \cdot 10^{-7}$	$4.0 \cdot 10^{-7}$
$B_c^+ \to B^{*+} P(P \to \mu^+\mu^-)$	$h_{12}^{(U)}$	$4.1 \cdot 10^{-10}$	$4.4 \cdot 10^{-8}$	$8.2 \cdot 10^{-7}$
$B^+ \to K^{*+} P(P \to \mu^+\mu^-)$	$h_{23}^{(D)}$	$3.8 \cdot 10^{-9}$	$5.2 \cdot 10^{-6}$	$5.1 \cdot 10^{-6}$
$B^0 \to K^{*0} P(P \to \mu^+\mu^-)$		$3.5 \cdot 10^{-9}$	$4.8 \cdot 10^{-6}$	$4.7 \cdot 10^{-6}$
$B^0 \to \rho P(P \to \mu^+\mu^-)$	$h_{13}^{(D)}$	$3.1 \cdot 10^{-9}$	$4.2 \cdot 10^{-6}$	$1.4 \cdot 10^{-7}$
$B^+ \to \rho^+ P(P \to \mu^+\mu^-)$		$3.3 \cdot 10^{-9}$	$4.6 \cdot 10^{-6}$	$1.3 \cdot 10^{-7}$
$D^0 \to \rho P(P \to \mu^+\mu^-)$	$h_{12}^{(U)}$	$1.4 \cdot 10^{-9}$	$1.5 \cdot 10^{-7}$	$2.8 \cdot 10^{-6}$
$D^+ \to \rho^+ P(P \to \mu^+\mu^-)$		$3.5 \cdot 10^{-9}$	$3.7 \cdot 10^{-7}$	$7.0 \cdot 10^{-6}$

$$\mathrm{Br}\left(B^+ \to K^{*+}\mu^+\mu^-\right) < 2.2 \times 10^{-6},$$

Decays of ρ-, ω- and ϕ-mesons

- Another possible signature of sgoldstino: $\mathscr{V} \to P\gamma$.
- Two contributions to matrix element



$$\mathscr{L}_1 = \frac{1}{4\sqrt{2}}\varepsilon^{\mu\nu\lambda\rho}\left(\frac{M_{\gamma\gamma}}{F}PF_{\mu\nu}F_{\lambda\rho} + \frac{M_3}{F}PG^a_{\mu\nu}G^a_{\lambda\rho}\right) ,$$

where $M_{\gamma\gamma} = M_1\cos^2\theta_W + M_2\sin^2\theta_W$

$$\mathscr{L}_{VMD} = \frac{e}{g}A_\mu\left(\sqrt{2}m_\rho^2\rho^\mu + \frac{\sqrt{2}}{3}m_\omega^2\omega^\mu - \frac{2}{3}m_\phi\phi^\mu\right) , \quad g \simeq 8.6$$

Decays of ρ-, ω- and ϕ-mesons

- Mixing of sgoldstino with π^0, η and η'

$$\mathcal{L}_{mix} = C_{P\pi^0} P\pi^0 + C_{P\eta} P\eta + C_{P\eta'} P\eta'$$

- Interactions of vector and pseudoscalar mesons with photon

$$\mathcal{L}_{\mathcal{V}\mathcal{P}\gamma} = e g_{\mathcal{V}\mathcal{P}\gamma} \varepsilon_{\mu\nu\lambda\rho} \partial_\mu A_\nu \partial_\lambda \mathcal{V}_\rho \mathcal{P} \ .$$

where $g_{\mathcal{V}\mathcal{P}\gamma}$ are tuned to saturate the decays $\mathcal{P} \to \mathcal{V}\gamma$ or $\mathcal{V} \to \mathcal{P}\gamma$.

Numerical results

- The width of the decay:

$$\Gamma(\mathscr{V} \to P\gamma) = \frac{C_{\mathscr{V}}^2}{96\pi} \frac{\left(m_{\mathscr{V}}^2 - m_P^2\right)^3}{m_{\mathscr{V}}^3} ,$$

where

$$C_{\mathscr{V}} = -\frac{\sqrt{2} a_{\mathscr{V}} e M_{\gamma\gamma}}{gF} + \sum_{\mathscr{P}=\pi^0,\eta,\eta'} \frac{e g_{\mathscr{V}\mathscr{P}\gamma} C_{P\mathscr{P}}}{m_P^2 - m_{\mathscr{P}}^2} .$$

$$1.8 \times 10^{-13} < Br(\phi \to \gamma P(P \to \mu^+\mu^-)) < 1.6 \times 10^{-7} ,$$

$$9.1 \times 10^{-15} < Br(\rho \to \gamma P(P \to \mu^+\mu^-)) < 3.3 \times 10^{-7} ,$$

$$1.8 \times 10^{-14} < Br(\omega \to \gamma P(P \to \mu^+\mu^-)) < 3.4 \times 10^{-7} .$$

Conclusions

- We considered the possibility to check the sgoldstino interpretation of the HyperCP events in the decays of D-, B-, ρ-, ω- and ϕ-mesons
- Estimated branchings of the decays $P_{B,D} \to VP(P \to \mu^+\mu^-)$ (and $m_P = 214$ MeV) can be at the level $10^{-8} \div 10^{-6}$
- The branchings of the decays ρ-, ω- and ϕ-mesons $\mathscr{V} \to P\gamma$ are in the range $10^{-13} \div 10^{-7}$