

DarkSHINE — Search for Light Dark Matter at the SHINE facility in Shanghai

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The future Shanghai high repetition rate XFEL and extreme light facility (SHINE) being the first hard X-ray Free Electron Laser facility in China enables great potential to explore the dark sector through its high repetition rate electron beam via the fixed-target experimental approach. DarkSHINE is a light dark matter search experiment under proposal aiming to probe the dark sector through a dark photon mediator. This talk briefly introduces the prospect and scheme of DarkSHINE experiment and the latest R&D progresses.

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1. Background Stories

Throughout our universe's evolution history, there are so many mysteries that are greatly inspiring the human beings to quest for the infinity and unknowns. We are always wondering what our universe is made up of, how our universe came into being and evolving, how the elementary particles interact in the microscopic world and form our universe eventually. Among all such big questions, Dark Matter (DM) and Dark Energy are the keys to probe such mysteries given their well demonstrated existence through astronomical observations and challenges to the foundation of the successful Standard Model (SM) particle physics which by far has no explicit clue to have the DM particles and their new interactions incorporated. Despite the DM characteristics being studied with combined efforts from particle physics, cosmology and astronomy, the general descriptions of DM particles being non-baryonic, massive, electrically neutral, gravitational and stable are broadly referred to when developing beyond Standard Model (BSM) physics theories and designing various particle physics experiments searching for them.

DM search experiments have diverse technical approaches based on not only the model-dependent DM particle characteristics but also different production and interaction schemes. One may typically categorize the DM search experiments into direct searches through nuclear recoils from DM-nuclei scattering (e.g. XENONnT, LZ, CDEX, PandaX, ...), indirect searches focusing on probing DM annihilation (e.g. DAMPE, HESS, IceCube, ...), and collider searches assuming DM particles produced in high-energy collisions would lead to SM particle productions in association with significant missing energy representing the DM signatures.

2. Introduction to DarkSHINE

The collider-based DM search experiments, or moreover the accelerator-based searches, generally put focus on the DM production through collisions with missing energy/momentum phenomena being the typical signatures. With the SM particles accelerated to relativistic velocity, accelerator-based DM searches have unique advantages to minimize the searched phenomenological differences throughout theory parameter space so that one may have more general probes to a variety of different DM theory models predicting various DM particle masses and spins. In addition to those outstanding general-purpose collider experiments (e.g. the Large Hadron Collider, BES-III@BEPC-II, Belle-II@SuperKEKB, etc.), one may also think of probing the dark sector through fixed-target experiments making use of relatively low energy incident SM particles inducing dark force mediators which further decay into the dark matter particles.

Presently, there are quite a few experiments or proposed experiments aiming to search for dark mediators and light DM particles via fixed-target approaches such as NA64 [1], LDMX [2], DarkLight [3], DarkMESA [4] and DarkQuest [5], which help to well establish the new frontier for accelerator based fixed-target DM search experiment with worldwide focus in general. Shanghai high repetition rate XFEL and extreme light facility (SHINE) is under construction and aims to deliver its first electron beam at GeV energy scale before end of 2025. With the great potential of the future SHINE facility [6–8], we expect to have the opportunity to deploy the first high repetition rate single electron beamline in the near future. The conceptual design and schematic illustration of such a beamline with a dedicated kicker is shown in Fig. 1.

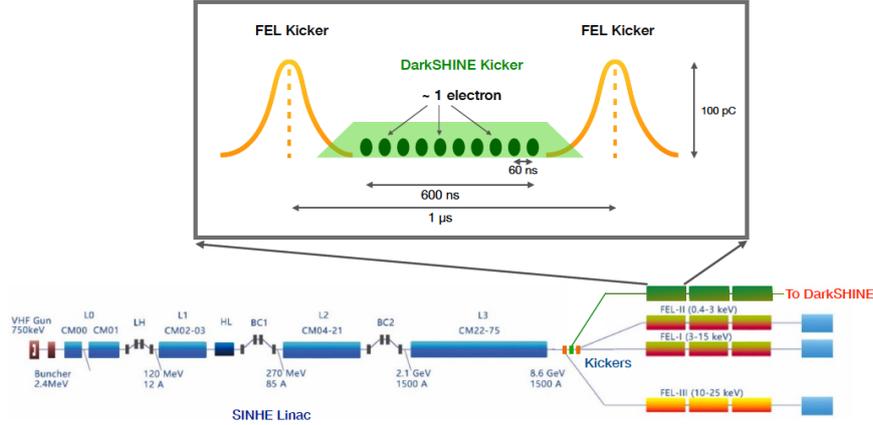


Figure 1: DarkSHINE Kicker and beamline design in a nutshell. [9]

As a result, the idea of DarkSHINE [9–11] as a new initiative has been proposed to carry out the dark mediator and light DM searches with electron-on-target type experiment benefiting from the high-repetition rate single electron beam to be provided by the SHINE facility. DarkSHINE benchmark design put special focus on searching for the invisible decays of the dark mediator: Dark Photon, which bridges the SM particles and DM particles while kinetically mixing with the SM photons. In one of the most simplified scenarios, one may introduce an extra $U(1)$ symmetry predicting a new gauge field (X) and a corresponding new vector boson Dark Photon. [12, 13] The characteristics of Dark Photon invisible decays drive the benchmark conceptual design of DarkSHINE detector system. [9–11]

3. DarkSHINE Detector R&D Status

The DarkSHINE experiment focuses on searching for an invisibly decaying dark photon into light DM so that missing energy/momentum phenomena give the straightforward guidance to the DarkSHINE detector system design. The detector system, as shown in Fig. 2, consists of three major sub-systems: a silicon strip tracker system including the tagging tracker and the recoil tracker with the tungsten target embeded right in between and immersed in a magnetic field providing good momentum/trajjectory reconstruction and identification sensitivity for incident and recoil electrons [14]; an electromagnetic calorimeter system (ECAL) to provide good resolution for desposited energies from the recoil electrons to hint whether there is any significant energy loss [15, 16]; a hadronic calorimeter (HCAL) [17, 18] sampling and vetoing the energy deposit from neutral hadrons and muons which would easily mimick the energy loss from the electron-on-target recoiling processes.

With the independently developed simulation framework [19] to realize the detector system and generator process modeling of Dark Photon signal and SM backgrounds, the prospective studies were conducted and concluded on a competitive sensivity to constrain the Dark Photon kinetic mixing parameter [9, 10] as shown in Fig. 3. The prototyping of each sub-detector system is being

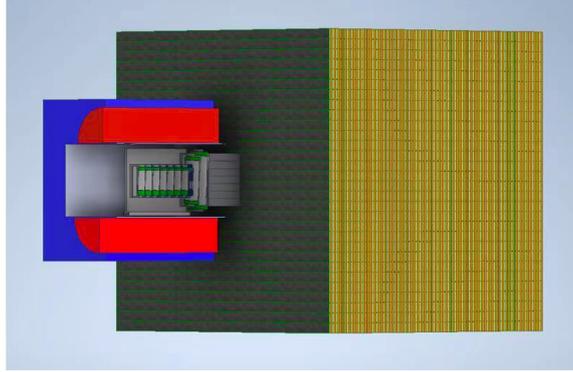


Figure 2: DarkSHINE Detector System sketch. [9]

carried out in-lab with the first strip tracker module tested with high position resolution [14], the first multi-channel mini-prototype of ECAL successfully tested at DESY with good energy resolution and the first design of high-speed readout electronics preliminarily finished [20]. While the beamline design and deployment are being considered by the SHINE facility host, further optimization of the DarkSHINE detector system and larger scale prototyping and technical demonstrations are being continued presently and progressing towards the near future.

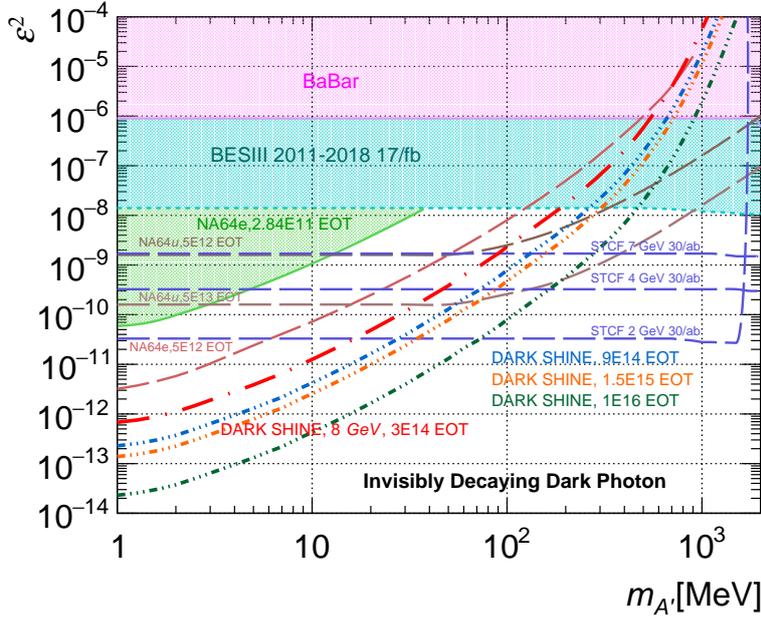


Figure 3: DarkSHINE 90% expected C.L. exclusion limits on ϵ^2 as a function of the Dark Photon mass $m_{A'}$, estimated with 3×10^{14} EOTs (red), 9×10^{14} EOTs (blue), 1.5×10^{15} EOTs (orange), and 10^{16} EOTs (green) statistics, in comparison with NA64 [1], BaBar [21], BESIII [22] (and future STCF). [9]

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