Visualizing CMS muon drift tubes' currents

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Abstract

This report documents my work as a summer student in the CMS DT group at CERN in July and August of 2015. During that time, I have participated in relocating DT monitoring experiment to GIF++ site and creating software to analyze drift tubes' wires current dependence on luminosity and radioactivity.

Contents

1 CMS DT overview

The Compact Muon Solenoid (CMS) is a general-purpose detector at the Large Hadron Collider (LHC). CMS uses several types of detectors to identify, track and measure particles' momentum. Drift tubes (DT) are one of the detectors in CMS to track muons in a barrel region.

Each 4-cm-wide tube contains a stretched wire within a gas volume. When a muon or any charged particle passes through the volume it knocks electrons off the atoms of the gas. These follow the electric field ending up at the positively-charged wire. By registering where along the wire electrons hit as well as by calculating the muon's original distance away from the wire DTs give two coordinates for the muon's position (Fig 1, left). [1]

Tubes have several electrical connections to generate desired electric field and measure currents. During normal operation the voltages applied are 3600 V for wires and -1800 V for cathodes. Separate strips are placed near the wire at 1800 V to have electrical field configuration where effectively all charged particles are collected by a wire or a cathode (Fig 1, right).

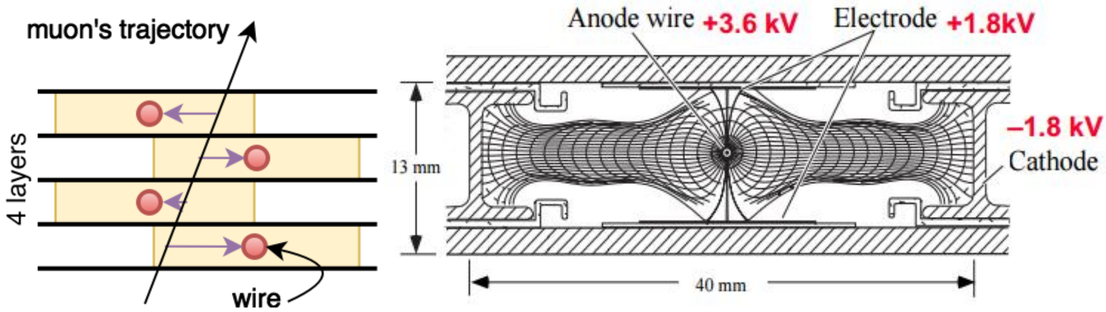

Figure 1. Left: Muon's track in a DT superlayer. Right: Section of a DT cell [2].

DT chambers consist of 3 superlayers (except for chambers MB4, which have 2 superlayers). Middle superlayer measures the coordinate ϑ along the beamline and the two outer superlayers measure the coordinate in the bending plane φ. Each superlayer has 4 layers of drift tubes (Fig 2, left).

The barrel system is subdivided into 5 wheels, named YB-2, YB-1, YB0, YB+1 and YB+2, . Wheels are composed of 12 sectors, covering 30° degrees each. There are 4 stations in each sector, MB1 being closest to the beam. Top and bottom sectors (S04 and S10) MB4 are cut in half to avoid having wires longer than 4 meters.

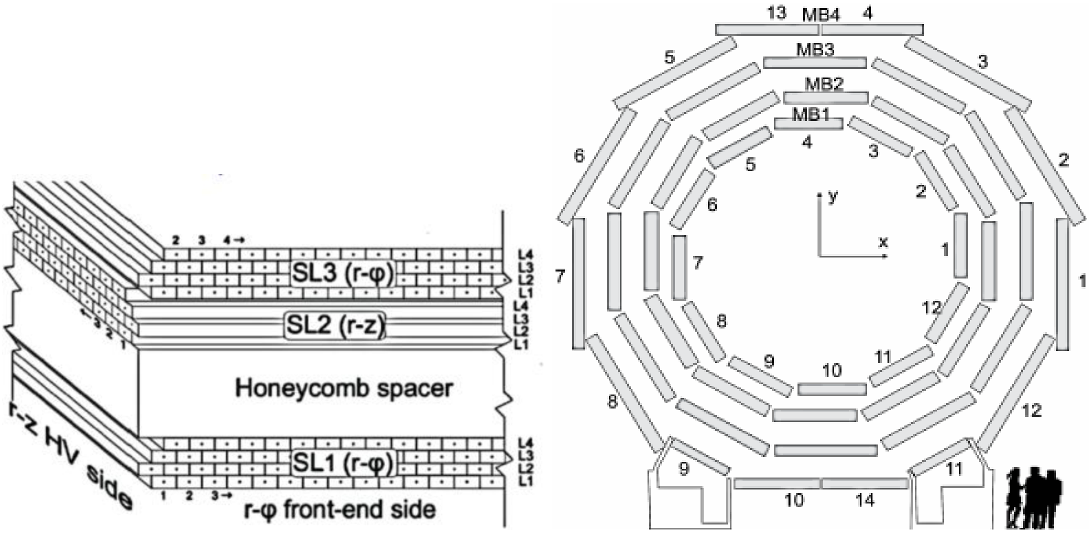

Figure 2. Left: Superlayer (top left), chamber (bottom left) and wheel (right) layout. [3]

2 Aim of the project

The High Luminosity LHC (HL-LHC) is a planned upgrade to the LHC, where luminosity is increased by a factor of 10. It is necessary to analyze how detectors would withstand higher luminosity and what modifications must be done to ensure safe operation.

With higher luminosity more particles created from proton-proton collisions are recorded per second, which raises currents flowing through the wires and cathodes. DT wires currents and luminosity are recorded during LHC fills to analyze how currents are affected by luminosity.

Beam protons are interacting with residual gas atoms and materials surrounding the beams. Some of these reactions produce secondary particles which are radioactive. Replacing malfunctioned equipment is difficult during LHC run, maintenance opportunities are limited, therefore detectors' electronics should be able to last several years in a radioactive environment. CERN Gamma Irradiation Facility (GIF++) is used to study detectors' performance and stability with high radiation background. In this site high momentum muon beam (up to 100 GeV/c) and 14 TBq ^{137}Cs source are available to test detectors in an environment similar to the HL-LHC [4]. DT chamber is installed in a GIF++ and exposed to radiation while currents are recorded to measure radiation effects.

DT currents' data have been previously visualized in Excel. Quite often only selected chambers' currents are saved, which makes reusing the same worksheets difficult. Custom software is needed to simplify importing recorded data and plotting.

3 Project description

3.1 Luminosity dependence

DT currents have been previously measured in 2012 and 2015. Data files contain several rows with timestamp, luminosity and each wire's currents for selected chambers. In order to visualize the current data, Python class was written, which imports all available chambers data for one fill, subtracts background current and can filter data by wheel, station, sector, superlayer, layer and wire. Another helper class was added to simplify plotting – add labels, legends, set axes limits and save plots. Source code is available at Github [5].

Average wire current grows linearly with each chamber having a different slope (Fig 3, left). Background current is usually negligible, making slope the most important parameter to predict wire currents. In the chambers near the beam (MB1) first superlayers are closer to the beam and receiving higher particle flux. Muons originating from hadronic punchthrough are more prevalent near the endcaps (Fig 3, right).

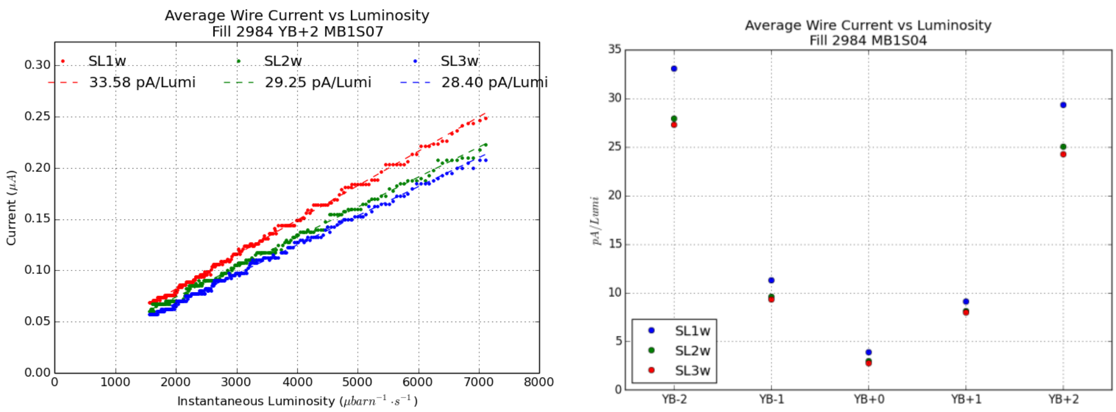

Figure 3. Left: Wire currents during the fill. Right: Extracted slope for different wheels.

Outer stations current (MB4) is generally higher than in chambers closer to the beam. Considerably larger currents are measured in sector 4 (top side of the barrel), since these have larger area and are more exposed to the background radiation (Fig 4, left). LHC beam has a small proton loss, which interacts with a material close to the beam and produces secondary particles [6]. Some of these particles can enter muon chambers, ionize the gas and create false signals. In the CMS cavern there is free space above the detector and more ionizing radiation can enter from above. Shielding has been installed for MB4 S04 YB±2 in 2014 to absorb particles coming from the outside. YB+2 is protected with 30 mm borated polyethylene and 7 mm Pb, while YB-2 has only 7 mm lead layer. After the shielding currents within these chambers are lower than in the center wheels (Fig 4, right).

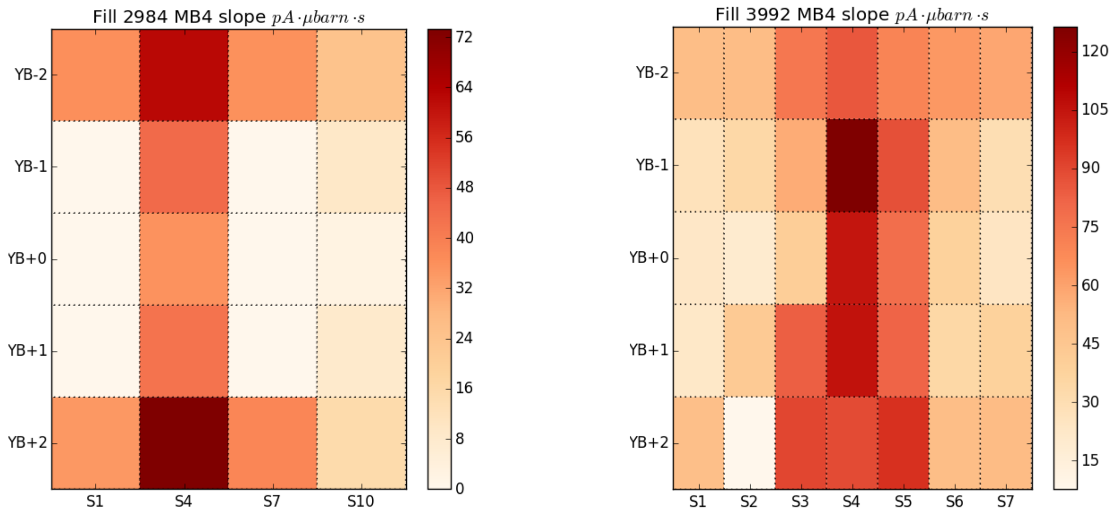

Figure 4. Left: Current/luminosity slopes in 2012. Right: Slopes in 2015. MB4S04 YB±2 slopes are more moderate after the shields have been installed.

3.2 Irradiation measurements

In August CMS DT group installed DT current measuring experiment in Gamma Irradiation Facility (GIF++). The author of the project helped with relocating the setup and installing equipment in the electronics service area rack. Separate Python script was created to analyze data saved in GIF++ site [7].

Experiments were carried out at different distances from the radiation source and with several filters combinations. GIF++ filter systems have 3 filter holders, which combined allow to use many different attenuations. ^{137}Cs source produces much higher currents, at lower attenuations wire current exceeded 20 μA and tests were carried out with lowered voltages (Fig 5, left). Chamber cells are receiving different amounts of radiation. Chamber could be positioned partially inside the irradiation cone, also some of the flux is absorbed in source-facing superlayers (Fig 5, right). Phi1 superlayer receiving constantly larger doses than phi2 can also affect chambers stability.

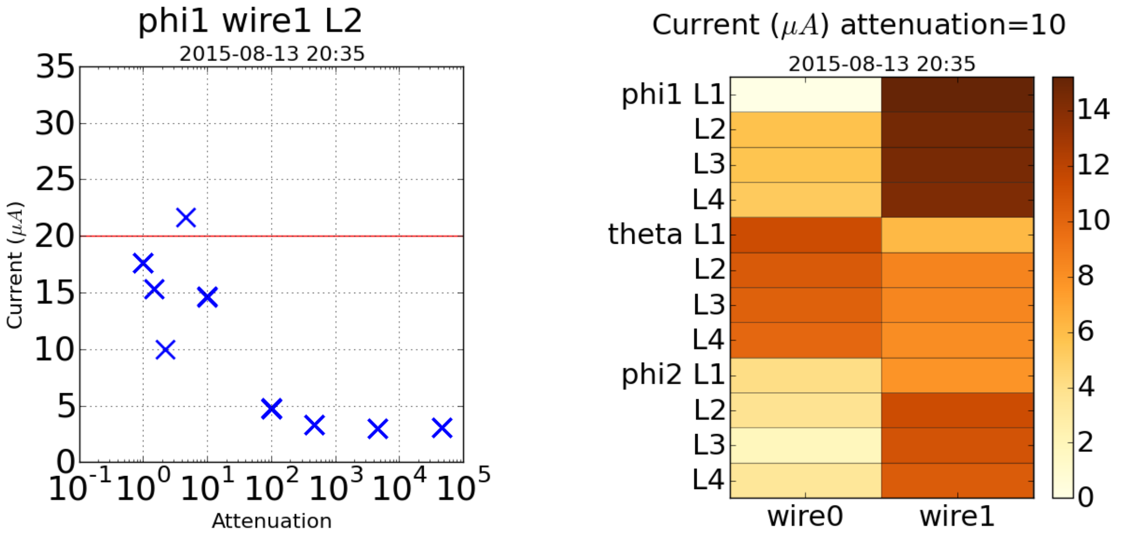

Figure 5. Left: Wire currents with different filter combinations at GIF++. Right: Chamber wire currents for one attenuation level.

4 Conclusions

During this project the software for visualizing the drift tube's currents was developed. This software is already in use to analyze ongoing tests in Gamma Irradiation Facility. Program has a documentation and codebase is open source, which makes it easier to use and improve it in the future.

Acknowledgements

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References

[1] http://cms.web.cern.ch/news/muon-drift-tubes

[2] http://www.phys.ufl.edu/~acosta/cms/cmshi.pdf

[3] http://arxiv.org/pdf/0911.4895.pdf

[4] http://ph-dep-dt.web.cern.ch/irradiation-facilities/gif

[5] https://github.com/lwd8cmd/DTCurrent.git

[6] http://lhc-closer.es/taking_a_closer_look_at_lhc/0.ionizing_radiation

[7] https://github.com/lwd8cmd/DTGIFplots.git