CODEX-b: status and plans

COmpact Detector for EXotics at LHCb

[1708.09395, 1901.09966 (PBC BSM WG), 1909.xxxxx (EoI)]

Biplab Dey

+ Vava Gligorov, Simon Knapen, Michele Papucci, Dean Robinson

(for the CODEX-b WG)

EPS-HEP, 12th July 2019, Ghent
OUTLINE

1. The CODEX-b proposal and theory
2. Background studies: measurement campaign
3. Background studies: simulation
4. Track and boost reconstruction
5. Detector hardware proposals
6. Summary
CODEX-b proposal in LHCb cavern

- DAQ racks in UXA-D1 move to surface in LS2. One floor available by end-2019.
- Entire UXA-D can potentially be available.
- Instrument with tracking layers ⇒ CODEX-b

- Shielded, underground, $10 \times 10 \times 10$ m$^3$ vol, $\sim 30$ m from IP8.
- Unique feature: possibility to tag w/ LHCb events (more later).
**Complementarity:** Dark Photon Example

- Mass, coupling and $\sqrt{s}$: large $c\tau$ (v. weakly coupled) particles tend to be produced via intermediate heavy states (large $\sqrt{s}$)

- Low mass/$c\tau$ dark photons at LHCb: see C. Sierra’s morning talk.
Part of the PBC BSM WG. Featured in several Granada ES talks.

**CODEX-b: Wide Physics Reach**

- **Dark photon**
- **ALPs**
- **RPV neutralinos**
- **Dark Gluball**
- **HNL’s**

**New!**
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Understanding background rates critical for reach studies.

Summer student in 2018 to measure charged flux at different points behind the LHCb shielding wall (UXA85) [CERN-STUDENTS-Note-2018-213].

D3 platform behind shield wall, during Run II

30 × 30cm² plastic scintillators from Herschel det. in LHCb

Very successful campaign: ~ 50K triggers in 17 days

Validate simulation employing these measurements
Four measurement positions on D3 platform

30 \times 30 \times 2\text{cm}^3 parallel plates

- 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

- Rate increases from upstream (pos. 1) to downstream (pos. 4) end.
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**Geometry elements in LHCb simulation**

- Bkgd. simulation this far away from the detector is non-trivial.

- Concrete: shield wall + additional cavern shielding.

- LHCb: magnet, VELO, RICH1, TT
**Existing Cavern Shielding Elements**

- Ongoing studies: understand existing shielding elements in cavern.
- *Preliminary* studies on secondary decay vertices (MC truth):

  - Concrete wall around RICH1 “qualitatively” explains the depletion of hits in upstream region, seen in the BG measurements.
**Another background estimate study**

- LBNL group updated study with improvements in the high energy tail, neutrino, geometry, neutral-muon correlations.

1909.xxxxx (EoI), in preparation:

<table>
<thead>
<tr>
<th>BG species</th>
<th>Net ($E_{\text{kin}}^{\text{neutral}} &gt; 0.6$ GeV)</th>
<th>Shield Veto</th>
<th>Eff. yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>$0.12 \pm 0.02$</td>
<td>$(8.79 \pm 0.81) \times 10^4$</td>
<td>-</td>
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<tr>
<td>$\bar{n}$</td>
<td>$8.05 \pm 0.65$</td>
<td>$(4.59 \pm 0.19) \times 10^5$</td>
<td>$\gtrsim 1$</td>
</tr>
<tr>
<td>$\bar{n}$ (no cut)</td>
<td>$(3.24 \pm 0.72) \times 10^{-3}$</td>
<td>$83.60 \pm 67.30$</td>
<td>$\ll 1$</td>
</tr>
<tr>
<td>$K_L^0$</td>
<td>$0.35 \pm 0.04$</td>
<td>$(3.25 \pm 1.60) \times 10^3$</td>
<td>$\lesssim 0.1$</td>
</tr>
<tr>
<td>$K_S^0$</td>
<td>$(5.26 \pm 1.14) \times 10^{-3}$</td>
<td>$(2.45 \pm 1.74) \times 10^2$</td>
<td>$\ll 1$</td>
</tr>
<tr>
<td>$\nu + \bar{\nu}$</td>
<td>$(2.32 \pm 0.00) \times 10^{13}$</td>
<td>$(2.96 \pm 0.07) \times 10^6$</td>
<td>$\lesssim 0.1$</td>
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<tr>
<td>$p^+$</td>
<td>$(1.29 \pm 0.25) \times 10^2$</td>
<td>$(1.62 \pm 0.06) \times 10^6$</td>
<td>-</td>
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<tr>
<td>$e^+$</td>
<td>$(3.47 \pm 0.18) \times 10^2$</td>
<td>$(2.08 \pm 0.01) \times 10^7$</td>
<td>-</td>
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<tr>
<td>$\pi^+$</td>
<td>$10.90 \pm 1.05$</td>
<td>$(5.73 \pm 0.34) \times 10^5$</td>
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<tr>
<td>$\pi^-$</td>
<td>$9.91 \pm 0.92$</td>
<td>$(5.37 \pm 0.33) \times 10^5$</td>
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<tr>
<td>$K^+$</td>
<td>$0.60 \pm 0.23$</td>
<td>$(7.15 \pm 2.84) \times 10^3$</td>
<td>-</td>
</tr>
<tr>
<td>$K^-$</td>
<td>$0.15 \pm 0.08$</td>
<td>$(2.43 \pm 1.68) \times 10^3$</td>
<td>-</td>
</tr>
<tr>
<td>$\mu^+$</td>
<td>$(9.40 \pm 0.01) \times 10^4$</td>
<td>$(9.40 \pm 0.01) \times 10^9$</td>
<td>-</td>
</tr>
<tr>
<td>$\mu^-$</td>
<td>$(7.28 \pm 0.01) \times 10^4$</td>
<td>$(7.28 \pm 0.01) \times 10^9$</td>
<td>-</td>
</tr>
</tbody>
</table>
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Towards signal track reconstruction...

- Resistive Plate Chambers (RPC’s) – fast, precise, cheap for large area
- 6 RPC layers at 4 cm intervals on each box face with 1 cm granularity

- 5 equally spaced triplets along the depth to minimize distance between reconstructed vertex and 1st measurement. \( \epsilon_{\text{tracking}} \sim O(1) \).
- \( O(100) \) ps (R&D) timing from RPC’s for mass reconstruction
**Track reconstruction**

- Preliminary tracking in place for nominal geometry:

Angle reconstruction:

Reconstruction efficiency:
**Boost reconstruction**

- **Boost** determination important for sensitivity to the LLP mass
- Studies ongoing on both 2-body $A' \rightarrow \mu\mu$ and more complicated multi-body $A' \rightarrow \tau\tau$, with $\tau \rightarrow 3\pi$ topology.
- **Neural net** from topological variables to reconstruct boost.
- **Optimize geometry** from # hits in different RPC planes.

**exotic $h \rightarrow A'$**

$m_{A'} = 20$ GeV
Tagging CODEX-b events with LHCb activity

- CODEX-b is around 30 m (100 ns) from LHCb IP8: 4 LHC bunch crossings

- Tagging CODEX-b with LHCb activity could be very interesting.

- Studies ongoing with $h \rightarrow A'A'$, $A' \rightarrow \mu\mu$, with one $A'$ each in LHCb/CODEX-b acceptance.

- Associated jets (in LHCb) studies from exotic Higgs production.

- Also $b \rightarrow X_s\chi$ and $b \rightarrow X_c\mu N$ where the SM particles are detected inside LHCb
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RPC’s from ATLAS Muon Upgrade

- RPC technology + expertise from ATLAS Muon Upgrade as baseline
- ATLAS Phase I (BIS78) upgrade for the demonstrator: 1mm gas gap, 1.2mm bakelite electrodes, 25 mm strips ($\sigma \sim 1\ mm$ w/ charge-centroid analysis)

BIS78 pre-final prototype assembly (BB5, CERN site)

- ATLAS Phase II Upgrade (BI) RPC’s for full CODEX-b.
- 20mm strips, faster integrated FE.
CODEX-b demonstrator for Run III

- $2 \times 2 \times 2m^3$ box: 1/25 of the full detector

- Install in D1 during 2021 for data taking during Run III.

- Uses 14 ATLAS BIS78 triplet chambers.

- ATLAS BI type R/O: will deploy preliminary version of TDC integrated in the FPGA. Time resolution $\sim 800/\sqrt{12} \sim 230$ ps.

- Main goals: detect $K_L^0$'s and proof of concept for R/O integration with LHCb.

- Fruitful discussion with LHCb management in March’19. Received list of materials to prepare ⇒ EoI targeting Sep’19 LHCb week.
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SUMMARY AND OUTLOOK

- CODEX-b: wide physics reach, complementary with other experiments/proposals. Relatively inexpensive.

- Progress in understanding 2018 BG measurements, via simulation as well as CODEX-b BG simulation ongoing.

- Boost-reco/tracking performance on-track or better than in proof-of-concept paper.

- Concrete proposal to install a $2 \times 2 \times 2m^3$ demonstrator using ATLAS Phase I Upgrade RPC’s in end 2021.

- Preparing an EoI for submission to LHCb management.
List of contributors/collaborators

- Theory: J. Evans, S. Knapen, M. Papucci, H. Ramani, D. Robinson
- LHCb expertise and help: M. Frank, G. Corti, B. Couturier, D. Mueller, N. Neufeld, R. Lindner and others
- New collaborators are most welcome
Backup slides
If DELPHI is removed, access to even $20 \times 10 \times 10$ m box.

Angular acceptance $\sim 1\%$. 
**Infrastructure support requests to LHCb**

- **Infrastructure**: space, power, gas. Gas racks close to D1.

- **Online**: LHC clock (BXID) and LHCb tagging information

- **Backend** readout has two possibilities:
  - BE close to FE in D1 and standalone CODEX-b R/O sent to surface. Bring LHC clock to D1.
  - Data sent from D1 to UX85B (LHCb side) to be integrated into the LHCb stream.

- From ATLAS RPC group: BIS78 R/O has an FPGA-based DCT board that collects data from the FE’s.

- The DCT board hosts one IpGBTx chip that should communicate with an LHCb PCIe40 board via bi-dir. GBT links.