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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.

List of changes between versions

- version 1
  - Start version.
- version 1.01
  - Add figures in each section and rewrite.
- version 1.02
  - Add contents at each section.
- version 1.03
  - Write summary and change the size of pictures.
- version 1.04
  - First draft for the report.
- version 1.05
  - Remove empty paper.
  - Change the author list and mention that this is a summer student report.
  - Remove bold, fix colloquial, change word.
  - Modify the first sentence in meamesurment (Reference should be fixed).
  - Mention at the Figure 5, this is not approved officially.
  - Fix caption at the Table 1.
  - Add more explanation at the last part of simulation chapter.
  - Divide to subfigure (Need to fix).
  - Enlarge the last figure at the simulation chapter.
  - Add acknowledgements.
  - Add abstract

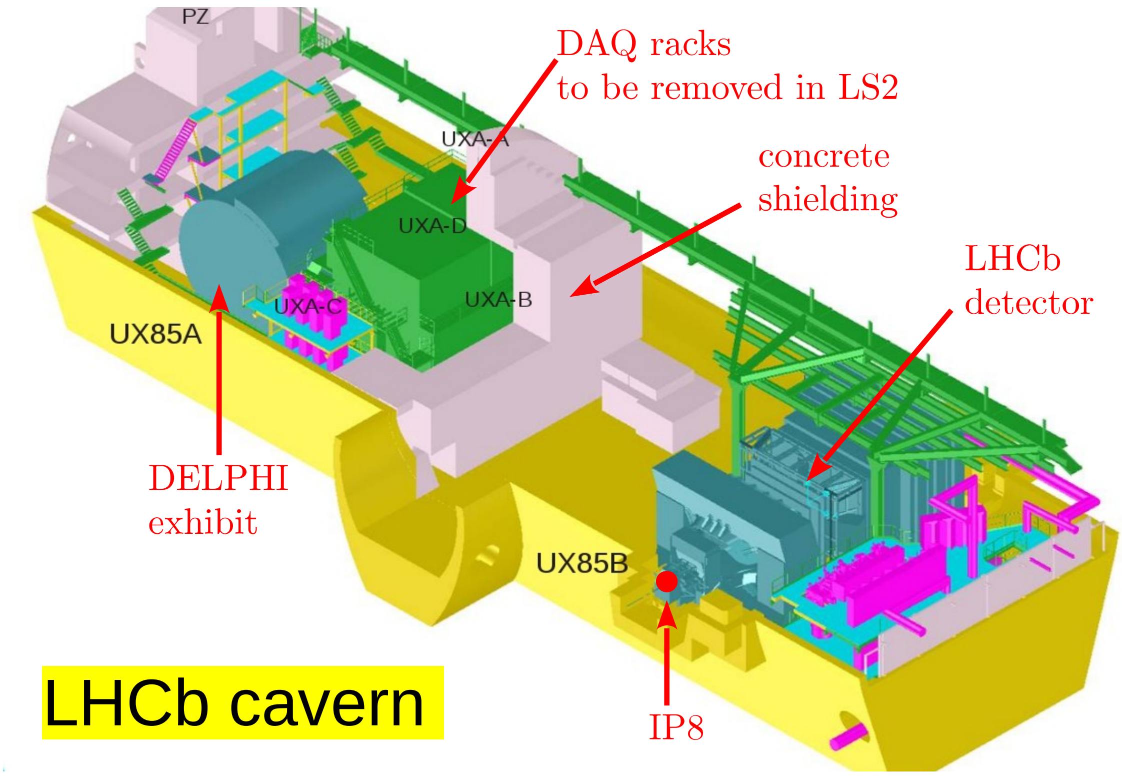


Figure 1: A schematic plot of the LHCb cavern.

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 successly 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

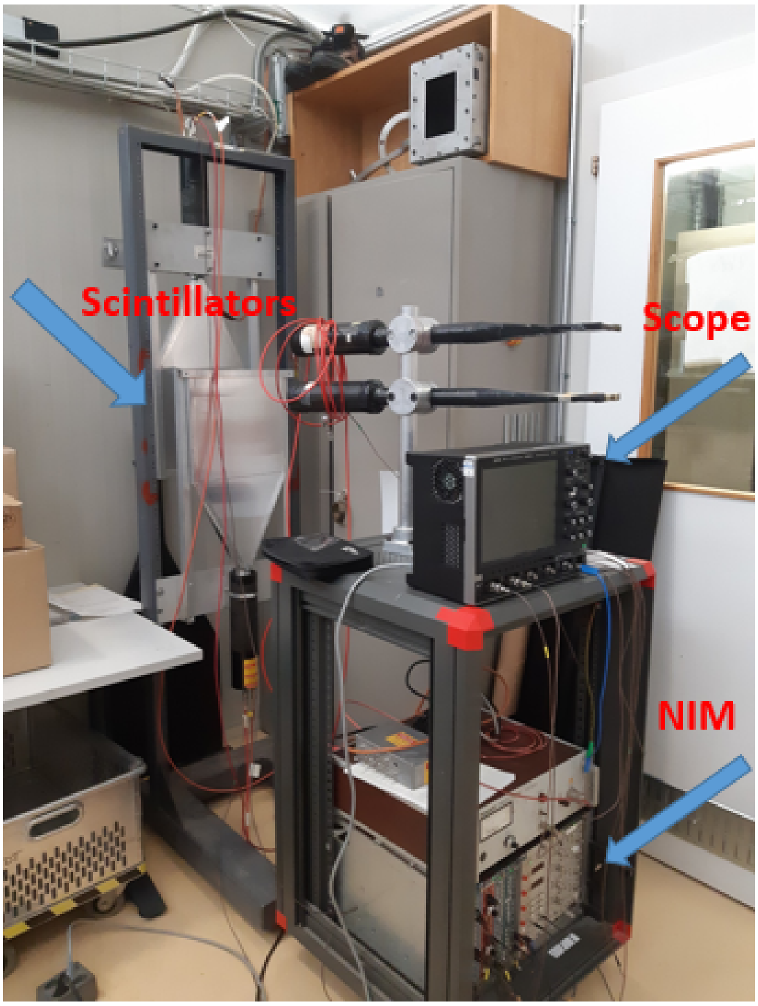


Figure 2: Test-bench assembly in the VeloPix lab, showing the Herschel scintillators, the DAQ system comprising a NIM crate and oscilloscope.

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

2 Measurement

2.1 Test-bench

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

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

2.2 Trigger

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

2.3 Measurements positions and configurations on the D3 platform

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

2.4 Results

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

Below tables are shown hit rate based on measurement position and configuration. The rate of *pp* collisions is 25 MHz. First table is about ambient background hit rate

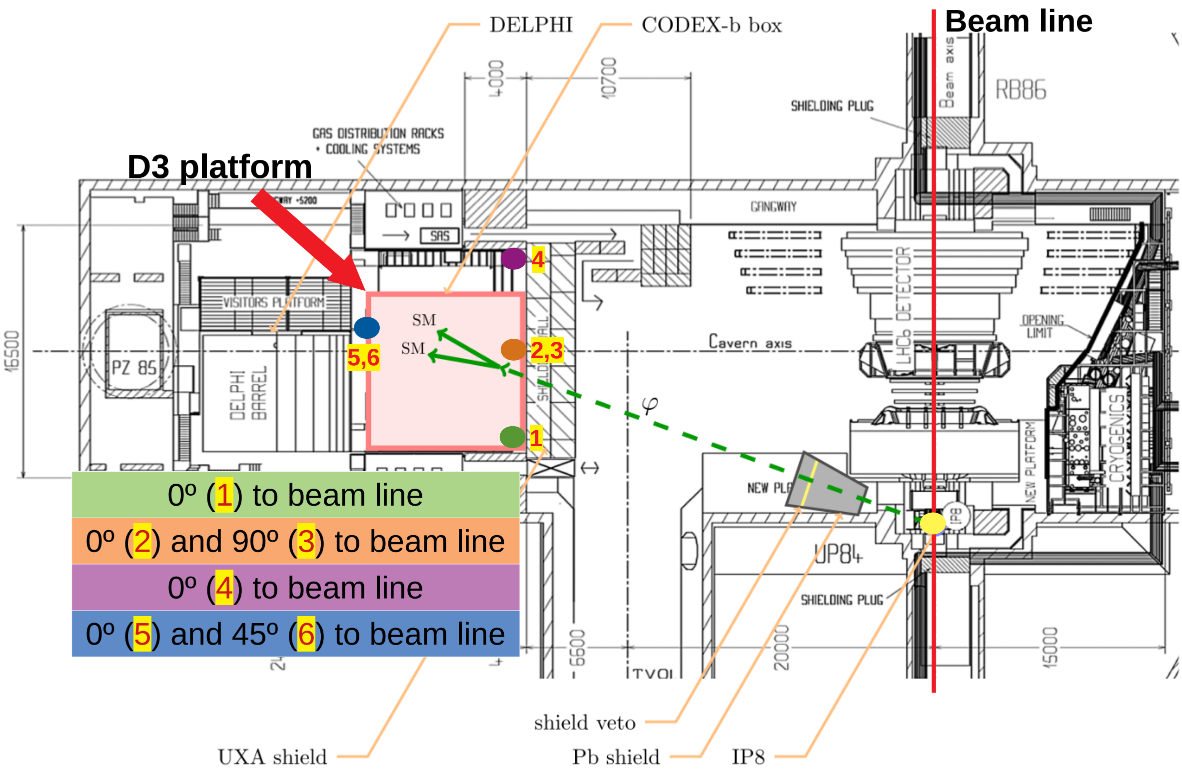


Figure 4: The four measurement positions on the D3 level inside the LHCb cavern. The configurations are labelled from P1-P6.

between fills and in MD without beam.

The average hit rate of each position and configuration is 2 mHz. It is indicated that background can be negligible. However, during stable beam, hit rate increases a large. By

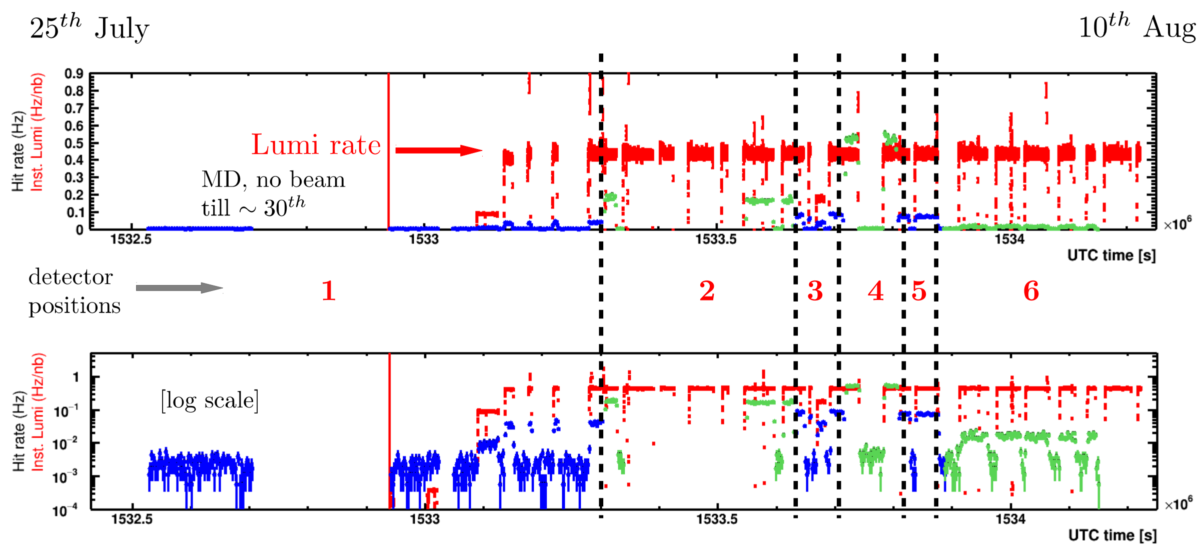


Figure 5: Hit rate plots during the run based on 6 positions/configurations linear and log scale. Red dots mean the lumi rate of LHCb, blue and green dots mean hit rates. The results are not approved by the LHCb collaboration.

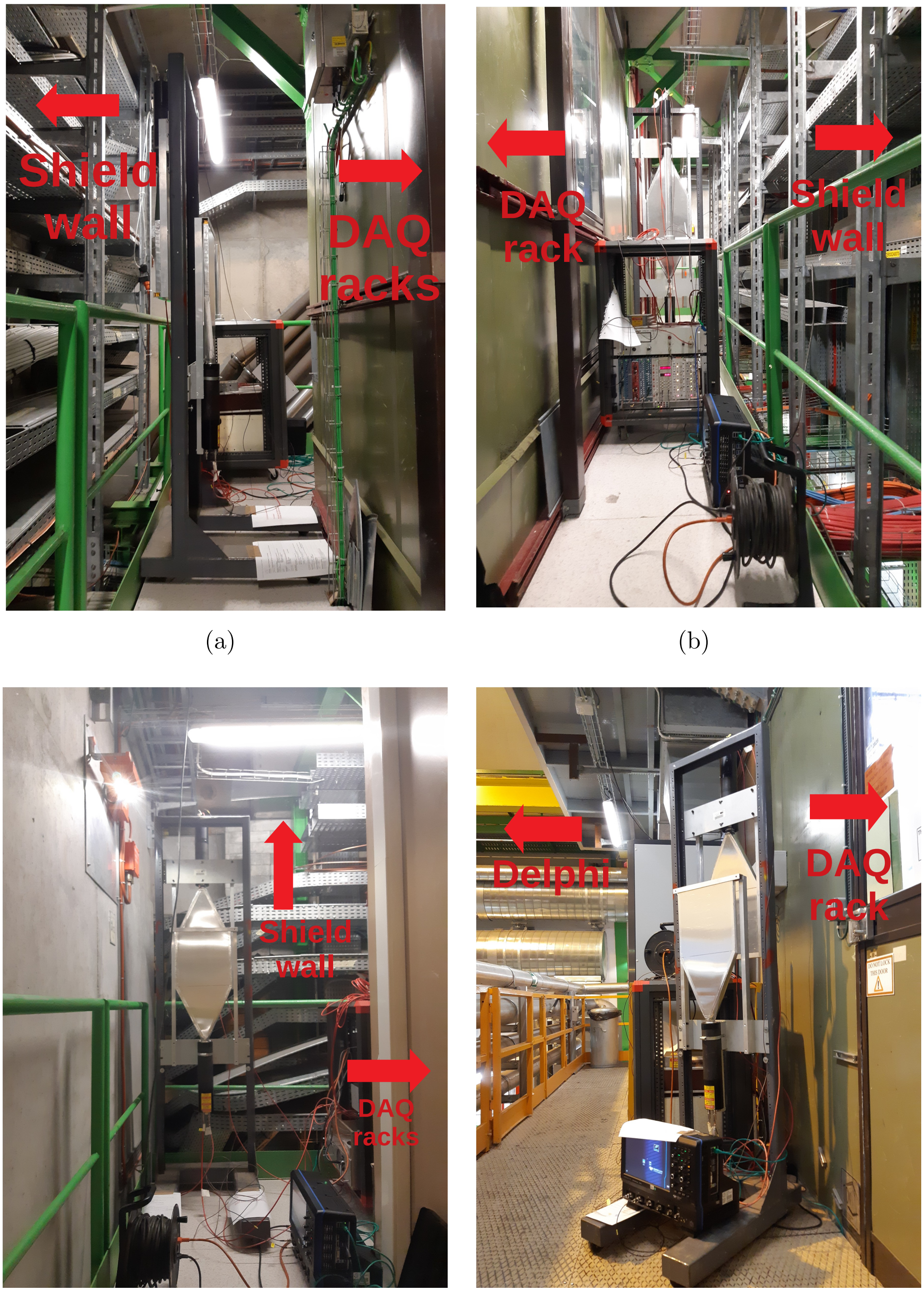
Position	Description	Hit rate [mHz]
P1	shield, right corner, $\parallel$ to beam	1.99 ± 0.07
P2	shield, center, $\parallel$ to beam	2.76 ± 0.03
P3	shield, center, $\perp$ to beam	2.26 ± 0.03
P4	shield, left corner, $\parallel$ to beam	3.11 ± 0.03
P5	shield + D3 racks, center, $\parallel$ to beam	1.95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

Table 1: Background hit rates based on each configuration when the beam is off.

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

Table 2: Average hit rates measured during stable beam, at various configurations.

moving position from P1 to P2, from P2 to P4, we found that hit rate depends on η Also, DAQ racks add some shielding effect based on the hit rates of P5 and P6.



(a) (b)

(c) (d)

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

3 Simulation

3.1 Detector Description for High Energy Physics

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

3.2 Simulation geometry

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

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

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

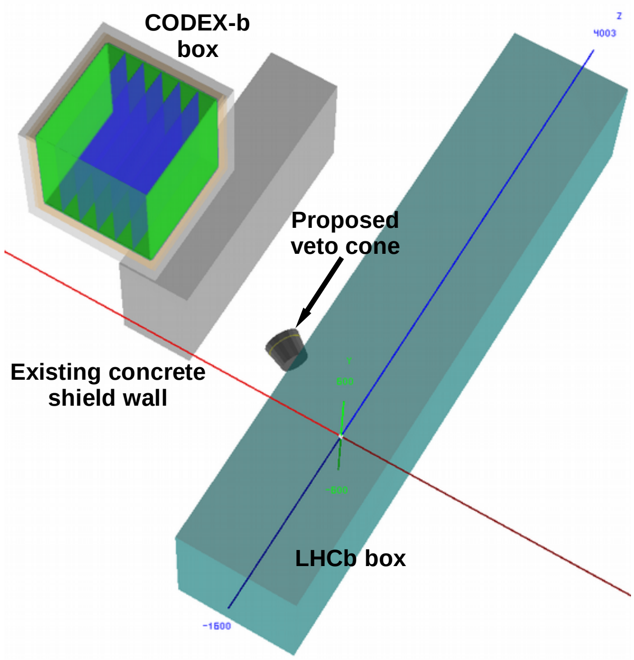
3.3 Simulation status

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

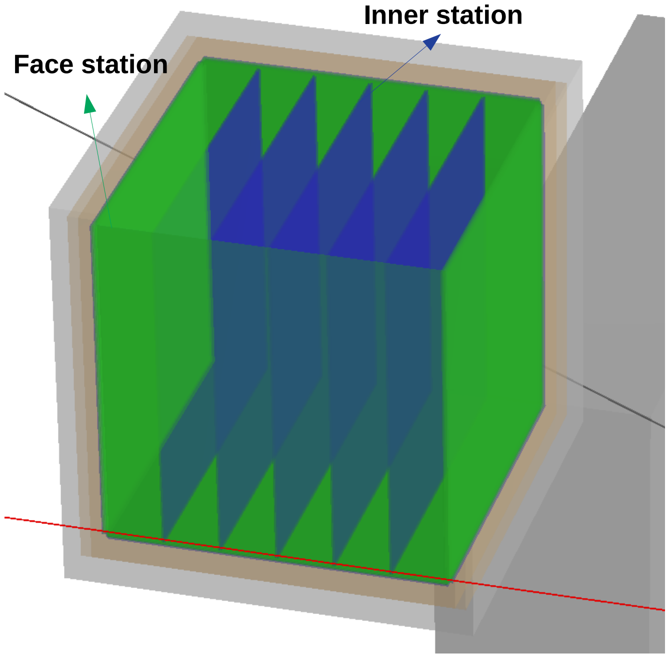
There was no hits on the CODEX-b layers when tested minbias events with the concrete wall. We decided to remove the shield wall to check performance of layers. The Figure 8 upper plot is shown that hits from minbias events. Also we recovered the concrete wall and changed CODEX-b geometry to two scintillator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

4 Summary

It was a very successful measurement campaign at D3 platform. We measured hit rates of mip based on 2x fold coincidence trigger using Herschel detector and scope. We could also manage run and data by remote connect to scope. The average hit rates in the stable beam condition is much higher than the average hit rates of pure background. Based



(a)

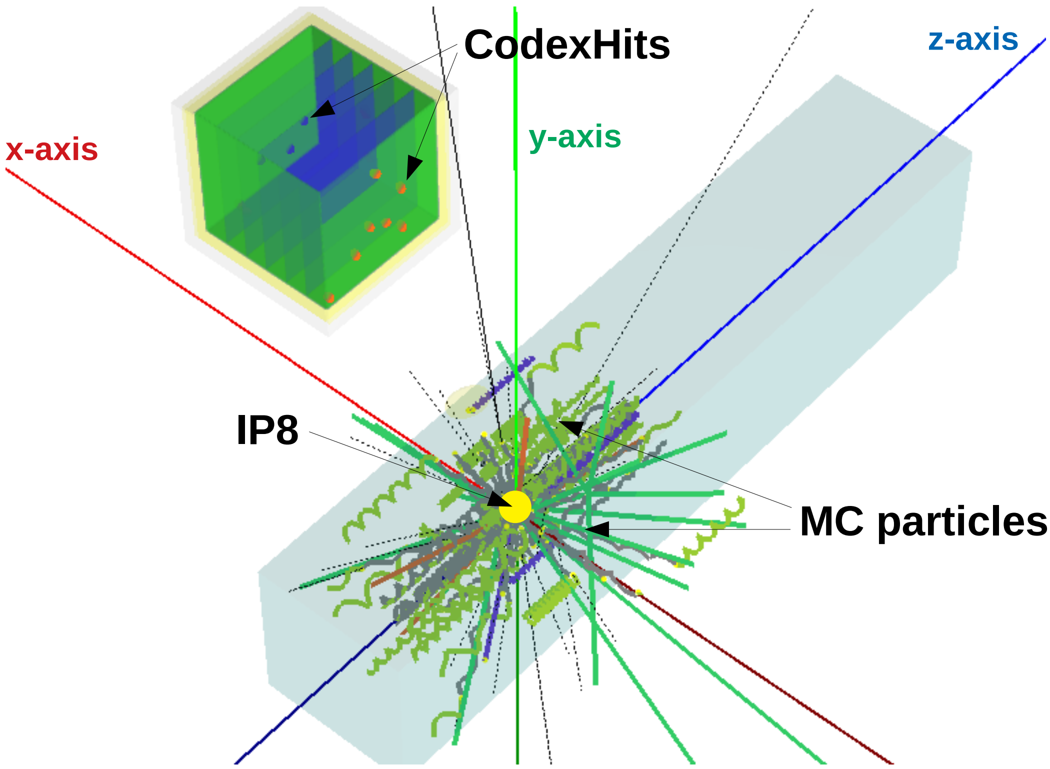


(b)

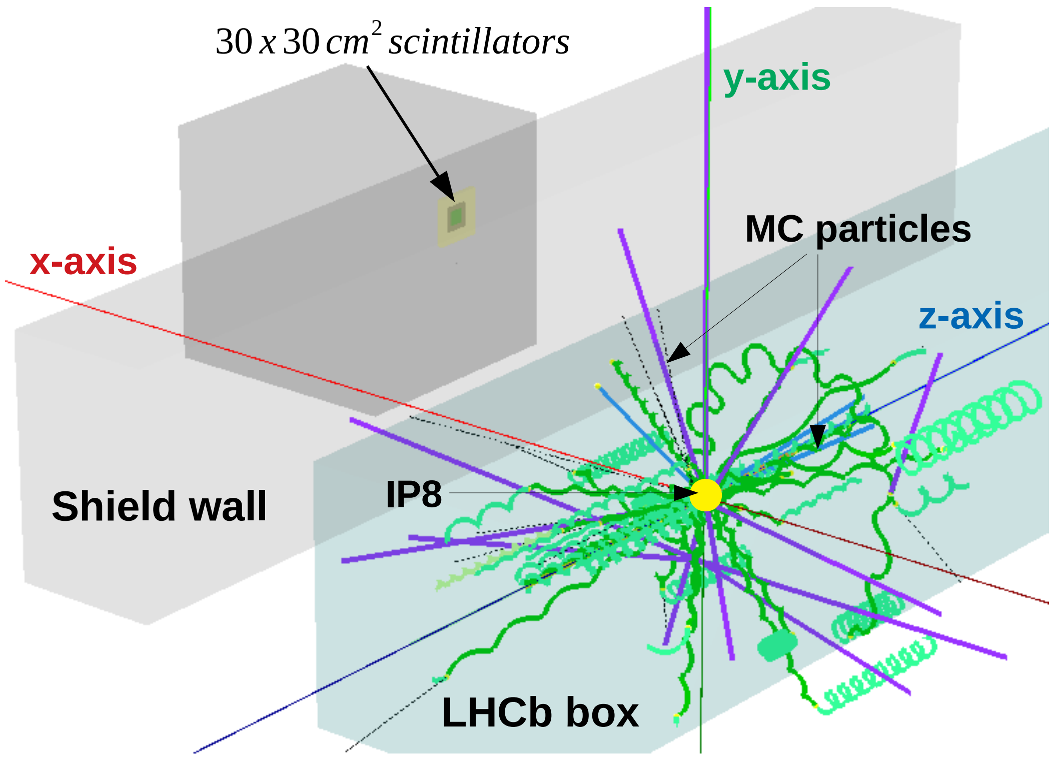
Figure 7: CODEX-b simulation geometry: (a) overall, (b) close-up view.

on this result, we can ignore pure background. The background rate just behind the concrete shield wall around 0.5 Hz over 900 cm^2 size scintillators. Also the hit rates have η dependence when moving far from the impact point. The D3 racks behave like a shield from the P5 and P6 results but it is difficult to simulate because of complicated structure.

About the simulation, DD4hep had been used to design CODEX-b and backgrond measurement campaign. Built a hierachy system to implement a bundle of 6 silicon



(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.

layers (these layers are planed to change to RPC layers) and a triplet bundle. Reminding that CODEX-b geometry is a final version. Detail information about components of designed CODEX-b using DD4hep is following. The layer runs as a tracker which measure hit position of particles and the size is 10x10 m^2 with 2 cm thickness. Using similar hierachy system, background measurement campaign geometry had been made. The size of scintillator plate is 30x30 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 μ particle gun with and without concrete shield wall. There were hits on the layers without shield wall and checked particles hit positions and deposit energy. Tested with minimum bias events generated from standalone Gauss showed hits on the layers without concrete wall. When the wall was existed, there was no hit on the layers. These results indicate that every part in the simulation worked properly.

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

Acknowledgements

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References

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