

# Background measurements and simulation for CODEX-b

CERN summer student report

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## Abstract

Include abstract here.

1      List of changes between versions

2      • version 1

3            – Start version.

4      • version 1.01

5            – Add figures in each section and rewrite.

6      • version 1.02

7            – Add contents at each section.

8      • version 1.03

9            – Write summary and change the size of pictures.

10     • version 1.04

11        – First draft for the report.

12     • version 1.05

13        – Change the author list and mention that this is a summer student report.

14        – Remove bold, fix colloquial, change word.

15        – Modify the first sentence in meamesurment.

16        – Mention at the Figure 5, this is not approved officially.

17        – Fix caption at the Table 1.

18        – Add more explanation at the last part of simulation chapter.

19        – Divide to subfigure (Need to fix)

# 20 1 Introduction and motivation

21 This is the reference [1]

22 “The results shown are unofficial and have not been formally approved by the  
23 LHCb collaboration”

## 24 1.1 Motivations

25 There is no clear observation of new physics (NP) at the LHC as yet. The NP portal is  
26 considered in weakly coupled sector with long lifetime. The long lifetimes are very generic  
27 in any theory with multiple mass scales, broken symmetries, etc. Standard Model (SM) is  
28 a good example since it contains low mass particles with long lifetime such as electron,  
29 neutrino, proton and neutron. There are several experiments for searching longlived  
30 particles (LLPs). Likewise we introduce a new detector to measure LLPs based on high  
31 luminosity large hadron collider (HL-LHC).

## 32 1.2 Compact Detector for Exotics at LHCb

33 The Compact Detector for Exotics at LHCb (CODEX-b) was proposed to detect weakly  
34 coupled LLPs in LHCb cavern. Since ATLAS and CMS focused on high  $p_T$  and large  
35 QCD backgrounds and restricted lifetime of LHCb, current detectors can miss signals  
36 from weakly coupled LLPs. By following the fig. 1, the DAQ racks will be moved to the  
37 surface before run 3 and the CODEX-b will be placed at the site with 10 X 10 X 10 m  
38 size. The CODEX-b apart 25 m from the impact point 8. If the DELPHI is removed,  
39 the size can be expanded to 20 X 10 X 10 m.

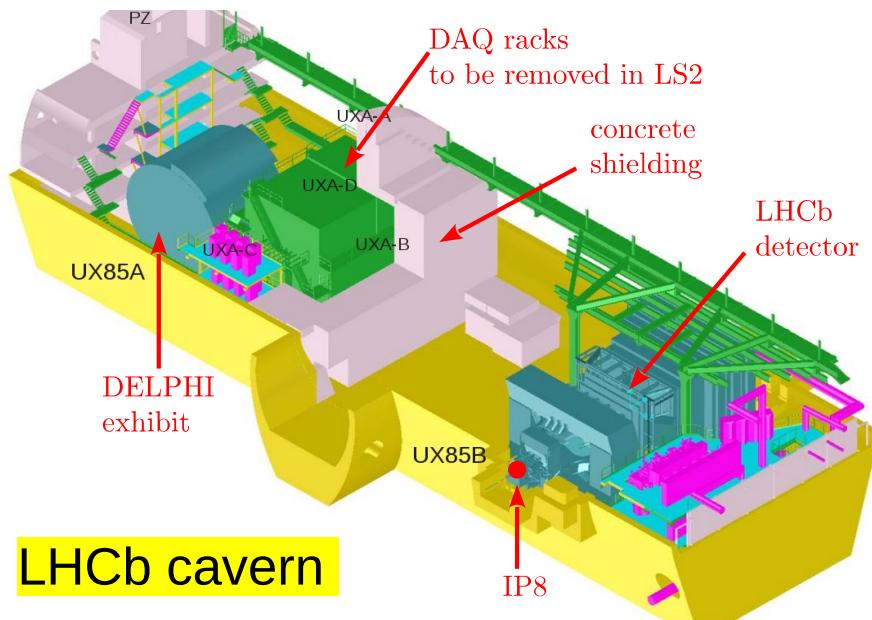


Figure 1: Schematic plot of LHCb cavern

## 40 2 Measurement

### 41 2.1 Test-bench

42 We used scintillators from the Herschel detector. [1] For PMT, model: R1828-01 Because,  
43 it has high anode current upper limit, wide range of gain variation, fast time response to  
44 fit in 25 ns, large entry window to increase light yield, good single electron separation. The  
45 test-bench includes cosmic stand, scope with extended functions (auto save waveforms,  
46 coincidence logic), high voltage power supplies (1.5 kV, bias 350 V), current-voltage meter,  
47 laptop to remote connect to scope.

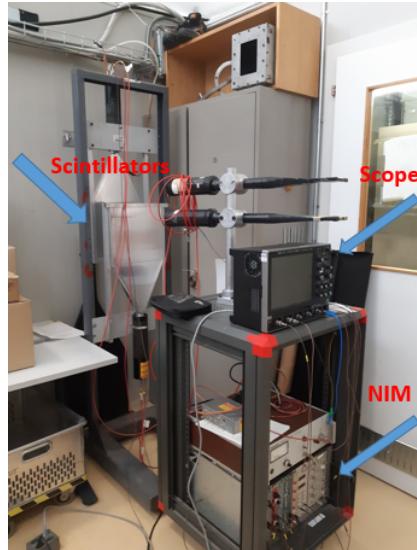


Figure 2: Test-bench photo

### 48 2.2 Trigger

49 We used simple 2x fold coincidence and a distance between two scintillators 2 cm. For  
50 this measurement, a discrimination (scope) threshold set as 30 mV. When first scintillator  
51 receive a signal and the other scintillator also receives a signal in 5 ns, scope counts.  
52 The scope automatically saved two waveforms from each scintillator and the number of  
53 minimum ionizing particles (mip) counted during the run. The test-bench and trigger had  
54 been tested with cosmic rays in the lab. Figure 3 is a scope screen when triggering the  
55 cosmic rays.



Figure 3: Trigger setup using coincidence occurrence of two signals in 5 ns.

## 56 2.3 Detail Configuration

57 The background measurement was taken at the LHCb cavern on D3 platform. The  
 58 equipment had been set at 3 positions between DAQ racks and the concrete shield wall  
 59 and the position between the DELPHI and DAQ racks. We basically placed the scintillator  
 60 stand parallel to the beam line but also rotated 45° and perpendicular to the beam line.  
 61 Fig 4. shows positions and configurations of measurement.

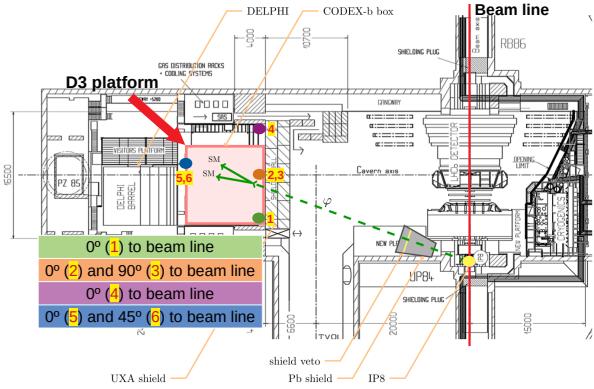


Figure 4: Four measurement positions at the LHCb cavern

## 62 2.4 Results

63 The measurement campaign spanning 17 days in July-Aug 2018. The scope performed  
 64 52036 triggers during the run. The LHCb lumi rate was stable during the measurement.  
 65 There was no beam until July 30th because of machine develop and power cut happened  
 66 during measurement.

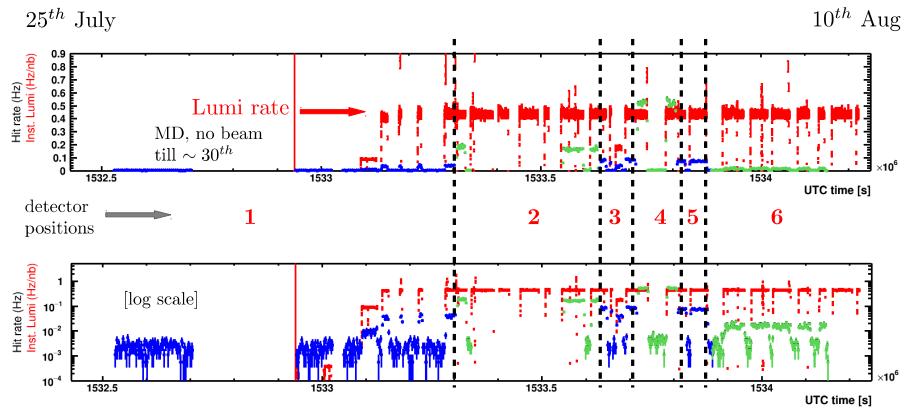


Figure 5: Hit rate plots during the run based on 6 positions/configurations linear and log scale. Red dots mean the lumi rate of LHCb, blue and green dots mean hit rates. The results are not approved by the LHCb collaboration.

67 Below tables are shown hit rate based on measurement position and configuration.  
 68 The rate of  $pp$  collisions is 25 MHz. First table is about ambient background hit rate  
 69 between fills and in MD without beam.

Position	Description	Hit rate [mHz]
P1	shield, right corner, $\parallel$ to beam	$1.99 \pm 0.07$
P2	shield, center, $\parallel$ to beam	$2.76 \pm 0.03$
P3	shield, center, $\perp$ to beam	$2.26 \pm 0.03$
P4	shield, left corner, $\parallel$ to beam	$3.11 \pm 0.03$
P5	shield + D3 racks, center, $\parallel$ to beam	$1.95 \pm 0.03$
P6	shield + D3 racks, center, $45^\circ$ to beam	$2.22 \pm 0.02$

Table 1: Background hit rates based on each configuration when beam is offline

Position	Description	Hit rate [mHz]
P1	shield, right corner, $\parallel$ to beam	$38.99 \pm 0.99$
P2	shield, center, $\parallel$ to beam	$167.10 \pm 1.43$
P3	shield, center, $\perp$ to beam	$82.81 \pm 1.55$
P4	shield, left corner, $\parallel$ to beam	$517.45 \pm 3.52$
P5	shield + D3 racks, center, $\parallel$ to beam	$73.58 \pm 1.18$
P6	shield + D3 racks, center, $45^\circ$ to beam	$15.71 \pm 0.33$

Table 2: Average hit rates during the stable beam measured by the Herschel detector

70        The average hit rate of each position and configuration is 2 mHz. It is indicated that  
 71        background can be negligible. However, during stable beam, hit rate increases a large. By  
 72        moving position from P1 to P2, from P2 to P4, we found that hit rate depends on  $\eta$ . Also,  
 73        DAQ racks add some shielding effect based on the hit rates of P5 and P6.

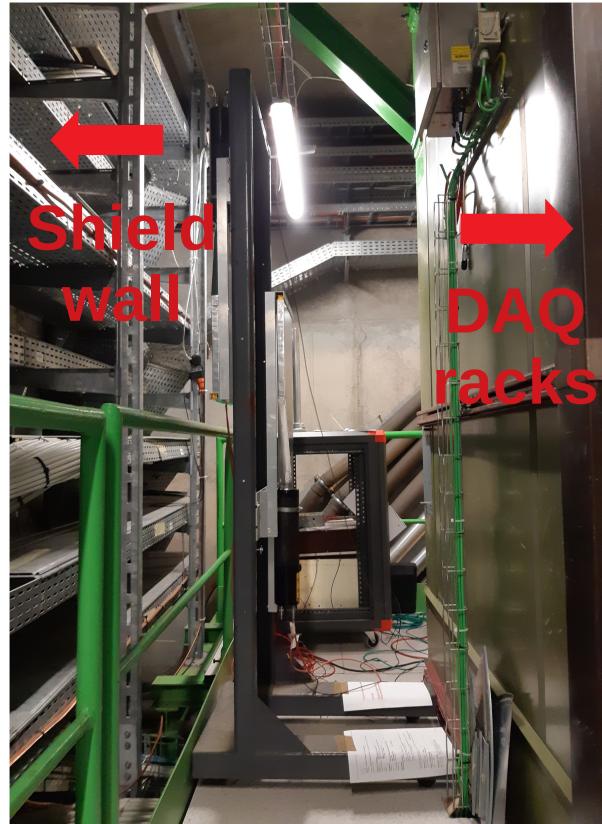


Figure 6:  $\parallel$  to the beam line (P1)



Figure 7:  $\perp$  to the beam line (P3)



## 74 3 Simulation

### 75 3.1 Detector Description for High Energy Physics

76 We used Detector Description for High Energy Physics (DD4hep) standalone version.  
77 DD4hep is a software framework to provide overall detector description for experiments.  
78 It offers a consistent description through a single source of detector information for  
79 simulation, reconstruction, analysis, etc. Additionally, DD4hep being developed for high  
80 luminosity large hadron collider (HL-LHC) detector simulation. During the internship,  
81 we built the geometry of CODEX-b constructing hierarchy system. We designed concrete  
82 shield wall to block particles from particle gun or MC and herschel detector since we used  
83 as a scintillator for our measurement. For validation  $\mu$  particle gun and minbias event  
84 had been used. We also checked energy deposits and positions of CODEX-b hits.

### 85 3.2 Simulation geometry

86 First geometry is the CODEX-b. CODEX-b consists of two parts face station and inner  
87 station. Based on the paper, face station has 6 resistive plate chambers (RPCs) layers  
88 at 4 cm intervals with 1 cm granularity. The size of each layer is  $10 \times 10 m^2$  and the  
89 thickness is 2 cm. In this simulation we had been implemented layers as a tracker instead  
90 of RPCs. Inner station also has same configuration except number of layers. It will be  
91 equally spaced with triplets along the depth to minimize distance between reconstructed  
92 vertex and 1st measurement.

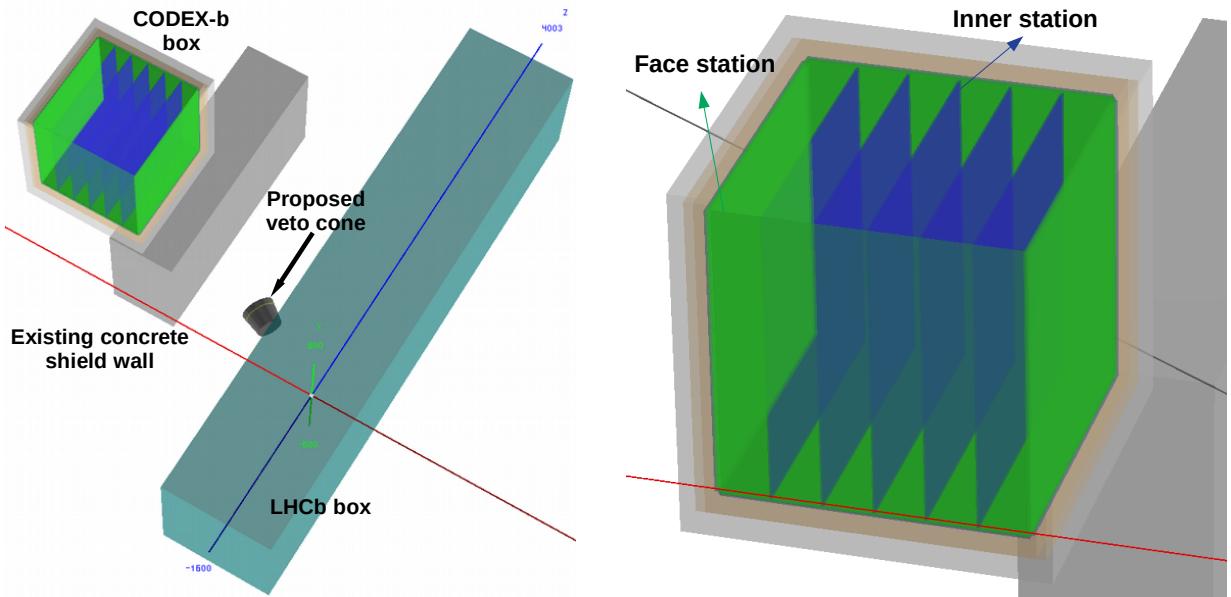


Figure 11: Wide view of CODEX-b simulation geometry

93 We also created a concrete shield wall with 3.2 m thickness. It was placed just front  
94 of CODEX-b box. Between the LHCb box and the concrete wall, there is a proposed veto  
95 cone. It contains two lead absorber and one active silicon layer.

96 Second geometry was consists of two scintillator plates which is the same as our  
 97 measurement configurations. The material of scintillator was

### 98 3.3 Simulation status

99 We designed two different detectors based on the paper and the measurement, the former  
 100 is the CODEX-b and the latter is a scintillator. Both were tested with  $\mu$  particle gun  
 101 with 1 TeV and the minimum bias events generated from the standalone Gauss.

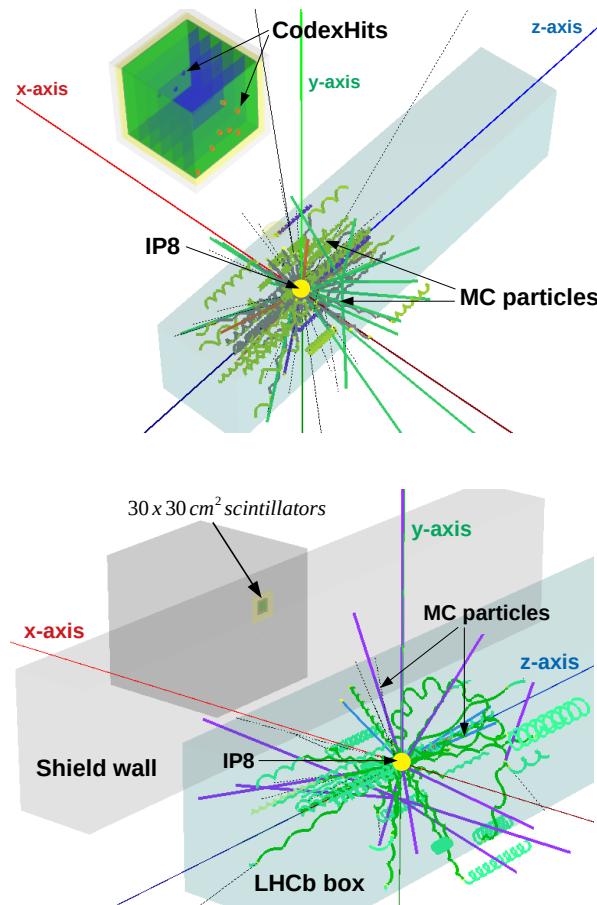


Figure 12: Validation of the CODEX-b simulation by removing the concrete shield wall with minimum bias events

102 There was no hits on the CODEX-b layers when tested minbias events with the  
 103 concrete wall. We decided to remove the shield wall to check performance of layers. The  
 104 Figure 8 upper plot is shown that hits from minbias events. Also we recovered the concrete  
 105 wall and changed CODEX-b geometry to two scintillator plates and tested with minbias  
 106 events. Following the lower plot of Fig 8, there is no hit on the scintillators. Because its  
 107 size is too small to measure hits and the concrete wall blocks particles from collisions.

108 **4 Summary**

109 It was a very successful measurement campaign at D3 platform. We measured hit rates of  
110 mip based on 2x fold coincidence trigger using Herschel detector and scope. We could  
111 also manage run and data by remote connect to scope. The average hit rates in the stable  
112 beam condition is much higher than the average hit rates of pure background. Based  
113 on this result, we can ignore pure background. The background rate just behind the  
114 concrete shield wall around 0.5 Hz over  $900 \text{ cm}^2$  size scintillators. Also the hit rates have  
115  $\eta$  dependence when moving far from the impact point. The D3 racks behave like a shield  
116 from the P5 and P6 results but it is difficult to simulate because of complicated structure.

117 About the simulation, DD4hep had been used to design CODEX-b and background  
118 measurement campaign. Built a hierarchy system to implement a bundle of 6 silicon  
119 layers (these layers are planned to change to RPC layers) and a triplet bundle. Reminding  
120 that CODEX-b geometry is a final version. Detail information about components of  
121 designed CODEX-b using DD4hep is following. The layer runs as a tracker which measure  
122 hit position of particles and the size is  $10 \times 10 \text{ m}^2$  with 2 cm thickness. Using similar  
123 hierarchy system, background measurement campaign geometry had been made. The size  
124 of scintillator plate is  $30 \times 30 \text{ cm}^2$  and 2 cm thickness. The distance of them is 2 cm. The  
125 material of scintillator is the same as the Herschel detector. Veto cone and concrete shield  
126 wall were generated using DD4hep.

127 All geometries were tested with  $\mu$  particle gun with and without concrete shield wall.  
128 There were hits on the layers without shield wall and checked particles hit positions  
129 and deposit energy. Tested with minimum bias events generated from standalone Gauss  
130 showed hits on the layers without concrete wall. When the wall was existed, there was no  
131 hit on the layers. These results indicate that every part in the simulation worked properly.

132 The future plan is working on more efficient MC generation in Gauss with generator  
133 cuts and optimizing the simulation environments.

<sup>134</sup> **References**

- <sup>135</sup> [1] V. V. Gligorov, S. Knapen, M. Papucci, and D. J. Robinson, *Searching for Long-lived*  
<sup>136</sup> *Particles: A Compact Detector for Exotics at LHCb*, Phys. Rev. **D97** (2018) 015023,  
<sup>137</sup> arXiv:1708.09395.