Latest results on dark sector and tau physics at Belle II

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Abstract

The first results on dark sector searches for axion-like particles, Z', and dark photons will be described. In addition, the status and prospects for tau property measurements and searches for lepton-flavour violating tau decays will be described.

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The SuperKEKB collider [1] in Japan collides electrons (7 GeV) with positrons (4 GeV) and has a target integrated luminosity of $50\,\mathrm{ab}^{-1}$. The Belle II detector records the e^+e^- collisions and the experiment was designed to study the weak interactions of quarks, to do precision measurements, such as the τ mass measurement, and to do searches for new physics, including the dark sector searches for axion-like particles, the invisible Z', and dark photons, as well as the lepton-flavour violating τ decay searches.

The τ lepton decays both leptonically and hadronically, and is produced with a large cross-section at SuperKEKB. In the Standard Model (SM), the τ mass, m_τ, is not predicted and must be measured. Precision measurements of m_τ are an important test of lepton universality. Belle II has measured m_τ in τ-pair events with a 4-track final state using the pseudomass method developed by the ARGUS Collaboration [2]. One tau was required to decay into three charged pions and the other to decay via a 1-prong decay. The pseudomass, M_{min}, approximates the mass of the tau from the decay of the 3-prong decaying tau in each event, and $M_{\mathrm{min}} \leq m_\tau$. After fitting the pseudomass distribution for the distribution end-point (distribution shown in Figure 1) and applying a correction for the measured end-point (derived from simulations), the mass was measured to be $m_\tau = 1777.28 \pm 0.75\,(\mathrm{stat.}) \pm 0.33\,(\mathrm{syst.})\ \mathrm{MeV}/c^2$, which already has a systematic uncertainty better than that of Belle but with only $8.8\,\mathrm{fb}^{-1}$ worth of Belle II data [3].

Searches for lepton flavour violating τ decays, "LFV τ-decays", test lepton flavour conservation in the SM. The LFV τ decay model most recently investigated by Belle II, $\tau \to e\alpha$, where α is invisible and could be a dark matter (DM) candidate, could have exclusion limits that extend existing limits by an order of magnitude using just the existing data set [4].

There are several other searches at Belle II for particles connected to a dark sector. Belle II will be able to probe single photon final state DM models (e.g. in an invisible dark

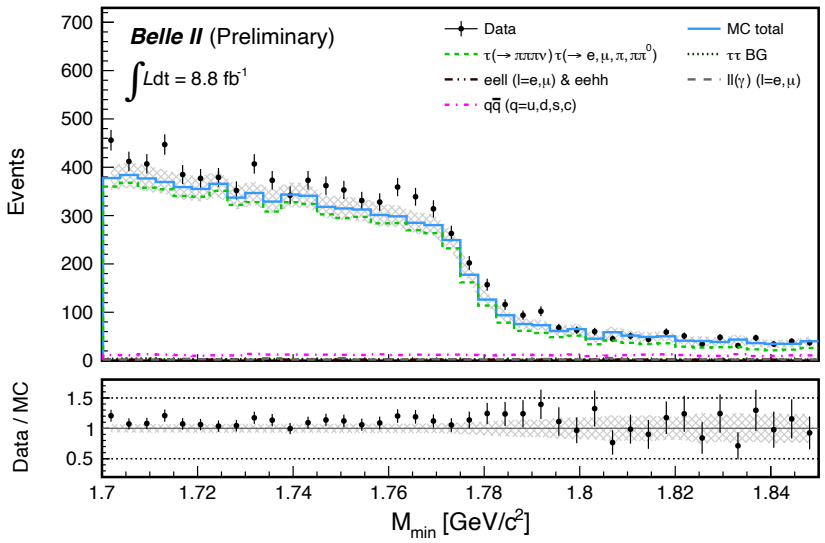

FIG. 1. Distribution of M_{min} around the τ mass for data and simulated events [3].

photon search) using a single photon trigger that has a 0.5 GeV threshold. The Belle II search for an axion-like particle, a, or "ALP", probes models where the ALP decays $a \to \gamma\gamma$ and would be a pseudoscalar portal to DM candidates. A search for an ALP, performed by looking for a resonance in $ee \to \gamma\gamma\gamma$ events while requiring the photons to all have times consistent with one another, extended exclusion limits using just 445 ± 3 pb^{-1} of data, as seen in Figure 2 [5].

Belle II also searched for an invisible Z' from the $L_\mu - L_\tau$ model, where the Z' does not

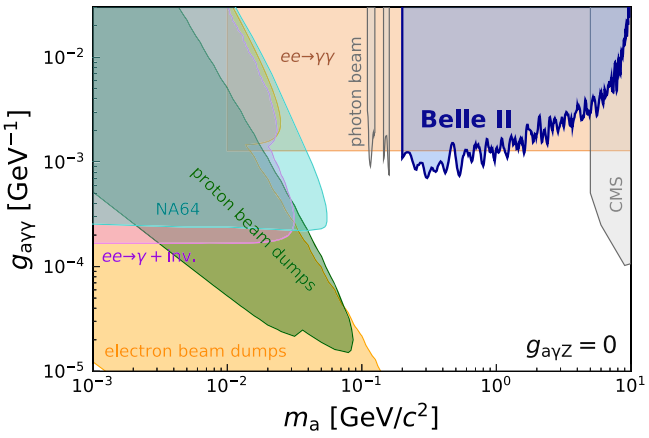

FIG. 2. Upper limit (95% C.L.) on the ALP-photon coupling as a function of the ALP mass from the Belle II $ee \to a\gamma\,(a \to \gamma\gamma)$ analysis and previous constraints from various experiments [5].

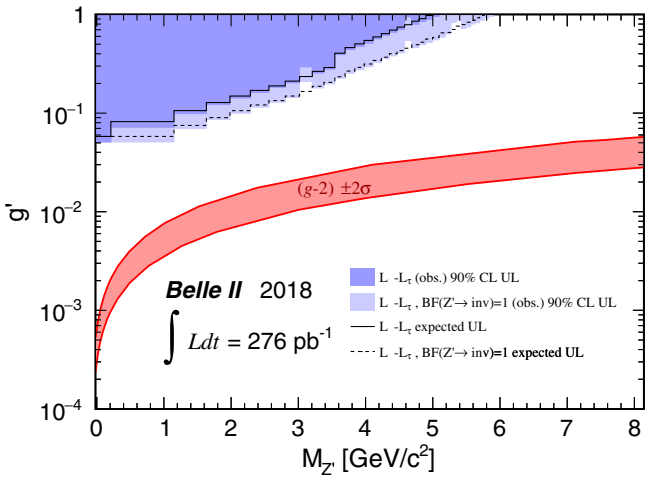

FIG. 3. 90% C.L. upper limits on coupling constant g' as a function of the Z' mass. Dark blue filled areas show the exclusion regions for g' at 90% C.L., assuming the branching fraction predicted by the $L_\mu - L_\tau$ model for $Z' \to$ invisible; light blue areas are for BF $(Z' \to \text{invisible}) = 1$ [7].

interact with first generation leptons [6]. Figure 3 shows the exclusion limits set by a search for an invisible Z' in a di-muon final state with missing energy using only $276\,\text{pb}^{-1}$ of data [7].

These Belle II analyses show how the experiment has now started probing unexplored regions of phase space and producing precision measurement in several early dark sector and τ properties analyses.

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