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The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

February 03, 2006

Electromagnetic Secondaries and Punchthrough Effects in the CMS ME1/1

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Abstract

The aim of this work is to estimate the shower leakage from the CMS Endcap Hadron calorimeter (HE) due to electromagnetic secondaries and punch-through in the region of the ME1/1 Forward Muon Station. Two configurations are considered: with and without the CMS Endcap Electromagnetic calorimeter (EE). The experimental data has been taken during the combined beam test of CMS subdetectors (HE, ME, RPC, DT) at the CERN H2 beam facility in 2004. Serial CSC chambers (ready for installation in CMS) fully equipped with readout electronics have been exposed. Simulation of beam test setup has been performed using the GEANT4-based simulation package OSCAR.

1 Introduction

The cathode strip chambers (CSCs) are devoted to the measurement of muon spatial coordinates in the Endcap muon stations of the CMS experiment [1]. Each CSC is composed of 6 layers [2,3]. In order to achieve the required momentum resolution the CSCs of the Forward Muon Station ME1/1 should provide high spatial resolution (~150 µm per layer). The ME1/1 station is located behind the electromagnetic and hadron calorimeters (EE+HE). High energy muons and pions passing through calorimeters produce a significant number of the secondary particles in the region of ME1/1 which can lower spatial resolution [4] and track reconstruction efficiency [5] of detectors.

In this note an estimate of the shower leakage in the ME1/1 region of the CMS detector is done analysing experimental data taken in the combined beam test of ME1/1 and HE at the CERN H2 beam facility in 2004. To study the punch-through effect two experimental configurations were considered – with and without the EE (as possible startup scenario for the CMS Endcap) located in front of the HE. This study provided the fraction of events corresponding to the two configurations.

The simulation has been performed with the OSCAR package [6] based on GEANT4. In this simulation the different models used for the simulation of hadronic showers in GEANT4 have been considered.

2 Experimental Setup

The tests were performed at the H2 beam line in the SPS North Area (EHN1). The H2 beam provides hadrons, electrons or muons in the range from 10 up to 400 GeV. The experimental test setup is schematically shown in Figure 1. The magnet has a hole along a beam line. During the beam test the magnet was switched off.

To match the real CMS geometry all the detectors were turned to the angle of ~20 degrees with respect to the beam axis. Four CSCs of muon stations ME1/1, ME1/2, ME2/2, and ME3/2 were installed behind the H2 magnet (base line configuration). A 5th chamber (ME1/1′) was assembled on HE module located on the HE moving table.

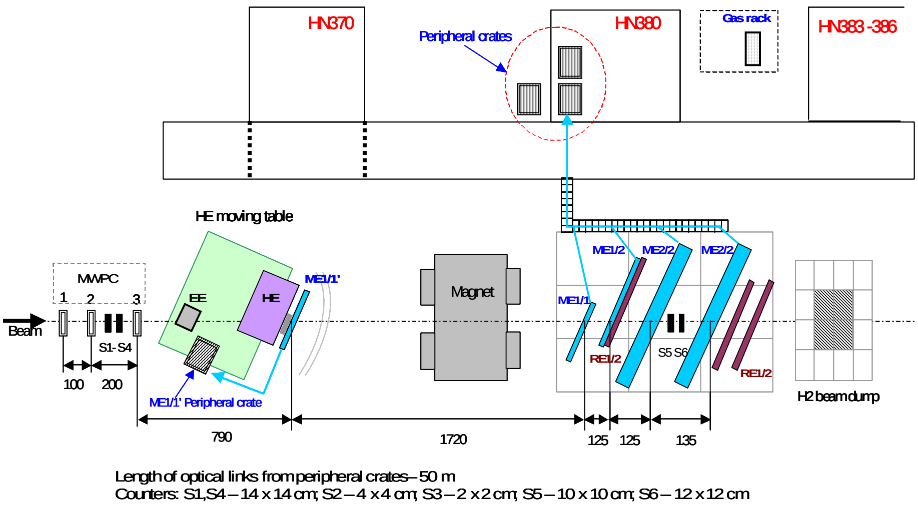

Figure 1: The experimental setup (distances given in cm).

The base-line configuration was used for DAQ and Trigger system tests. The configuration of HE+EE+ME1/1′ which reproduce the CMS geometry ($\eta \approx 1.7$ and $\varphi \approx 1.54$) and material was used for investigation of the shower leakage in ME1/1 region (see Figure 2). The electronics of the 5th chamber was distributed across 4 peripheral crates and read-out by the detector dependent unit (DDU) board. Parallel path via the detector clock control unit (DCC) S-Link was used for readout monitoring and event display.

For the study of the punch-through and electromagnetic secondaries a trigger based on different combination of the scintillation counters S1-4 has been used. The ME1/1′ chamber operated with the anode local charge track board (ALCT) coincidence 2-out-of-6. This means that the chamber takes the event if at least 2 of 6 layers have hits.

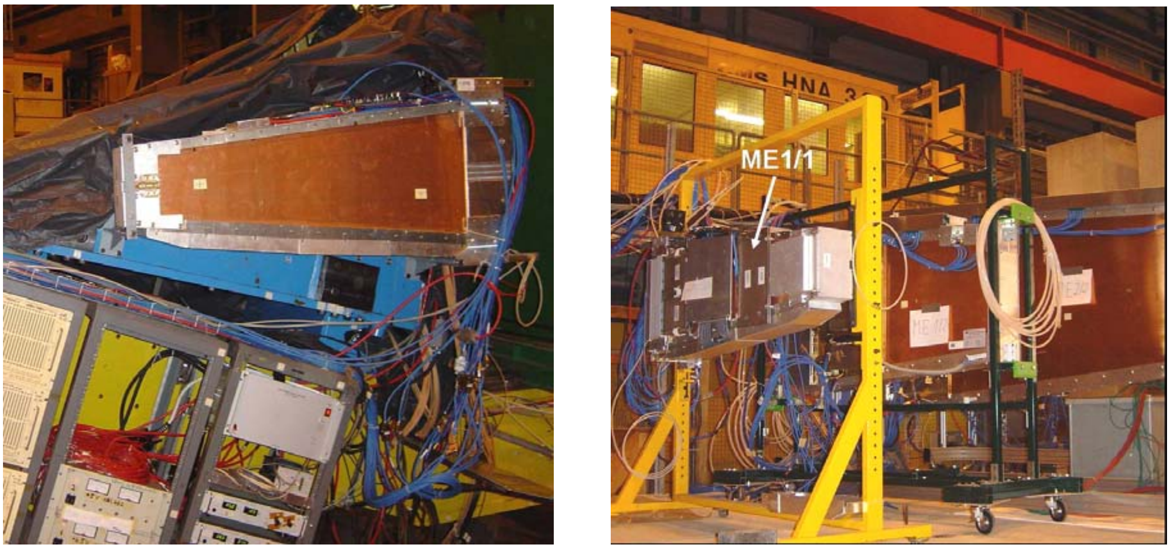

Figure 2: ME1/1′ mounted on HE turn table and ME1/1 in the base-line configuration of the CMS endcap muon chambers in H2 beam.

3 Electromagnetic Secondaries

High energy muons passing through dense materials induce electromagnetically secondary particles which contaminate the track trajectories. From the point of view of the primary muon track reconstruction these secondary particle hits are outliers, and lead to degradation of muon reconstruction efficiency and precision. During the beam test we have collected experimental data for muon beam energies of 30, 50, 100, 150, 300 GeV. A typical experimental 300 GeV muon event with electromagnetic secondaries (production of knock-on delta-electron and gammas by ionisation, bremsstrahlung and e+e- production) in ME1/1´ is given in Figure 3. The secondaries look like additional separate clusters or distorted muon clusters.

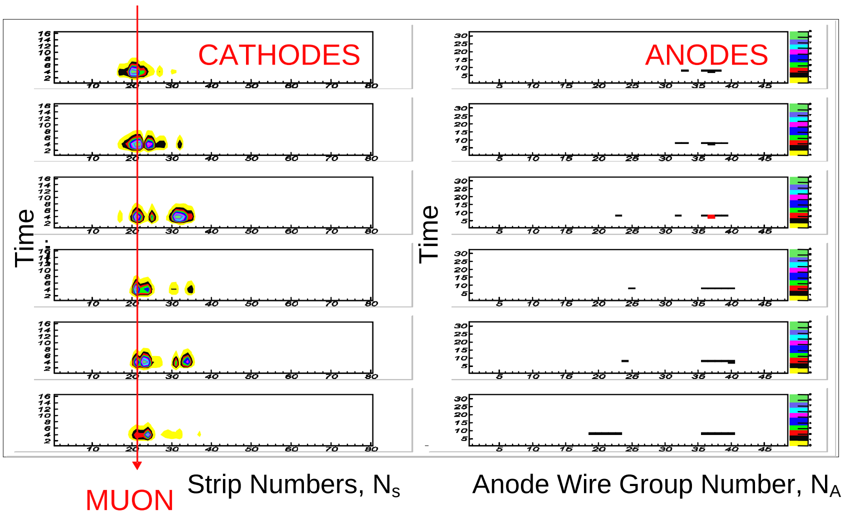

Figure 3: Experimental event with electromagnetic secondaries in ME1/1′ (300 GeV muons).

The event is taken as having secondaries if another cathode cluster (which can be overlapped with a muon cluster) appears at a distance of more than 2cm from the muon track or a muon track has a sequence of more than three distorted clusters. This cut effectively rejects the influence of the knock-on electrons produced inside ME1/1′. In the experiment we have registered events with secondaries both from HE and ME1/1′. Figure 4 (squares) shows electromagnetic secondaries probability for this case. The total fraction of events with the secondaries is about 27% for muons with energy of 300 GeV. This result is in agreement with a previous test made in 1995 [5]. On it’s face side the chamber has copper cooling system, electronics and copper shielding with total thickness about 9 g/cm^2. To calculate the fraction of events with secondaries produced in ME1/1′ itself we select the events without secondaries in ME1/1′ and then analyze the events in ME1/1 staying 17m downstream the beam line. According to the results [7] the fraction of events with secondaries as a function of a distance from the absorber is decreasing quickly. Secondaries produced after the 6th layer in ME1/1′ stop before ME1/1 because of the distance between the chambers is 17 m and ME1/1 has 10 mm of Cu (secondaries in ME1/1 originated from ME1/1′ back panel (~0.4 g/cm^2) can be neglected). Figure 4 (triangles) shows the electromagnetic secondaries probability for ME1/1. In the case of the 300 GeV muon this value is about 20%. Thus for high energy muons the fraction of events contained secondaries from HE is only about 7% (Figure 4, circles).

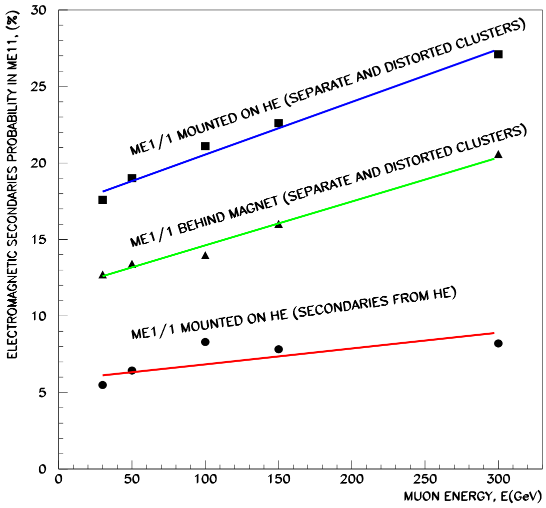

Figure 4: Electromagnetic secondaries probability in ME1/1′ vs muon beam energy.

4 Hadronic punch-through

The punch-through (hadrons, electrons, muons, gammas) is induced by high energy pions passing through the calorimeters. The experimental data have been collected for pion beam energies of 50, 100, 150, 300 GeV (for HE+ME1/1′) and 300 GeV (for EE+HE+ME1/1′). The data was taken with the ME1/1′ 2/6 ALCT trigger option. An example of experimental event with punch-through from ME1/1′ is given in Figure 5. A punch-through event looks like a random cluster in any anode or cathode layer. Due to the anode trigger requirement, 2-out-of-6 trigger option, a punch-through event is really defined as event with at least two anode clusters in two layers (one cluster per layer).

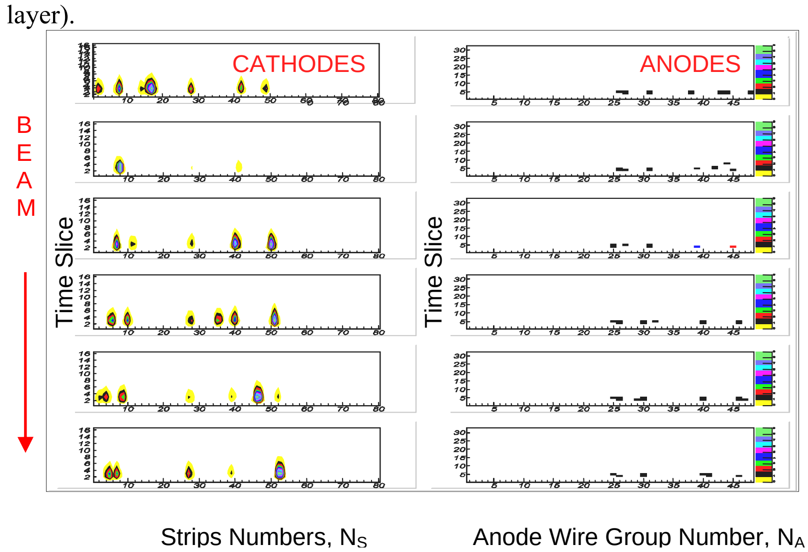

Figure 5: The experimental event with punch-through in ME1/1′ (pion with energy of 300GeV).

For a correct analysis of punch-through effects one should reject the muon component in the primary pion beam (about 10 %). The signal from a pion is covering a 3×3 HE matrix while for a muon the signal is collected in a single tower. Pions and muons with the same energy have rather different signal distributions in HE towers [8] (Figure 6). Thus, the signal from the muon component can be rejected by applying a cut (70 fC) on the total signal from the HE. The rejection efficiency is above 94 %. After these requirements the fraction of muon in the pion beam is less than 0.6 %. The punch-through probability as a function of the beam energy is given in Figure 7. One can see that 300 GeV pion beam produces 38% of the events with punch-through for HE+ME1/1′ and 17% for EE+HE+ME1/1′.

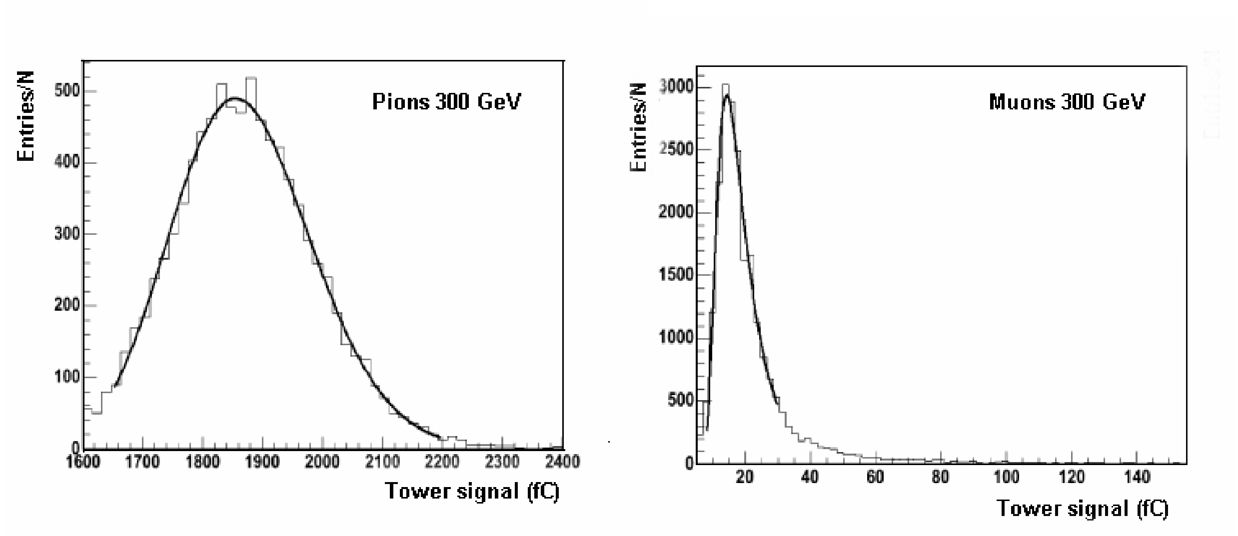

Figure 6: Amplitude spectra for pions (left) and for muons (right) in HE towers for beam energy of 300 GeV. For pions the signal is from a 3×3 matrix of towers, or muons from a single tower.

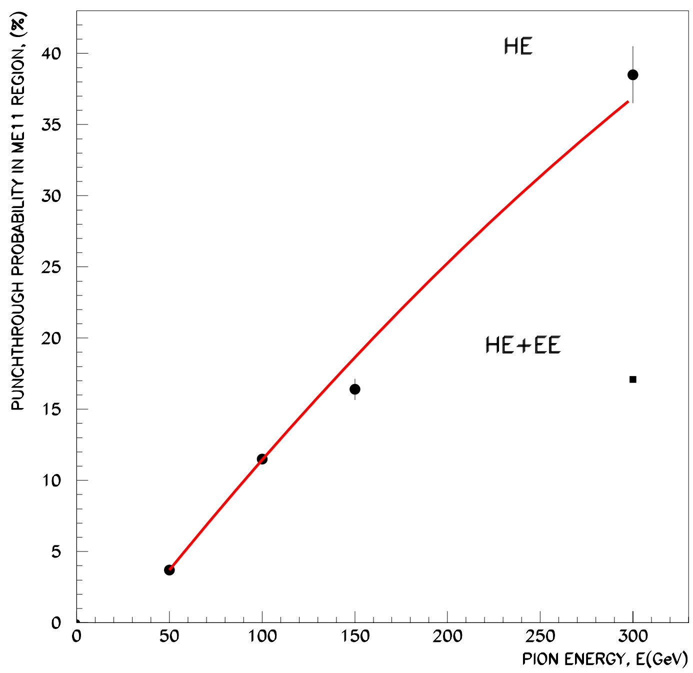

Figure 7: The punch-through probability vs pion beam energy for the HE+ME1/1 configuration (solid line, circles) and for the HE+EE+ME1/1 configuration (square).

The next important question is the punch-through event structure. We have performed track reconstruction for the punch-through events in ME1/1′ with ALCT option 4/6, 5/6, 6/6. This means that at least 4 layers of the chamber have anode hits. It was found that about 80% of the events have tracks reconstructed with hits in 4-6 layers. Figure 8 shows distribution of number of tracks for punch-through events with tracks found. The punch-through profile in anode wire groups is shown in Figure 9. The width of one anode group is 2.7 cm. Thus the punch-through width is about 160 cm.

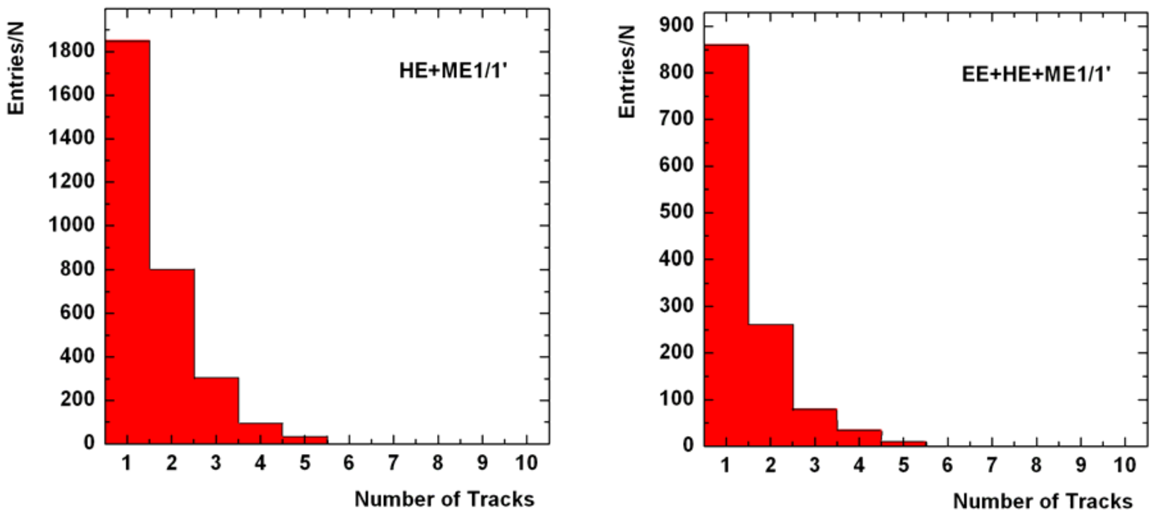

Figure 8: Track number distribution for punch-through events in ME1/1′ for HE+ME1/1′ (left) and EE+HE+ME1/1′ (right).

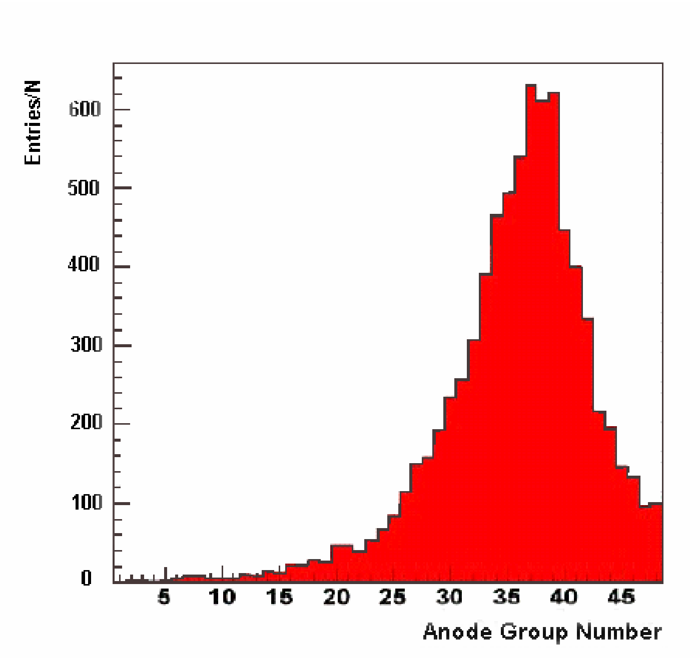

Figure 9: ME1/1′ anode filling histogram for 300 GeV pion beam (the width of the anode group is 2.7 cm).

5 Simulation

To compare the study of the beam tests results with simulation data, we have used the official CMS simulation package OSCAR [6], based on GEANT4. The geometry of the beam test experiment was designed to reproduce the standard CMS geometry for the ME1/1′+HE+EE configuration therefore no dedicated beam test geometry was needed to study secondaries in ME 1/1′. The simulation fully reproduced the amount of material before ME1/1 in the beam test.

Single particle events were generated at fixed values of η and φ, and different values of p_T (between 1 GeV/c and 1 TeV/c). Two kinds of events were generated: containing a single muon (μ-) and a single pion (π+). A number of data samples, with 1000 events each, were generated. It should be noted that at high η ≈ 1.7 such p_T values correspond to 2.8 times higher momentum.

Part of the beam test data was collected with the EE placed outside the beam. In order to simulate this configuration we have modified the simulation geometry substituting the material for all EE volumes by vacuum.

The detector response and digitization were simulated using the official CMS reconstruction package ORCA version 8_7_1 [9]. The magnetic field was switched off for both detector simulation and event reconstruction.

For event analysis reconstruction the package ORCA_8_7_4 [8] was used. Events simulation was performed using full CMS detector geometry, but during the analysis phase only the measurements of one ME1/1 chamber were considered, the one which was pointed by single particle beam.

To perform the muon secondaries analysis the number of reconstructed hits outside of +/- 2 cm (in phi direction) corridor from a muon was counted. Figure 10 shows the experimental data and simulation results for the electromagnetic secondaries probability as a function of muon momentum. These results demonstrate the good agreement between data and simulation for the default OSCAR simulation. The statistical errors only are given for simulated data.

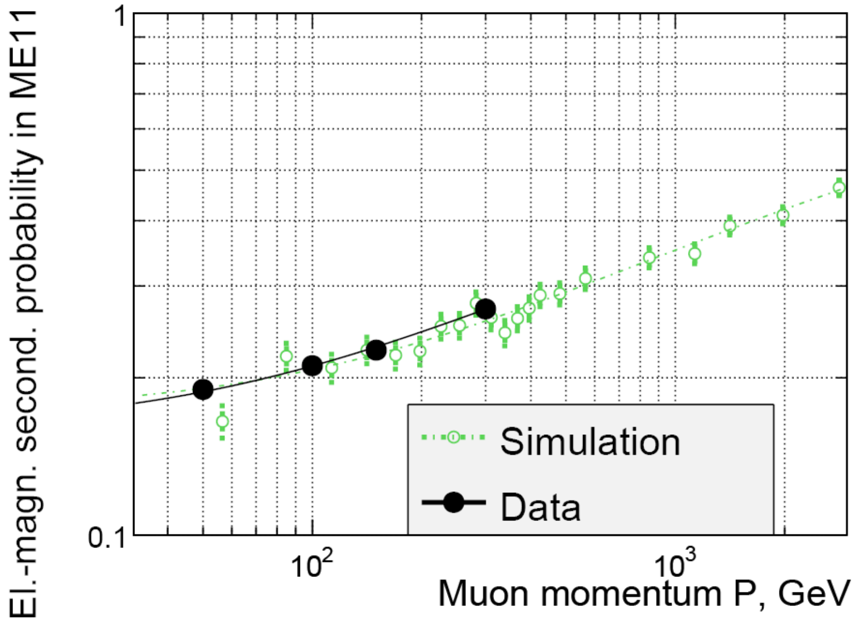

Figure10: Electromagnetic secondaries probability in ME1/1 vs muon beam energy. Simulation for four GEANT4 model lists is given for extended region up to 3 TeV/c.

The description of electromagnetic processes in GEANT4 based on precise theory (quantum electrodynamics) was already extensively tested and validated with different energies and materials. Hadronic physics for interesting energy range lies outside pertrubative QCD and simulation of hadronic processes is based on several models. Generation of datasets was repeated several times, implementing different hadronic shower models [10]:

- QGSP, implements theory driven modeling. It employs the quark -gluon string model for the punch-through interactions of the projectile with a nucleus, the string excitation cross-section being calculated in quasi-eiconal approximation. It is the default for OSCAR.
- QGSC is like QGSP for the initial reaction, but uses chiral invariant phase-space decay (multi-quasmon fragmentation) to simulate the behavior of the system's fragmentation
- LHEP, uses LEP and HEP parameterized models for inelastic scattering

- FTFP is similar to QGSP for the treatment of the fragmentation, but the string excitation/fragmentation is changed from quark-gluon string model to a diffractive string excitation

For the simulation of the punch-through probability the trigger logics was the same as that for the data taking. For this study, the simulation results significantly depend on the model used – three of them (QGSP, QGSC and FTFP) give same values for the punch-through probability, while for LHEP this probability is 6 % and 11 % higher for 300 GeV pion for configuration with ECAL inserted (Figure 11) and without (Figure 12) respectively. With that, in both cases, the simulation with the LHEP showering model reproduces the experimental data better.

In summary, from a comparison of experimental results with simulation data both for secondaries and punch-through, we conclude that the CMS simulation gives reasonable results which can be used for physics analysis.

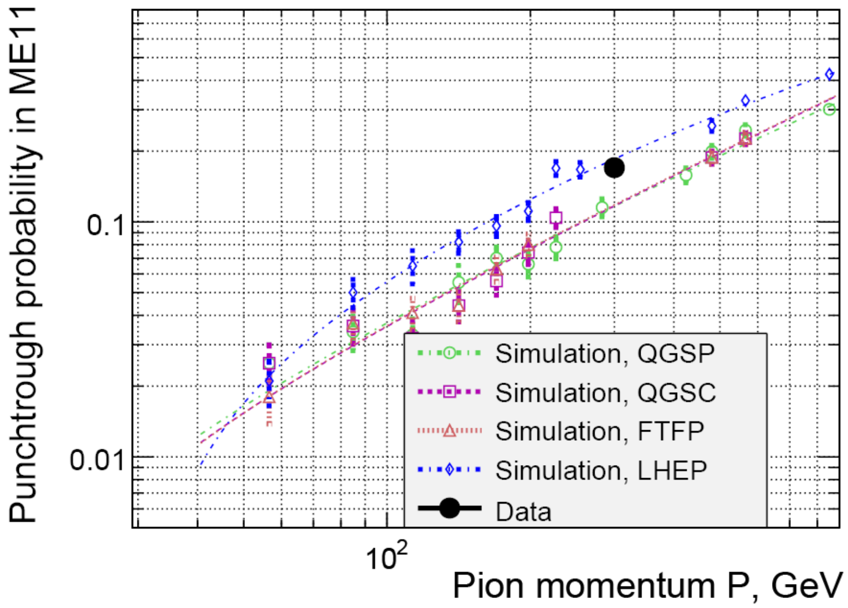

Figure11: Punch-through probability vs pion beam energy for EE+HE +ME1/1 configuration. Simulation for four GEANT4 model considered is given for extended region up to 1 TeV/c.

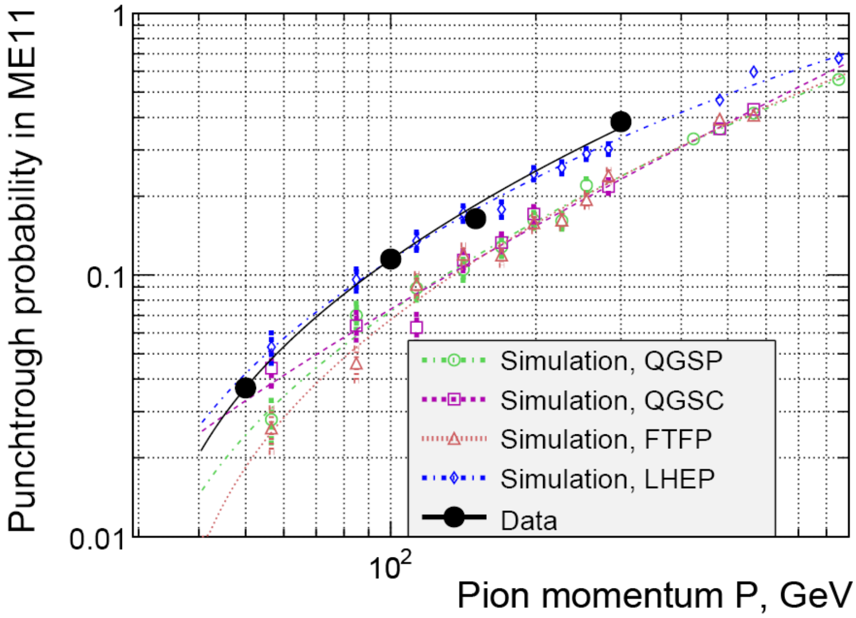

Figure12: Punch-through probability vs pion beam energy for HE+ME1/1 configuration. Simulation for four GEANT4 model considered is given for extended region up to 1 TeV/c.

6 Conclusion

The analysis of the experimental data of the combined HE-ME beam test has been presented. It is shown that muons with energies 30–300 GeV produce 17–27% of events with electromagnetic secondaries which can contaminate the muon track significantly. Most of them originate from the CSC face material (CSC shielding, electronics, cooling plate 9 g/cm^2). Pions at 300 GeV produce 17% of the events with punch-through for the EE+HE+ME1/1 configuration. It is found that around 80% of the hadronic punch-through events have up to 1÷5 tracks in the ME1/1 station. The shower radius is about 80 cm. The CMS GEANT4-based simulation reproduces reasonably experimental data both for secondaries and punch-through.

Acknowledgment

We thank our colleagues from the EMU and PRS muon group for their advice and fruitful discussions, in particular Darin Acosta, Frank Geurts, Dragoslav Lasic, Martin von der Mey, Pedro Arce, Tim Cox, Jeremy Mans, Ugo Gasparini, and Igor Gramenitski. Also we would like to thank Yves Sirois and Roberto Tenchini for helpful remarks and comments on the text of this note.

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