DESY Summer Student programme report

Study of the cosmics for the CMS tracker

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Abstract

Good quality cosmics events are required for the purpose of tracker alignment. In this paper I present the calculation of the rates of cosmic rays for the CMS tracker. *HLT_TrackerCosmics* trigger gives stable rate with the value about 0.5 Hz. I also enclose basic tracks analysis, for instance distributions of momentum, pseudorapidity and number of hits in the tracker subdetectors. Moreover, I describe issues related to preparation of data set, such as runs with magnetic field 0 T and I discuss observations of different triggers activity.

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1 Introduction

This paper contains a report on my work, which I have done during Summer Student programme at DESY in year 2010. Presented results are the part of the analysis of cosmic rays for the purpose of the Compact Muon Solenoid (CMS) detector tracker alignment.

Muons are produced in the atmosphere in pions decays. Their tracks are important tool for the alignment. This is an independent source of trajectories crossing the detector vertically at different angles and connecting both upper and lower parts of the tracker barrels modules. Thus, there is an opportunity to synchronize them with respect to each other. There is no such a possibility using only tracks of particles produced during collisions. Therefore, effort to understand cosmics behaviour must be taken. An example of a cosmics event registered by the CMS detector is presented in the fig. 1.

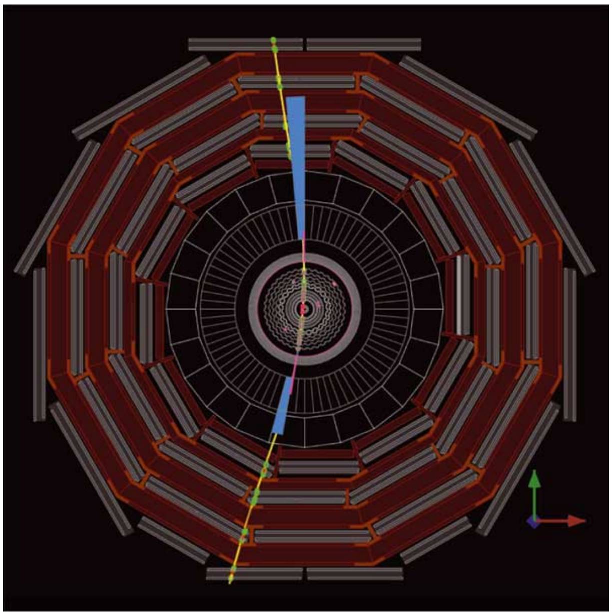


Figure 1: An example of a cosmics event registered by the CMS detector

1.1 The CMS experiment

The CMS experiment is designed as a general-purpose particle physics detector built on the Large Hadron Collider (LHC) at CERN to observe a wide range of particles and phenomena produced in high-energy (up to $\sqrt{s} = 14\ TeV$) proton-proton collisions.

1.2 Silicon tracking detector

The CMS silicon tracking detector (*tracker*) is the world's largest silicon detector ever bulit with 205 m^2 of silicon sensors. It is one of the components of the CMS experiment, consists of 1440 silicon pixel and 15148 silicon strip detector modules and is located inside a superconducting solenoidal magnet operating at a field of 3.8 T. Its aim is the measurement of the trajectories of charged particles (*tracks*) with excellent momentum, angle and position resolution. Fig. 2 shows an $r - z$ view of the modules in one quarter of the CMS tracker: TIB and TID (Tracker Inner Barrel and Disk), TOB (Tracker Outer Barrel), TEC (Tracker Endcaps). Whole system is described in detail in [1].

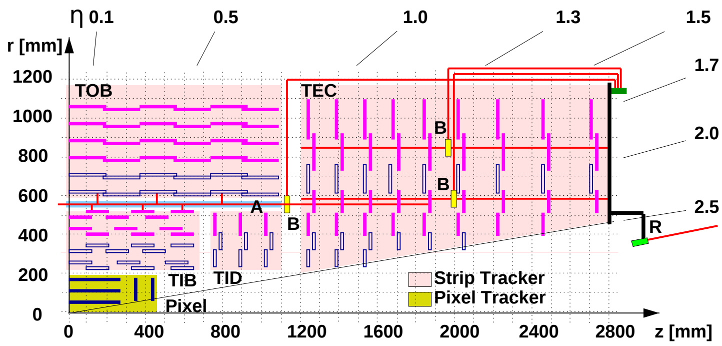


Figure 2: $r - z$ view of one quarter of the CMS tracker [2]

1.3 Tracker alignment

Alignment, that is determining position and orientation of all silicon pixel and strip sensors, is performed by minimizing the objective function:

$$\chi^2(\mathbf{p}, \mathbf{q}) = \sum_j^{tracks} \sum_i^{hits} \mathbf{r}_{ij}^T(\mathbf{p}, \mathbf{q}_j)\mathbf{V}_{ij}^{-1}\mathbf{r}_{ij}(\mathbf{p}, \mathbf{q}_j), \quad (1)$$

with respect to alignment parameters $\mathbf{p}$ and track parameters $\mathbf{q}_j$, where $\mathbf{r}_{ij}$ are the track residuals and $\mathbf{V}_{ij}$ their covariance matrix. Two alignment algorithms are consecutively applied to the data: A global method (Millepede II) and a local method (HIP).

2 Rate of cosmic rays

The first task was to calculate the cosmics rate, that is how many cosmic muons is registered by the tracker in a unit of time and to observe behaviour of this parameter for subsequent runs. The calculation should be repeated for different selection of triggers.

2.1 Rates for `/Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO`

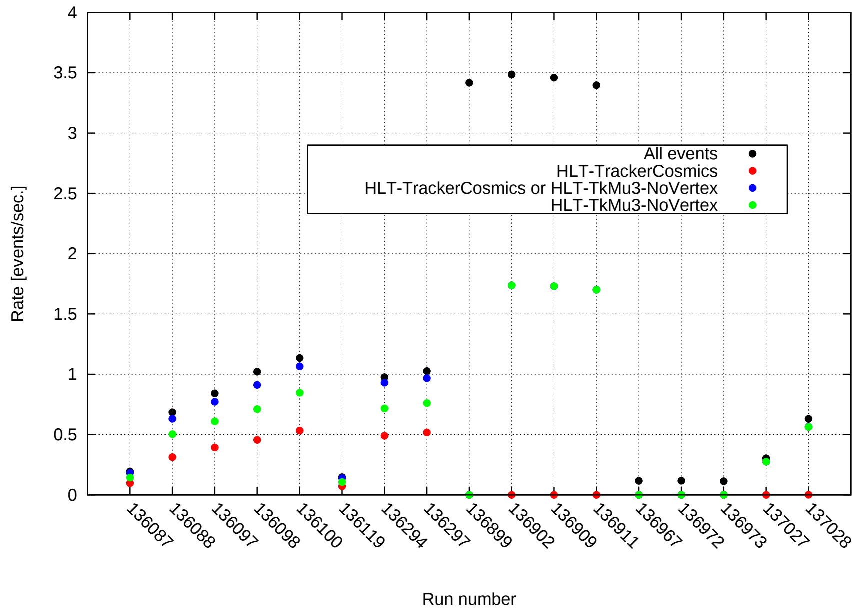
The comparison of results obtained for runs numbered from 136087 to 137028 from `/Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO` data base is presented in the fig. 3a, empty runs, containing no information about events, have been omitted. These data, the same as all data analyzed in this paper, have been taken during pp collisions at $\sqrt{s} = 7\,TeV$ in the period between May and August. In addition, figure 3b shows the number of events in each run. In total there have been 193494 events analyzed in this data set. Two remarks are needed. The first, if there is a value for certain trigger, it means that given trigger has worked, but there is no information about the other triggers provided. The second, rates are calculated as number of events divided by run time, thus they are in fact average rates for specified run. One can observe that *HLT_TrackerCosmics* [3] trigger gives no events starting from run no. 136899. This fact was the starting point for further analysis. Distributions of basic variables are shown in the fig. 4, all runs are included without any additional selection criteria. Distributions of number of hits in different tracker subdetectors for all events and for requirement of *HLT_TrackerCosmics* and *HLT_TkMu3_NoVertex* triggers are presented in the fig. 5. It is worth to notice that the *HLT_TrackerCosmics* trigger is mainly characterized by the barrels, while *HLT_TkMu3_NoVertex* trigger includes also information form the Endcaps. It has an influence for number of hits distributions seen in the fig. 5.

2.2 Data preparation, magnetic field issue

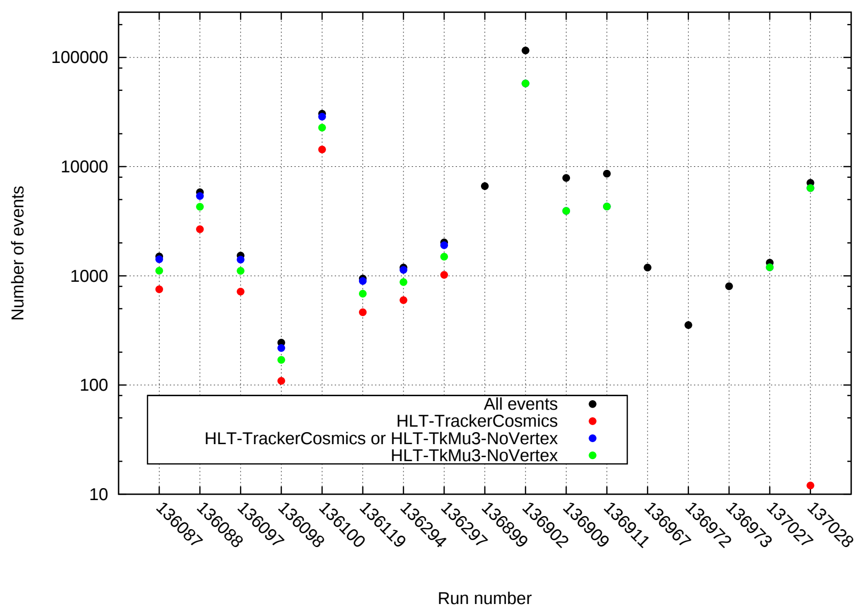
Investigating rates and the case of *HLT_TrackerCosmics* trigger, talked in section 2.1, it was necessary to repeat above procedure for larger set of data. Therefore `/Cosmics /Run2010A-TkAlCosmics0T-v4/ALCARECO` data have been taken for processing. First step, to make this base useful for analysis, was to reject empty runs. Then it has been found, that for some runs, momentum distribution looks like a sharp and narrow peak at 5 GeV. The reason is in switched off magnetic field. Following this issue, there have been also runs, for which the value of the field was significantly less than nominal 3.8 T, they have been also eliminated (see table 2.2 for the complete list). After applying basic selection criteria: momentum $p \geq 4\ GeV$ (`pMin = 4`), minimal number of detector hits equal eight (`nHitMin = 8`), at least one two-dimensional hit (`nHitMin2D = 1`) and requiring runs with resonable statistics (more than 1000 events in each run), there were 173 runs chosen out of 1057.

2.3 Rates for `/Cosmics/Run2010A-TkAlCosmics0T-v4/ALCARECO`

After selection of proper runs (discussed in section 2.2), there was a possibility to derive rates for a large data set. Results are presented on the plots in the fig. 6. It must be emphasised that collecting of this data ended less than month before writing this report, so these had been the newest possible data. Having them, one can analyze stability of the rate during subsequent runs. It can be seen that the rate for *HLT_TrackerCosmics* trigger is usually not larger than a bit above 0.5 Hz. In the latest runs, *HLT_TkMu3_NoVertex* trigger appears to be turned off. All events rate varies from slightly more than zero to a little above 4 Hz. The question arises, what is the reason for registering relatively much more events in some runs, and parallelly, why there is so large drop in the rate observed for *HLT_TrackerCosmics* trigger for runs with the greatest all ALCARECO events rate. Is it caused by the trigger malfunction or excess events is triggered by other systems and it might be useful for the purpose of alignment?

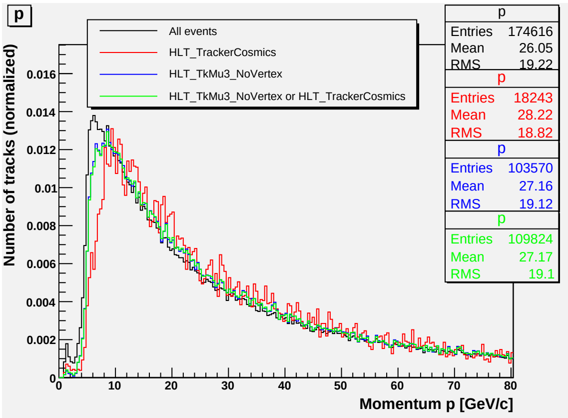


(a) Rates

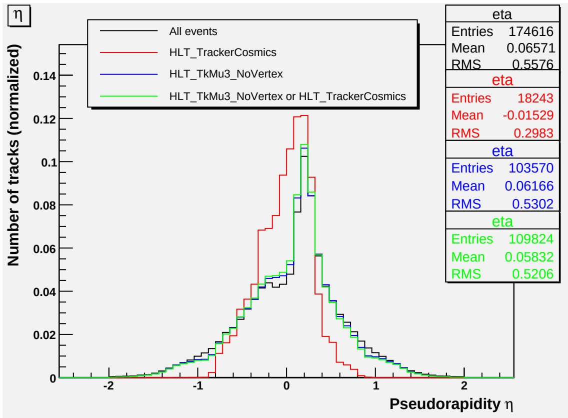


(b) Number of events

Figure 3: Comparision of rates and numbers of events for different selection of triggers for given set of runs from `/Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO` data set

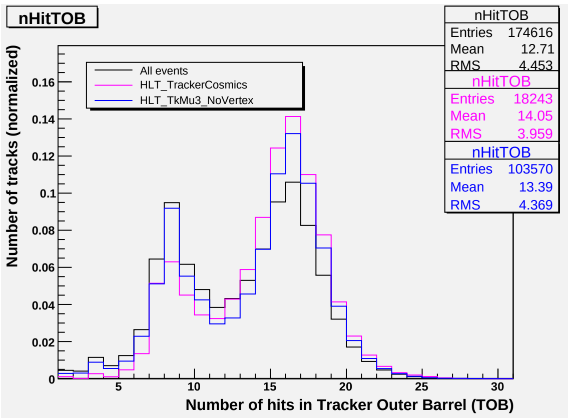


(a) Momentum

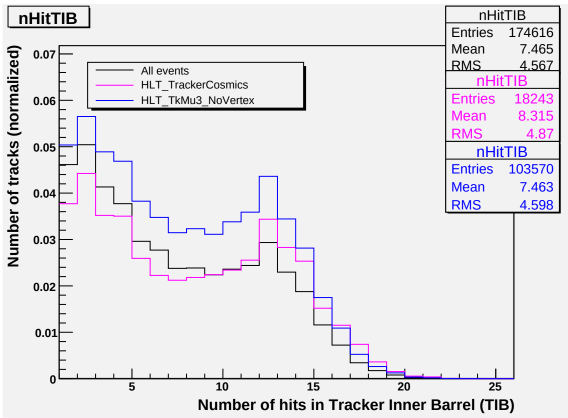


(b) Pseudorapidity

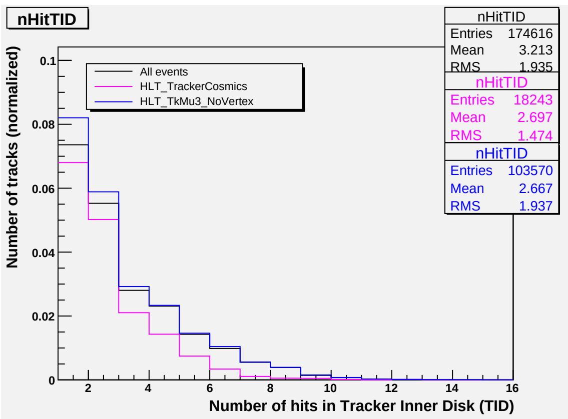
Figure 4: Momentum and pseudorapidity distributions (normalized to a unity) for runs 136087 – 137028 from `/Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO` data base



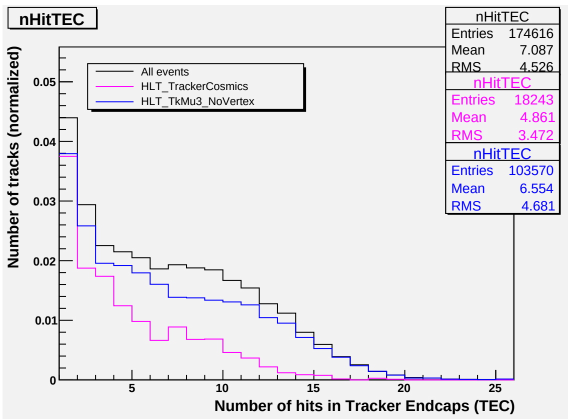
(a) Tracker Outer Barrel



(b) Tracker Inner Barrel



(c) Tracker Inner Disk



(d) Tracker Endcaps

Figure 5: Number of hits distributions (normalized to a unity) for different tracker subdetectors for runs 136087 – 137028 from `/Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO` data base

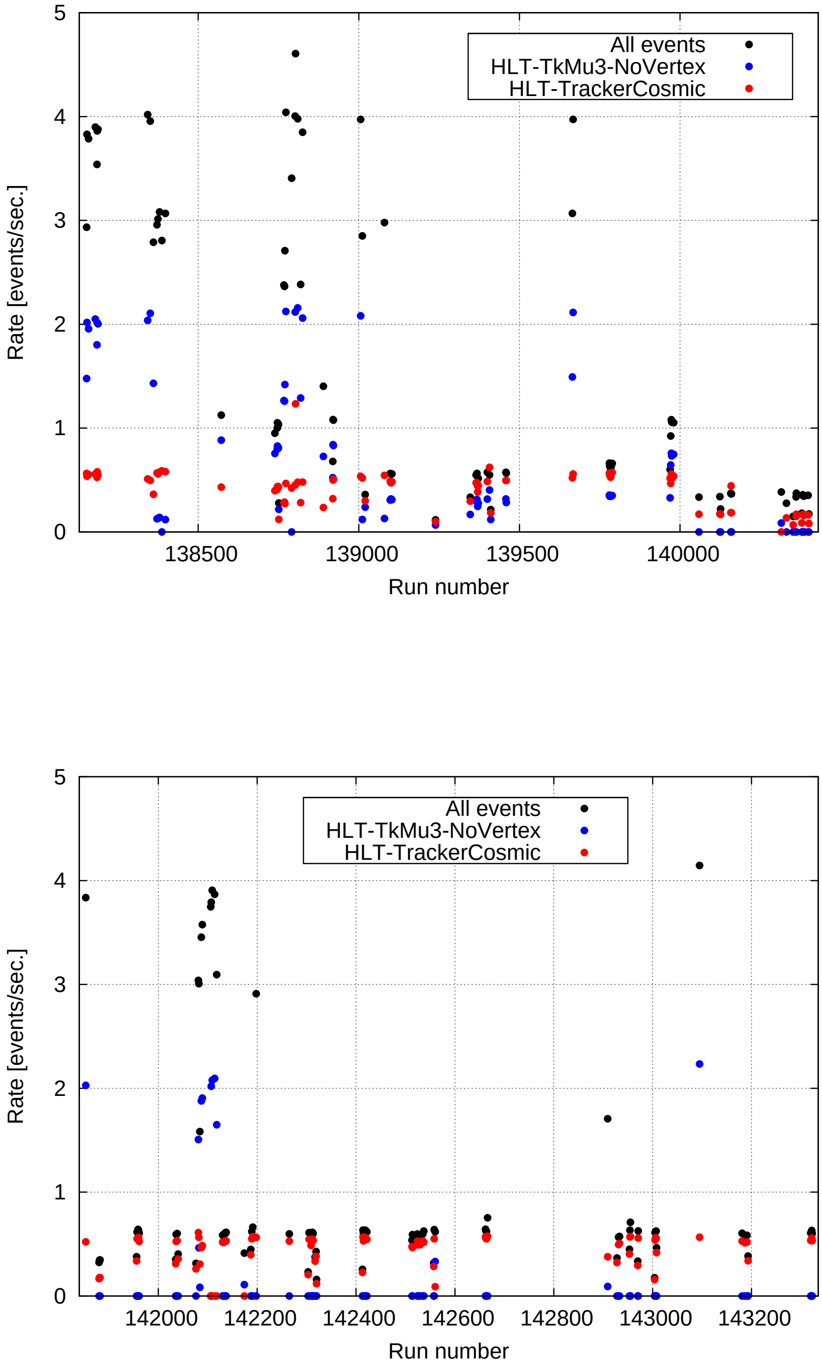


Figure 6: Rates for runs 138153 − 143323 from /Cosmics/Run2010A-TkAlCosmics0T-v4 /ALCARECO data set for different trigger requirements

Table 1: List of runs from /Cosmics/Run2010A-TkAlCosmics0T-v4/ALCARECO data base with improper value of the magnetic field

Run number	Magnetic field [T]
140520	3.3
140523	3.2
140524	3.1
140525	2.9
140527	2.5
140528	2.3
140529	2.1
140530 − 141748	0
141757	2.3
141759	2.4
141760	3
141762	2.9
143032	0
143075	1.9
143088	3.5

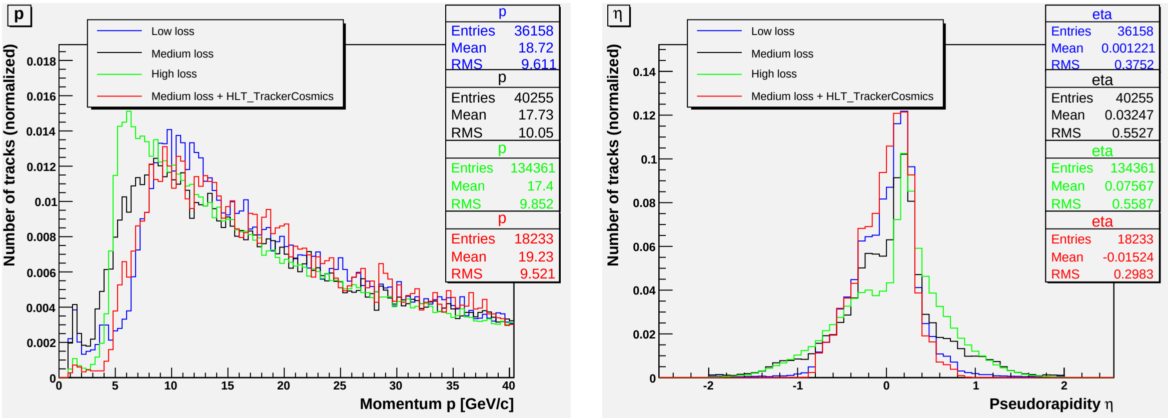
Table 2: List of runs with different rate loss for *HLT_TrackerCosmics* trigger

Type	Set of runs
High loss	136899 − 137028 (taken from /Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO)
Medium loss	136087 − 136297 (/Cosmics/Run2010A-TkAlCosmics0T-v2/ALCARECO)
Low loss	142953 − 143006, but without 142957 and 142974 (/Cosmics/Run2010A-TkAlCosmics0T-v4/ALCARECO)

2.4 Triggers study

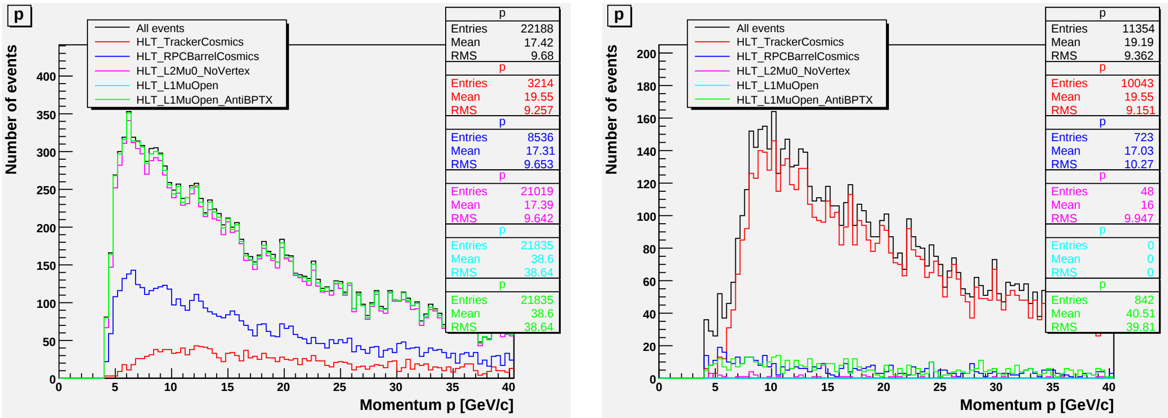
Searching for hints to solve the problem discussed in section 2.3, one can examine momentum and pseudorapidity distributions for four cases. There have been three sets of data selected. The first one includes runs, for which rate loss after requiring *HLT_Tracker-Cosmics* trigger is high (close to 100%), the second and the third consist of runs with loss on medium (around 50%) and low (at most 10%) level, respectively (see table 2 for summary). Distributions for all ALCARECO events for these data are shown in the fig. 7. Moreover, they are comapared with distribution for the set with medium loss, but also with additional requirement of use *HLT_TrackerCosmics* trigger. One can observe, that its shape goes to that one for the low loss case excluding events with momenta between 4 and 9 GeV. No additional selection criteria have been applied here.

Next point was to check which triggers give signicifant contribution in runs with the greatest all events rate and to compare their activity for lower rate runs. This also means



(a) Momentum (b) Pseudorapidity

Figure 7: Momentum and pseudorapidity distributions (normalized to a unity) for sets of runs with different rate loss for *HLT_TrackerCosmics* trigger (see table 2)



(a) High loss (b) Low loss

Figure 8: Comparision of different triggers activity for data with high and low rate loss (see section 2.4 paragraph 2)

to analyze cases with high and low rate loss for *HLT_TrackerCosmics* trigger. There have been following runs selected: 143321, 143322, 143323 (as those with low loss) and 138154, 138185, 138154 (as those with high loss). All data have been taken from `/Cosmics /Run2010A-TkAlCosmics0T-v4/ALCARECO` base. This time, there have been also basic selection criteria applied (see section 2.2). Momentum distributions for set of triggers for both sets of data are presented in the fig. 8. It is visible that there is a large input from *RPCBarrelCosmics*, *L2Mu0_NoVertex*, *L1MuOpen*, *L1MuOpen_AntiBPTX* triggers for high loss case, while there is almost no contribution for low loss runs.

3 Conclusion

This research was focused mainly on observation of *HLT_TrackerCosmics* trigger activity, its rate and thus the usefulness for detecting cosmic rays.

It is important to be convinced that *HLT_TrackerCosmics* trigger rate is quite stable with value about 0.5 Hz, therefore one can be sure that this trigger is able to deliver cosmics events in predictable way.

After selection of proper runs (section 2.2), there is above 1.2 million events in `/Cosmics /Run2010A-TkAlCosmics0T-v4/ALCARECO` base which gives about 1.08 million tracks useful for tracker alignment. One has to remember that this base has been growing and now there should be even more good tracks.

4 Acknowledgements

I would like to thank DESY for giving me an opportunity to participate in DESY Summer Student programme and for financial support during my stay in Hamburg. I also thank my supervisor Justyna Tomaszewska for co-operation and valuable guidance.

References

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[2] CMS Collaboration: *Alignment of the CMS Silicon Tracker during Commissioning with Cosmic Rays*, 2010, JINST **5** T03009, arXiv:0910.2505.

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