PROCEEDINGS OF SCIENCE

Dark Sector Physics with Belle II

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The Belle II experiment is a substantial upgrade of the Belle detector and will operate at the SuperKEKB energy-asymmetric e^+e^- collider. The accelerator has already successfully completed the first phase of commissioning in 2016 and first electron positron collisions in Belle II are expected for April 2018. The design luminosity of SuperKEKB is $8 \times 10^{35} cm^{-2}s^{-1}$ and the Belle II experiment aims to record 50 ab^{-1} of data, a factor of 50 more than the Belle experiment. This data set offers the possibility to search for a large variety of dark sector particles in the GeV mass range complementary to LHC and dedicated low energy experiments. These searches will profit both from the size of the Belle II data, and from specifically designed triggers for the early running of Belle II. This talk will review planned dark sector searches with a focus on the discovery potential of the first data.

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1. Dark Photons

A dark photon A' is a particle that couples to the Standard Model photon $\mathscr{L} \subset \varepsilon V_\mu J^\mu_{SM}$ with strength ε and can decay to invisible dark matter particles if they are sufficiently light, or visible fermions. The signatures observed are $e^+e^- \to \gamma + inv$ or $e^+e^- \to \gamma + l^+l^-$. The production process is shown in Fig. 1 with an initial state radiation photon with energy $E_\gamma = \frac{(E^2_{CM} - E^2_{A'})}{2E_{CM}}$.

The signal selection is done based on the ISR photon energy and polar angle. For lower masses of the dark photon, a tighter selection is done to further cut irreducible 2γ, 3γ and radiative Bhabha background. Trigger efficiency and signal selection simulations are shown in Fig.2.

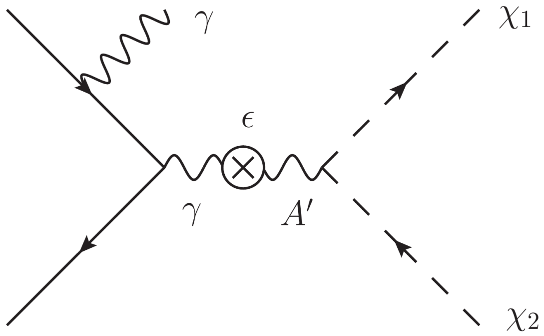

Figure 1: A Feynman diagram of dark photon production with an initial state radiation photon

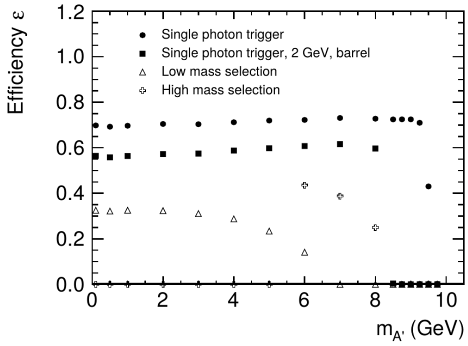

Figure 2: Simulated trigger and dark photon signal selection efficiencies [1]

Belle II will be able to reach lower regions of ε coupling with early data as shown in Fig. 3 for invisible dark photon decays, and with several ab^{-1} of data for visible dark photon decays (Fig.4).

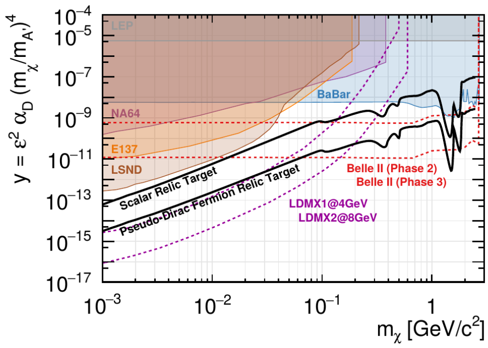

Figure 3: Estimated sensitivity to invisible dark photon decays in Belle II (red dashed lines) [1]

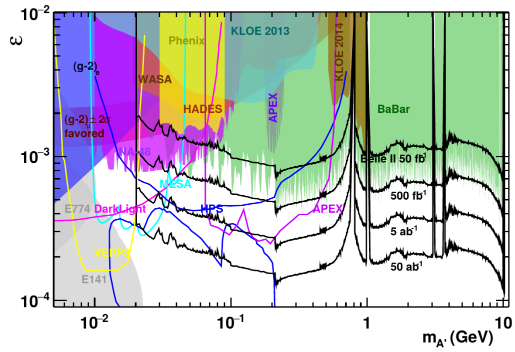

Figure 4: Projected sensitivity to visible dark photon decays in Belle II (black lines) [1]

2. Axion-like particles

Axion-like particles (ALPs) are pseudo-scalars that, in the scope of this search, can couple to photons and massive gauge bosons $\mathscr{L} \subset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{4} a F_{\mu\nu}\tilde{Z}^{\mu\nu}$

There are two cases of interest at Belle II - photon coupling ALP ($g_{a\gamma\gamma} \gg g_{a\gamma Z}$) and hypercharge coupling ALP ($g_{a\gamma\gamma} \approx -g_{a\gamma Z}$), and focus is on ALP-strahlung process (Fig. 5), with ALP decaying to SM photons or dark matter particles, with signatures $e^+e^- \to 3\gamma$ and $e^+e^- \to \gamma + inv$.

If ALP decays to photons inside the detector volume, the final state consists of a recoil photon and two photons in the opposite direction. The signal selection efficiency simulation is shown in Fig. 6. In the case when ALP decays to DM, the search is done as the dark photon search described in previous section.

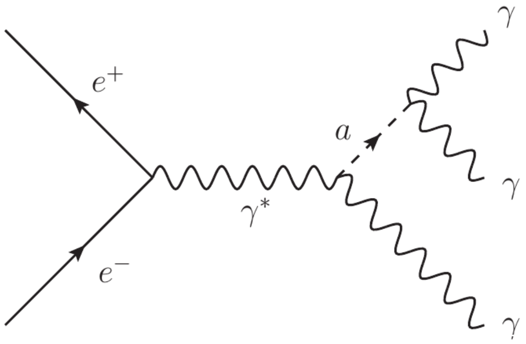

Figure 5: A Feynman diagram of an ALP-strahlung process

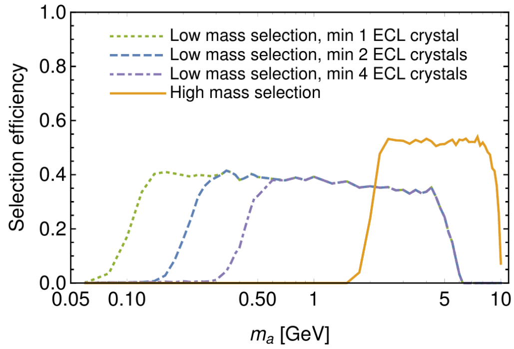

Figure 6: Simulated axion-like particle signal selection efficiency [2]

The estimations of Belle II sensitivity for early dataset and full dataset are shown in Fig. 7.

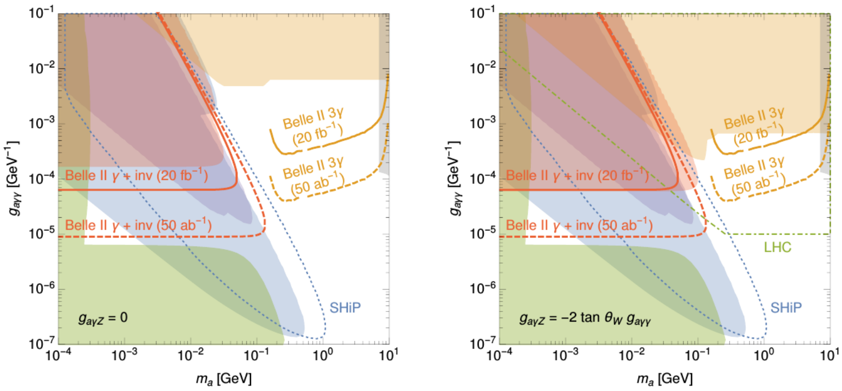

Figure 7: Estimated sensitivity of Belle II to axion-like particles in case of photon (left) and hypercharge (right) couplings [2]

3. Magnetic Monopoles

Magnetic monopoles are particles carrying magnetic charge. Previous experiments mostly looked for high ionisation of Dirac monopoles with magnetic charge $g > 68.5e$, while the region of small charges have not been very accessible. The signature of magnetic particles is non-helical tracks that are straight in transverse plane and curved along the magnetic field fig. 8, so that the $z(s)$ has an extra quadratic term: $z(s) = z_0 + \frac{p_z}{p_T}s + \frac{gBm}{2p_T^2}s^2$

The ionisation loss of a magnetic charge is lower because $1/\beta^2$ dependence is absent in magnetic Bethe-Bloch formula [3], thus producing 2-6 times less hits in the drift chamber. However, monopoles are still reconstructed in the electromagnetic calorimeter. A dedicated tracking algorithm is being developed that is able to overcome those issues.

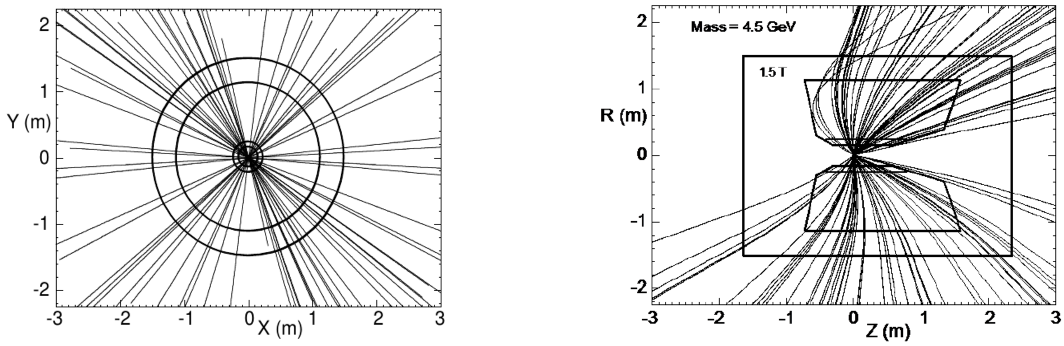

Figure 8: Possible topologies of monopole axial (left) and stereo (right) tracks [4]

With low backgrounds of phase 2 and good drift chamber resolution, Belle II will be able to reach much better sensitivity to the monopole pair events, compared to existing limits, even with low statistics (Fig. 10).

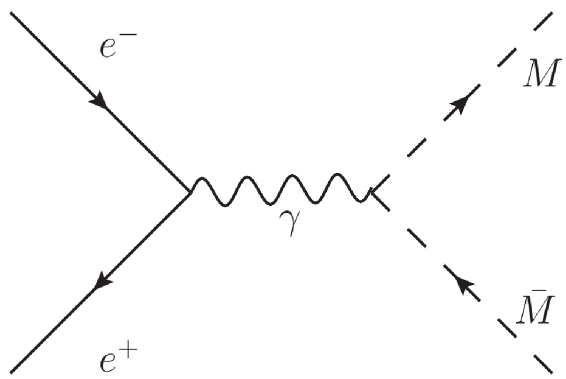

Figure 9: A Feynman diagram of monopole anti-monopole pair production

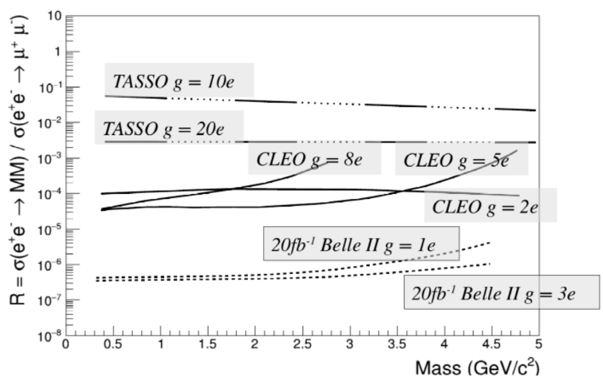

Figure 10: Projected sensitivity to production of magnetic monopoles in Belle II [5] [6]

References

[1] E. Kou, P. Urquijo et al., *The Belle II Physics Book*, *To be published in PTEP* [hep-ex/1808.10567]

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[3] Steven P. Ahlen, *Theoretical and experimental aspects of the energy loss of relativistic heavily ionizing particles*, *Rev. Mod. Phys.* **52**, 121 (1980)

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