CKM-77

Note on distance between the CsI and the MVS

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The problem of CsI/MVS separation

One of numerous questions needed to be resolved before we can make final design of the CKM experiment is the distance between the FVS (CsI calorimeter in current design) and MVS. Intuitively one would place the MVS as close as possible to the CsI. However, that is not possible, because space is needed for photomultipliers, bases, electronics, and because CsI crystalls require "house" to provide special microclimate. According to information from reliable sources, it would be rather difficult to make CsI house less than 0.5 m long. Cost of very short CsI house can also be unacceptably high. Thus we need some understanding of how Csi/MVS separation influences MVS functionality.

General features of the MVS responce to pions and muons

Typical muon will pass through the MVS. Average ionization loss for longest MVS (30 layers) is about 2 GeV. This is much less than minimum energy of potentially dangerous muons, which is 10 GeV. Typical pion will shower in the MVS and usually will be completely absorbed. Thus simple separation algorithm could make a dicision by looking at signal in the last scintillator plane. However, there are few ways for a muon to stop in the MVS, and thus impersonate a pion.

- Decay upstream of the MVS
- Decay in the MVS

- A catastrophic bremstrahlung
- Two or more catastrophic bremstrahlungs
- A catastrophic muon-nucleon interaction

These processes make impossible easy achivement of muon vetoing on a 10^{-5} or better level. That is why we use segmented system, capable of providing information about longitudinal and lateral shower developement. Shower shape analysis can provide better separation, which is ultimately limited by catastrophic muon-nucleon interactions. In pracrice finite segmentation also limits separation ability.

Muon vetoing in a combined CsI/MVS system

In the test beam measurement the beam was incident directly into the MVS prototype. In the CKM experiment, however, an FVS (presumably the CsI) will be placed upstream of the MVS. Pion/muon separation criteria for a combined system will differ from those derived for the MVS alone, and separation power can be different as well. This is bound to happen no matter what the distance between the CsI and MVS is.

Since CsI is an active detector we can use it in muon veto algorithm. In fact, if we want to veto muon decays upstream and inside the CsI and retain good pion detection efficiency, we probably must use it.

About 30% of pions and almost all muons will leave 1 MIP in the CsI. In that case separation is almost the same as without the CsI. However, most of the time pion will interact in the CsI, producing a hadron shower. Muon can also produce a shower in the CsI. Usually it will be due to decay or bremstrahlung, which give electromagnetic showers.

Consequently, CsI shape analysis can help MVS.

Let's suppose that CsI shower has been identified as a hadron shower. For that class of events we can get better muon suppression, or relax MVS cuts and raise pion detection efficiency, or allow some loss of information and have the same muon suppression and pion detection. The last option can be used if few secondary particles miss the MVS due to significant CsI/MVS distance.

However, if we can not say with great confidence that the shower is hadronic, we again must use all the power of the MVS. Since some energy will be deposited in the CsI, the cuts will probably differ from 1 MIP case.

So exactly how useful CsI shower analysis can be is determined by the dependency between hadron and photon identification efficiencies in the CsI. That is an important question we shoud try to answer. Maybe someone from KTeV can give the answer immediately.

Qualitative analysis

Let us first recall how muons were vetoed in the MVS prototype test beam run. Except the cut on the final scintillation veto counter, following variables were used in the analysis:

- n_1 — number of planes with just 1 hit
- n_3 — number of planes with 3 or more hits
- w_t — lateral (transverse) size of the shower[1]
- w_l — longitudinal size of the shower[1]

In the analysis cuts on all variables did not depend on the cuts on any other variable.

It seems that changes in the distance between CsI and MVS can not significantly affect MVS responce to muons. Suppose we increase CsI/MVS distance by 1 m. Most muons will leave 1 MIP in the CsI, which obviously have no effect on the MVS response. A bremstrahlung in the CsI will typically produce some punchthrough, which will be absorbed by the very first layers of the MVS. Probability of muon decay between the CsI and the MVS increases, but these events are rare and have distinct characteristics to be rejected with good efficiency.

However, there can be changes in MVS responce to pions. Most pions will interact in the CsI. Interaction products will spread as they travel towards the MVS, and some of them can miss it. Increase of distance between CsI and MVS leads to wider shower spread, what means that more particles will miss the MVS. That situation will be referred to as leakage.

Assuming the leakage is small, this does not necessarily present a problem for pion/muon separation. It is known that hadron showers are of irregular

[1] To avoid accidentals, shower sizes were calculated in two iterations. All counters were used in the first iteration, while only counters, located in 3σ from shower center, were used in the second iteration.

shape, and in order to retain high efficiency to pions we must accept showers of almost any shape. Hadron showers in steel are usually larger both laterally and longitudinally than electromagnetic showers, thus small shower spread could even help!

The best answer to the separation problem would be test beam data. Unfortunately, during MVS test beam run we were so concerned with mere possibility to veto muons with our MVS prototype at sufficient level, that we did not take any pion data with material upstream of the prototype.

At present it does not seem possible to make precise simulations of hadron shower developement because of abcence of approapriate hadron interaction simulation generator. But since no detailed shower shape analysis is performed by the separation algorithm, and all cuts are made on few variables representing integrated shower properties, it seems reasonable to expect that even imperfect generator will give useful approximation.

Simulation

A toy GEANT-based MC was written to simulate combined CsI/MVS system. Test geometry and example of an event are shown in Fig. 1. Length of the MVS was set to 24 layers. There were no central holes in the detectors. GEANT cuts for electromagnetic processes were set to 1 MeV. GEANT-FLUKA was used for hadron interaction. Vertex of beam particles was uniformly smeared from -4 to 4 cm in X and Y. Momentum of beam particles was uniformly distributed from 14 to 21 GeV, momentum angle — from 3 to 15 mrad. Clearly, leakage effects due to finite transverse MVS size should be small in this toy geometry.

Distances of 0, 0.5, 1.0 and 2.0 m were simulated for pion beam. Distributions over n_1, n_3, w_l and w_t variables, in case there was an interaction in the CsI, are shown in Figs. 2–5. As expected, there is little difference in distribution over n_1. Distributions over n_3 and w_l are similar also, however, there is an enhancement near zero which grows as CsI/MVS distance increases. These are events with very little energy deposit in the MVS. Clearly muons can not produce such small signals, so these events will not cost us separation power. Distribution over w_t has the same feature near zero, otherwise it behaves as expected: transverse shower size increases, which is good rather than bad.

Analysis of the discussed distributions has shown that leakage may be not negligible. To obtain some idea about it average energy, deposited in both passive and active layers of the MVS, was calculated. It constitutes 7.13, 7.02, 6.75 and 6.13 GeV for four chosen distances. For 2 m distance energy deposition drops by $\simeq 15\%$. From the point of pion/muon separation it seems small. However, this is central geometry, while for events at the edge more careful analysis seems desireable.

Pion distribution in the MVS is almost circular while MVS is square. Thus actual leakage depends on the pion position. Maximal leakage will occur if pion azimuthal angle is close to 0, 90, 180 or 270 degrees. Due to angle/momentum corellation in our signal acceptance region, all pions which go at the MVS edge are of low momentum. Correspondingly, pion energy in leakage simulation at the MVS edge was distributed from 14 to 15 GeV. For the described worst case geometry average energy loss in the MVS, as a function of distance from the edge, is shown in Fig. 6. At the moment it is planned to have MVS area larger than the signal pion distribution by 20 cm, or 5 counters. It is necessary to allow for shower developement in the MVS independently of the distance to CsI. It looks like we can not significantly increase acceptance by adding few more counters.

It seems reasonable to assume that in case of high energy leakage the shower will often be identified as hadronic. As it was discussed before, in that case we do not need full MVS power to get the same pion/muon separation.

Other MVS questions

One of the interesting questions is upper limit for pion detection efficiency in the proposed MVS. Clearly it strongly depends upon the muon veto inefficiency. We want to work at the inefficiency of the order of 10^{-5}. Then we must veto all muon decays, since probability of 16 GeV muon decay on 1 m is $\approx 1{\cdot}10^{-5}$. Since these decays result in an electromagnetic shower, they are not distinguishable from hadron interactions which produce, for example, only π^0. In practice the same is true if produced charged hadrons have low energy. So one of the physical limitations for pion detection efficiency is set by the part of the electromagnetic energy produced in a hadron interaction. This quantity was histogrammed for pion interaction in the CsI and is shown in Fig. 7. Relative number of events with $R > 0.9$ is 0.5%, with $R > 0.8$ is 2.7%, with $R > 0.7$ is 5.3%, with $R > 0.6$ is 9.3%, with $R > 0.5$ is 15.2%. Let's consider the case of $R > 0.9$. In that case we have an electromagnetic shower of $\sim$ 16 GeV and one or more hadrons with total energy of $\sim$ 1.8 GeV. We can not hope to identify such an event as a pion. So it is clear that with the proposed design we can not achive 99.5% pion efficiency. A goal of 95% pion efficiency looks feasible, but maybe not easy.

Conclusions

Pion/muon separation cuts will be different from those used in the test beam run. This is due to CsI presence and has nothing to do with distance problem. We need to understand CsI hadron identification ability. Presumably KTeV has all the answers.

Qualitative analysis of the CsI/MVS distance problem shows that there should be no significant changes in pion/muon separation provided that energy leakage is small. This is confirmed by simulations.

Energy leakage is noticeable for low momentum pions. In the worst case geometry it can not be fully compensated by modest increase of the MVS transverse size. Depending on the CsI hadron shower identification ability, this may or may not decrease pion efficiency.

We have all the reasons to believe that increase of the CsI/MVS distance will not change muon suppression level. This may cost little bit in pion detection efficiency. Thus we found no physical requirements for very small CsI/MVS distance. It looks like it is a matter of overall cost/performance optimization.

Final touch: if the cost of new CsI house is high, one could consider "shashlyk" FVS option as described in proposal, which will allow small CsI/MVS distance, and will also nicely solve the problem of insufficient FVS size.

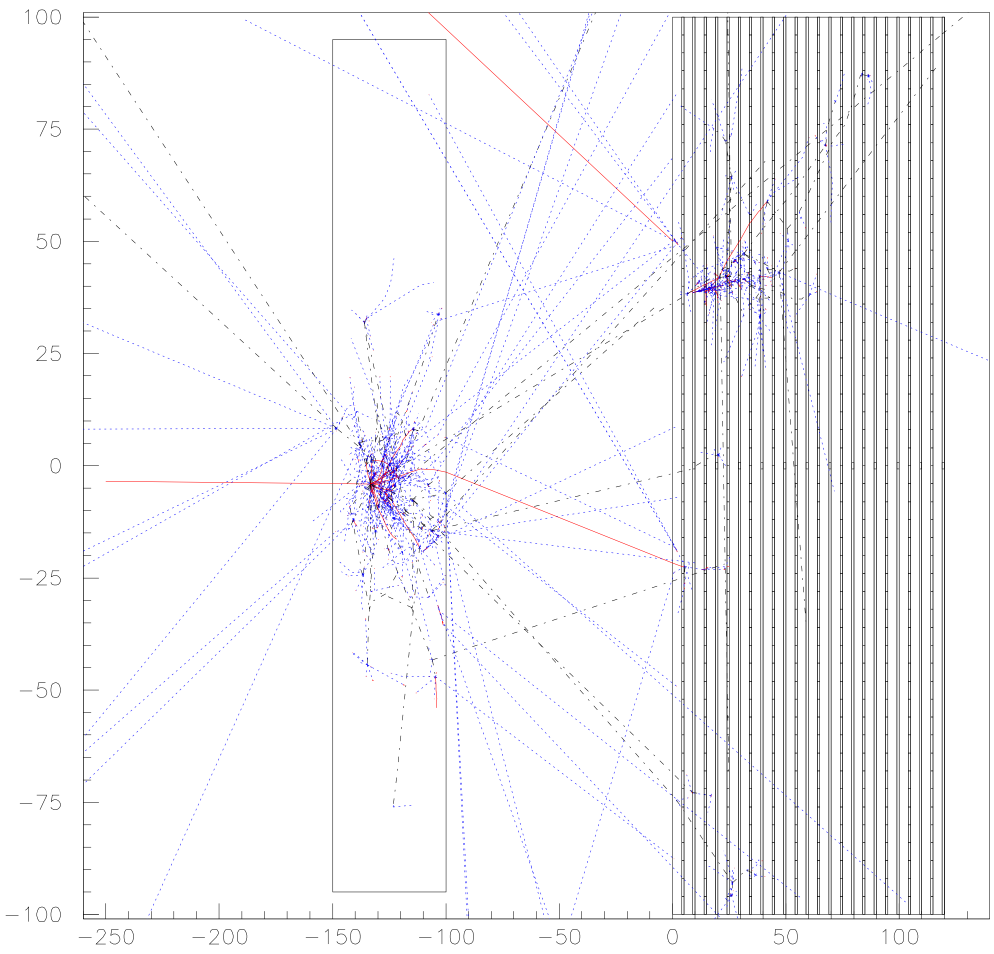

Figure 1: Toy geometry: an event.

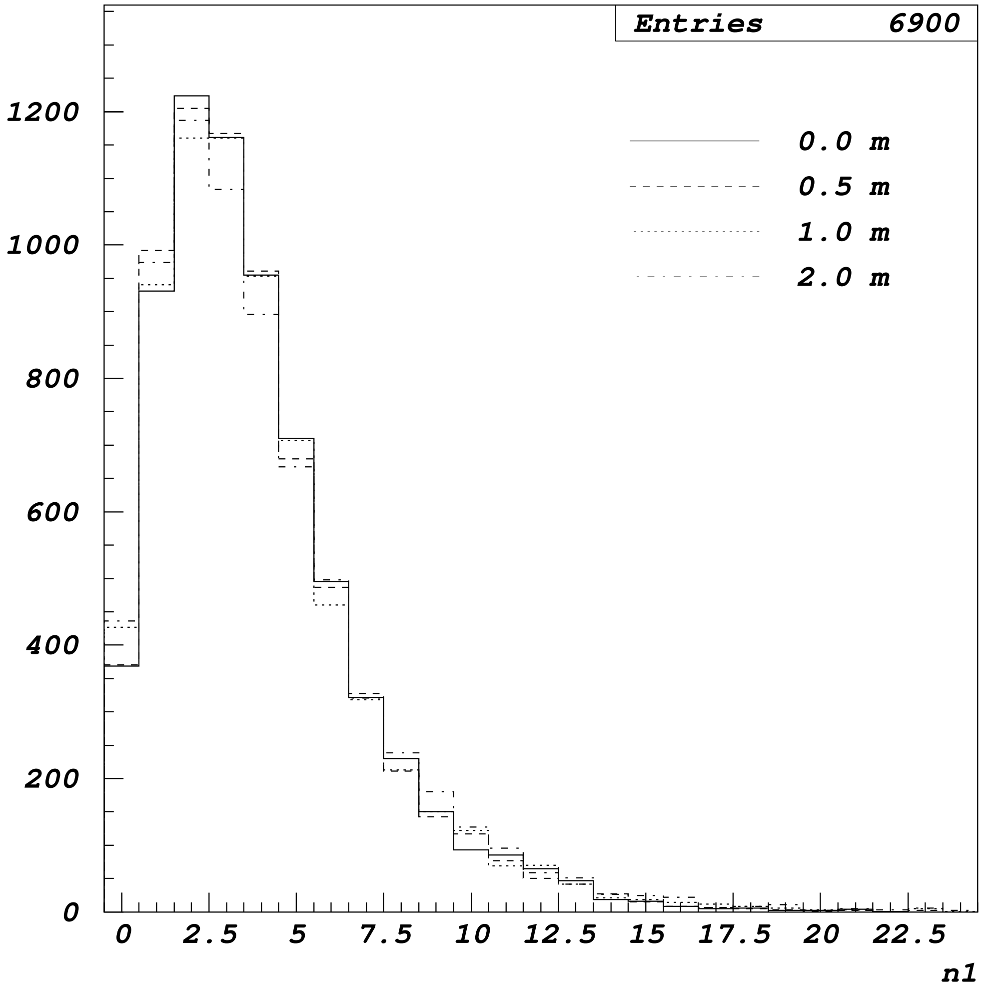

Figure 2: Distribution of events with interaction in the CsI over n_1.

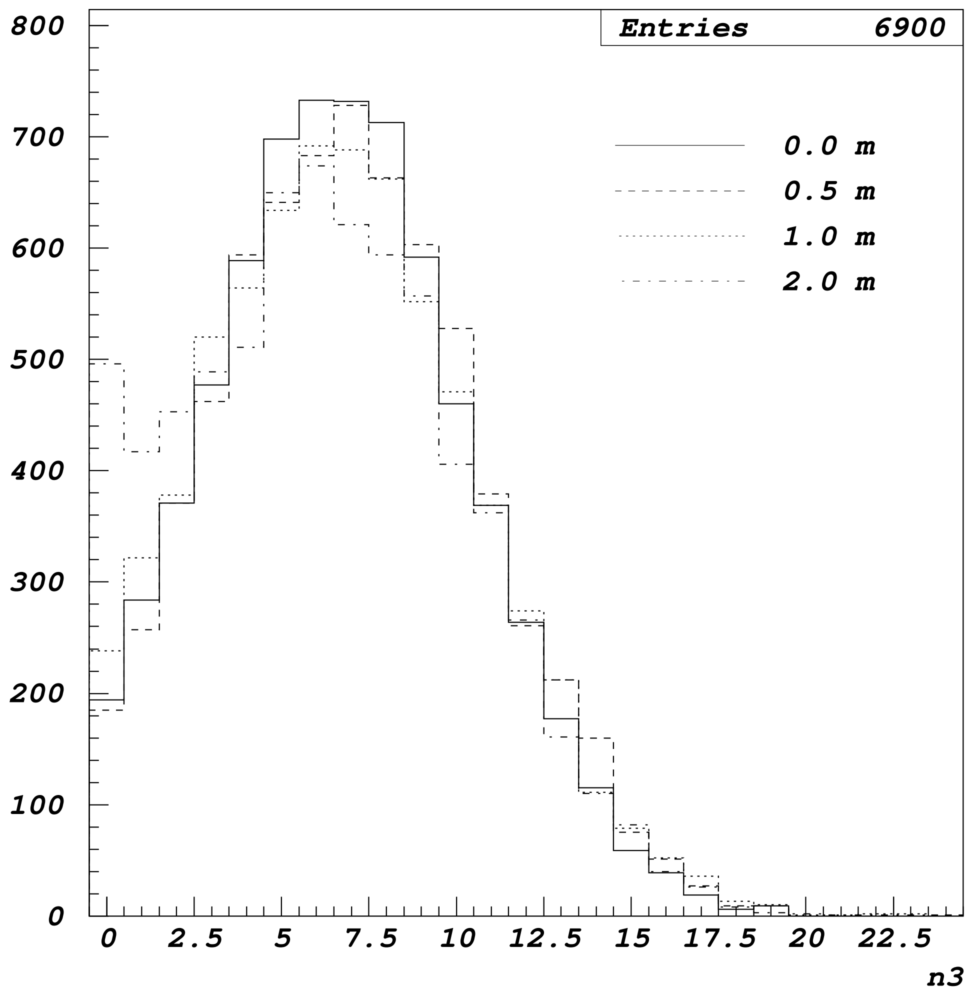

Figure 3: Distribution of events with interaction in the CsI over n_3.

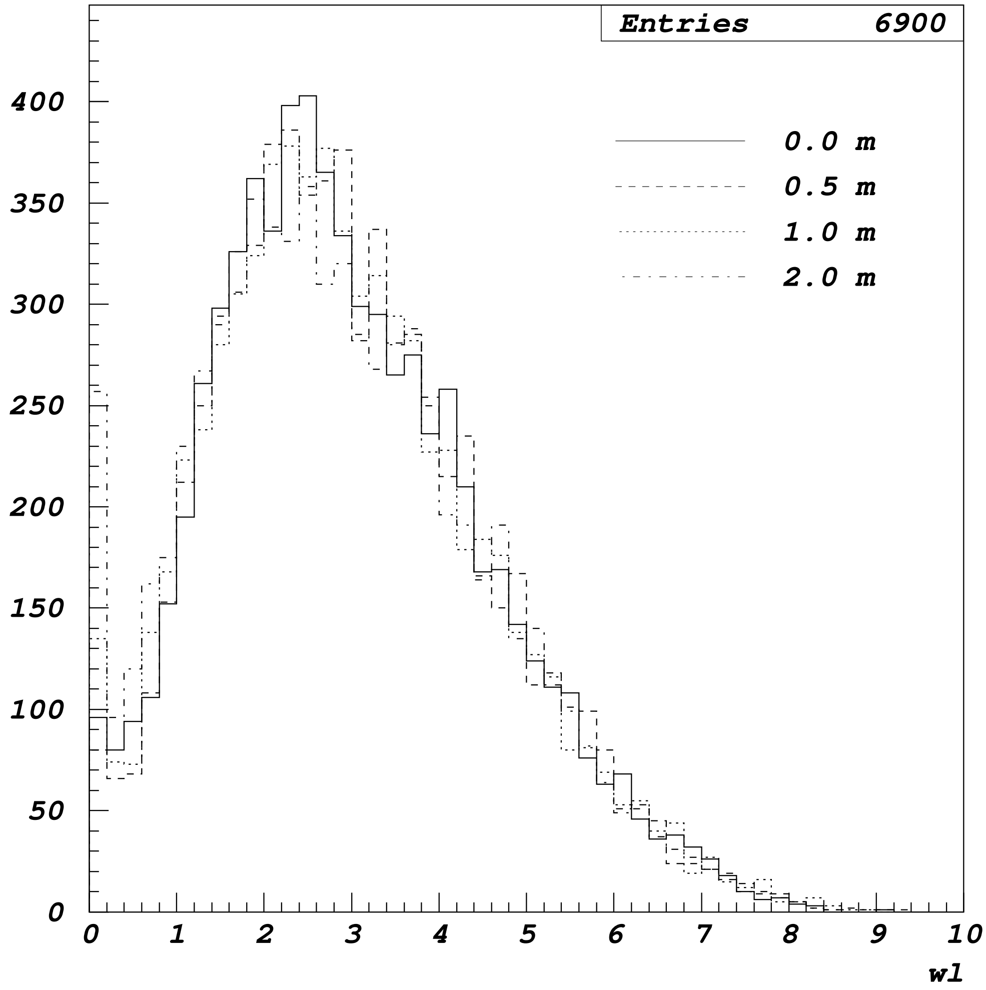

Figure 4: Distribution of events with interaction in the CsI over w_l.

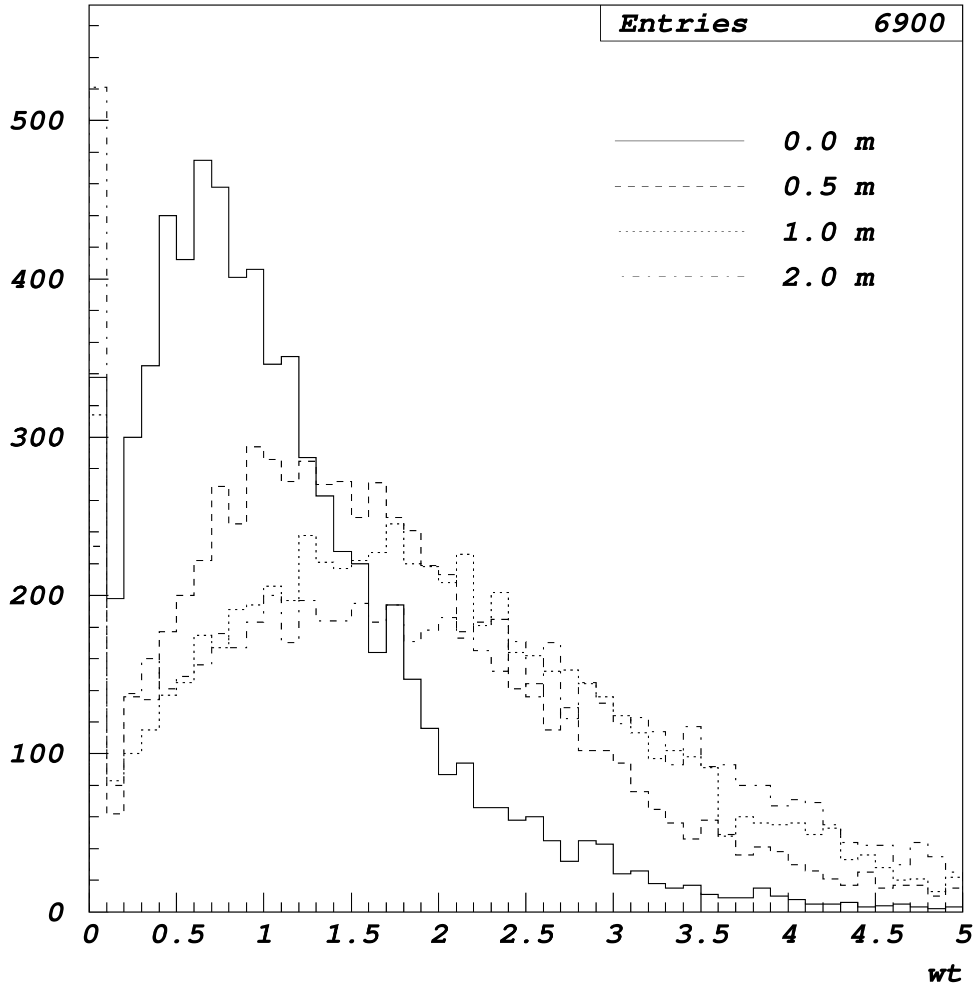

Figure 5: Distribution of events with interaction in the CsI over w_t.

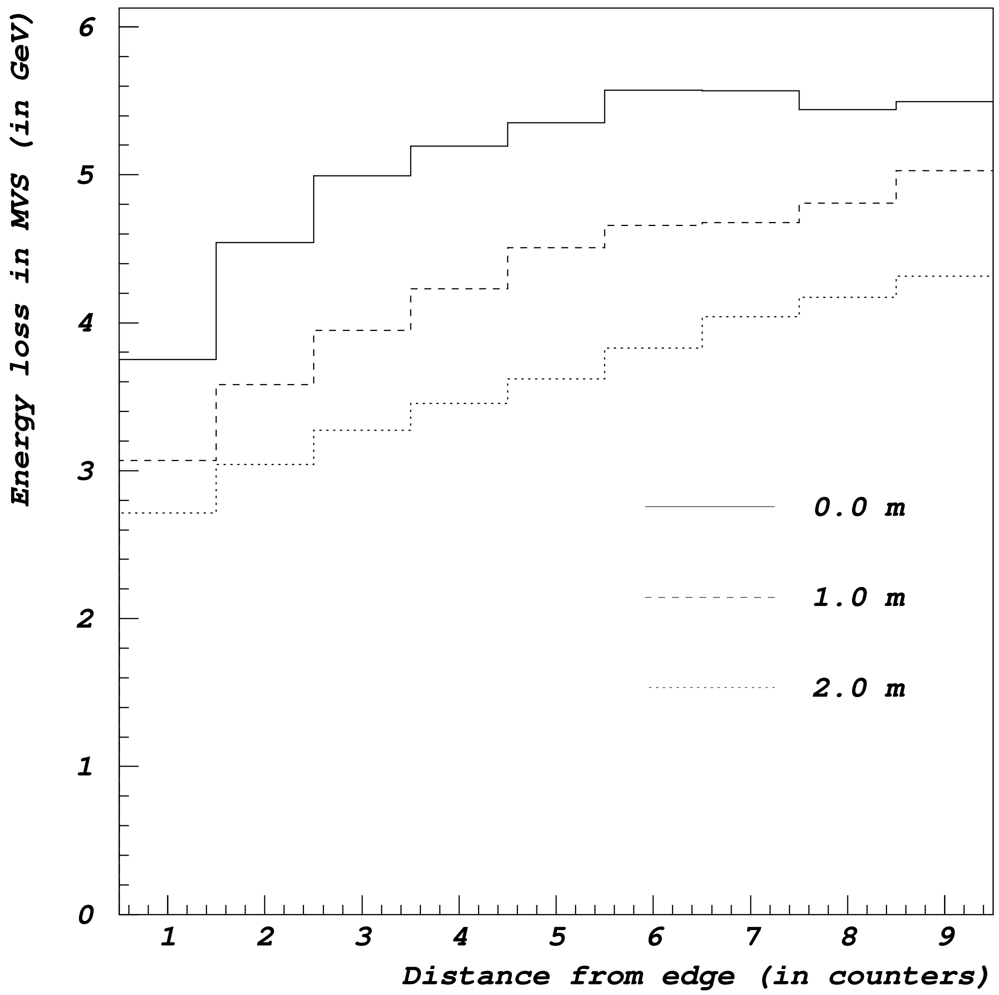

Figure 6: Average energy deposition for 14–15 GeV pions, hitting edge of the MVS.

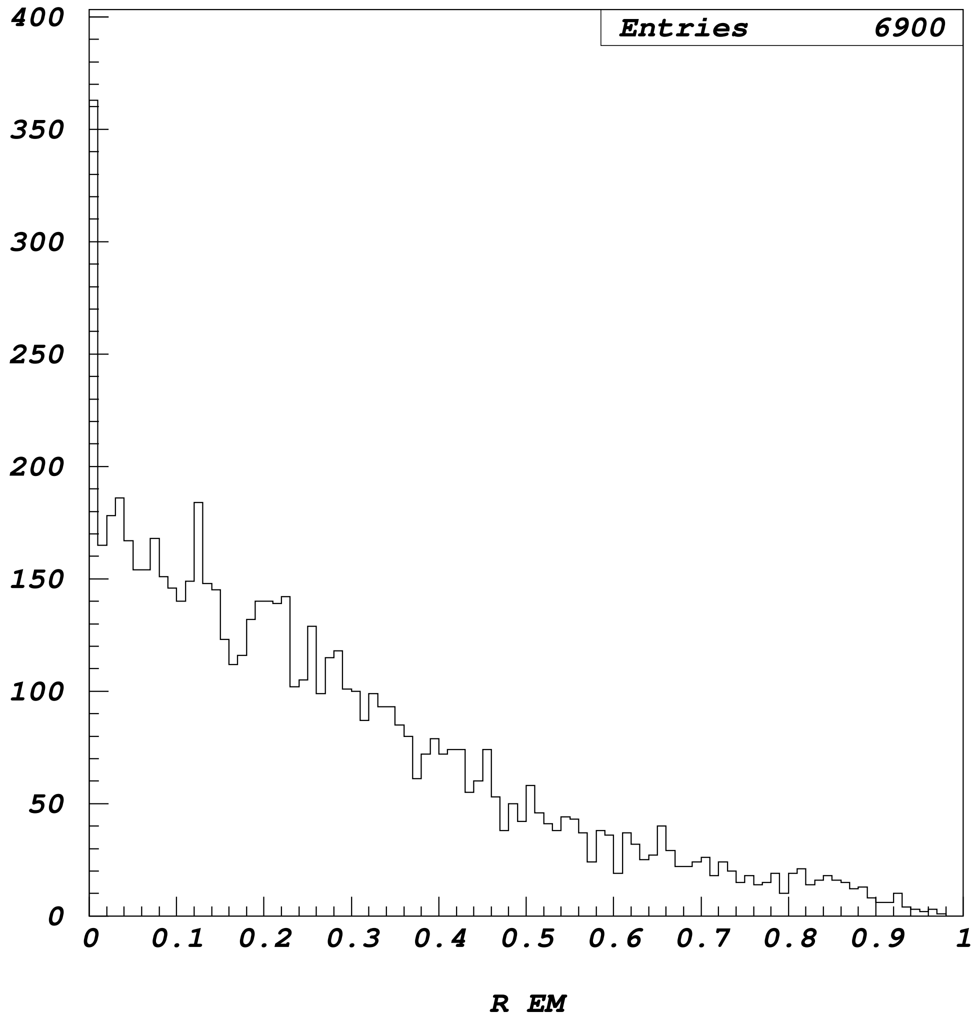

Figure 7: Part of the electromagnetic energy in the first pion interaction.