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Vertex and Tracking detector for the LDMX experiment

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The constituents of dark matter (DM) are still unknown, and the viable possibilities span a very large mass range. Considerable experimental attention has been given to exploring Weakly Interacting Massive Particles in the upper end of this range (few GeV – TeV), while the region MeV to GeV is largely unexplored. If there is an interaction between light DM and ordinary matter, as there must be in the case of a thermal origin, then there necessarily is a production mechanism in accelerator-based experiments. The most sensitive way, (if the interaction is not electron-phobic) to search for this production is to use a primary electron beam to produce DM in fixed-target collisions. The Light Dark Matter eXperiment (LDMX) is a planned electron-beam fixed-target missing-momentum experiment to be based at the Linac to End Station A (LESA) beamline, which is being constructed at SLAC [1]. The LDMX experiment has unique sensitivity to light DM in the sub-GeV range and, if a signal would be observed, can estimate the dark matter mass scale. The LDMX working principle is based on the efficient reconstruction of the incoming beam electron on target as well as the precise measurement of the transverse momentum of the scattered recoil electron. The experiment employs two silicon strip based trackers, named Tagger and Recoil trackers, specifically designed to achieve the experiment physics requirements. This contribution will give an overview of the LDMX experiment tracking system, its projected performance and details on the reconstruction techniques in a highly inhomogeneous magnetic field.

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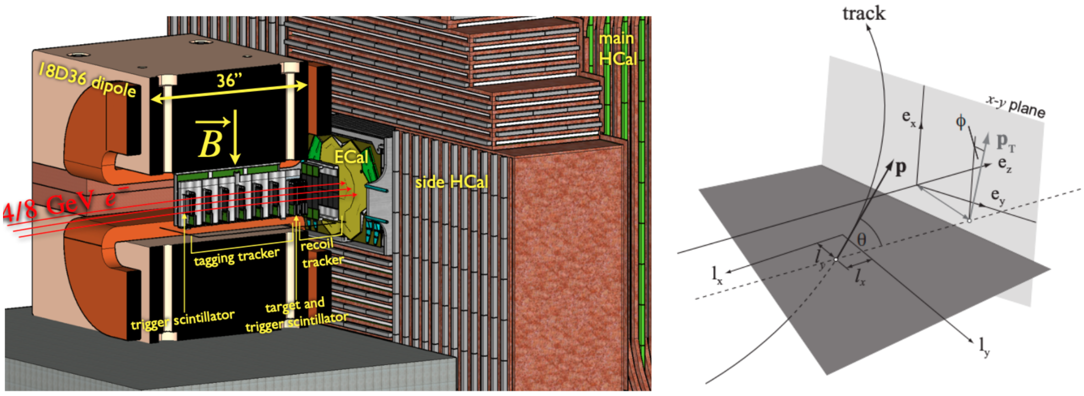
PoS(VERTEX2023)037



(a) (b)

Figure 1: (a) The LDMX detector concept. (b) Track parameters on a detector or target surface.

1. Introduction

The Light Dark Matter Experiment (LDMX) [2] is a future electron-beam-on-target experiment focusing on the search for invisible low mass Dark Matter, which can be produced through a "dark-bremsstrahlung" process in the target material. The produced Dark Matter will escape detection leading to a very clean signature with a single recoil electron with largely depleted energy with respect to the initial beam energy and significant momentum in the plane transverse to the beam direction. The design of the LDMX detector is motivated by the objective of accurately measuring both of these characteristics while effectively suppressing Standard Model backgrounds.

2. The LDMX Tracking system

The LDMX detector concept features two distinct silicon-based tracking systems as shown in Fig 1a. While a brief description is provided in this document, a more complete and detailed description can be found in [2]. The active elements of the tracking system are silicon microstrips sensors, similar to those of the Silicon Vertex Tracker for the Heavy Photon Search experiment [3], with a readout(sense) pitch of 60 μm (30μm).

The *Tagging Tracker* is composed of 7 single axial-stereo 4cm x 10cm low-mass (0.7% X_0) modules placed at 10cm intervals upstream of a 0.1 X_0 Tungsten target and immersed in a 1.5 T dipole magnetic field. The axial sensors are oriented vertically to provide the sensitive measurement ($\sigma_x \sim 6\mu m$) in the bending plane, while the stereo sensor is oriented with an alternating pattern of $\pm$100 mrad stereo angle to provide a measurement in the vertical direction ($\sigma_y \sim 60\mu m$). The design driver for the tagging tracker is the necessity to eliminate incoming electrons with energies below the beam energy, to provide a precise measurement of the tracks momentum and to ensure high fidelity pattern recognition.

The *Recoil Tracker* is a very compact tracker located in the fringe field of the dipole magnet allowing it to identify and precisely measure low-momentum electrons in the range between 50 MeV to few GeV. The recoil tracker features 4 axial-stereo layers located at 1.5cm intervals and 2

PoS(VERTEX2023)037

axial-only layers composed of 10 single-sided sensors located at 9cm and 18cm, respectively, in order to provide the best momentum measurement together with increased geometrical acceptance.

3. Event simulation and track reconstruction

Both Dark Matter signal and inclusive electron beam-on-target background simulated events are used to study the performance of the LDMX trackers, using the benchmark model with a dark photon mediator. The simulated signal events are generated with a custom version of MadGraph/MadEvent [5] with various dark-photon mass hypotheses m'_A = 1 MeV, 10 MeV, 100 MeV and 1 GeV. The inclusive electron background sample was generated directly in Geant4 and is filtered by selecting electrons that undergo Bremsstrahlung in the target volume. Both samples are generated at a beam energy E_{beam} = 4 GeV. The propagation of particles through the detector along with their interactions with material is simulated using a custom version of the Geant4 [6, 7] toolkit. A detailed description of the event simulation can be found in [4].

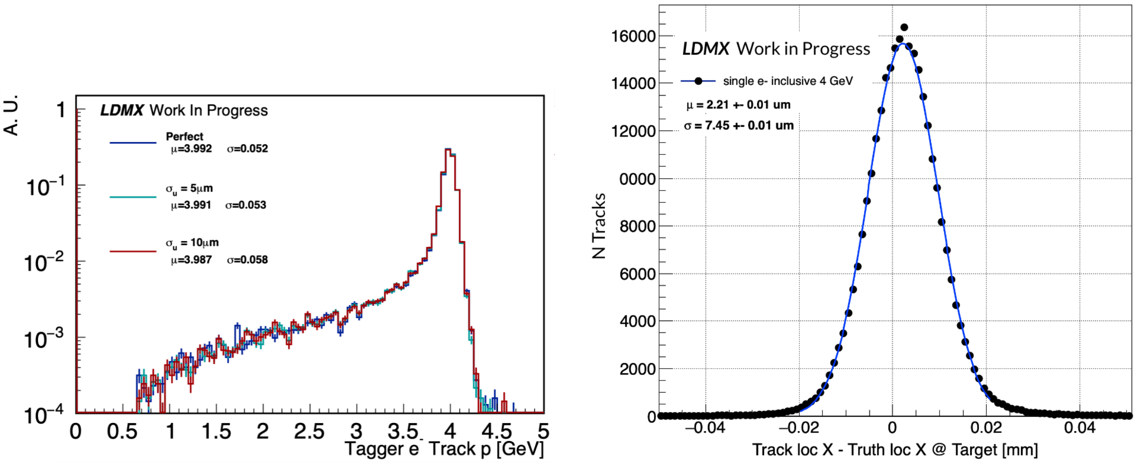
The reconstruction of charged particles in the LDMX experiment uses the algorithms implemented in the *A Common Tracking Software* (ACTS) [8] package. The ACTS track reconstruction suite is an actively developed open-source software package with contributions from various particle physics collaborations. Initially created for the ATLAS experiment at the High-Luminosity Large Hadron Collider, the library's versatile track finding and fitting algorithms enable their seamless integration into the LDMX experiment, characterized by telescope geometry and a highly non-uniform magnetic field in the rear region of the recoil tracker system. The results reported in this document are derived by using the following reconstruction chain:

- The Geant4 simulated hits left in the detector elements are smeared in order to simulate the detector response using gaussian noise corresponding to the detector resolution.
- Seed finding provides a first estimation of the track parameters which is used as an input of the track finding. A truth based seeding was chosen for the studies presented in this document. The algorithm takes the true parameters of the particles at their origin at the beam generation position or at the target for the the tagger tracker and the recoil tracker, respectively. The truth track parameters are smeared applying a gaussian noise to emulate the detector response.
- Track finding and fitting is based on a Combinatorial Kalman Filter (CKF). The parameters describing the reconstructed tracks are expressed on plane surfaces, such as detector elements or target, as shown in Fig 1b.

4. Tracking System Key Performance Parameters

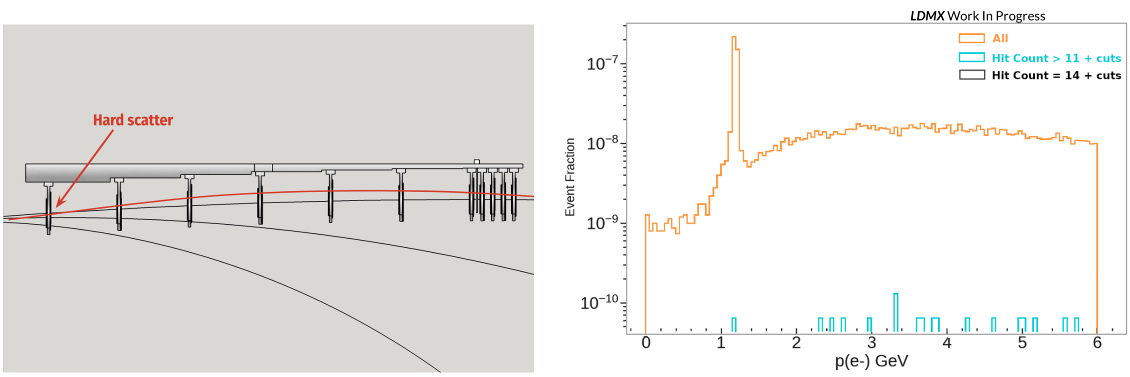
In order to extract the key performance parameters (KPP) of the trackers, reconstructed tracks are required to have $p > 50$ MeV and at least 8 strip-hits. Reconstructed tracks are also required to be matched to truth generated particles by comparing the measurements associated to each track to the Geant4 particle that produced those hits and applying a cut-off threshold. Only Geant4 particles with $p > 50$ MeV and that leave at least 8 strip-hits in the detector are considered *findable* in the studies reported in this document.

PoS(VERTEX2023)037



(a) **(b)**

Figure 2: (a) Momentum distribution for beam e^- reconstructed in the tagger tracker for E_{beam} = 4 GeV for perfect measurements and with 5μm and 10μm hit-smearing factors. (b) The residual between the local-x position of the tracks with the Geant4 particles at the target surface.



(a) **(b)**

Figure 3: (a) Sketch of an example of an off-beam-energy electron traversing the tagger tracker. (b) Reconstructed momentum for off-beam electrons for various track quality selections.

4.1 Tagger Tracker performance

In Fig 2a the momentum resolution of the tagger tracker is reported. Various smearing factors applied to the Geant4 hits were used during reconstruction in order to simulate the effects detector effects on the momentum measurement. We observe a momentum resolution of ∼ 50 MeV for an electron beam at E_{beam} = 4 GeV. The resolution on the track impact parameters at the target surface are extracted from the residual of the local predictions of the track with the Geant4 truth hits of the matched particle as shown in Fig 2b. We obtain a resolution of σ_{l_x} = 7μm and σ_{l_y} = 90μm in the horizontal and vertical direction, respectively. These results include the accounting of the detector material and indicate that by applying tight requirements on the incoming electron energy and trajectory at the target, will efficiently identify signal events and remove off-beam-energy background. In fact, one of the goals of the tagger tracker specific design is to efficiently veto

PoS(VERTEX2023)037

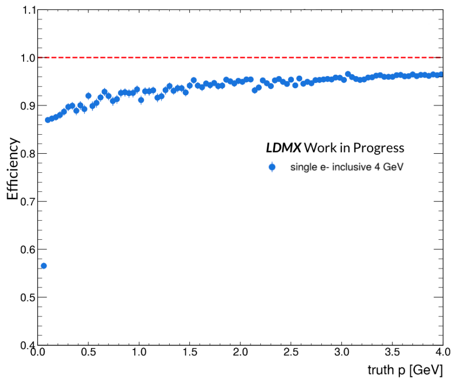


Figure 4: Reconstruction efficiency for a *findable* recoil electron particle.

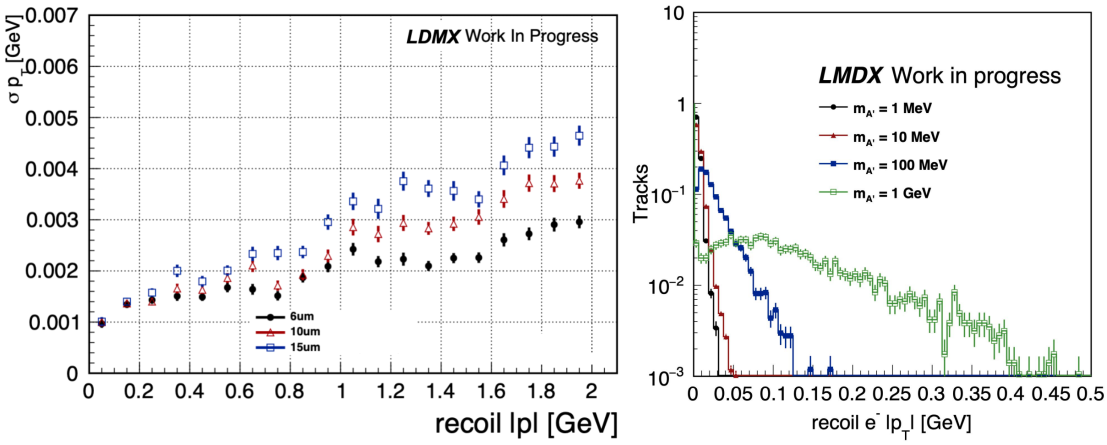
the off-energy electrons that might be deflected by large scatters in the detector material and reach the target region. This capability has been tested using a dedicated simulated sample by selecting electrons with $E_{e^-} < 1.2$ GeV[1] that leave at least 8 hits in the detector. Of the 1.5×10^{10} electrons on target (EoT) generated[2], about 6.5×10^3 passed the above requirements. In Fig 3a a sketch representing a possible trajectory of an off-beam electron undergoing a large scatter is shown. While such tracks can be efficiently removed by requiring 14 strip-hits on tracks, a considerable background is left when loosening this requirement. In order to improve the veto capabilities of the tagger tracker, reconstructed electron tracks are required to intersect the target region in the region $|l_x^{tgt}| < 10$mm and $|l_y^{tgt}| < 40$mm, corresponding to the size of the expected beamspot from simulation, and with angles at target surface $|\phi_{tgt}| < 40$mrad and $1.54 < \theta_{tgt} < 1.6$, as expected from a the nominal trajectory of a 4 GeV beam electron. With this preliminary selection, the expected efficiency in reconstructing off-beam electrons in the region $3.8 < p_{e^-} < 4.2$ GeV is around $\epsilon = 2 \times 10^{-10}$ as shown in Fig 3b.

4.2 Recoil Tracker performance

The reconstruction efficiency for electrons in the recoil tracker as function of the generated recoil electron momentum is shown in Fig 4. The reconstruction efficiency is above 90% for *findable* electrons with $p_{e^-} > 500$ MeV. A sharp drop in the reconstruction efficiency at low momenta around $p_{e^-} = 50$ MeV is observed. Since the CKF algorithm uses truth particle seeding to initiate the pattern recognition, this effect is expected to be due to a sub-optimal tuning of current track finding configuration in this kinematic region and will improve with future developments of the reconstruction chain. The recoil transverse momentum's ability to differentiate signal from background is constrained by multiple scattering in the target, estimated to lead to 4 MeV smearing in the recoil electron transverse momentum. The design of the recoil tracker, considering material budget and single-hit resolutions, ensures that transverse momentum resolution is primarily constrained by target multiple scattering across the signal recoil momentum range. Fig 5b shows the recoil electron momentum resolution in the plane transverse to the beam direction. It can be observed that the expected resolution from the tracker is better than the smearing term due to the presence of the

[1]The choice of using electrons with $E_{e^-} < 1.2$ GeV is driven by the signal region definition described in [4].
[2]This amount is equivalent to the expected off-beam background for $\sim 1 \times 10^{10}$ EoT.

PoS(VERTEX2023)037



(a)

(b)

Figure 5: (a) The recoil electron transverse momentum resolution as function of the reconstructed total momentum. (b) The recoil electron transverse momentum for various dark mediator masses hypotheses.

target material in the region of interest $p_{e^-} < 1.2$ GeV and has been also confirmed with various hit-smearing terms up to 15μm to account for larger sources of degraded resolution at hit-level. In Fig 5a, the transverse momentum distributions for signal samples are presented at different mediator masses. This demonstrates that the tracker design and the current reconstruction chain is capable of sensitivity to the mass scale of the dark matter signal.

5. Conclusions

The studies reported in this document show the track reconstruction performance with the current design of the LDMX detector tracking system. The preliminary results show that the layout mathces the expectations for the LDMX physics search. Future plans and developments will be aimed towards a more realistic setup making use of a detector digitization, a non-truth based seeder as well as studies of systematic effects on reconstruction such as misalignments of the sensitive devices and distortions of the magnetic field.

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PoS(VERTEX2023)037

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PoS(VERTEX2023)037