CMS TN/93-62
1.02.93

Optimization of muon momentum measurement

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The aim of this paper is to study how the momentum resolution depends on various parameters of the CMS detector. Presented results are based on the simulation performed by the CMSIM package (CMS TN/93-61). This package contains a geometry description of the CMS detector, tracking tools and interface to the ISAJET generator. It uses GEANT 3.15 together with GEANE. The presented work is an extension to the resolution calculations presented in CMS TN/92-12.

1 Momentum measurement in CMS

A muon track in the CMS detector is measured by the inner tracker and the muon system. In the barrel the inner tracker consists of 3 superlayers. The first one is made of 4 layers of silicon strips having 15 μm resolution. Next two consist of 4 layers of microstrip gaseous chamber (MSGC) each. Resolution of the single MSGC layer is about 60 μm. The inner tracker measures bending of a track in 4T magnetic field. Four muon stations placed outside the coil and interleaved with 1.8T iron yoke form the muon system. Each muon station has been simulated as two superlayers 30 cm apart, 100 μm resolution each. Important constraint to the measurement is given by the vertex position which can be known with a precision of the order of 20 μm. It is a great advantage of the CMS design that the measurement can be done by the tracker and the muon system independently. Their contributions to the overall momentum measurement is shown in Fig.1. The inner measurement in the air with high magnetic field gives high precision for the tracks up to 200 GeV momentum. High granularity of the detectors guarants low occupancy at the highest luminosities considered for LHC. However, even in the case when one or two superlayers cannot be used, remaining planes still ensure the measurement with only moderately decreased precision. For the highest momenta when the effect of multiple scattering in iron is smaller then say 100 μm, the muon system takes over the precision of the measurement. It is also important that the muon system alone is able to measure momentum with quite good precision. This is necessary for efficient p_t cut at the trigger level when the inner measurement is not yet available. Precise measurement by the muon system provides a reliable extrapolation of a track down to the inner tracker and enables proper identification of the muon inner track among large number of candidates. It also supports the difficult pattern recognition task.

2 Vertex position constraint

The impact of the vertex precision on the momentum measurement is shown in Fig.2. It is seen that to achieve the highest possible resolution it is necessary to know the vertex with a precision of 20 μm. If the knowledge of the vertex position is very crude we still have the Silicon Tracker placed close to the beam (see next chapter). Therefore, even in this case, the resolution is not appreciably degraded, 50 % at most. On the trigger level when the vertex position is not so precisely known, the muon system alone has to provide good momentum resolution to keep the trigger rate at an acceptable level without losing the efficiency. It is seen from Fig.2 that this is the case up to about 200 GeV, which is highly sufficient.

3 Importance of the Silicon Detector

In order to monitor the vertex position with the above mentioned precision it is important to have a high precision detector close to the interaction point. In the CMS design four layers of silicon strips, 15 μm resolution each, play this role. If for any reason the vertex precision is unknown, the silicon detector takes over the measurement and ensures that the resolution will not be degraded more than 50 %. It can be seen from comparison of Figs 2 and 3.

4 Comparison with the L3P detector

This part of the study has been motivated by the CMS referee of the LHCC, Prof. L. Foa, who asked us what is the quantitative impact of particular design criteria on the detector performance. To answer this question we consider CMS and L3P versions presented in the LOIs as well as two modified versions called CMSa and L3Pa. The key difference between CMS and L3P is a "compactness" of the detector, which can be expressed in terms of eg. inner radius of electro-magnetic calorimeter R_e. CMSa is a version having highest possible R_e keeping the size of the coil and the magnetic field value, and L3Pa has much smaller R_e than the L3P, again keeping their coil and field. With the smaller radius R_e it is possible to equip the L3Pa detector with four muon stations. The list of parameters of all the options are given in Tab.1. Layouts of the simulated geometries are shown in Fig.4. The muon momentum resolution for all four options is presented in Fig.5. It is seen that the full L3P detector has the resolution slightly better than the CMS one (0.8 % in comparison to 1.1 % for 100 GeV track). On the other hand the CMS muon system alone is nearly two times more precise than that of the L3P (6.5 % and 11.5 % respectively). This is very important at the trigger level.

Increasing the radius of the CMS the full detector resolution improves whereas the muon system alone is slightly worse. On the contrary, the L3Pa muon system resolution is much better than in case of the L3P and matches that of CMSa, but the overall momentum measurement is now much worse. Thus one can not easily say which version is the best and the proper choice must be a subject of more complicated optimization which we attempted to present in the last section.

5 Optimisation of detector geometry

The aim of this section is to follow the LHCC suggestion to look for possible detector which would be a compromise between the CMS and L3P versions presented in the LOIs. A possible variation is presented in Fig.6a where the placement of major components is drawn as a function of the inner radius of the electromagnetic calorimeter R_e. Left side represents the CMS design and the right one the LOI version of the L3P.

Starting from the CMS case one can increase R_e moving part of the HCAL outside the coil. To avoid exploding the cost we require the number of channels of the inner tracker to be constant. This can be done without deteriorating the resolution by increasing the length of the strips. However there is a technical limit of about 25 cm coming from the facts that the capacitance becomes unacceptably large and manufacturing of strips longer than 25 cm might not be feasible. Thus at R_e=1.7 m one has to change technology and use eg. straw tubes as in the case of L3P. On the other hand, decreasing the radius of L3P has an advantage that it creates room to install more muon stations which is crucial to provide full acceptance and make a system robust against em. showers produced by radiating muons. Thus we have a full spectrum of intermediate designs which we attempt to study in terms of momentum resolution performed by the system.

A variety of options has been simulated and their parameters are given in Tab.2 together with the obtained momentum resolution. Resulting curves of the momentum resolution performed by full detector and a muon system alone are presented in Fig.6b. Concerning the overall resolution one can see two minima, almost equally deep, one about R_e=1.7 m and the second one at R_e=2.9 m. This proves that the two detectors presented to LHCC do not represent a random choice of dimensions, but they came out from the optimization procedures.

The reason why the CMS has chosen the left minimum can be seen from the curve representing muon system measurement which is much better for small R_e. Additional argument, already mentioned above, comes from the necessity of having more muon stations. Exact position in the region of R_e=1.3–1.7m is a compromise between the performance and the cost. We believe that R_e=1.3 m is an optimum, because increasing it improves performance only slightly, but cost increment is significant. However we could consider increasing the radius, if it turns out that eg. the price of MSGCs or ECAL is lower than we have expected.