Search for a Low Mass Particle Decaying into $\mu^+\mu^-$ in $B^0 \to K^{*0}X$ and $B^0 \to \rho^0 X$ at Belle

H. J. Hyun,16 H. O. Kim,16 H. Park,16 H. Aihara,3 K. Arinstein,1,31 T. Aushev,17,11 A. M. Bakich,38 E. Barberio,21 A. Bay,17 K. Belous,10 M. Bischofberger,23 A. Bondar,1,31 A. Bozek,27 M. Bračko,19,12 M.-C. Chang,4 P. Chang,26 Y. Chao,26 A. Chen,24 P. Chen,26 B. G. Cheon,6 L.-S. Cho,47 Y. Choi,37 J. Dalseno,20,40 M. Danilov,11 M. Dash,46 A. Drutskev,3 S. Eidelman,1,31 N. Gabysev,1,31 B. Golob,18 H. Ha,15 T. Hara,8 Y. Horii,42 Y. Hoshi,41 W.-S. Hou,26 Y. B. Hsiung,26 K. Inami,22 Y. Iwasaki,8 N. J. Joshi,39 D. H. Kah,16 J. H. Kang,47 P. Kapusta,77 P. Katory,27 T. Kawasaki,29 H. Kichimi,8 C. Kiesling,20 H. J. Kim,16 J. H. Kim,14 M. J. Kim,16 B. B. Ko,15 P. Kodyš,2 P. Križan,18,12 A. Kuzmin,1,31 Y.-J. Kwon,47 S.-H. Kyeong,47 J. S. Lange,5 S.-H. Lee,15 J. Li,7 D. Liventsev,11 R. Louvot,17 A. Matyja,27 S. McOnie,38 K. Miyabayashi,23 H. Miyata,29 Y. Miyazaki,22 G. B. Mohanty,39 E. Nakano,32 H. Nakazawa,8 S. Nishida,38 A. Nisimura,8 K. Nishimura,7 O. Nitoh,45 T. Ohshima,22 S. Okuno,13 S. L. Olsen,36,7 H. Palka,27 C. W. Park,37 R. Pestotnik,12 M. Petrič,12 L. E. Piilonen,46 S. Ryu,36 H. Sahoo,7 Y. Sakai,8 O. Schneider,17 M. E. Sevior,21 M. Shapkin,10 J.-G. Shiu,26 B. Shwartz,1,31 J. B. Singh,33 S. Stanić,30 M. Starić,12 T. Sumiyoshi,44 S. Suzuki,34 Y. Teramoto,32 K. Trabelsi,8 S. Uehara,8 Y. Unno,6 S. Uno,8 G. Varner,7 K. E. Varvell,38 K. Vervink,17 C. H. Wang,25 M.-Z. Wang,26 P. Wang,9 X. L. Wang,9 R. Wedd,21 E. Won,15 B. D. Yabsley,28 Y. Yamashita,28 Z. P. Zhang,35 V. Zhilich,1,31 and O. Zyukova,1,31 (The Belle Collaboration)

1 Budker Institute of Nuclear Physics, Novosibirsk
2 Faculty of Mathematics and Physics, Charles University, Prague
3 University of Cincinnati, Cincinnati, Ohio 45221
4 Department of Physics, Fu Jen Catholic University, Taipei
5 Justus-Liebig-Universität Gießen, Gießen
6 Hanyang University, Seoul
7 University of Hawaii, Honolulu, Hawaii 96822
8 High Energy Accelerator Research Organization (KEK), Tsukuba
9 Institute of High Energy Physics, Chinese Academy of Sciences, Beijing
10 Institute of High Energy Physics, Protvino
11 Institute for Theoretical and Experimental Physics, Moscow
12 J. Stefan Institute, Ljubljana
13 Kanagawa University, Yokohama
14 Korea Institute of Science and Technology Information, Daejeon
15 Korea University, Seoul
16 Kyungpook National University, Taegu
17 École Polytechnique Fédérale de Lausanne (EPFL), Lausanne
18 Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana
19 University of Maribor, Maribor
20 Max-Planck-Institut für Physik, München
21 University of Melbourne, School of Physics, Victoria 3010
22 Nagoya University, Nagoya
23 Nara Women’s University, Nara
24 National Central University, Chung-li
25 National United University, Miaoli
26 Department of Physics, National Taiwan University, Taipei
27 H. Niewodniczanski Institute of Nuclear Physics, Krakow
28 Nippon Dental University, Niigata
29 Niigata University, Niigata
30 University of Nova Gorica, Nova Gorica
31 Novosibirsk State University, Novosibirsk
32 Osaka City University, Osaka
33 Panjab University, Chandigarh
34 Saga University, Saga
35 University of Science and Technology of China, Hefei
36 Seoul National University, Seoul
37 Sungkyunkwan University, Suwon
38 School of Physics, University of Sydney, NSW 2006
39 Tata Institute of Fundamental Research, Mumbai
40 Excellence Cluster Universe, Technische Universität München, Garching
41 Tohoku Gakuin University, Tagajo
The possibility of a weakly interacting light particle with a mass from a few MeV to a few GeV has been extensively discussed \[1\]. Recent astrophysical observations by PAMELA \[2\] and ATIC \[3\] have been interpreted as dark matter annihilation mediated by a light gauge boson, called the $U$-boson \[4\], which couples to Standard Model particles. In addition, the HyperCP collaboration \[5\] has reported three $\Sigma^+ \to p\mu^+\mu^-$ events with dimuon invariant masses clustered around 214.3 MeV/c$^2$ that are consistent with the process $\Sigma^+ \to pX, X \to \mu^+\mu^-$. Phenomenologically, $X$ could either be a pseudoscalar or an axial-vector particle \[6\] with a lifetime for the pseudoscalar case estimated to be about $10^{-14}$ s \[5\]. Many plausible explanations for such a particle have been proposed; a pseudoscalar Goldstino particle \[3\] in various supersymmetric models \[9\], a light pseudoscalar Higgs boson \[10\] in the Next-to-Minimal-Supersymmetric Standard Model as well as a vector $U$-boson \[11\] as described above.

Recently there have been searches for a similar light particle at the Tevatron \[12\], $e^+e^-$ colliders \[13\] and fixed-target experiments \[14,15\]. In those searches, the light particle was assumed to be a pseudoscalar and no evidence has been found. The KTeV result in $K_L$ decay disfavors a pseudoscalar explanation of the HyperCP results \[13\].

The large sample of $B^0$ decays at the Belle provides a good opportunity to search for a light scalar or vector particle. In particular, the estimated branching fractions for $B^0 \to VX, X \to \mu^+\mu^-$ where $X$ is a Goldstino particle with a mass of 214.3 MeV/c$^2$ and $V$ is either a $K^{*0}$ or $\rho^0$ meson, are in the range $10^{-9}$ to $10^{-6}$ \[16\].

We report a search for a light particle using the modes,

$B^0 \to K^{*0}X, K^{*0} \to K^+\pi^-, X \to \mu^+\mu^- (B^0_{K^*X})$ and $B^0 \to \rho^0X, \rho^0 \to \pi^+\pi^-, X \to \mu^+\mu^- (B^0_{\rho X})$ using a data sample of $657 \times 10^6 BB$ pairs collected with the Belle detector \[17\] at the KEKB asymmetric-energy $e^+e^-$ collider \[18\]. The analysis for $B^0_{K^*X}$ uses the same dataset as Ref. \[19\]. In this analysis, we assume that the light $X$ particle is either a scalar or vector particle. Unless specified otherwise, charge-conjugate modes are implied. The term scalar (vector) $X$ particle implies either a scalar (vector) or pseudoscalar (axial-vector) particle throughout this letter.

The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) crystals located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return located outside of the coil is instrumented to detect $K_L^0$ mesons and to identify muons (KLM).

In the initial event selection, at least two oppositely charged muon tracks with momenta larger than 0.690 GeV/c are required. These muon tracks are selected using a likelihood ratio formed from a combination of the track penetration depth and hit pattern in the KLM system. We reduce the number of badly reconstructed tracks by requiring that $|dz| < 5.0$ cm and $dr < 1.0$ cm, where $|dz|$ and $dr$ are distances of closest approach of a track to the interaction point in the beam direction ($z$) and in the transverse plane ($r - \phi$), respectively. Charged kaons and pions are identified using information from the ACC and TOF systems and the energy loss (dE/dx) measurements in the CDC \[18\].

The reconstruction of $K^{*0}$ ($\rho^0$) in the $B^0_{K^*X}$ ($B^0_{\rho X}$) decay uses identified $K^+$ ($\pi^+$) and $\pi^-$ ($\pi^-$) tracks. The reconstructed invariant mass $M_{K\rho}$ ($M_{\rho\rho}$) of $K^{*0}$ ($\rho^0$) candidates for the decay mode $B^0_{K^*X}$ ($B^0_{\rho X}$) is required to be in the ranges $0.815$ GeV/c$^2 < M_{K\rho} < 0.975$ GeV/c$^2$ ($0.633$ GeV/c$^2 < M_{\rho\rho} < 0.908$ GeV/c$^2$), corresponding to $\pm 1.5\sigma$ ($\pm 1\sigma$) in the reconstructed mass distribution. The $\mu^+\mu^-$ dimuon tracks are used to reconstruct low mass $X$ candidates.

$B^0_{K^*X}$ ($B^0_{\rho X}$) candidates are reconstructed from a $K^{*0}$ ($\rho^0$) candidate and a pair of muons. Reconstructed $B^0$ candidates are selected using the beam-energy-constrained mass $M_{bc} = \sqrt{E_{beam} - p_B^2}$ and en-
energy difference $\Delta E = E_B - E_{\text{beam}}$, where $E_{\text{beam}}$ is the beam energy and $E_B (p_B)$ are the energy (momentum) of the reconstructed $B^0$ candidates evaluated in the center-of-mass frame. $B^0$ candidates are required to lie in the signal regions, $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$ and $-0.03 \text{ GeV} < \Delta E < 0.04 \text{ GeV}$ ($-0.04 \text{ GeV} < \Delta E < 0.04 \text{ GeV}$) for the decay $B_{K^*}^0 \rightarrow X (B_{\rho X}^0)$. In events containing more than one $B^0$ candidate, we select the best $B^0$ candidate with the smallest $\chi^2$ value, where $\chi^2$ is obtained when the four charged tracks are fitted to a common vertex. Using this algorithm, we select the correct $B_{K^*}^0$ and $B_{\rho X}^0$ combinations in the $M_{bc}$ and $\Delta E$ signal region 96.6% (96.7%) and 93.7% (93.5%) of the time for a scalar (vector) $X$ particle, respectively. The signature for $X \rightarrow \mu^+\mu^-$ in $B_{K^*}^0$ and $B_{\rho X}^0$ decays would be a peak in the dimuon mass. The width of the signal region for the light particle search with mass below 300 MeV/c$^2$ is $3\sigma$ in dimuon mass resolution. The dimuon mass resolutions for $B_{K^*}^0$ and $B_{\rho X}^0$ vary from 0.5 MeV/c$^2$ to 1.9 MeV/c$^2$ as the mass of $X (M_X)$ increases from 212 MeV/c$^2$ to 300 MeV/c$^2$. However, the signal region for dimuon mass ($M_{\mu\mu}$) for 214.3 MeV/c$^2$ of the HyperCP event search is defined to be 211.6 MeV/c$^2 < M_{\mu\mu} < 217.2$ MeV/c$^2$ where the width of the search region is $3\sigma$ in the combined mass resolution, which is obtained by linearly summing the mass resolutions of the HyperCP and Belle detectors.

For background studies, we employ two different techniques referred to as the counting ($C$) and fitting ($F$) methods. Method $C$ uses generic $B\bar{B}$ and continuum ($e^+e^- \rightarrow q\bar{q}, q = u,d,s,c$) Monte Carlo (MC) samples that correspond to an integrated luminosity about three times larger than the data sample. In the $\Delta E - M_{bc}$ signal region, there are no events in the dimuon mass region $M_{\mu\mu} < 225 \text{ MeV}/c^2$ ($M_{\mu\mu} < 230 \text{ MeV}/c^2$) for the decay $B_{K^*}^0 \rightarrow X (B_{\rho X}^0)$. In method $F$, we use the MC samples as described above, and select $B^0$ candidates in the sideband regions defined as $-0.12 \text{ GeV} < \Delta E < -0.06 \text{ GeV}$ and $0.06 \text{ GeV} < \Delta E < 0.12 \text{ GeV}$, and $5.25 \text{ GeV}/c^2 < M_{bc} < 5.27 \text{ GeV}/c^2$.

By fitting the dimuon mass distributions for the $B^0$ candidates with a probability density function, $(x - 0.21)^n$ for $x > 2\mu_m$, where $x$ is a dimuon mass in GeV/c$^2$, $\mu_m$ is the muon mass and the parameter $n$ is extracted from the fit, we estimate the number of background events with dimuon mass below 300 MeV/c$^2$. We also compare the shape of the probability density function with the $B^0$ candidates in data sideband regions. No significant discrepancy is found. The estimated numbers of background events for methods $C$ and $F$ for the HyperCP event search are 0 (0) and 0.13$^{+0.04}_{-0.03}$ (0.12$^{+0.03}_{-0.02}$) for the decays $B_{K^*}^0 \rightarrow X (B_{\rho X}^0)$, respectively. The background estimates for both methods give results that are equivalent within statistical errors for masses below 300 MeV/c$^2$.

Before examining the full data sample, various distributions, including $M_{bc}, \Delta E$, dimuon mass and $dz$ in the background MC samples are compared with a small fraction of the data. These are in good agreement. Figure 1 shows the data and MC comparison for $\Delta E$ and $M_{bc}$ distributions for $B_{K^*}^0$ (top) and $B_{\rho X}^0$ (bottom) candidates. The points with error bars and histograms represent data and background MC, respectively.

![Figure 1: Data and MC comparison for $\Delta E$ and $M_{bc}$ distributions for $B_{K^*}^0$ (top) and $B_{\rho X}^0$ (bottom) candidates. The points with error bars and histograms represent data and background MC, respectively.](image-url)
TABLE I: Summary of the number of observed events \( N_{\text{obs}} \), estimated number of background events \( N_{\text{bg}} \), efficiencies \( (\epsilon) \), signal yields \( (S_{90}) \) and upper limits \( (U.L.) \) at 90\% C.L. for the decays \( B_{0}^{0} \to K^{*0}X, \ K^{*0} \to K^{+}\pi^{-}, \ X \to \mu^{+}\mu^{-} \) and \( B_{0}^{0} \to \rho^{0}X, \ \rho^{0} \to \pi^{+}\pi^{-}, \ X \to \mu^{+}\mu^{-} \) with the scalar (vector) \( X \) particle. The errors on \( N_{\text{bg}} \) are statistical only.

| \( M_{\mu\mu} \) (MeV/c\(^{2}\)) | \( N_{\text{obs}} \) | \( N_{\text{bg}} \) | \( \epsilon \) | \( S_{90} \) | \( U.L. \) (10\(^{-8}\)) |
|-----------------|-----------|--------|------|--------|-----------------|
| 212.0           | 0         | 0.03\(^{+0.01}_{-0.03}\) | 23.8 (23.7) | 2.43 (2.43) | 2.34 (2.34) |
| 214.3           | 0         | 0.13\(^{+0.02}_{-0.03}\) | 23.6 (23.5) | 2.33 (2.33) | 2.26 (2.27) |
| 220.0           | 0         | 0.13\(^{+0.02}_{-0.02}\) | 23.0 (22.9) | 2.33 (2.33) | 2.31 (2.33) |
| 230.0           | 1         | 0.24\(^{+0.02}_{-0.02}\) | 21.4 (21.4) | 4.09 (4.12) | 4.37 (4.40) |
| 240.0           | 0         | 0.38\(^{+0.02}_{-0.02}\) | 20.0 (20.0) | 2.09 (2.09) | 2.40 (2.39) |
| 250.0           | 0         | 0.51\(^{+0.01}_{-0.01}\) | 18.0 (18.4) | 1.92 (1.94) | 2.43 (2.41) |
| 260.0           | 0         | 0.63\(^{+0.01}_{-0.01}\) | 16.5 (17.2) | 1.83 (1.83) | 2.54 (2.43) |
| 270.0           | 0         | 0.75\(^{+0.02}_{-0.02}\) | 15.4 (16.4) | 1.76 (1.76) | 2.61 (2.45) |
| 280.0           | 0         | 0.69\(^{+0.01}_{-0.01}\) | 14.6 (15.8) | 1.78 (1.69) | 2.78 (2.45) |
| 290.0           | 1         | 0.98\(^{+0.06}_{-0.06}\) | 14.0 (15.5) | 3.35 (3.37) | 5.47 (4.99) |
| 300.0           | 1         | 1.08\(^{+0.08}_{-0.08}\) | 13.6 (15.1) | 3.28 (3.28) | 5.53 (4.97) |

FIG. 2: Dimuon mass distribution for the \( B_{0}^{0} \to K^{*0}X \) (top) and \( B_{0}^{0} \to \rho^{0}X \) (bottom) candidates in the signal regions for \( M_{\mu\mu} \) and \( \Delta E \). The shaded region in the inset shows the HyperCP mass region.

where \( V \) stands for either \( K^{*0} \) or \( \rho^{0} \), and \( B_{V} \) are the intermediate vector meson branching fractions, \( B(K^{*0} \to K^{+}\pi^{-}) \) or \( B(\rho^{0} \to \pi^{+}\pi^{-}) \). Here \( N_{BB} \) and \( \epsilon \) denote the number of \( BB \) pairs and the signal efficiency with small data/MC corrections for charged particle identification, respectively.

The signal efficiency is determined by applying the same selection criteria to the signal MC sample as those used for the data. The signal MC samples for a scalar (vector) \( X \) particle are generated for \( M_{X} \) in the range \( 212 \) MeV/c\(^{2}\) \( \leq M_{X} \leq 300 \) MeV/c\(^{2}\) using the \( P \to VS \) (\( P \to VV \)) model in the EvGen generator [24] for a scalar (vector) \( X \) particle. In the MC generation of the vector \( X \) particle, we assume that the polarization of \( X \) is either fully longitudinal or transverse. The efficiency differences between longitudinal and transverse polarizations of the \( X \) for both modes in the search range are less than 7\%. Since the efficiencies for a fully longitudinally polarized \( X \) are lower than for a fully transversely polarized \( X \), we conservatively use the efficiencies for full longitudinal polarization of the \( X \) for upper limit estimations. In the HyperCP event search for a scalar (vector) \( X \) particle, the efficiencies for \( B_{0}^{0} \to K^{*0}X \) and \( B_{0}^{0} \to \rho^{0}X \) decays are 23.6\% (23.5\%) and 20.7\% (20.7\%), respectively. We also check the efficiencies for different \( X \) lifetimes. The efficiencies are the same for lifetimes below 10\(^{-12}\) s because the primary and secondary vertices are indistinguishable. The efficiencies for the two different vertex fitting methods for the HyperCP event search are compared. One method assumes that the dimuon tracks from the \( X \) originate from the primary \( B_{0}^{0} \) decay vertex, while the other assumes that the dimuon tracks from the \( X \) are from a secondary vertex. The difference in the efficiencies is about 1\%.

To obtain the final upper limit, we use the backgrounds determined from the fitting method. Since the efficiencies for a scalar (vector) and a pseudoscalar (axial-vector) are the same, the upper limits for the scalar (vector) and the pseudoscalar (axial-vector) \( X \) searches are identical. From the \( B_{0}^{0} \to K^{*0}X \) (\( B_{0}^{0} \to \rho^{0}X \)) sample, the upper limits for a scalar and vector \( X \) particle in the HyperCP mass range are determined to be 2.26 (1.73) \times 10^{-8} and 2.27 (1.73) \times 10^{-8}, respectively. Table II summarizes the number of observed events, the expected number of background events, the efficiencies, the signal yields, and the upper limits at 90\% C.L. in the interval 212 MeV/c\(^{2}\) \( \leq M_{X} \leq 300 \) MeV/c\(^{2}\).
TABLE II: Summary of fractional systematic uncertainties in the upper limit for a scalar (vector) X particle in the HyperCP mass range for the decays $B_{K^+,X}$ and $B_{\rho,X}$, respectively.

| Source | $B_{K^+,X}$ | $B_{\rho,X}$ |
|--------|-------------|--------------|
| $N_{B_{ll}}$ | 1.4 (1.4) | 1.4 (1.4) |
| $\mu^\pm$ identification | 4.2 (4.2) | 4.1 (4.1) |
| $K^\pm$ identification | 0.8 (0.8) | - |
| $\pi^\pm$ identification | 0.5 (0.5) | 1.0 (1.0) |
| Tracking efficiency | 4.2 (4.2) | 4.4 (4.3) |
| $M_{bc}$ | 0.5 (0.3) | 0.3 (0.6) |
| $\Delta E$ | 0.5 (0.3) | 0.3 (0.6) |
| $K^{*0}$ tagging | 0.5 (0.3) | - |
| $\rho^0$ tagging | - | 0.3 (0.6) |
| MC statistics | 0.1 (0.1) | 0.1 (0.1) |
| Total | 6.2 (6.2) | 6.2 (6.3) |

$M_X \leq 300 \text{ MeV}/c^2$.

The systematic uncertainties in the upper limits for the decays $B_{K^+,X}$ and $B_{\rho,X}$ in the HyperCP mass range are summarized in Table II. The total systematic uncertainties in the upper limits for both decay modes vary from 6% to 8% as the mass of $X$ increases from 212 MeV/$c^2$ to 300 MeV/$c^2$. The dominant systematic uncertainties come from tracking efficiency and muon identification. The uncertainty for the tracking efficiency is estimated by linearly summing the single track systematic errors, which are $\sim 1$%/track. The uncertainty of muon identification is measured as a function of momentum and direction by using the $\gamma\gamma \rightarrow \mu^+\mu^-$ data sample.

In summary, we searched for a scalar and vector particle in the decays $B^0 \rightarrow K^{*0}X$, $K^{*0} \rightarrow K^\pm\pi^\mp$, $X \rightarrow \mu^+\mu^-$ and $B^0 \rightarrow \rho^0 X$, $\rho^0 \rightarrow \pi^+\pi^-$, $X \rightarrow \mu^+\mu^-$ in the mass region $212 < M_X < 300 \text{ MeV}/c^2$. No significant signals are observed in a sample of $657 \times 10^6 BB$ pairs. We set 90% C.L. upper limits of $B(B^0 \rightarrow K^{*0}X, K^{*0} \rightarrow K^\pm\pi^\mp, X \rightarrow \mu^+\mu^-) < 2.26 \times 10^{-8}$ ($2.27 \times 10^{-8}$) and $B(B^0 \rightarrow \rho^0 X, \rho^0 \rightarrow \pi^+\pi^-, X \rightarrow \mu^+\mu^-) < 1.73 \times 10^{-8}$ ($1.73 \times 10^{-8}$) for a 214.3 MeV/$c^2$ mass scalar (vector) X particle; our results rule out models II and III for the sgkdstino interpretation of the HyperCP observation [14].

We thank the KEKB group for excellent operation of the accelerator, the KEK cryogenics group for efficient solenoid operations, and the KEK computer group and the NII for valuable computing and SINET3 network support. We acknowledge support from MEXT, JSPS and Nagoya’s TLPRC (Japan); ARC and DIISR (Australia); NSFC (China); MSMT (Czechia); DST (India); MEST, NRF, NSDC of KISTI and WCU (Korea); MNiSW (Poland); MES and RFAAE (Russia); ARRS (Slovenia); SNSF (Switzerland); NSC and MOE (Taiwan); and DOE (USA). H. Park acknowledges support by NRF Grant No. R01-2008-000-10477-0.

* Corresponding author. Email: hkpark@knu.ac.kr

[1] Y. Kahn, M. Schmitt and T.M. P. Tait, Phys. Rev. D 78, 115002 (2008); R. Dermisek and J.F. Gunion, Phys. Rev. D 73, 111701 (2006); C. Bouchiat and P. Fayet, Phys. Lett. B 608, 87 (2005); C. Boehm et al., Phys. Rev. Lett. 92, 101301 (2004); D.S. Gorbunov and V.A. Rubakov, Phys. Rev. D 64, 054008 (2001).
[2] O. Adriani et al. (PAMELA Collaboration), Nature 458, 607 (2009).
[3] J. Chang et al. (ATIC Collaboration), Nature 456, 362 (2008).
[4] M. Pospelov, A. Ritz and M.B. Voloshin, Phys. Lett. B 662, 53 (2008); N. Arkani-Hamed and N. Weiner, JHEP 0812 (2008).
[5] H.K. Park et al. (HyperCP Collaboration), Phys. Rev. Lett. 94, 021801 (2005).
[6] X.-G. He, J. Tandean and G. Valencia, Phys. Lett. B 631, 100 (2005).
[7] C.Q. Geng and Y.K. Hsiao, Phys. Lett. B 632, 215 (2006).
[8] D.S. Gorbunov and V.A. Rubakov, Phys. Rev. D 73, 035802 (2006).
[9] J. Ellis, K. Enqvist and D. Nanopoulos, Phys. Lett. B 147, 99 (1984); T. Bhattacharya and P. Roy, Phys. Rev. D 38, 2284 (1988); G. Giudice and R. Rattazzi, Phys. Rep. 322, 419 (1999).
[10] X.-G. He, J. Tandean and G. Valencia, Phys. Rev. Lett. 98, 081802 (2007).
[11] M. Reece and L.-T. Wang, JHEP 0907, 51 (2009); M. Pospelov, Phys. Rev. D 80, 095002 (2009); C.-Q. Geng and C.-W. Kao, Phys. Lett. B 663, 100 (2008).
[12] V.M. Abazov et al. (D0 Collaboration), Phys. Rev. Lett. 103, 061801 (2009).
[13] W. Love et al. (CLEO Collaboration), Phys. Rev. Lett. 101, 151802 (2008); B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. 103, 081803 (2009).
[14] Y.C. Tung et al. (E391a Collaboration), Phys. Rev. Lett. 102, 051802 (2009); A.V. Artamonov et al. (BNL-E949 Collaboration), Phys. Rev. D 79, 092004 (2009).
[15] L. Bellantoni et al. (KTeV collaboration), arXiv:0911.4516 [hep-ex].
[16] S.V. Demidov and D.S. Gorbunov, JETP Lett. 84, 479 (2007).
[17] A. Abashian et al. (Belle collaboration), Nucl. Instr. and Meth. A 479, 117 (2002).
[18] S. Kurokawa and E. Kikutani, Nucl. Instr. and Meth. A 499, 1 (2003), and other papers included in this volume.
[19] J.-T. Wei et al. (Belle collaboration), Phys. Rev. Lett. 103, 171801 (2009).
[20] E. Nakano, Nucl. Instr. and Meth. A 494, 402 (2002).
[21] J. Conrad, O. Botner, A. Hallgren and C. Perez de los Heros, Phys. Rev. D 67, 012002 (2003).
[22] G.J. Feldman and R.D. Cousins, Phys. Rev. D 57, 3873 (1998).
[23] C. Amster et al. (Particle Data Group), Phys. Lett. B 667, 1 (2008).
[24] We use the EvtGen B-meson decay generator developed by the CLEO and the BaBar collaboration, see http://www.slac.stanford.edu/~lange/EvtGen/