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Stoponium search at photon linear collider

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Abstract: In some supersymmetric extensions of the Standard Model fairly light superpartner of t-quark is predicted, which may form bound states (*stoponiums*) under certain conditions. We study prospects of search for stoponium at the future Photon Linear Collider. It is found that this machine could be the best machine for discovery and study of these resonances at some scenarios of supersymmetric extension of the Standard Model. In particular, if the hh decay channel is dominant stoponium could be observed at the beginning of PLC run with collision energy tuned at the stoponium mass. If this channel is kinematically closed stoponium could be discovered in gg, $\gamma\gamma$ and ZZ decay channels but higher statistics are needed. Effects of the stoponium-Higgs mixing and degeneracy are briefly discussed.

Keywords: Beyond Standard Model, Supersymmetric Standard Model, Electromagnetic Processes and Properties, QCD.

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1. Introduction

The broken supersymmetry is favorite among the different extensions of the Standard Model. It can happen that superpartners of top-quarks (*stops*, $\tilde{t}$) are long-living enough to compose (colorless) bound states, *stoponiums*, denoted as S in what follows. In this scenario experimental study of the corresponding resonances could provide precise value of stop mass and stoponium partial widths, consequently yielding precise values of various parameters of SUSY lagrangian. Then, if the difference between stop and LSP masses is very small, the search for stop evidence in collisions at high energy could be problematic. Observation of stoponium bound states will be the signature of such models confirming the existence of stop.

There are theoretical motivations for stop to be fairly light. First one appeals to the renormalization group behavior of soft mass terms. Indeed, gauge couplings raise while Yukawa couplings reduce these terms when energy scale evolves down, with Yukawa contributions being very large for stop. The next motivation concerns left-right mixing in squark sector, which is proportional to Yukawa coupling and decreases the mass of the lightest stop. Therefore, light stop may appear in different SUSY models (see, e.g. refs. [1] for examples in the frameworks of supergravity and gauge mediation). Experimental bound on stoponium mass comes from searches for stop at LEP2 and TEVATRON. The concrete number depends on the MSSM spectrum [2]: lower bound is about 90 GeV for sneutrino masses larger than 45–50 GeV or for neutralino masses larger than 50 GeV (ALEPH), while CDF excludes stop mass up to 130 GeV for smaller sneutrino masses. The limitation is weaker if stop and neutralino masses are degenerate, it is about 60 GeV (ALEPH).

Stoponium was studied in refs. [3, 4] in detail, in particular its effective couplings and partial widths were calculated, and probability to be discovered at LHC were estimated. In ref. [4] it was briefly mentioned also the possibility to observe stoponiums in photon collisions, however, without analyzing this phenomenology.

Now, when main characteristics of future Photon Linear Colliders (PLC)[1] are under technical discussion (see, e.g. ref. [6]) one should understand clearly signatures of stop bound states in this type of high energy collisions. This is of special interest due to debates on PLC advantages in comparison with further increasing of the collision energy for basic electron-positron mode of the linear collider when the run at $\sqrt{s_{e^+e^-}} = 500\,\mathrm{GeV}$ will be completed (see, e.g. ref. [7] and references therein). One can easily perceive that e^+e^- colliders (LEP2 or linear electron-positron colliders) have no good chances to observe stoponiums. Indeed, high powers of the coupling constants, $\alpha^2\alpha_s^5$, emerge in the squared matrix elements: α^2 arises from two electroweak vertices, and α_s^5 comes from squared derivative of the stoponium wave function (scalar stoponium can be created there only in P-wave by propagation of vector particle, photon or Z). At the same time two powers of α_s are eliminated in the case of $\gamma\gamma$ collisions since stoponium can be produced in S-wave. So, one can expect much higher rate of the stoponium production at PLC.

In hadron collisions the stoponium production is also available in S-wave through the gluon fusion. So, effective ggS vertex includes $\alpha_s^{5/2}$ and one can anticipate large stoponium cross sections as well. However, main decay channel gg is too dirty due to huge QCD 2 jets background. Then, as it was found in ref. [4], the most promising decay channel at LHC is $\gamma\gamma$, but in order to discover stoponiums one year of LHC operating at high luminosity is needed, or even more (depending on SUSY scenario).

It is shown in this letter that Photon Linear Collider will be the best machine to discover and study stoponiums. For estimates we use basic parameters of the first stage of TESLA project: $\sqrt{s_{ee}} \leq 500\,\mathrm{GeV}$ and integrated luminosity $500\,\mathrm{fb}^{-1}$ [8] for basic electron-positron mode. It is well known that high energy photon beam at the PLC conversion point will have a rather wide spectrum [5]. However, there are various ideas under discussion how to get more or less monochromatic photon beams. So, for estimates one can take the photon-photon collision energy spread within the interval of 15% below the maximal energy $E_{\gamma\gamma}^{\max} \sim 0.8\sqrt{s_{ee}}$ [6]. We set effective integrated luminosity of *the first* PLC equal to $100\,\mathrm{fb}^{-1}$ for this 15% window, although one can judge this figure as too pessimistic — in ref. [6] this characteristic is argued to be at the same level as for basic e^+e^- mode.

We consider stoponium mass range $M_S = 200$–$400\,\mathrm{GeV}$, which could be surely probed by *the first* PLC. Of course tuning the $\gamma\gamma$ collision energy at the stoponium mass point is necessary. It is worth to note that the same interval is not an exceptional case for SUSY models with stoponiums as a quasistationary state, as we discuss briefly in the next section.

[1]The possibility to get real photon beams by means of Compton backscattering of laser photons on high energy electrons from the basic electron beams was proposed a long time ago [5].

2. Stop bound states

It is clear that gluons try to bind two stops as well as ordinary quarks. The corresponding bound state can be described as a quasistationary system with energy levels E_n (< 0) and masses $M_n = 2m_{\tilde{t}} + E_n$ similarly to quarkonium. For stoponium mass $M_S = 200$–$600\,\mathrm{GeV}$ the binding energies E_n are of order $1\,\mathrm{GeV}$ [9]. This treatment is valid if the formation process (time scale $\sim |E_n|^{-1}$) is faster than destroying one.

Among destroying mechanisms the obvious ones are the stop decays[2]: $\tilde{t} \to t$+LSP, $b +$ chargino and $c +$ neutralino. At first, let us consider the third decay. It proceeds only through loop diagrams, that is motivated by the absence of FCNC (thus, leading to universality-like soft terms). So, partial width is highly reduced by a factor of $\sim 10^{-7}$ in comparison with the first two tree-level decay processes [10]. The rates of latter decays depend on the parameters of the model. As an example, in the framework of gravity mediation, where LSP is neutralino, these decays proceed at the tree level and the corresponding partial widths are of order $\mathcal{O}(\alpha m_{\tilde{t}})$. In the framework of models with gauge mediated supersymmetry breaking [11], where LSP is gravitino, the first process is strongly suppressed by supersymmetry breaking scale, but remaining one has the same partial width as in gravity mediation. Hence, the possibility of existence of stoponium is a subject of special study in each concrete model. For instance, in models with the lightest chargino being mostly wino and the lightest stop being mostly right stop (i.e. $m_{t_L} > m_{t_R}$), decay into chargino is damped and stoponium could exist if $m_{\tilde{t}} - m_{\mathrm{LSP}} < m_t$, i.e. when the first decay channel is kinematically forbidden. One can state that SUSY scenario, where tree-level decay channels, $\tilde{t} \to t$+LSP and $\tilde{t} \to b +$ chargino, are somehow suppressed and, therefore, stop decay can not destroy the stoponium formation, is not an exceptional case.

Next destroying mechanism is related to the stop annihilation. Here two gluon channel is always open with partial width about $1\,\mathrm{MeV}$. Generally the gluon channel is dominant. However, for the certain choice of model parameters, partial width into two lightest Higgs bosons, $S \to hh$, can be larger, increasing the stoponium total width by a factor of ~ 5–10. In ref. [4] these figures were analyzed and found that quasistationary description is valid for $M_S < 600\,\mathrm{GeV}$ in models with forbidden stop tree-level decays and neutralino being mostly bino. The worst case is a model with chargino and neutralino states are both higgsino-like. Here the stoponium total width increases rapidly with M_S and quasistationary treatment fails for $M_S > 300\,\mathrm{GeV}$.

To be concrete let us describe one of the models studied in ref. [4], where stoponium exists up to $M_S < 600\,\mathrm{GeV}$. This is MSSM with $\mu = -300\,\mathrm{GeV}$, $m_{t_L} = 400\,\mathrm{GeV}$, $m_{t_R} = 300\,\mathrm{GeV}$ and mass of the lightest stop (so, M_S) varied with trilinear soft term A_t. The hh decay channel dominates at $2m_h \leq M_S \leq 2m_h + 150\,\mathrm{GeV}$.

[2]We suppose R-parity to be conserved, as favored by the absence of rapid proton decay and lepton flavor violating processes.

Gluonic decay mode prevails in other cases, excluding the vicinity of the degenerate point with Higgs boson mass $M_S = M_H$ where $b\bar{b}$ or $t\bar{t}$ channels becomes principal because of s-channel Higgs propogator enhancement. In scenarios with $A_t = 2m_{t_L} = 2m_{t_R}$ and $\mu = 500\,\mathrm{GeV}$ decay into hh final state dominates for wider range, $2m_h \leq M_S \leq 600\,\mathrm{GeV}$.

3. Stoponium in $\gamma\gamma$ collisions

The main effect associated with stoponium would be a direct resonance production. The corresponding monochromatic cross section can be written in the Breit-Wigner form if collision energy is close to the resonance peak

$$\sigma_{\gamma\gamma\to S\to f}(\hat{s}) = 8\pi \cdot \frac{\Gamma_{\gamma\gamma}\,\Gamma_f}{\left(\hat{s}-M_S^2\right)^2 + \Gamma_{\mathrm{tot}}^2 M_S^2}\,,$$

where Γ_f is the stoponium partial width for the decay into state f and Γ_{tot} is stoponium total width. At the resonance point this cross section reads $\sigma^{\mathrm{res}} = \frac{8\pi}{M_S^2}\,\mathrm{Br}_{\gamma\gamma}\,\mathrm{Br}_f$, where $\mathrm{Br}_f = \Gamma_f/\Gamma_{\mathrm{tot}}$ is the corresponding branching fraction. The observable cross section can be estimated as $\sigma^{\mathrm{res}} \cdot 2\Gamma_{\mathrm{tot}}/(0.15 E_{\gamma\gamma}^{\mathrm{max}})$ with $E_{\gamma\gamma}^{\mathrm{max}} \sim M_S$. Photon beams are planned to be highly polarized. Hence, as stoponium is a scalar the production cross section will be enhanced by factor two if initial photons have opposite helicities. Hereafter we include this factor 2 in our estimates of signal rates. Finally, we parameterize the stoponium cross sections as follows:[3]

$$\sigma_f \;\approx\; 130\,\mathrm{fb}\cdot\left(\frac{\mathrm{Br}_{\gamma\gamma}}{4\cdot 10^{-3}}\right)\cdot \mathrm{Br}_f \cdot\left(\frac{\Gamma_{\mathrm{tot}}}{1\,\mathrm{MeV}}\right)\cdot\left(\frac{200\,\mathrm{GeV}}{M_S}\right)^3. \tag{3.1}$$

As it has been stressed above one can discuss two main variants of the SUSY models, one with dominant gg decay mode and another with stoponium total width being saturated by hh mode. Let us make qualitative *signal/background* analysis for different decay channels within these two variants. The signal significance can be evaluated by ratio $N_S/\sqrt{N_B}$ because one deals with resonance and background rate in the signal bin can be fixed as average cross section in neighboring bins (here $N_{S,B}$ are numbers of signal and background events). We used the results for stoponium width and branching ratios calculated in ref. [4] with some corrections. Namely, comparing our formulas with formulas in ref. [4] we conclude that stoponium partial widths into two gluons and into two photons were overestimated in ref. [4] because of extra factor 2 in eqs. (A.1) and (A.2). In particular, it means that the signal cross sections were overestimated there. In the first scenario for gg and $\gamma\gamma$ modes the correct cross sections are smaller by factor 2. In the second scenario for gg and $\gamma\gamma$ modes this factor is 4, while for other modes it is 2.

[3]Where, in addition, one should take into account that squared stoponium wave function at the origin, attending in Γ_{tot}, scales as a square root of its mass [9].

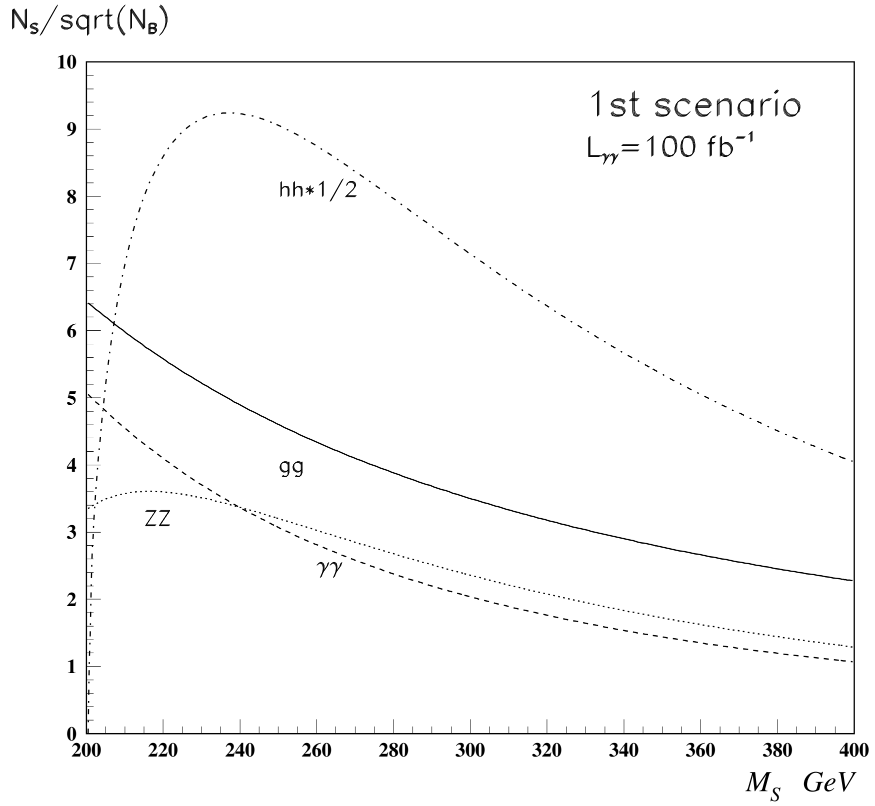

Figure 1: Signal significance of stoponium events in various channels for the first scenario; mass of the lightest higgs boson is taken equal to 100 GeV.

Cross sections for various tree-level background processes were evaluated with the help of CompHEP package [12].

1. In the first scenario stoponium total width $\approx 1.3\,\mathrm{MeV}$ at $M_S = 200\,\mathrm{GeV}$ and photon-photon branching is $\mathrm{Br}_{\gamma\gamma} \approx 3.4 \cdot 10^{-3}$. By making use of eq. (3.1) one obtains the signal rate at the level of 140 fb for $M_S = 200\,\mathrm{GeV}$. So, more than ten thousand stoponiums will be produced. Background is two jet production, where subprocess $\gamma\gamma \to q\bar{q}$ gives main contribution with very large cross section, $\sim 50\,\mathrm{pb}$ (if cuts on the jet angle of 5° are applied). Since jet energy resolution is of order $\mathcal{O}(10)$ GeV, background events should be counted within whole 15% photon-photon energy window. One can estimate background rate directly as the average cross section in this window, $\sim 50\,\mathrm{pb}$. Hence dominant gg channel is fairly dirty — the *signal/background* ratio is $\sim 1/350$. Nevertheless, for statistics $100\,\mathrm{fb}^{-1}$ signal significance is not too small, about $6 \div 3$ for $M_S = 200 \div 300\,\mathrm{GeV}$, see figure 1.

For two photon channel the background process, $\gamma\gamma \to \gamma\gamma$, proceeds through one-loop diagrams, so the corresponding cross section is small, about 10 fb [13]. One should note that the photon-photon invariant mass bin can be taken equal to $2\,\mathrm{GeV} \cdot \sqrt{M_S/100\,\mathrm{GeV}}$ for CMS-like crystal electromagnetic calorimeter [14]. Thus,

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for $M_{\gamma\gamma} = 200 \pm 1.4\,\mathrm{GeV}$ window the background rate can be estimated as 1 fb. For $M_S = 200 \div 300\,\mathrm{GeV}$ the signal rate is $0.5 \div 0.2\,\mathrm{fb}$, providing the signal significance about $5 \div 2$.

Some other decay channels within the first scenario should be discussed. First note, that WW final state has no chance for the detection of stoponiums due to huge SM background, $\sigma^{\mathrm{tot}}_{\gamma\gamma\to WW} \sim 60\,\mathrm{pb}$ at $\sqrt{s_{\gamma\gamma}} = 200\,\mathrm{GeV}$. More promising are decay channels with background processes arising at higher orders of perturbation theory. For instance, SM background to γZ and ZZ final states comes from 1) one-loop α^4 processes $\gamma\gamma \to \gamma Z$ (10–15 fb [15]) and $\gamma\gamma \to ZZ$ ($\sim$ 50 fb [16]), and 2) from tree-level α^3 processes (e.g. $\gamma\gamma \to \gamma q\bar{q}$ for $S \to \gamma Z \to \gamma + 2$ jets), with total cross section smaller than 1 fb within cuts on final γ and jets reasonably motivated by 2-body ($\gamma + Z$) kinematics of the signal events. These figures should be considered as estimates of the background rates in these channels for 15% energy spread photon beams because of the same level of the energy resolution for final jets.

As to signal γZ rate one can get from ref. [4] the branching $\mathrm{Br}_{\gamma Z} \sim 2 \cdot 10^{-3}$, so $\sigma_{\gamma Z} \sim 0.3\,\mathrm{fb}$ already for $M_S = 200\,\mathrm{GeV}$. It means very low level of the signal significance, lower than 1 for statistics $100\,\mathrm{fb}^{-1}$.

Natural level of ZZ branching is about $4 \cdot 10^{-2}$ for stoponium masses far from the threshold, 250–400 GeV, although in some points it could fall down due to opening of new channels or degeneration of stoponium and Higgs masses. This provides signal rate $\sim 2.2\,\mathrm{fb}$ for $M_S = 250\,\mathrm{GeV}$ and significance[4] at the level of 3.

The hh decay channel, where h is the lightest Higgs boson, is open if $M_S > 2m_h$. As current limit on h mass is about 80–100 GeV this channel could exist for $M_S > 200\,\mathrm{GeV}$. If consider mass region far from the threshold (say $M_S > 230\,\mathrm{GeV}$ for $m_h = 100\,\mathrm{GeV}$) the hh branching is about $2 \cdot 10^{-2}$ or even higher. In this case the signal rate is about 1 fb or larger. The background from direct double hh production through one-loop diagrams can be estimated by the cross section of this process in SM, $\sim 0.2\,\mathrm{fb}$ [17]. There are no reasons for very large additional contributions to this process in supersymmetric models. Then, we found that direct electroweak production of four b quarks ($\gamma\gamma \to bbbb$) together with contribution from $cccc$ final state (assuming 10% of b/c misidentification) has the rate smaller than 0.1 fb. Sum of these cross sections can be taken as the estimate of the background rate for 15% energy spread photon beams again, because larger scale of the resolution bin for invariant mass of the stoponium decay products. Therefore hh decay mode will be the best channel for the observation of stoponiums — the signal significance is about 20 for $M_S = 230\,\mathrm{GeV}$. The signal rate is not so low, about hundred stoponium events $S \to hh$ will be produced for statistics $100\,\mathrm{fb}^{-1}$ and with S/B ratio about 3.

We present signal significance for stoponium events in various channels at figure 1.

[4] Here and for hh channel we take into account the threshold effects.

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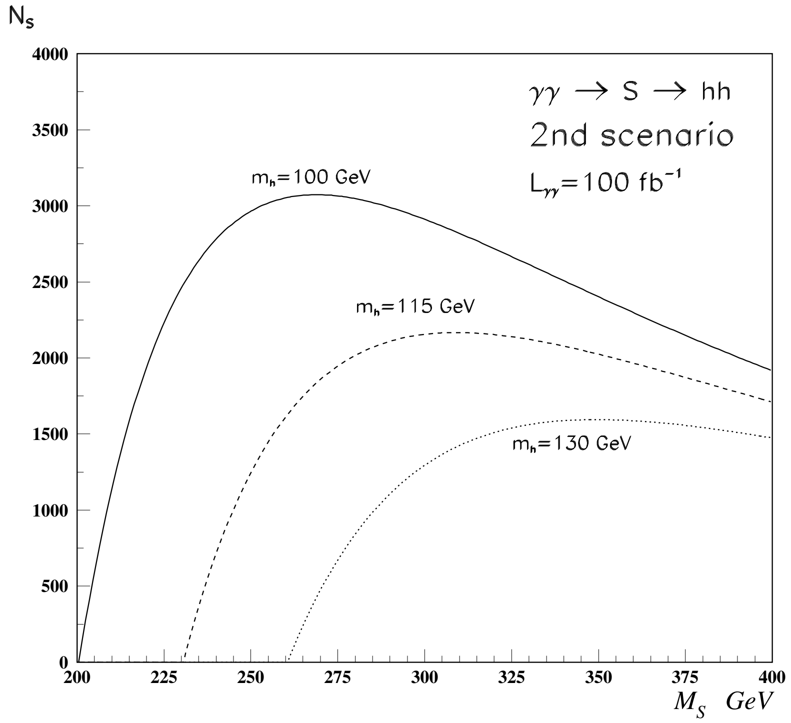

Figure 2: Total number of stoponium events in dominant hh-channel for the second scenario. Background (direct production of double lisght Higgses and $4b-$jets) is expected less than 100 events.

To resume the first scenario we conclude that, if stoponium decay into two lightest Higgs bosons is allowed kinematically, this bound state could be discovered after a few weeks of PLC operating. Otherwise, a year is necessary in order to observe stoponiums in gg, $\gamma\gamma$ and ZZ channels. Then, one can probe the stoponium effective couplings in all these channels if higher statistics will be accumulated.

Note that LHC (at high luminosity operating stage) has good prospects to observe light stoponium in $\gamma\gamma$ mode in this scenario [4], where signal significance is comparable with the significance of hh mode at PLC. Thus, these two colliders could be complementary in study of different effective stoponium couplings, $S\gamma\gamma$ and Shh correspondingly.

2. In the second scenario stoponium total width could be about 10 MeV or even larger. The photon-photon branching in this case is smaller, $\sim$ (2–4) $\cdot\, 10^{-4}$. So, thousands of stoponiums will be produced per year and almost all of them will decay to pairs of lightest Higgs bosons. We plot total number of stoponium events at various M_S and m_h in figure 2.

This result means, that stoponium will be discovered practically immediately after PLC start, since the background (hh, $bbbb$, ...) is very small.

Note that in this scenario several years of operating at high luminosity is needed in order to observe stoponium at LHC [4].

Other branchings are at the same level as in the first scenario, or even smaller. Thus, one can not hope to distinguish stoponium events in these channels with statistics $100\,\mathrm{fb}^{-1}$. Nevertheless, once stoponium has been discovered the gg, $\gamma\gamma$ and ZZ channels will exhibit possibilities of study stoponium effective couplings with higher statistics.

There is a range of parameters in the model with light stop quarks and large A_t, where coupling between the lightest stops and the lightest Higgs boson tends to increase in comparison with $t\bar{t}h$ in SM [18], and which correlates with the parameter range of scenario 2. So, one can expect some enhancement of hh production at PLC in this case due to stop-loop contribution. However, in the second scenario this stop-Higgs enhancement for sure can not reduce excellent discovery potential of the dominant hh decay channel.

4. Conclusions and further comments

1. Main conclusion is that for some scenarios of supersymmetric extension of the Standard Model photon linear collider will be the best machine to discover and study bound state of stops if it exists.

In the decay channel into two lightest Higgs bosons (if it is permitted kinematically) stoponiums will be observed at the beginning of PLC operating.

In scenario with hh decay mode being principal the stoponium discovery mass range will be limited only by attainable values of the $\gamma\gamma$ collision energy, which is discussed up to $0.8\cdot 500\,\mathrm{GeV}$. In this case PLC will be a *stoponium factory* producing thousands of these heavy strong resonances practically without background. Fine structure of their spectroscopy would be available for study.

The tuning of PLC collision energy at the resonance point is necessary within the 15% window.

If $S \to hh$ mode is closed, the search for stoponiums would be not easy, this bound state could be discovered in gg, $\gamma\gamma$ and ZZ channels after a year. Anyway, if $500\,\mathrm{fb}^{-1}$ of integrated statistics will be really available for the first PLC these channels will allow to observe stoponium for sure.

All these channels (hh, gg, $\gamma\gamma$ and ZZ) have good chances for probing the corresponding effective coupling constants with statistics $500\,\mathrm{fb}^{-1}$.

2. A few comments can be made. The first one is related to the circumstance that ground state of stoponium could not be distinguished from excited states due to the detector resolutions. Therefore, the resonance peak will include contributions from ground state and all excitations, leading to enhancement factor of about 2 [4] in all cross sections. At the same time there is a big uncertainty because of poor understanding of the stoponium wave function, that results in 30–50% error when the stoponium rates are estimated [4].

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The second comment concerns the models with stoponium and the heaviest CP-even Higgs boson masses being almost degenerate, $M_S \simeq m_H$. One can note that there is no motivation for this scenario. Nevertheless, this degeneration exhibits specific physics. In this case, all "standard" decay modes (determined by the same mechanisms as for quarkoniums) are highly suppressed, by a factor of 10^{-3}–10^{-4}, due to huge increasing of the stoponium total width saturated there by Higgs-originated channels, e.g. $b\bar{b}$ at high $\tan\beta$ or $t\bar{t}$ at large M_S. Certainly, if the mass degeneration is exact, $M_S = m_H$, quasistationary description of stoponium formation is spoilt by too fast annihilation through Higgs boson into $b\bar{b}$ ($t\bar{t}$). Nevertheless, in some vicinity of the degeneration point partial width of the corresponding dominant decay channel could be enhanced not so greatly and stoponium could be composed. In eq. (3.1) the corresponding suppressing factor in the $\gamma\gamma$ branching will be compensated by the same factor inverted in the stoponium total width. As a result the signal rate in the main (Higgs originated) decay channel will be at the level of the total stoponium production rate in the nondegenerate case: 140–50 fb for $M_S = 200$–300 GeV. One can check that $\gamma\gamma \to b\bar{b}$ background has cross section about 1.8–0.9 pb for $\sqrt{s} =$ 200–300 GeV. Therefore, stoponiums will be discovered in $b\bar{b}$ decay mode when PLC starts. At large M_S in models with low and intermediate $\tan\beta$, $t\bar{t}$ channel will dominate, and the stoponium production will be about 10 fb for $M_S = A_t =$ 500 GeV. The background ($\gamma\gamma \to t\bar{t}$) cross section is about 1 pb, that yields the signal significance of 3 for statistics 100 fb^{-1}. Hence, in such model heavy stoponium will be observed after accumulating of three years statistics.

The third comment is dedicated to the fact that stoponium and CP-even Higgs bosons have the same quantum numbers. Hence, first, they can be mixed and interfere in the collision experiments. The corresponding off-diagonal insertion δM^2 into mass squared matrix may be estimated as $A_t M_S(|\psi(0)|/M_S^{3/2})$, where $\psi(0)$ is stoponium wave function at the origin. By making use of results of ref. [9], where $\psi(0)$ was evaluated, we obtain $\delta M^2 \sim 2\% M_S A_t$ for $M_S \simeq 200$–600 GeV. At $A_t = M_S = 200$ GeV this contribution alters mass of the heaviest CP-even Higgs boson on 2 MeV–2 GeV depending on the degeneracy between stoponium and Higgs masses (we consider $M_H < 600$ GeV). Moreover, stoponium could be mixed with the lightest Higgs boson leading to the contribution of a few MeV to the Higgs mass. Note, that in LHC and linear e^+e^-500 experiments the mass of Higgs boson will be measured with accuracy of about 1 GeV, or even better. Thus, the effect of M_H change due to *stoponium-Higgs* mixing could be valuable. We stress, that this effect can be detected even if stoponium is not observed directly.

It is worth to note, that construction of muon collider (which is under discussion now [19]) with unique energy resolution will allow the observation of the Higgs mass shifting at the level of tens MeV's (maybe even a few MeV's). Consequently, if stop bound states exist, the sector of neutral scalar resonances in supersymmetric models could have more complicated structure than it could be deduced from the MSSM

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lagrangian. This mixing effect should be taken into account in the reconstruction of the Higgs potential (parameters of the symmetry breaking mechanism).

Then, stoponium may be misidentified with Higgs boson, because there is a range of parameters, where (dominant) partial widths of these two heavy objects almost coincide. In this case the observation of subdominant modes will be required in order to distinguish these two resonances.

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