# The road ahead for CODEX-b

(CODEX-b collaboration)

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## I. INTRODUCTION

The primary LHC experiments (ATLAS, CMS, LHCb, ALICE) are scheduled for ongoing upgrades and data collection for at least another 15 years. A central component of the (HL-)LHC program will be searches for dark or hidden sectors beyond the Standard Model (BSM). A compelling signature of such sectors are displaced decays-in-flight of exotic long-lived particles (LLPs), which generically arise in any theory containing a hierarchy of scales or small parameters, and are therefore ubiquitous in BSM scenarios featuring *e.g.* Dark Matter, Baryogenesis, Supersymmetry or Neutral Naturalness.

The CODEX-b (*"COmpact Detector for EXotics at LHCb"*) experiment [1, 2, 4], is a unique detector, actively seeking funding, proposed to be installed near LHCbs interaction point to search for displaced decays-in-flight of exotic LLPs. In a recent Expression of Interest (EoI) [2], the physics case and extensive experimental and simulation studies were presented for the CODEX-b proposal. The core advantages of CODEX-b are: (i) Very competitive sensitivity to a wide range BSM LLP scenarios, exceeding or complementary to the sensitivity of other existing or proposed detectors; (ii) An achievable zero background environment, as well as an accessible experimental location with many of the necessary services already in place; (iii) The ability to tag events of interest within the existing LHCb detector, independently from the LHCb physics program; (iv) A compact size and consequently modest cost, with the realistic possibility to extend detector capabilities for neutral particles in the final state.

The proposed CODEX-b location is located roughly 25 meters from the LHCb interaction point 8 (IP8), with a nominal fiducial volume of 10 m×10 m×10 m (see Fig. 1). The location roughly corresponds to the pseudorapidity range $0.13 < \eta < 0.54$. Backgrounds are controlled by passive shielding provided by the existing concrete UXA radiation wall, combined with an array of of active vetos and passive shielding to be installed adjacent to IP8. The CODEX-b proposal will provide competitive sensitivity over a large range of different LLP production and decay mechanisms; extensive studies of this nature can be found in the EoI [2].

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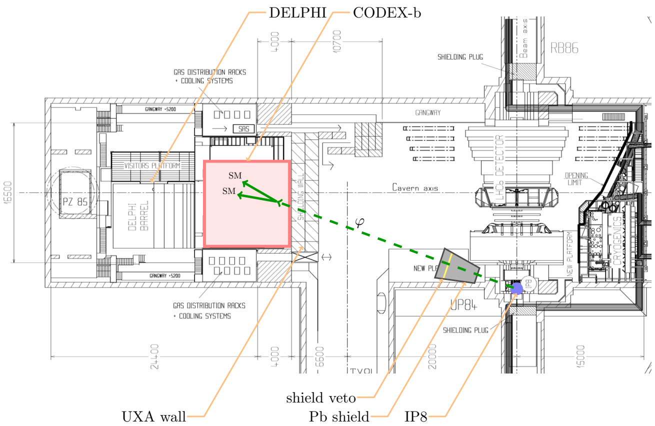


**FIG. 1:** Layout of the LHCb experimental cavern UX85 at point 8 of the LHC, overlaid with the CODEX-b volume [1].

A smaller proof-of-concept demonstrator detector, "CODEX-$\beta$", is proposed to be operated during Run 3 of the LHC, with installation planned for the winter of 2022-2023. This detector will be placed in the proposed location of CODEX-b, shielded only by the existing, concrete UXA wall. Funding to begin the development of CODEX-$\beta$ has already been secured.

## II. PROPOSAL

Multiple studies and efforts have been completed or are underway that consider various theoretical and experimental aspects of the CODEX-b detector and the CODEX-$\beta$ demonstrator. These studies touch on various questions relevant to the Snowmass Energy as well as Rare and Precision Frontiers. For each of these studies or efforts we are eager to welcome interested collaborators.

### A. Theory benchmarks

The question of how to characterize and compare reach of LLP proposals has resulted in the development of several standard benchmark models, either arising from minimal/simplified model setups, or UV complete approaches. An extensive array were considered e.g. in the Physics Beyond Colliders (PBC) report [6]. In some cases, the reach of various LLP experiments is subject to residual theory ambiguities which may be clarified further; in others, the reach estimate incorporates an incomplete description of LLP production and/or decay mechanisms.

Several of these issues were addressed in the CODEX-b Expression of Interest (EoI) [2], for example Axion-like Particle (ALP) production in parton showers and lifetimes for fermion-coupled ALPs. Several novel benchmarks were also considered. A cooperative contribution from various groups may be required to harmonize benchmark models across various existing and proposed experiments, building on the PBC report [6].

### B. Simulation, backgrounds and event reconstruction

Initial studies to optimize the event reconstruction assuming a nominal detector design have already been carried out. Because of the very low background environment, the full event reconstruction will be rather straightforward, especially in comparison with the much more challenging conditions faced by ATLAS, CMS and LHCb.

The next, ongoing steps are therefore the development of a full simulation of the detector and the corresponding event reconstruction algorithms. These tools will permit extensive simulation studies – modelling the response of LLP detector geometries to different simulated BSM production channels – in order to optimize detector sensitivity over the space of these LLP scenarios. Optimized reconstruction capabilities may further improve background rejection and reduce shielding costs. The feasibility of particle identification using pre-shower calorimeter elements will be investigated.

The many different LLP scenarios moreover feature many different signatures and kinematics, so that particle reconstruction requirements, efficiencies and acceptances vary widely. Further, in many well-motivated benchmark scenarios, the LLP may decay to various final states involving missing energy, photons, or high multiplicity, softer final states. These more complex decay morphologies can be much more challenging to detect or reconstruct, and the comparative importance of these decay modes must be accessed.

### C. CODEX-$\beta$ demonstrator detector

A first campaign to measure backgrounds has already been carried out, and has determined the muon flux at various relevant locations in the experimental hall [2, 4]. The results were used to validate an extensive `Geant4` simulation of the existing concrete shield (UXA wall, see Fig. 1).

Measurements by the CODEX-$\beta$ detector – in particular, the large expected $K_L$, muon and neutron fluxes – will permit further data-driven calibration of our `Geant4` simulations of the CODEX-b backgrounds, shielding response and the surrounding cavern [1–4], as well as our simulations of tracking, mass and event reconstruction [2].

Implementation of a full simulation of the demonstrator detector is underway. This will include the means to incorporate results into specific tunes of `Pythia8` or refined `Geant4` physics lists, relevant for LLP detector background simulation.

### D. LHCb integration

The data stream of CODEX-b can be integrated with LHCb data, permitting the tagging of events of interest in the LHCb detector. If LLP events are detected, this would aid in the identification of the underlying identity of the LLP and its production processes. Further studies are required to understand the physics potential of this capability for a number of well-motivated scenarios, e.g. Higgs VBF production and exotic $B$ meson decays.

## NEW COLLABORATORS

We are eager to welcome new collaborators, in particular physicists with an interest in detector R&D and simulation, as well as event reconstruction. If interested, please contact Phil Ilten (philten@cern.ch).


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