CODEX-\(\beta\): opening the book for CODEX-b

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7TH LLP WORKSHOP
Expression of Interest for the CODEX-b Detector


- **A Compact Detector for Exotics at LHCb**
- letter of interest released last November, arXiv:1911.00481 [hep-ex]
- letter of intent submitted
- collaboration growing: 28 contributors and 16 institutes
CODEX-b in a Nutshell
Zooming In
A Picture is Worth . . .

**Schematic**

- **LHC coverage**
  (ATLAS, CMS, LHCb)

- **Forward**
  (FASER, SHiP, NA62, . . .)

- **Transverse**
  (CODEX-b, MATHUSLA, AL3X, . . .)

**Parameters**
- $m_{\mathrm{LLP}}$
- Lighter ($\lesssim 10$ MeV)
- Heavier ($\gtrsim 10$ GeV)
- Near ($\sim m$)
- Far

$c\tau$
A Picture is Worth . . .

- **LHC coverage** (ATLAS, CMS, LHCb)
- **Forward** (FASER, SHiP, NA62, . . .)
- **Transverse** (CODEX-b, MATHUSLA, AL3X, . . .)

**Schematic**

- Lighter (≤10 MeV)
- Heavier (>10 GeV)
- $m_{\text{L}}$
- $\sqrt{s}$
Why CODEX-b?

1. we need a transverse detector at the LHC
2. probes a wide range of LLP models; complementary or competitive with existing/proposed detectors
3. accessible zero background location with necessary services, DELPHI/UXA cavern
4. integration with LHCb trigger-less readout
5. compact size and modest cost with ability to extend
• significant progress has been made
• priority is finalising CODEX-\(\beta\) design and plans
• Birmingham (James Glover) working on technical drawings
• more detailed design informed from CODEX-\(\beta\)
Reach
_model overview

vector \( A' \)  
- \( hA'A' \)  
- \( FF' \)  
  - yes  
  - no reach

scalar \( S \)  
- \( SH^\dagger H \)  
- \( S^2 H^\dagger H \)  
  - yes  
  - yes

HNL \( N \)  
- \( HLN \)  
  - yes

ALP \( a \)  
- \( \partial_\mu a q^\gamma^\mu \gamma^5 q \)  
- \( a\tilde{G}G \)  
- \( a\tilde{F}F \)  
- \( a(W\tilde{W} - B\tilde{B}) \)  
  - yes  
  - yes  
  - pending  
  - pending

production portal  
decay portal  
UV operator
Dark Photon

- no sensitivity to inclusive production from EM currents
- sensitive to production from $H \rightarrow A'A'$ decays
$\lambda = 1.6 \times 10^{-3}$

Reach

Higgs Portal
Reach

Gluon Coupled ALPs

ALP w/ gluon couplings, \( \Lambda = 1\text{TeV} \)

- CODEX-b, 300/fb
- CHARM
- Excl. 1811.03474
- FASER2, 3/ab
- REDTop, 10^{17}\text{pot}
- CODEX-b w/calo
- MATHUSLA200, 3/ab, \( \epsilon_{\text{floor}} = 10^{-5} \)

Reach
Building CODEX-b
Shielding

$K^0, n, \ldots$

- "upstream" stopped-parent secondary
- suppressed by passive shield

$\mu$

- "downstream" stopped-parent secondary
- rejected by shield veto

Pb shield

IP8

shield veto

CODEX-b

UXA wall
Background Simulation

BG Flux/300 fb$^{-1}$

$L_{\text{shield}}$ [\(\lambda_{\text{Pb}}\)]

Type; \(\varepsilon_{\text{veto}}\)

- \(n; 10^{-2}\)
- \(n; 10^{-3}\)
- \(n; 10^{-4}\)
- \(n; 10^{-5}\)

- \(K^0_L; 10^{-2}\)
- \(K^0_L; 10^{-3}\)
- \(K^0_L; 10^{-4}\)
- \(K^0_L; 10^{-5}\)
Background Measurement

0° (1) to beam line
0° (2) and 90° (3) to beam line
0° (4) to beam line
0° (5) and 45° (6) to beam line
Building CODEX-b

**Background Measurement**

- 0.2 Hz hit rate at point 2 indicates GEANT4 prediction of 10 Hz is conservative

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**25th July**

![Graph showing hit rate and luminosity rate over time.](image)

**Lumi rate**

MD, no beam till ~ 30th

- Detector positions

**10th Aug**

[Graph showing hit rate and luminosity rate over time.](image)
Building CODEX-b

**CODEX-β**

- $2 \times 2 \times 2 \text{ m}^3$ with central layer, each layer with triplet of RPCs
- each layer made of $2 \times 1 \text{ m}^2$ RPC block, 42 such layers
- expected hardware cost of 150k EUR

1. *Demonstrate the ability to detect and reconstruct charged particles which penetrate into the DELPHI cavern as well as the decay products of neutral particles decaying within the DELPHI cavern.*

2. *Detect and reconstruct a reasonable rate of neutral particles decaying inside the hermetic detector volume.*

3. *Show that CODEX-b can be integrated into the LHCb DAQ and demonstrate an ability to give a trigger to LHCb to retain an event that looks interesting in CODEX-b.*
Triplet Support

- ETA readout 1
- ETA readout 2
- Gas IO 1
- Gas IO 2
- Gas & HV IO 1
- Gas & HV IO 2
- PHI readout 1
- PHI readout 2
Outside Support

1951 mm

1892 mm
Full Structure
Outlook
Some Thoughts

- forward/beam-dump experiments give us light LLPs with medium/long lifetimes and low $\sqrt{s}$
- LHC detectors give us heavy LLPs with long lifetimes
- transverse detectors give us light LLPs with long lifetimes and high $\sqrt{s}$
- we need a transverse detector at LHC

- CODEX-b covers does not have world-leading reach . . .
- covers significant portions of parameter space
- low cost in comparison to other proposals

- clear path forward for building CODEX-b
- first steps taken, CODEX-$\beta$ plans underway

Looking for new collaborators!
Backups
Dark Sector Candidates, Anomalies, and Search Techniques

- QCD Axion
- Ultralight Dark Matter
  - Pre-Inflationary Axion
  - Post-Inflationary Axion
- Hidden Sector Dark Matter
- Hidden Thermal Relics / WIMPless DM
- Asymmetric DM
- Freeze-In DM
- SIMPs / ELDERS
- Beryllium-8
- Muon g-2
- Small-Scale Structure

Small Experiments: Coherent Field Searches, Direct Detection, Nuclear and Atomic Physics, Accelerators

- Microlensing

Backups
Simultaneous Searches

- sensitive to long lifetimes
- EM background free
- difficult to normalise

- sensitive to shorter lifetimes
- bump hunt on large EM background
- normalised from sidebands

- do both simultaneously for best of both worlds
- real-time calibration and full event reconstruction in Run 2
- inclusive dimuon from threshold and jet triggers in Run 2
- full detector readout in Run 3
Higgs Portal

\[ \lambda = 0 \]

\[
\begin{array}{c}
\text{CODEX-b} \\
\text{HADES} \\
\text{AL3X} \\
\text{CHARM} \\
\text{LHCb} \\
\end{array}
\]

\[
\begin{array}{c}
\text{FASER2} \\
\text{SHiP} \\
\text{MATHUSLA} \\
\end{array}
\]

\[
\begin{array}{c}
\text{LHCb} \\
\text{3 fb} \\
\text{10 fb} \\
\text{300 fb} \\
\end{array}
\]

\[
\begin{array}{c}
\text{NA62} \\
\end{array}
\]

\[ \lambda = 1.6 \times 10^{-3} \]

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\]

\[
\begin{array}{c}
\text{NA62} \\
\end{array}
\]
Fermion Coupled ALPs

ALP w/ universal fermion couplings, $\Lambda=1\,\text{TeV}$

- CODEX-b, 300/fb
- LHCb, $B \rightarrow K\mu\mu$
- LHCb, $B \rightarrow K^*\mu\mu$
- CHARM
- REDTop, $10^{17}$ pot
- E949
- FASER2, 3/ab
- KLEVER, $5 \cdot 10^{19}$ pot
- MATHUSLA200, 3/ab w/ $\epsilon_{\text{floor}}=10^{-5}$
Heavy Neutral Leptons

\[ |U_{eN}|^2 \] vs. \[ m_N \text{ [GeV]} \]

- NA62
- DUNE
- SHiP
- MATHUSLA(200)
- FASER2
- CODEX-b

<table>
<thead>
<tr>
<th>( m_N ) [GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

- \( 10^{-10} \)
- \( 10^{-8} \)
- \( 10^{-6} \)
- \( 10^{-4} \)
- \( 10^{-2} \)
Heavy Neutral Leptons

| $|U_{\mu N}|^2$ | $m_N$ [GeV] |
|-----------------|--------------|
| $10^{-10}$      | 0.2          |
| $10^{-8}$       | 1            |
| $10^{-6}$       | 10           |
| $10^{-4}$       | 100          |
| $10^{-2}$       | 1000         |
| $10^{-1}$       | 10000        |

Experiments:
- NA62
- DUNE
- SHiP
- MATHUSLA(200)
- FASER2
- CODEX-b
## R-parity Violating Supersymmetry

- study from Dercks, Vries, Dreiner, and Wang in PRD 99 055039 (2019)

<table>
<thead>
<tr>
<th>benchmark</th>
<th>coupling</th>
<th>production</th>
<th>decay products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\chi'<em>{122}, \chi'</em>{112}$</td>
<td>$D_s^\pm \rightarrow \tilde{\chi}^0_1 + e^\pm$</td>
<td>$\eta, \eta', \phi, K^{0,\pm} + \nu_e, e^\mp$</td>
</tr>
<tr>
<td>4</td>
<td>$\chi'<em>{131}, \chi'</em>{121}$</td>
<td>$B^{0,\pm} \rightarrow \tilde{\chi}^0_1 + X^{0,\pm}$</td>
<td>$D^\pm, D^{*\pm} + e^\mp$</td>
</tr>
</tbody>
</table>

![Graph 1](graph1.png)

![Graph 2](graph2.png)
R-parity Violating Supersymmetry

- study from Helo, Hirsch, and Wang in *JHEP 07 056 (2018)*
Neutral Naturalness

- consider fraternal twin Higgs model and search for glueball
Dark Matter Models

- a number of models considered including inelastic, co-scattering, co-annihilation, *etc.*
Backups

Backgrounds

- $10^{14}$ neutrons and $K_L^0$ per 300 fb$^{-1}$
- this requires $32\lambda$ of shielding
- $7\lambda$ from UXA wall, $25\lambda$ from lead shield
- expect $\approx 10^9$ muons per 300 fb$^{-1}$ which can produce secondaries
- $10^3 K_L^0$ per 300 fb$^{-1}$ pass through the shield
- need active layer in shield for vetoing
- update of previous studies with detailed GEANT4 study