PROCEEDINGS OF SCIENCE

Recent Dark Matter related searches with the BaBaR detector

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We report on recent searches for low-mass New Physics states with the BaBar experiment, both in B-mesons decays and directly in e^+e^- interactions. The full dataset of 531 fb^1 is used, including 432 fb^1 at the $\Upsilon(4s)$ resonance. New results are presented on the search for B mesogenesis in B decays to a standard model baryon Λ or proton and a dark antibaryon. Recently published results on searches for Axion Like Particles and Darkonium lead to significant improvements in constraining the dark sector.

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1. Physics motivation and experimental framework

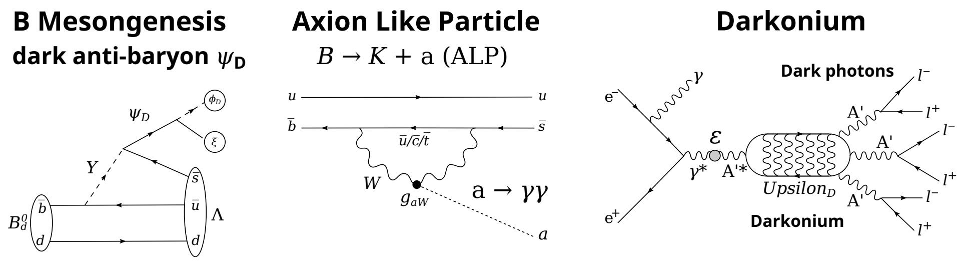

Figure 1: B mesogenesis (left), Axion like Particle (middle), Darkonium (right).

Many theoretical models could explain what Dark Matter is made of and its mass scale. The Effective theory approach provides different portal mediators to access the dark sector such as dark photons (A') and Axion Like Particles (ALP) [1]. Experiments can constrain associated operators, masses, and couplings.

Beauty factories are a great window to search for low mass New Physics produced through mixing between portal mediators and Standard Model (SM) particles both in B-mesons decays and directly in e^+e^- interactions, like the studies reported here (Fig. 1).

The clean e^+e^- environment and a quasi-hermetic detector allow a good missing energy (potential dark matter) reconstruction. Moreover, the reconstruction of displaced vertices from long-lived particles, the precise particle identification and reconstruction, and the high data statistics (precision frontier) opened the way to more than ten years of dark matter searches, in parallel to the initial goal to study CP violation.

Charge conjugate is implicit through this report.

2. Search for B mesogenesis

2.1 The B-mesogenesis model

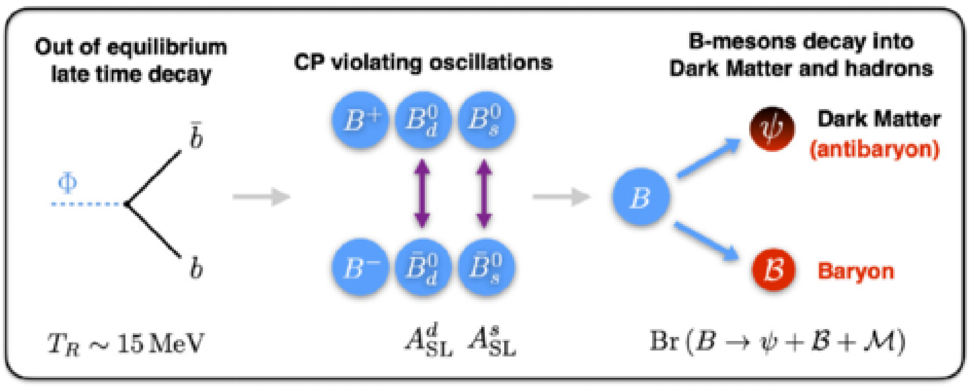

Figure 2: B mesogenesis mechanism as described in [3].

The B-meson baryogenesis or B mesogenesis [2, 3] is a recently proposed mechanism to explain both dark matter abundance and the Baryon Asymmetry of the Universe (Fig. 2). In the early universe, out of equilibrium and at a relatively low temperature around 15 MeV, neutral B-mesons undergo CP violating oscillations. This CP asymmetry is "frozen" as neutral B-mesons decay into a standard model baryon and a dark antibaryon, and possible additional light standard mesons. The dark antibaryon decays in turn into two stable dark particles, potential candidate for dark matter. Visible and dark sectors have equal but opposite matter-antimatter asymmetries, and the total baryon number is conserved.

For the decay $B \to \Psi_D + Baryon_{SM} + (Mesons)_{SM}$ to exist, a new Beyond Standard Model TeV-scale color-triplet scalar Y is needed, coupling Ψ_D and SM quarks. Four corresponding flavor combination O_{u_i,d_j} operators for B-meson decays appear in the effective low energy Lagrangian, when integrating out the heavy mediator Y. But only one was active in the early universe for the B-mesonogenesis mechanism.

2.2 BaBar search for $B^0 \to \Lambda\Psi_D$ and $B^+ \to p\Psi_D$

BaBar has recently searched for $B^0 \to \Lambda\Psi_D$ decay [4] (probing $O_{u,s}$) following Belle [5], and for the $B^+ \to p\Psi_D$ decay [6] (probing $O_{u,d}$) for the first time. The $B^+ \to \Lambda_c^+\Psi_D$ channel (probing $O_{c,d}$) is under study and results will be released soon.

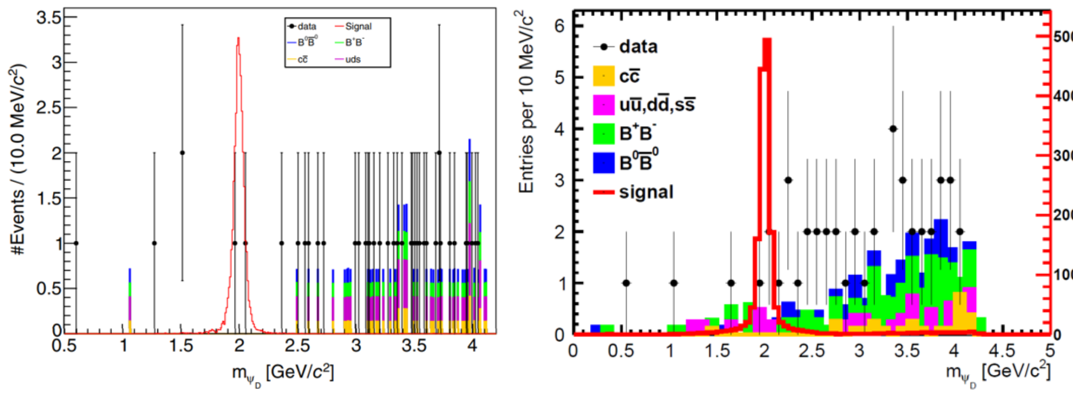

Figure 3: Distribution of the reconstruted mass m_{Ψ_D} of the dark antibaryon for the selected candidate decays $B^0 \to \Lambda\Psi_D$ (left) and $B^+ \to p\Psi_D$ (right). The dots stand for the data and the histograms stand for the simulation of the backgrounds and one example of signal at 2 GeV (red).

The analysis uses B-mesons pair events for which one of the B-meson is fully reconstructed in known hadronic modes. The signal B meson consists of a reconstructed standard model baryon Λ or proton, and a missing Ψ_D 4-momentum corresponding to a dark antibaryon escaping the detection. A boosted decision tree (BDT) is used to suppress residual combinatorial background from $q\bar{q}$ and $B\bar{B}$ decays. The background is estimated directly from the m_{Ψ_D} side band data. The main systematics of the analysis comes from the correction of the simulation in the BDT distributions using the control region in data. But the analysis is still dominated by statistical uncertainties.

Many m_{Ψ_D} mass hypotheses are tested. No signal is observed in the resulting m_{Ψ_D} mass distribution in the data compared to the ones of the background predictions (Fig. 3).

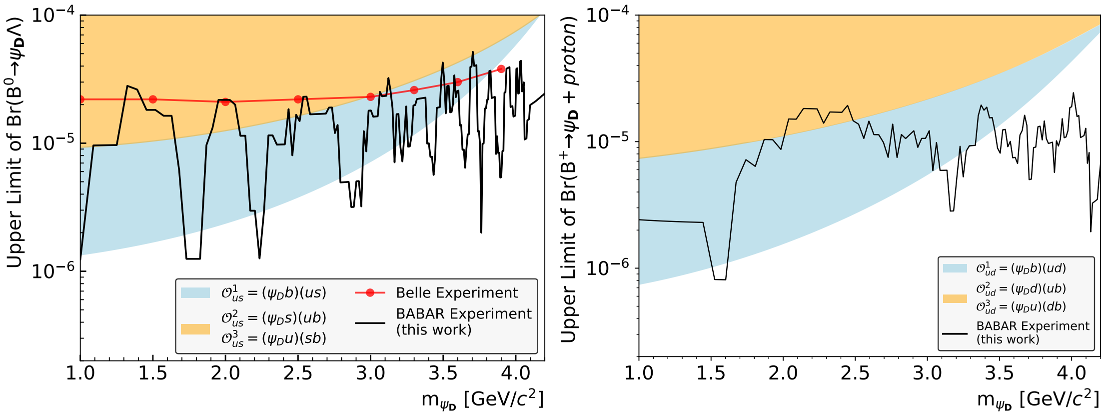

Figure 4: The 90% CL upper limits on the Branching ratio for $B^0 \to \Lambda\Psi_D$ (left) and $B^+ \to p\Psi_D$ (right) versus the assumed mass m_{Ψ_D} of the dark antibaryon. Those results are compared to the previous Belle result (red) for $B^0 \to \Lambda\Psi_D$, and to the theoretical ranges of parameters for the B mesogenesis mechanism to explain the observed Baryon Assymetry of the Universe (yellow and blue areas).

This allows one to exclude a large fraction of parameter space for B mesogenesis (Fig. 4). Note that this is true only for the two operators O_{us} and O_{ud}, out of the four operators that could have been active and responsible for the B mesogenesis in the early universe [3]. Searches for B decays probing the operators O_{cd} and O_{cs} also need to be performed.

The results on B-meson decays for B-mesogenesis searches are also useful to constrain the SUSY model [7].

3. Search for an Axion Like Particle (ALP) in B meson decays

Axion-Like Particles (ALPs) are Pseudo-Goldstone bosons resulting from Spontaneously-broken global symmetries, They could help resolve naturalness issues of *SM* parameters (like the CP strong problem) and serve as mediators to dark sectors. ALPs a can be produced in Flavor-Changing Neutral Current B decay processes, like $B \to Ka$, with $a \to \gamma\gamma$ [8].

BaBar has searched for peaks in the reconstructed $\gamma\gamma$ mass that could result from $B^+ \to K^+ a$, $a \to \gamma\gamma$ decays [9]. In the absence of signal, limits on the axion coupling g_{aW} with W pairs can be inferred from the measured $\gamma\gamma$ mass distribution (Fig. 5). Up to two orders of magnitude improvements over previous limits are reached in some axion mass areas.

4. Search for Darkonium

Darkonium such as the Υ_D ($J^{PC} = 1^{--}$) is a bound state of dark fermions χ, that can be created in e^+e^- interactions. The Υ_D can decay into three dark photons A', as a dark photon couples strongly to the dark matter fermions χ via the coupling α_D. Also, as the dark photon mixes with a *SM* photon via kinetic mixing with strength ϵ, it can decay into a pair of *SM* charged particles. [10].

BaBar has searched for Υ_D decaying into three dark photons, each dark photon decaying in turn in a pair of charged pions or leptons (e^+e^- or $\mu^+\mu^-$) [11]. A final state of six charged particles

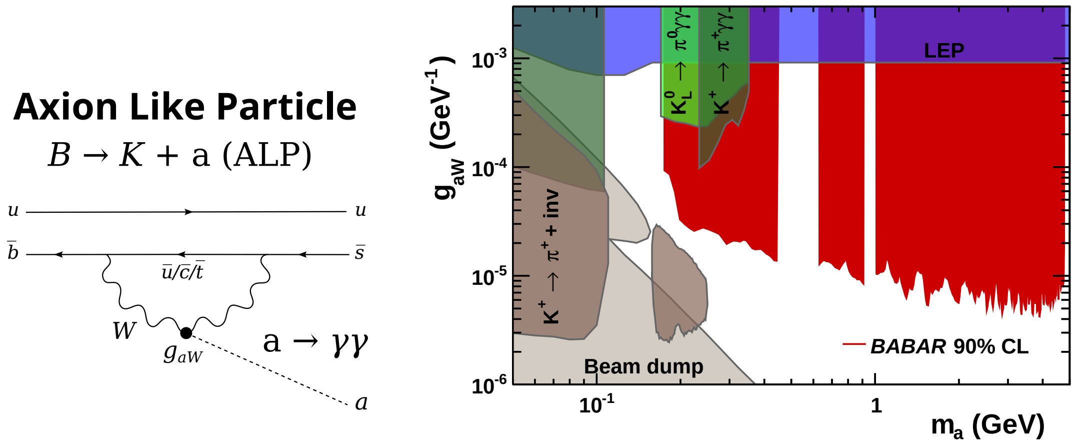

Figure 5: BaBar 90% CL upper limits on the coupling g_{aW} versus the ALP mass (red), together with existing constraints (blue, green, brown, and grey).

(with at least one pair of leptons) is selected. The dark photon lifetime can be long for small masses and small kinetic mixing ϵ hence prompt and displaced vertex signatures are searched for. As no significant signal is observed in either prompt or displaced decay searches, upper limits are set on the mixing parameter ϵ versus the mass $m_{A'}$ of the dark photon, for different values of m_{Υ_D} and the coupling α_D (Fig. 6). For larger values of m_{Υ_D} the limits on ϵ significantly improve compared to previous measurements.

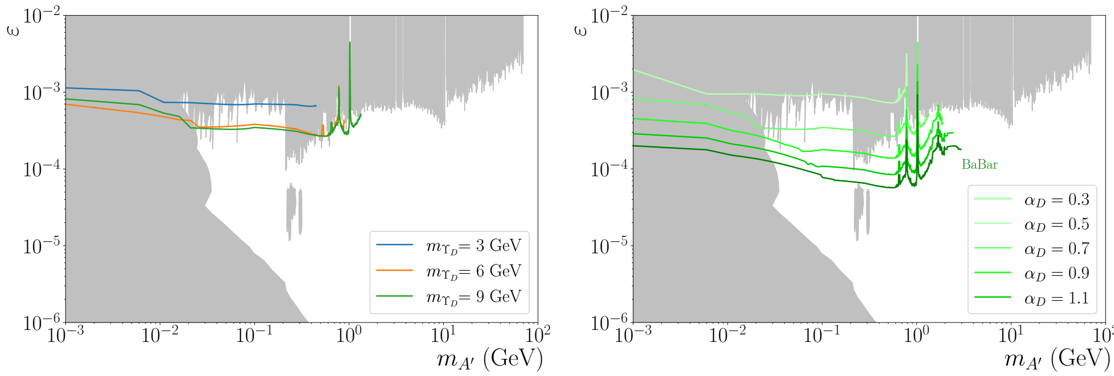

Figure 6: The 90% CL upper limits on the kinetic mixing ε for (left) various Υ_D masses assuming $\alpha_D = 0.5$ and (right) various α_D values assuming m_{Υ_D}= 9 GeV together with current constraints (gray area).

5. Conclusion

BaBar data opens an interesting window for searching for physics beyond the Standard Model. The clean B-factory environment is extremely well suited to searches for light dark sector, and significant improvements were achieved in constraining the dark sector. B mesogenesis, ALPs and darkonium searches presented in this report are the most recent in a long, flourishing, and still developing history of dark sector and exotic searches.

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