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INCREASING OF MUON-TRACK RECONSTRUCTION EFFICIENCY IN ME1/1 DUBNA PROTOTYPE FOR THE CMS/LHC

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The aim of this work is to increase the efficiency of muon track reconstruction and estimate a number of electromagnetic secondaries in the muon detector on experimental data of the Integrated Test set-up, the prototype of CMS endcap segment. The experimental data have shown that the high energy beam of muons (100 – 300 GeV) produces 20–25% of events with electromagnetic secondaries. Though the muon coordinate measurements were distorted by secondaries, we have managed to obtain a high efficiency ($\geq$ 92%) of the muon track reconstruction.

The investigation has been performed at the Laboratory of Computing Techniques and Automation and the Laboratory of Particle Physics.

Повышение эффективности реконструкции мюонных треков в дубненском прототипе камеры ME1/1 для эксперимента CMS/LHC

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Цель работы — увеличение эффективности реконструкции мюонных треков в мюонном детекторе за счет отделения мюонов от вторичного электромагнитного сопровождения, а также оценка этого сопровождения. Расчеты проведены на экспериментальных данных с Интегрального теста — прототипа торцевого сегмента установки CMS на строящемся в CERN ускорителе LHC. Полученные результаты показали, что для высокоэнергетичного пучка мюонов (100 - 300 ГэВ) 20-25 % событий в детекторе регистрируется с электромагнитным сопровождением, однако при этом удается достичь высокой эффективности ($\geq$ 92%) реконструкции мюонных треков.

Работа выполнена в Лаборатории вычислительной техники и автоматизации и Лаборатории сверхвысоких энергий ОИЯИ.

1. INTRODUCTION

The CMS muon system should provide a good efficiency of muon track reconstruction with a high spatial resolution. It is needed for achievement of required momentum resolution [1]. The muon detector is located behind the hadronic calorimeter. High energy muons themselves produce a significant number of electromagnetic (e.m.) secondaries passing through the calorimeter matter. A part of e.m. secondaries reaches the muon detector and makes the muon track reconstruction more difficult.

The aim of this note is to estimate a number of electromagnetic secondaries using the experimental data from the muon detector (ME1/1 prototype) and obtain a high efficiency of muon track reconstruction separating muon tracks from secondaries.

2. EXPERIMENTAL SET-UP

The Integrated Test experiment was carried out to test CMS endcap prototypes. The Integrated Test set-up located at the H2 beam line of the CERN SPS accelerator is shown in Fig.1.

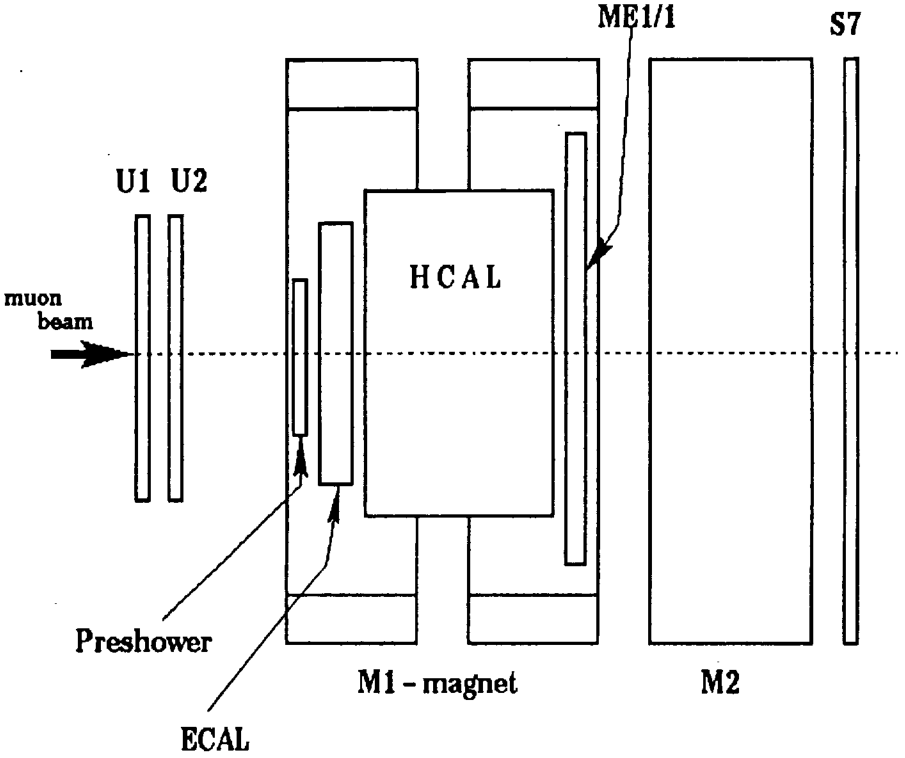


Fig. 1. The Integrated Test experimental set-up

The prototypes of the CMS endcap preshower, the electromagnetic calorimeter (ECAL), the hadronic calorimeter (HCAL) and the muon detector (ME1/1) were placed into the superconducting magnet M1. The axial magnetic field was oriented along the beam. The value of the magnetic field in the ME1/1 was approximately equal to 2.5–3 T. Data taking was performed with a negative charge muon beam having momenta of 100, 150, 225 and 300 GeV/c. Magnet M2 (switched off) worked as an absorber (3.8 m Fe). Scintillator S7 located behind M2 was used to identify muons. Beam chambers U1 and U2 located in front of the Integrated Test set-up were used to calculate parameters of the incoming muon beam.

Cathode Strip Chamber (CSC), a full-scale prototype of the 1/36 ME1/1, worked as a muon detector of the Integrated Test set-up. CSC is a 6-layer multiwire proportional chamber with strip cathode read-out. Precise position measuring of a charged particle (about 40-60 μm per layer [2]) is obtained by determinating the centre of gravity of the induced charge on the cathode strips each ~ 5 mm wide. However, in addition to muon hits, a lot of hits in CSC is produced by e.m. secondaries (γ and e^- / e^+). Muon generates these e.m. secondaries due to ionization (δ rays, also called «δ electrons»), bremsstrahlung and direct e^+e^--pair production. Bremsstrahlung and pair production in a region of several hundreds of GeV increase rapidly and produce full e.m. showers which can be close to a muon track and that is why the original muon position may be distorted.

3. MUON TRACKS RECONSTRUCTION

Muon events are selected from the μ-beam experimental data according to the following criteria:

- negligible energy deposition in the HCAL;
- hit in the S7 scintillator;
- anode hits within a wide road (± 55 mm) on ≥ 4 layers (anode wires are arranged to groups, 22 wires each);
- more than 3 cathode planes with clusters inside the beam profile.

There are only few percent of the events in the total number of experimental data which do not meet these requirements.

A charge induced on the cathode plane by one charged particle was distributed onto 3-5 strips. If the charged secondaries pass through the CSC layer at a distance less than 5 strips from the muon, the charges induced on the cathode overlap. This causes wide clusters (more than 5 strips). In this case we propose a procedure of splitting wide clusters into subclusters to define correctly the muon position. Because of only 10 bits of information per strip, more than 10 % of the cluster's information contain an overflow in the strip with the maximum charge.

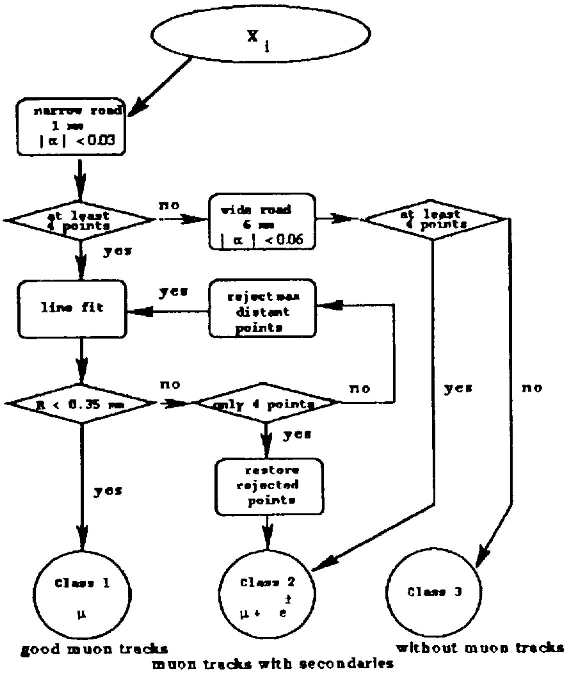


Fig. 2. The block-scheme of the algorithm of muon track reconstruction

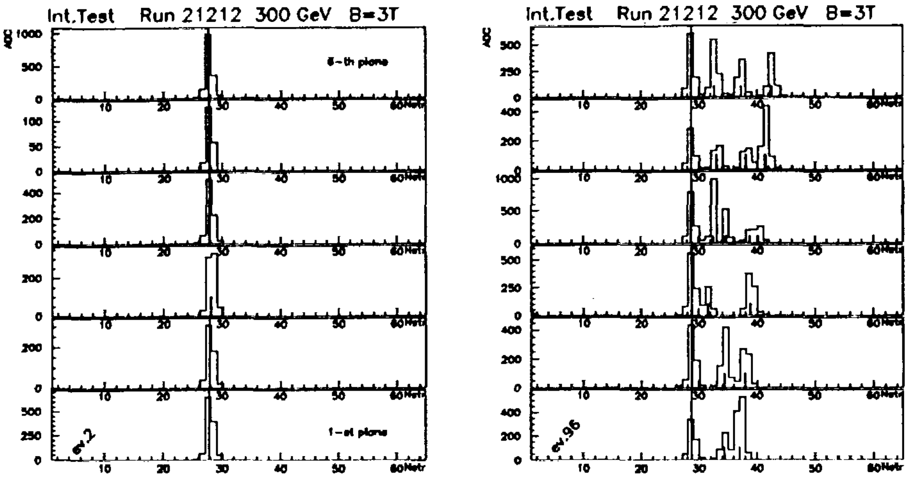
Shape parametrization of the charge induced on the cathode allows one to reconstruct the charge at the strip with the overflow. This procedure is helpful to improve identification of the muon position.

The calculation of the x coordinate of the cathode charge distribution centroid is made using the «ratio» method [3]. Muon track candidates are chosen from the x_i array at ≥ 4 planes in a narrow half-road (± 0.5 mm) according to the algorithm shown in Fig.2.

A muon track is supposed to satisfy the following requirements:

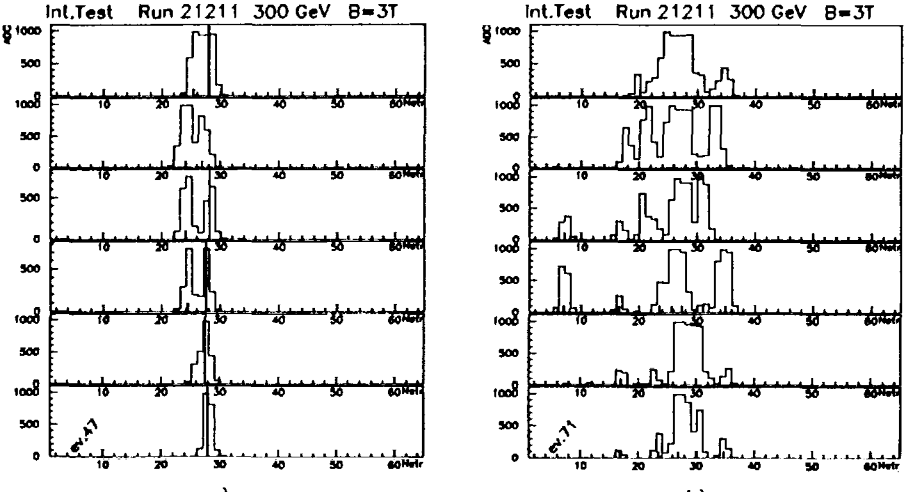
- at least 4 x_i coordinates must be within the road of 1 mm wide and it's slope $|\alpha| < 30$ mrad;
- a track-candidate should be inside the beam profile of ±20 mm.

After line fitting ($x^{\text{fit}} = az + b$) with the method of least squares, every track is classified.



a) b)

Fig. 3. *a*) The example of «good» μ-track event. The charge is induced on strips of the six cathode planes of the ME1/1 chamber. The reconstructed coordinates of charge distribution centroids are shown with thick segments. The track coordinates are drawn with long segments. The coordinate beyond the track is given with a short segment (on the 3rd plane). *b*) The example of a «good» μ-track event well separated from secondaries Muon track is selected unambignuosly if within the beam-profile range



a) b)

Fig. 4. *a*) The example of (μ + *e*)-track event reconstructed in a wide road. The segments indicating the track coordinates do not lie on the same line. *b*) The example of a«hard» event in which μ track was not reconstructed. Usually 10–20 strips are hitted in succession in every plane of the chamber with the overflow in many of them

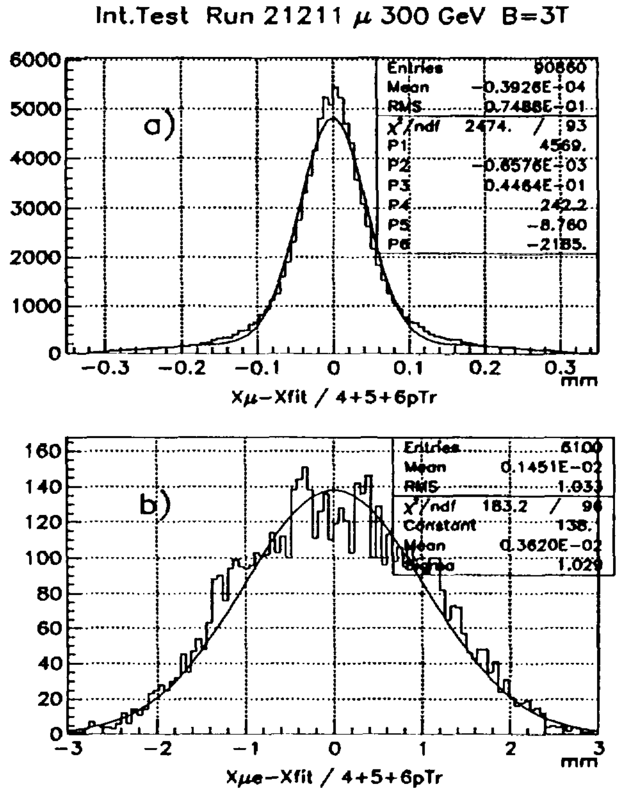


Fig. 5. The residuals $(x_i - x_i^{\text{fit}})$: *a*) — for «good» μ tracks (fitting with Gaussian + parabola), *b*) — for $(\mu + e)$ tracks (fitting with Gaussian)

(i) A «good» μ track (1st class) must satisfy the goodness-of-fit criterion:

$$R = \sqrt{\sum_{i=1}^{n} (x_i - x_i^{\text{fit}})^2 / (n - 2)} < 0.35 \text{ mm}, \qquad (1)$$

where n $(4 \le n \le 6)$ is a number of points per one track. Examples of such events are presented in Fig.3. If a track candidate with more than 4 coordinates does not satisfy this criterion, the most distant point from the fitted line is rejected and then the track is refitted.

(ii) If the 4-point track candidate does not satisfy the criterion (1), we restore the initial track candidate including all the rejected points. We classify these tracks to be of the 2nd class, calling them «μ tracks with e.m. secondaries».

If at the beginning of the track search we cannot reveal a track candidate in some narrow road, we try to reconstruct a track in some road 6 mm wide with angles $|\alpha| < 60$ mrad. If such a track contains ≥ 4 points, we classify it as a μ track with secondaries. This is the case when secondaries distort muon measurements in several planes. The example of the event is presented in Fig.4*a*.

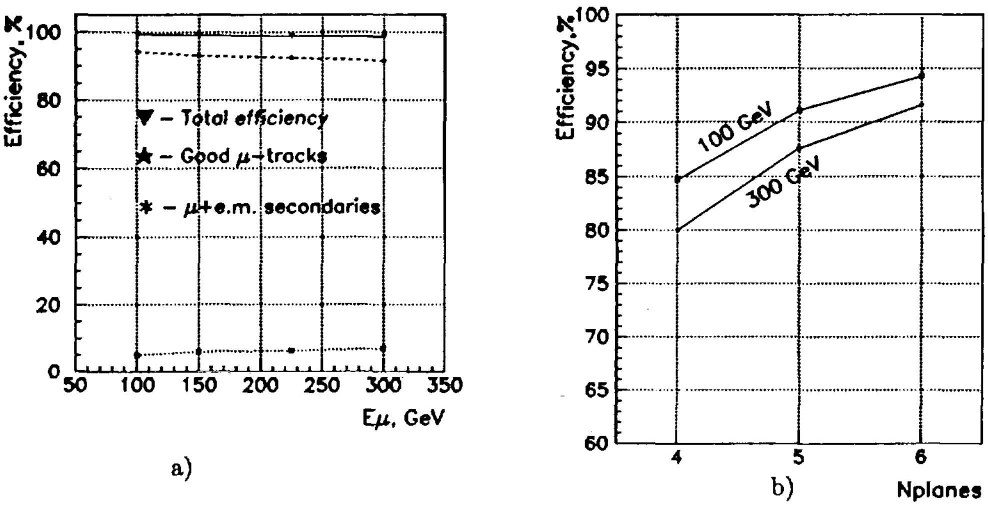


Fig. 6 *a*) The efficiency of muon-track reconstruction versus the energy of muon beam. The dashed line is the efficiency of «good» μ-tracks reconstruction, the dotted line — the efficiency of (μ + e.m.secondaries)-tracks reconstruction and the solid line — the sum of them. *b*) The muon-track reconstruction efficiency dependence on the number of layers in ME1/1 chamber

The quality of the reconstructed tracks can be illustrated by residuals ($x_i - x_i^{\rm fit}$). In Fig.5*a* we present residuals for all «good» μ tracks (1st class) on all planes summarized into one histogram.

The value of mean-root-square error (RMS) is equal to 75 μm. The «tails» seen in this histogram are caused by δ rays and secondaries passing too close to muons. Figure 5*b* shows residuals for the events of the 2nd class. The value of RMS is about 1 mm.

The efficiency of the 1st and 2nd class muon-track reconstruction versus the energy of the muon beam is shown in Fig.6a. One can see that the number of «good» μ tracks reduces from 94 to 91 % and the number of μ tracks with secondaries grows from 5 to 8 % while increasing the beam energy from 100 to 300 GeV.

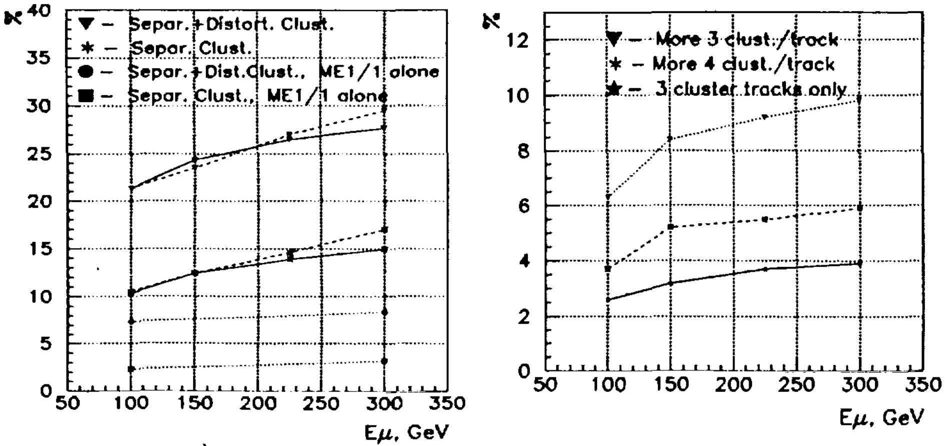
(iii) Less than 1 % of the events contain very «hard» e.m. showers and that is why it is impossible to reconstruct any track even in the wide road (events of the 3rd class; see example in Fig.4*b*).

Thus, we have estimated the efficiency of the μ-track reconstruction for the 6-layer CSC. However, if some layers are lost due to technical reasons or angle reorientation of strips on these layers (to solve the problem of «ghosts»), it may become necessary to estimate the efficiency of the CSC on the number of layers less than 6.

From Fig.6*b* it is clear that if one layer is lost, the efficiency of a μ-track reconstruction decreases by 5 %. The reconstruction of the μ track on 4 layers results in catastrophical decreasing of efficiency up to 80 %.

4. ELECTROMAGNETIC SECONDARIES IN THE MUON DETECTOR

Simultaneuosly with the muon-track reconstruction we propose an algorithm of accounting a part of the events with e.m. secondaries coming into the CSC from the calorimeter.



a) b)

Fig. 7. *a*) The percentage of events with electromagnetic secondaries from calorimeters versus the energy of muon beam. The solid line is Integrated Test experimental data, the dashed line — Integrated Test GEANT-simulated data, the dotted line — experimental data from ME1/1 without calorimeters. *b*) The percentage of events with additional tracks versus the energy of muon beam

Most of δ rays produced inside the chamber have low energy and disappear near muons. If an additional cluster («standing alone») is registered in some CSC layer (i.e., the distance between this charged particle and muon is more than 2 cm), we classify this event as the event with secondaries.

Since the probability of δ electron produced in one layer is about 12%, and the probability to achieve the next layer is ~ 20 % [4], then the probability of muon coordinates to be distorted in 3 planes by δ electrons is only few percent. Thereby we additionally account the events with muon coordinates distorted in $\geq$ 3 layers. From the track reconstruction algorithm one can see that the problem of track reconstruction appears just in this very case. Summing these events to the ones with additional clusters («standing alone»), we can estimate the part of the events with e.m. secondaries from calorimeters. While increasing the muon beam energy E_μ from 100 to 300 GeV, some part of these events increases from 20 to 25 % (see Fig.7*a*). GEANT simulation of secondaries caused by the muon passing through the Integrated Test set-up, gives a satisfactory agreement with the obtained experimental results shown in Fig.7*a*.

Using clusters «standing alone» and sub-clusters obtained after the wide cluster splitting, we can additionally try to find tracks of accompanying electrons. These tracks are required to have 3 points per track. Figure 7*b* shows the percentage of events with additional tracks to grow from 6 to 10 % while the beam energy increasing. A significiant part of these tracks has only 3 points.

5. CONCLUSIONS

The Integrated Test set-up experimental data have shown that the high energy beam of muons (100 – 300 GeV) produces 20 – 25 % of events with electromagnetic secondaries coming to the ME1/1 muon detector from the calorimeters. The situation in any endcap muon detector (ME2-ME4) seems to be the same.

Though the muon coordinate measurements were distorted by secondaries, we have managed to obtain a high efficiency ($\geq 92\%$) of the muon track reconstruction with a rather satisfactory accuracy due to splitting wide clusters into subclusters and restoring the charge on strips with overflow.

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