

# Background measurements and simulation for CODEX-b

CERN summer student report

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## Abstract

CODEX-b is a newly proposed detector [1] inside the existing LHCb cavern to search for long-lived particles, predicted in many extensions of the Standard Model. A critical component in the physics reach studies here is good understanding of the expected background rates inside the cavern. As CERN summer student in June-August, 2018, I participated in a campaign to measure the background in the UX85A cavern during Run 2  $pp$  collision data-taking. The measurements were performed at various positions and different configurations on the D3 platform in UXA just behind the existing concrete shield wall, and was very successful. In addition, I also developed a simulation framework for CODEX-b and the measurement setup using a **ROOT** based Detector Description package called **DD4Hep**, that will be used by the LHC experiments in the Upgrade era. Preliminary results not officially approved by the LHCb collaboration, are presented 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            – Remove empty paper.

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

15            – Remove bold, fix colloquial, change word.

16            – Modify the first sentence in meamesurment (Reference should be fixed).

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

18            – Fix caption at the Table 1.

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

20            – Divide to subfigure (Need to fix).

21            – Enlarge the last figure at the simulation chapter.

22            – Add acknowledgements.

23            – Add abstract

24     ● version 1.06

25            – Modifications to figures etc. by BD.

26     ● version 1.07

27            – Fix the sentences in section 2.1.

28            – Add DD4hep reference at the first sentence in section 3.1 (Reference should be updated at the last page).

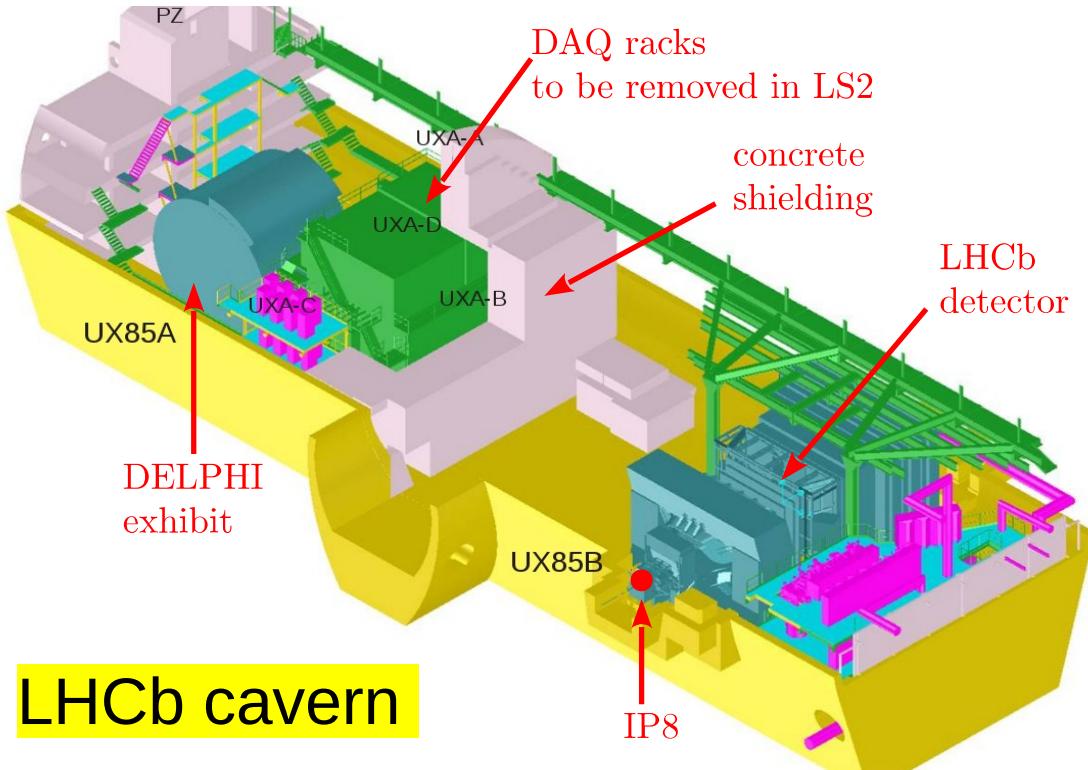


Figure 1: A schematic plot of the LHCb cavern.

## 1 Introduction and motivation

The discovery of the Higgs at the LHC in 2012 filled in the last missing piece of the Standard Model (SM). Apart from a few so-called “anomalies”, mostly in the flavor sector, the SM has been a spectacular successfully theoretical framework that can account for all observed phenomena. Yet, we know that it is also an incomplete theory that can not account for gravity, dark matter, observed matter-antimatter asymmetry in the universe, among other problems. NP searches at the LHC experiments have mostly focused on production of new particles that decay promptly, within the detector volume. However, an important NP portal is one that is very weakly coupled sector with the SM and therefore includes particles with long lifetimes. In fact, long lifetimes are very generic in any theory with multiple mass scales, broken symmetries, or restricted phase-space. The SM itself contains templates for low mass long lived particles (LLP) such as electron, neutrino, proton and neutron. There are several experiments for searching longlived particles (LLPs). Likewise we introduce a new detector to measure LLPs based on high luminosity large hadron collider (HL-LHC).

### 1.1 Compact Detector for Exotics at LHCb

The Compact Detector for Exotics at LHCb (CODEX-b) was proposed to detect weakly coupled LLPs in LHCb cavern. Since ATLAS and CMS focused on high  $p_T$  and large QCD backgrounds and restricted lifetime of LHCb, current detectors can miss signals from weakly coupled LLPs. By following the fig. 1, the DAQ racks will be moved to the surface before run 3 and the CODEX-b will be placed at the site with 10 X 10 X 10 m

51 size. The CODEX-b apart 25 m from the impact point 8. If the DELPHI is removed,  
52 the size can be expanded to 20 X 10 X 10 m.

## 53 **1.2 Other detector proposals for searching LLPs at LHC**

54 Not only the CODEX-b but also there are other detector proposals to search long-lived  
55 particles at LHC. The MATHUSLA (MAssive Timing Hodoscope for Ultra Stable neutrAL  
56 pArticles), the milliQan and the FASER (ForwArd Search ExpeRiment at the LHC)  
57 are based on the collider experiment. Also, there is a detector based on beam dump  
58 experiment called the SHiP (Search for Hidden Particles). CODEX-b has advantages  
59 comparing other detectors. Since the CODEX-b will be implemented underground and  
60 next to the concrete wall, it is easy to control background. It is expected that cosmic rays  
61 are blocked by ground and particles from beam collisions are blocked by the concrete wall.  
62 Also it will take less price because it plans to use existed place and equipments.

## 63 **2 Measurement**

### 64 **2.1 Test-bench**

65 We used scintillators from the Herschel detector. In this measurement, we used photo-  
66 tomultiplier tubes (PMT) R1828-01 model made from HAMAMATSU. Because it has  
67 high anode current upper limit, wide range of gain variation, fast time response to fit in  
68 25 ns, large entry window to increase light yield, good single electron separation. The  
69 test-bench includes cosmic stand, scope with extended functions (auto save waveforms,  
70 coincidence logic), high voltage power supplies (1.5 kV, bias 350 V), current-voltage meter  
71 and scintillators from the Herschel detector.

### 72 **2.2 Trigger**

73 We used simple 2x fold coincidence and a distance between two scintillators 2 cm. For  
74 this measurment, a discrimination (scope) threshold set as 30 mV. When first scintillator  
75 receive a signal and the other scintillator also receives a signal in 5 ns, scope counts.  
76 The scope automatically saved two waveforms from each scintillator and the number of  
77 mininum ionizing particles (mip) counted during the run. The test-bench and trigger had  
78 been tested with cosmic rays in the lab. Figure 3 is a scope screen when triggering the  
79 cosmic rays.

### 80 **2.3 Measurements positions and configurations on the D3 plat- 81 form**

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

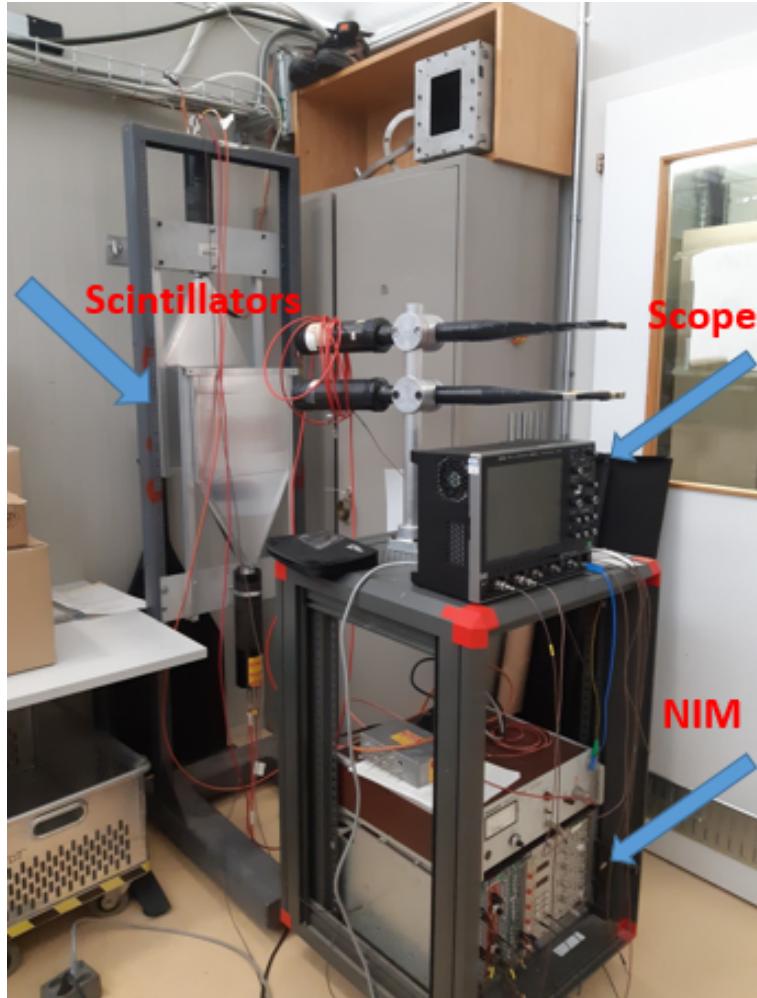


Figure 2: Test-bench assembly in the VeloPix lab, showing the Herschel scintillators, the DAQ system comprising a NIM crate and oscilloscope.

## 87 2.4 Results

88 The measurement campagin spanning 17 days in July-Aug 2018. The scope performed

89 52036 triggers during the run. The LHCb lumi rate was stable during the measurement.

90 There was no beam until July 30th because of machine develop and power cut happened

91 during measurement.

92 Below tables are shown hit rate based on measurement position and configuration.

93 The rate of  $pp$  collisions is 25 MHz. First table is about ambient background hit rate  
94 between fills and in MD without beam.

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



Figure 3: Trigger setup using coincidence occurrence of signals from the two scintillator PMT's within 5 ns.

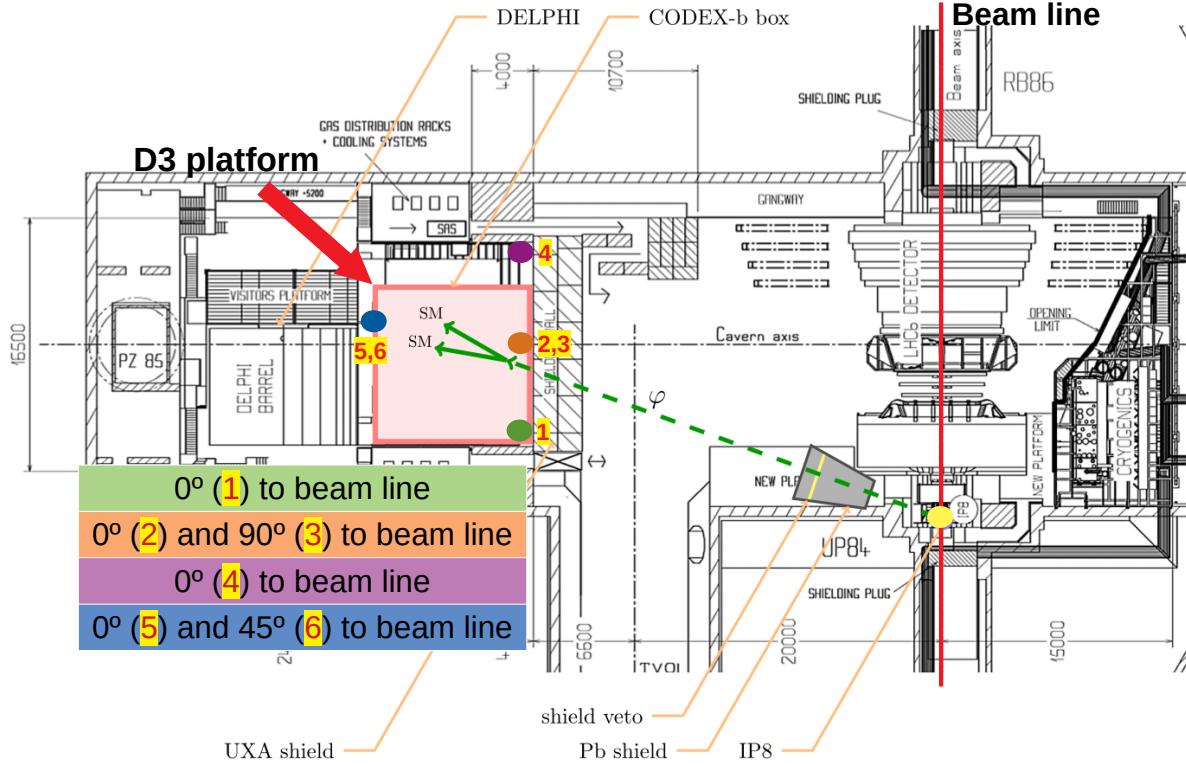


Figure 4: The four measurement positions on the D3 level inside the LHCb cavern. The configurations are labelled from P1-P6.

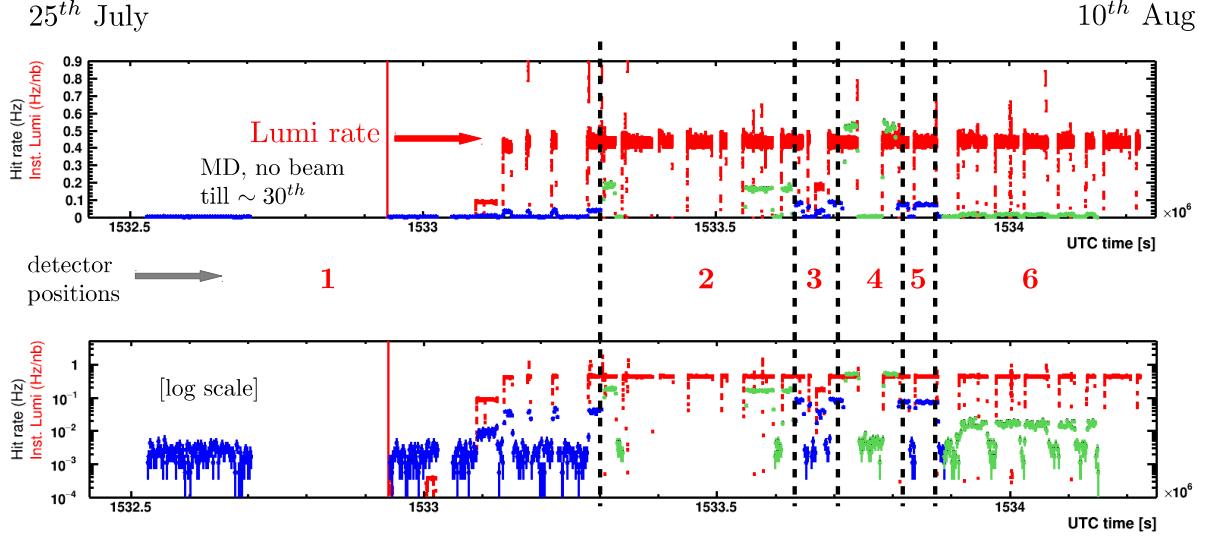


Figure 5: Hit rate plots during the run based on 6 positions/configurations linear and log scale. Red dots mean the lumi rate of LHCb, blue and green dots mean hit rates. The results are not approved by the LHCb collaboration.

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 the beam is off.

### 99 3 Simulation

#### 100 3.1 Detector Description for High Energy Physics

101 We used Detector Description for High Energy Physics (DD4hep) standalone version [2].

102 DD4hep is a software framework to provide overall detector description for experiments.

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 measured during stable beam, at various configurations.

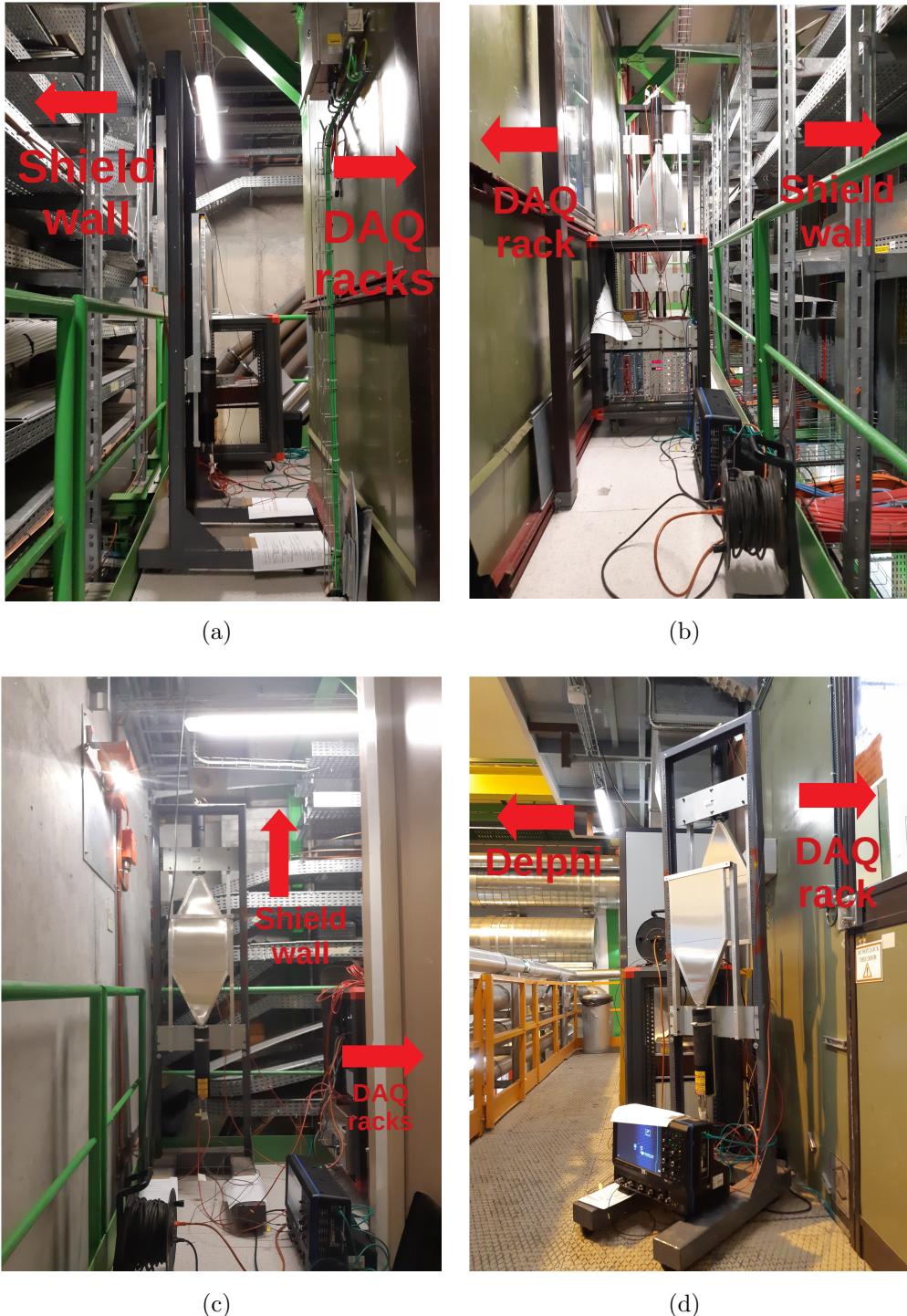


Figure 6: Photos of the equipment setup at various positions on the D3 platform: (a) P1, (b) P3, (c) P4, and (d) P6.

103 It offers a consistent description through a single source of detector information for  
 104 simulation, reconstruction, analysis, etc. Additionally, DD4hep being developed for high  
 105 luminosity large hadron collider (HL-LHC) detector simulation. During the internship,  
 106 we built the geometry of CODEX-b constructing hierarchy system. We designed concrete

107 shield wall to block particles from particle gun or MC and herschel detector since we used  
108 as a scintillator for our measurement. For validation  $\mu$  particle gun and minbias event  
109 had been used. We also checked energy deposits and positions of CODEX-b hits.

### 110 3.2 Simulation geometry

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

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

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

### 123 3.3 Simulation status

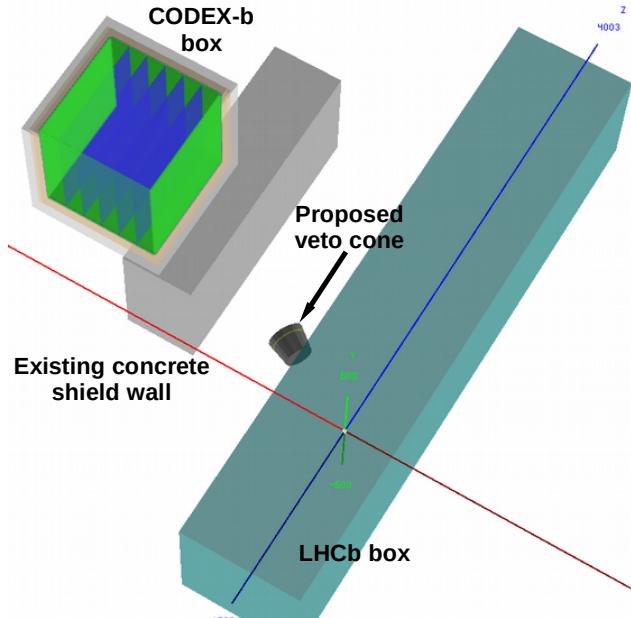
124 We designed two different detectors based on the paper and the measurement, the former  
125 is the CODEX-b and the latter is a scintillator. Both were tested with  $\mu$  particle gun  
126 with 1 TeV and the minimum bias events generated from the standalone Gauss.

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

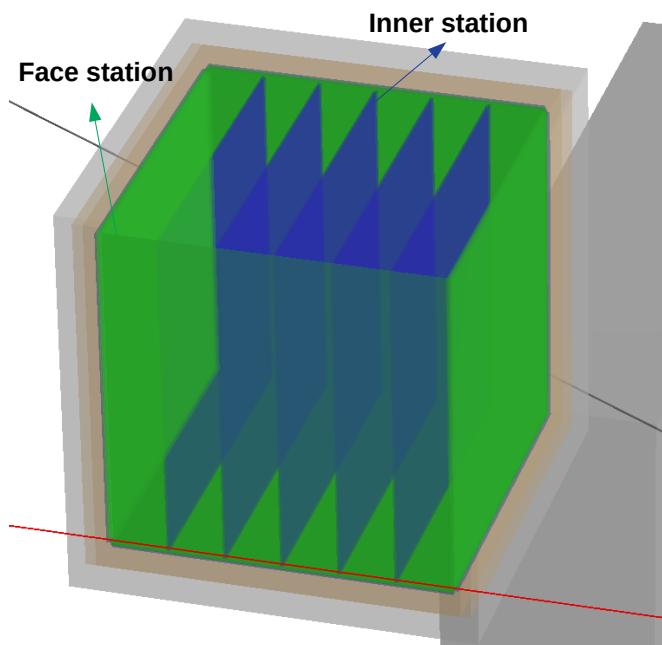
## 133 4 Summary

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

142 About the simulation, DD4hep had been used to design CODEX-b and backgrond  
143 measurement campaign. Built a hierachy system to implement a bundle of 6 silicon  
144 layers (these layers are planed to change to RPC layers) and a triplet bundle. Reminding  
145 that CODEX-b geometry is a final version. Detail information about components of  
146 designed CODEX-b using DD4hep is following. The layer runs as a tracker which measure



(a)

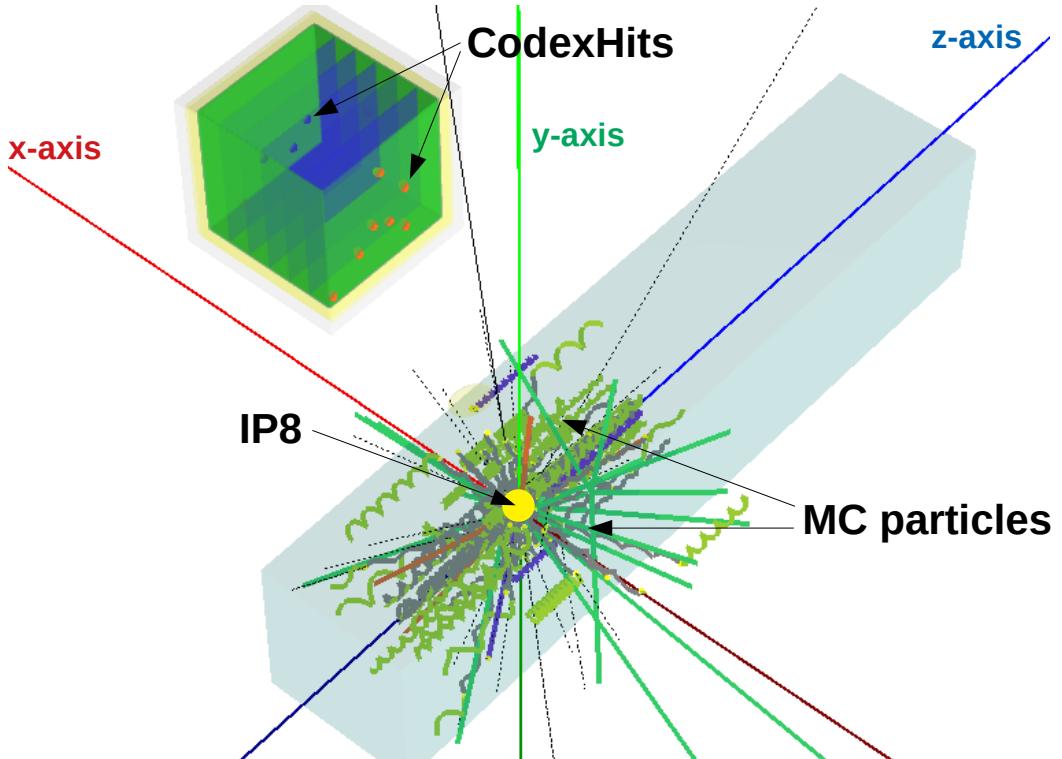


(b)

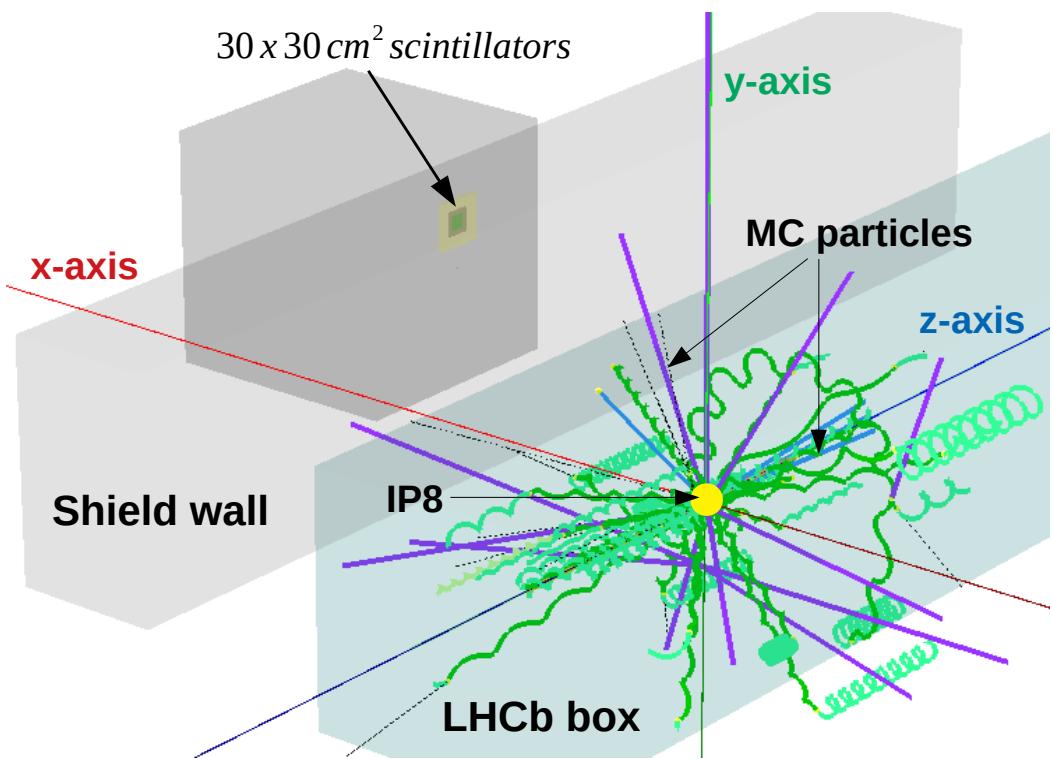
Figure 7: CODEX-b simulation geometry: (a) overall, (b) close-up view.

hit position of particles and the size is  $10 \times 10 m^2$  with 2 cm thickness. Using similar hierarchy system, background measurement campaign geometry had been made. The size of scintillator plate is  $30 \times 30 cm^2$  and 2 cm thickness. The distance of them is 2 cm. The material of scintillator is the same as the Herschel detector. Veto cone and concrete shield wall were generated using DD4hep.

All geometries were tested with  $\mu$  particle gun with and without concrete shield wall.



(a)



(b)

Figure 8: Validation of the DD4Hep based simulation with the concrete shield wall removed using minimum bias events: (a) CODEX-b box, and (b) two-plate scintillators for measurement campaign.

153 There were hits on the layers without shield wall and checked particles hit positions  
154 and deposit energy. Tested with minimum bias events generated from standalone Gauss  
155 showed hits on the layers without concrete wall. When the wall was existed, there was no  
156 hit on the layers. These results indicate that every part in the simulation worked properly.  
157 The future plan is working on more efficient MC generation in Gauss with generator  
158 cuts and optimizing the simulation environments.

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166 Kvaratskheliya (Set up equipments at the pit).

<sub>167</sub> **References**

- <sub>168</sub> [1] V. V. Gligorov, S. Knapen, M. Papucci, and D. J. Robinson, *Searching for Long-lived*  
<sub>169</sub> *Particles: A Compact Detector for Exotics at LHCb*, Phys. Rev. **D97** (2018) 015023,  
<sub>170</sub> arXiv:1708.09395.