
# Dark SHINE — a Dark Photon search initiative at SHINE facility

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**Abstract**

Dark SHINE is a newly proposed fixed-target experiment at SHINE (Shanghai high repetition rate XFEL and extreme light facility, being the 1st hard X-ray FEL in China) under construction targeting completion in 2026. Dark SHINE aims to search for the new mediator, Dark Photon, bridging the Dark sector and the ordinary matter. In this talk, we present the idea of this new project and 1st prospective study in search for Dark Photon decaying into light dark matter. It also provides the opportunity to incorporate broader scope of BSM search ideas utilizing the fixed-target experiment of this type.

Dark Matter (DM) has been widely regarded as an unknown physical mystery but with evidence from the astronomical observations and gravitational effects such as the phenomena from galactic rotation curves, gravitational lensing, cosmic microwave background anisotropies, etc. Despite the physical interpretation of DM is yet to be discovered and verified, the typical DM characteristics being Non-baryonic, massive, electrically neutral, gravitational and stable are broadly accepted by the physicists. Many Beyond Standard Model (BSM) theories predict DM mechanisms, such as the weakly interacting massive particle (WIMP) being one of the popular Dark Matter Candidates. Most of the BSM models predict the DM particles possibly produced through collider experiments interacting weakly with SM particles and pass invisibly through the particle detectors. This would lead to common "Missing Transverse Energy" ($E_T^{miss}$) phenomena when a collision event does not balance in plane transverse to beam.

Over the past decades, collider based DM search is among those major approaches to search for DM, while direct detection approach making use of the nuclear recoils from DM-nuclei scatterings (e.g. LZ, XENONnT, CDEX, PandaX, ...) and indirect detection approach utilizing the products from DM annihilations (e.g. DAMPE, HESS, IceCube, ...) are equally important 1.

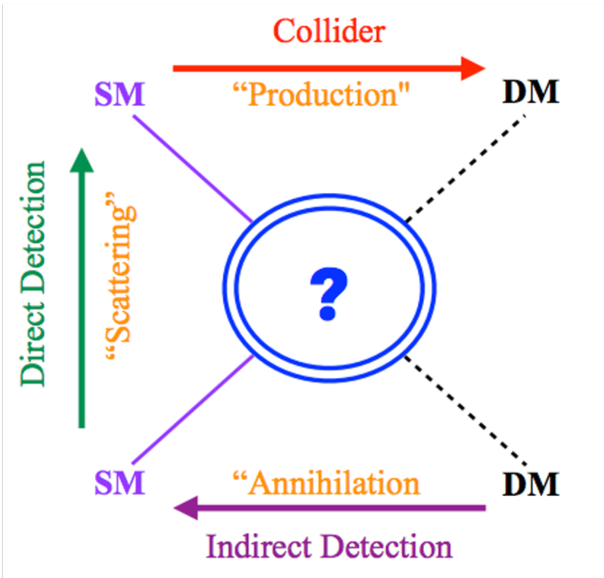


Figure 1: Dark Matter search approaches and connection with SM interactions.

Collider based DM search experiments make use of BSM predicted DM production mechanism in high-energy collisions, focusing on the $E_T miss$ phenomena along with SM particles productions. Many high energy collider experiments (e.g. the Large Hadron Collider (LHC), BESIII@BEPC-II, Belle-II@SuperKEKB, ...) naturally provide such search opportunity through either hadron-hadron collisions or lepton-lepton collisions spanning wide mass range and examining many BSM contexts. Besides the general collider experiments, other accelerator based DM search experiments are equally motivated to cover complementary search sensitivities, given the relatively lower center-of-mass energies compared to colliders.

When revisiting the DM search approaches, besides the regular searches aiming for detecting/observing DM candidate particles directly, one may also aim to look for DM mediators bridging the SM particles and the DM particles. One of the widely used new physics context to describe such mediator is Dark Photon, which in the most simplified scenario introduces an extra $U(1)$ symmetry predicting a new gauge field (X) and a corresponding new vector boson (i.e. Dark Photon $A'$) and extending the SM $U(1)_{em}$ symmetry as $U(1)_{em} \times U(1)_X$ [1, 2]. Such theory context is naturally and easliy renormalizable and gauge invariant while the predicted experimental phenomena can be very straightforward. The free parameters in a simplified scenario can be just the kinetic mixing constant ($\epsilon$) and mass ($m_{A'}$).

Shanghai high repetition rate XFEL and extreme light facility (SHINE) [3, 4, 5] is the first hard X-ray FEL facility in China. In this Dark Photon search initiative at Shanghai, namingly **Dark SHINE**, SHINE will play the role to deliver the high repetition rate high energy single electron beam with tungsten target to hit on. By means of the hypothetical dark bremsstrahlung interaction, the electron-on-target event would generate the mediator dark photon finally decaying into light dark matter particles, inducing significantly missing energy after recoiling the incident electron from the beam. The Dark SHINE kicker conceptual design and the way to integrate the design into the SHINE linac along with the FEL kicker is illustrated in Figure 2.

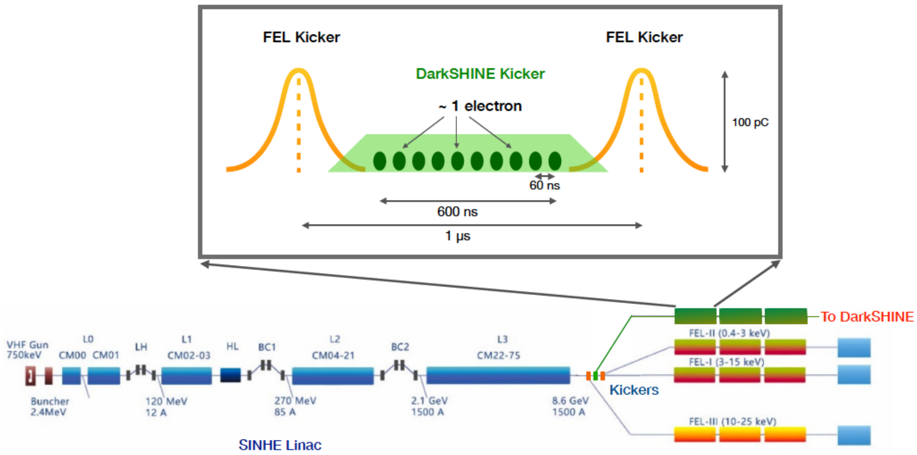


Figure 2: Dark SHINE Kicker. [6]

To measure precisely the recoil electron energy to hint the potential signal evidence of energy loss due to the presence of dark photon invisibly decaying into light dark matter particles, one needs to design also the detector system acquiring desired missing energy and missing momentum information with reasonably fast response, high resolution and radiation hardness. The Dark SHINE detector system is conceptually designed to constitute three sub-detector systems: silicon strip tracker, electromagnetic calorimeter (ECAL), and hadronic calorimeter (HCAL) as shown in Figure 3.

In MeV GeV mass range, Dark Photon invisibly decaying into light Dark Matter can be used to greatly suppress the backgrounds so that it becomes a very competitive and promising recipe among the Dark Matter search experiments. The Dark SHINE R&D team was established since 2019 and have been proactively working on the Dark SHINE experiments conceptual design and detector system prototyping, with independently developed simulation and analysis framework and gradually evolving in-lab hardware R&D activities. Based on the simulation, the team studied in details the Dark Photon signal efficiency and background rejection rate with the conceptual design prospects. In the prospective studies [6], one year run ($3 \times 10^{14}$ EOT) will gives a suppressed background yield at the level of 0.15 events, so that

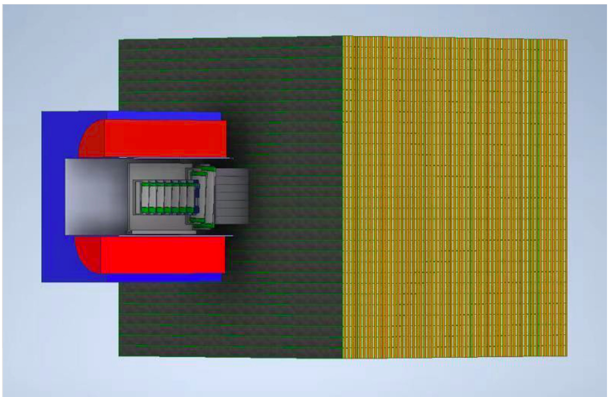

Figure 3: Dark SHINE Detector System sketch. [6]

the kinematic mixing parameter can be contrained to the level of $10^{-11}$ (for $\sim 1$ MeV Dark Photon) $\sim 3 \times 10^{-9}$ (for $\sim 100$ MeV Dark Photon), so that it can gives competitive exclusion limits on Dark Photon with respect to presently running and future experiments, as shown in Figure 4. Moreover, it is predicted that with three year runs ($9 \times 10^{14}$ EOT), many light Dark Matter models would be either concluded or excluded in MeV$\sim$GeV mass range with potentially competitive sensitivity with other international experiments.

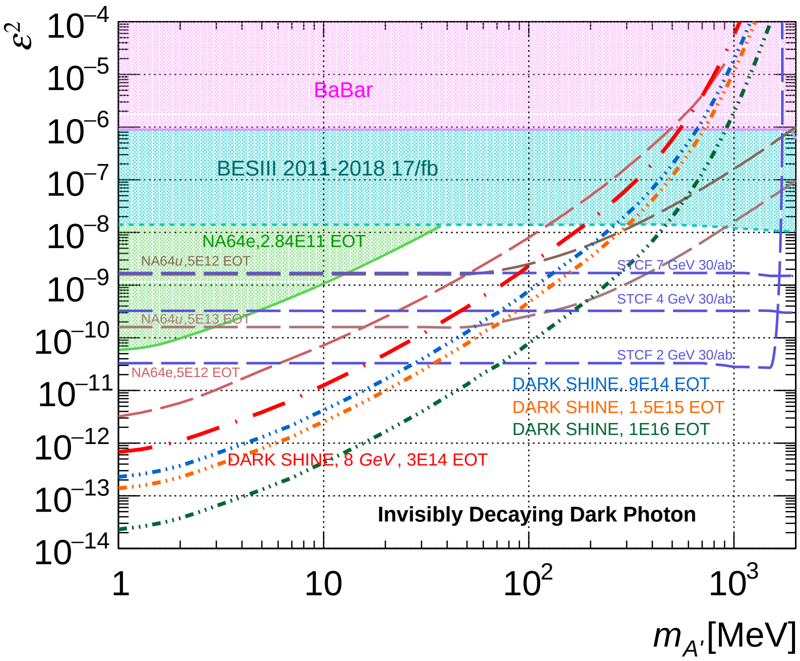


Figure 4: Dark SHINE 90% expected C.L. exclusion limits on $\epsilon^2$ as a function of the Dark Photon mass $m_{A'}$, estimated with $3 \times 10^{14}$ EOTs (red), $9 \times 10^{14}$ EOTs (blue), $1.5 \times 10^{15}$ EOTs (orange), and $10^{16}$ EOTs (green) statistics, in comparison with NA64 [7], BaBar [8], BESIII [9] (and future STCF). [6]

## References


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