Snowmass2021 - Letter of Interest

Photon-beam experiments and new light physics

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Thematic Areas:
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Abstract: (maximum 200 words)

Current and future photon-beam experiments, with their unprecedented beam intensities, provide a unique opportunity to explore MeV/c^2 to GeV/c^2 new light particles that couple feebly to the Standard Model. The new particles can be produced through the scatterings between the beam photons and the target nucleons or electrons via Primakoff or Compton-like processes, or the decays of $\eta^{(\prime)}$ mesons. To reach the discovery potential of the experiments, it is necessary to understand better the Standard Model backgrounds for the experimental energy range. Techniques such as measuring polarization observable with a polarized target can provide the data needed to reduce these backgrounds.

The light dark sector particles, such as dark photons and axion-like particles (ALPs), are well-motivated by many scenarios of physics beyond Standard Model (BSM) and are set to be intensively explored in the next decade [1, 2]. Current and future photon-beam experiments, such as GlueX [3], LEPS [4], LEPS2 [5], FOREST [6], A2/MAMI [7] and NPS/CPS [8, 9], will provide an unprecedented intensity of photons with energy of 75 MeV–10 GeV (see Tab. 1 for a summary). Those experiments thus provide a unique opportunity to probe the light dark particles in the MeV/c^2–GeV/c^2 mass range.

Experiments	Φ_γ [γ/sec]	E_γ range [GeV]	ΔE_γ [MeV]
GlueX	5×10^7	$9 - 12$	50
LEPS	5×10^6	$1.4 - 2.4$	12
LEPS2	5×10^6	$1.4 - 2.4$	12
FOREST	4.5×10^6	$0.8 - 1.2$	1
NPS/CPS	10^{12}	$5 - 11.5$	un-tagged
A2/MAMI	10^7	$0.068 - 1.488$	4
PRIMEX II	10^7	$4.3 - 5.2$	5

Table 1: Tagged photon-beam flux (Φ_γ), energy range, and detector resolution (ΔE_γ) for GlueX [3], LEPS [4], LEPS2 [5], FOREST [6], A2/MAMI [7], and NPS/CPS [8, 9]. We also add the information of PRIMEX II [10], a past photon-beam experiment, for comparison.

Below, we use the examples of the dark photons (A') and ALPs (a) to illustrate the physics potential of the photon-beam experiments. The projected sensitivities are shown in Fig. 1 for the two cases. Note that similar sensitivities can be reached for other dark sector particles such as dark scalars and dark pseudo-vectors. The main production channels for the dark sector particles at the real photon-beam experiments are: (1) **Primakoff-like process** $\gamma N \to aN$ and $\gamma e^- \to ae^-$ via t-channel photon exchange for ALPs coupling to photons, (2) **Compton-like process** $\gamma N \to (a/\phi/A'/pA')N$ and $\gamma e^- \to (a/\phi/A'/pA')e^-$ or ALPs, dark scalars (ϕ), dark photons, or dark pseudo-vectors (pA') coupling to the SM charged current, and (3) $\eta^{(\prime)}$ **meson decays** treated in two others Letter of Interest and a detailed study can be found in [11].

The detection channels can be classified as:

- **Prompt decays**, valid for Primakoff- and Compton-like processes. If their couplings to the SM photons or charged currents are large enough, the dark sector particles can decay promptly and result in $\gamma\gamma$ or $\ell^+\ell^-$ pairs. A signal peak can be reconstructed from the invariant mass distribution of $\gamma\gamma$ or $\ell^+\ell^-$. Note that, for ALPs with mass $m_{\pi^0} < m_a < m_\eta$ and large couplings to gluons, ALPs will mix with π^0 and η and then decay into $\gamma\gamma$ final states [12, 13].
- **Missing momentum**, valid for Compton-like processes. This is the detection channel if the dark sector particles are long-lived or dominantly decay into other dark sector particles. In this case, only the recoil atomic electron/nucleon can be detected. The signal can be reconstructed from the missing mass distribution derived from the recoiled momentum. This channel can be also used to search for milicharged DM [14]. A prominent example is shown in Ref. [15] for light dark matter decay for GlueX, LEPS, LEPS2, and FOREST detectors.
- **Displaced vertices,** valid for Primakoff- and Compton-like processes. With intermediate couplings, the dark sector particles may decay inside the detector with significant flight distance. This provides a better control of the background and a unique signature for BSM physics/detection. It should be noted that none of experiment considered here have a vertex detector.

For photoproductions off a nucleon or nuclei, the total cross sections of the SM backgrounds were well

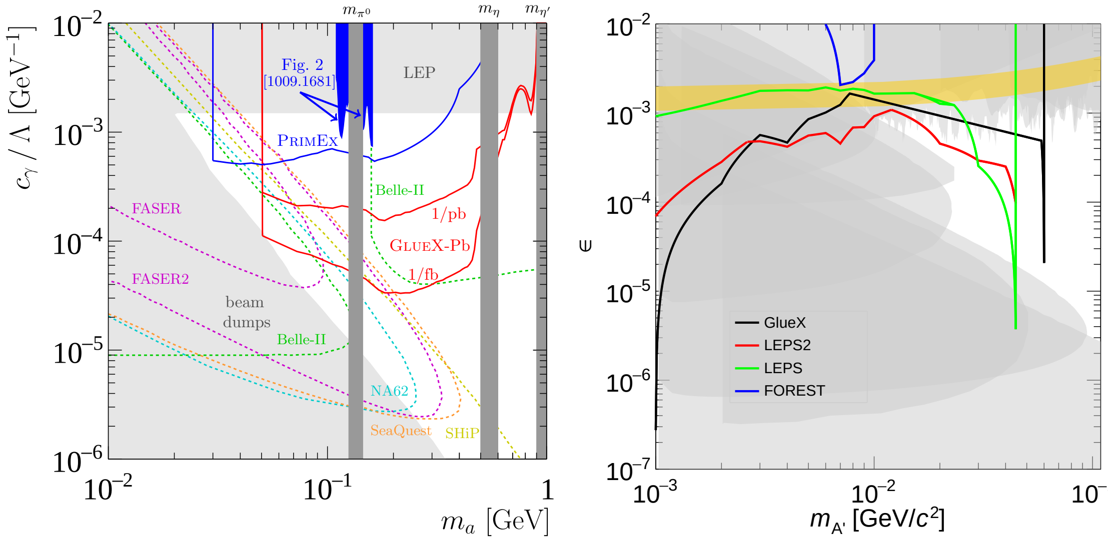

Figure 1: (Left) The projected sensitivities on ALP-photon couplings for PRIMEX (blue) and GlueX (red) [12] The ALPs are generated through the Primakoff process. (Right) The projected sensitivities on dark photon kinetic mixing for 1 month beam-time at FOREST (blue), LEPS2 (red), LEPS (green), and GlueX (black) [15]. The dark photons are produced through Compton-like scatterings between the beam photons and target electrons.

measured up to 6 GeV in incident photon-beam energy. But the differential cross sections and the polarization observables were only partially measured [16, 17, 18]. In particular, the very forward-angle was poorly measured. QCD based models are not able to provide first-principle predictions. Therefore, we need to develop a data-driven approach to estimate these backgrounds and subsequently tune the phenomenological models. In contrast, precise calculations of the differential observables are available for the SM processes photoproduced off an atomic electron [19, 20, 21]. Measurements at the photon-beam experiments will validate those predictions.

The photon-beams used in the experiments can be circularly or linearly polarized to a high degree. If the target is polarized in addition, it is possible to measure the single and double polarization observables [22] for visibly- and invisibly decayed dark sector particles. GlueX plans to measure the GDH sum rule [23] from 3 GeV up to 12 GeV in incident photon-beam energy with a highly circularly-polarized incident photon-beam and highly longitudinally-polarized proton and deuterium targets [24]. Hence, the experiment will also measure the spin observable $E = \frac{\sigma_{3/2}-\sigma_{1/2}}{\sigma_{1/2}+\sigma_{3/2}}$, where $\sigma_{1/2}$ and $\sigma_{3/2}$ correspond to the differential cross sections measured with right-handed and left-handed circularly-polarized photon-beam and a fixed spin-1/2 nucleon, respectively. A scalar- and vector-like particle, either from SM or dark sectors, will leave very distinct signature in the E-observable. Therefore, such measurement provide an extra handle to suppress the SM backgrounds [14]. Similar measurements can be conducted in other photon-beam experiments. In the planned GlueX setup, only the target nucleons are polarized and the target electrons are not. A highly polarized electron target can be potentially realized using ultra-cold trap of fully polarized atomic hydrogen [25].

In summary, photon-beam experiments provide a rich set of possible search strategies of light dark sector particles. We are still facing challenges such as optimizing the experimental setups and a better control of the SM backgrounds. We plan to provide a more detailed study of these opportunities and challenges in the Snowmass 2021 process.

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