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Monte Carlo Studies of the Texas Test Rig Performance

A. Vanyashin, G. Yost
SSC Laboratory

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To test the performance of different muon chamber technologies proposed for the GEM experiment at the SSC, the Texas Test Rig (TTR) will be established at the SSC Laboratory. The results of Monte Carlo studies of TTR are presented. An optimized off-line selection algorithm is found.

1 Introduction

The Letter of Intent for the GEM experiment at the SSC [1] considers four different drift chamber technologies as candidates for the GEM muon chambers. To make a choice between the different muon chamber technologies the Texas Test Rig (TTR) cosmic ray telescope at the SSC Laboratory is proposed as a site to test all the chambers.

The claimed high position resolution (50 – 100 μm) of the drift chambers to be tested makes the multiple scattering effects a factor to be aware of. Two factors will contribute to the measured position resolution. The first factor is the intrinsic position resolution of the drift chambers themselvs and the second factor is the contribution from multiple scattering effects. In principle the multiple scattering contribution is calculable and could be properly subtracted from the observed position resolution. To reduce the systematic error one needs to make multiple scattering effects less than the intrinsic position resolution of the chambers. To reduce multiple scattering effects the cosmic ray muon spectrum needs to be hardened. In Section 2 we present the results of calculations of multiple scattering effects in the most precise chambers to be tested — the Cathode Strip Chambers (CSC). The 1.5 GeV cutoff of the cosmic muon spectrum provided by the 1 m of non-magnetized iron is sufficient to make multiple scattering effects inside CSC less than the intrinsic position resolution of the chambers.

Another way to test prototypes' resolution is to compare hits in the chamber with muon tracks fitted using other technologies. As the overall fit involves tracks, which have traversed larger amounts of material, to achieve high precision one needs to raise the cutoff of low energy muons. To have this additional control over the muon cosmic ray spectrum, the iron shield at the TTR will be magnetized. Four layers of Iarocci tubes (two above and two below the magnet) will be used to select high energy muons. In Section 3 we present the result of Monte Carlo studies leading to a choice of TTR magnet configuration. In Section 4 the results of GEANT MC studies of TTR are presented.

Table 1: Materials used in the Cathode Strip Chambers

Element	Material	Thickness	% of R.L.
Readout board	Cu	0.014"	0.25
	G10	1/16"	0.82

2 Multiple Scattering Effects in Cathode Strip Chambers

Among all the drift chamber technologies considered as candidates for a GEM muon system the Cathode Strip Chambers (CSC) have the best claimed position resolution of 50 μm. Figure 1 presents the layout of these chambers. Table 1 summarizes the material thickness used in MC calculations of the multiple scattering effects.

To estimate the influence of multiple scattering effects we used an algorithm proposed by Frank Taylor [2]. This algorithm uses the difference in the measured incident angles in the upper and the lower part of the chambers as a measure of the CSC position resolution. If there is no multiple scattering inside the chambers the observed distribution of $\theta = \theta_1 - \theta_2$ (see Figure 2 for the angles' definition) would have r.m.s. value of 3.3 $mrad$ due to a 50 μm position resolution in each of four chambers.

Indeed, as $\theta_1 = (x_1 - x_2)/L$, $\theta_2 = (x_3 - x_4)/L$, then

$$\sigma_\theta^{pos.} = \frac{\sqrt{\Sigma\sigma_{x_i}^2}}{L} = 3.3 \times 10^{-3},$$

where x_i is the coordinate of the muon track, measured in each of four chambers, $\sigma_{x_i} = 50$ μm is the position resolution and $L = 30$ mm is the distance between the adjacent chambers in the upper and the lower halves of the CSC (see Figure 1). Figure 3b shows the result of the MC simulation of the difference, with no multiple scattering taken into account.

If one uses the Gaussian approximation for multiple scattering for a 1.5 GeV muon (such a cutoff is provided by an unmagnetized iron shield), one could estimate the r.m.s. angle of deviation due to multiple scattering between θ_1 and θ_2 measurements as

$$\sigma_\theta^{m.s.} = \frac{14.1MeV}{p}\sqrt{\frac{l}{L_R}}(1 + \frac{1}{9}\log_{10}(\frac{l}{L_R}))$$

If there are 4 G10 plates ($\frac{l}{L_R} = 4.3\%$) placed between the measurements of θ_i then for a 1.5 GeV muon

$$\sigma_\theta^{m.s.} = 2.2\, mrad$$

and the observed r.m.s. $\sigma_\theta^{obs.}$ would be approximately

$$\sigma_\theta^{obs.} = \sqrt{(\sigma_\theta^{pos.})^2 + (\sigma_\theta^{m.s.})^2} \approx 3.8\, mrad.$$

As $\sigma_\theta^{pos.} > \sigma_\theta^{m.s.}$, multiple scattering effects will not dominate measurement errors in $\sigma_\theta^{pos.}$ in the CSC's.

The resulting θ distribution from a GEANT MC of a 1.5 GeV muon track incident normally onto CSC planes is shown at Figure 3a. The CSC materials of (Table 1) were used. One can observe some increase in σ_θ due to a multiple scattering effects. With perfect position resolution, the multiple scattering alone would produce the θ distribution with $\sigma_\theta = 2.2\, mrad$, presented in Figure 3c. The results in Figure 3 are in agreement with our estimates.

3 Cosmic ray spectra with different shield configurations

To have additional control over the muon cosmic ray spectrum the TTR iron shield will be magnetized. Figure 4 shows the outgoing coordinate and angle of a 10 GeV muon track after traversing 1 m of magnetized iron. When the cosmic ray muon traverses the magnetized iron the measured parameters of the muon track will depend on the muon energy. It is possible to make a cut on a muon track position or a muon track angle after the magnet to harden the initial cosmic ray muon spectrum. As large deflections due to multiple scattering will primarily occur only at low momenta, one also could cut on bending angle in the non-bending plane to improve the high energy muon selection.

To optimize the magnet shape we simulated the muon cosmic ray spectra for the four iron shield configurations considered. In all cases we have assumed an iron thickness of 1 m, and an incoming muon cosmic ray spectrum of $1/E^2$. For a magnetized shield a magnetic field inside the iron of 1.5 T was assumed. To compare the different shield configurations and have a sufficient trigger rate, for each configuration the cuts were made in such a way as to retain approximately 50% efficiency for 10 GeV muons (Figure 4).

The resulting muon cosmic ray spectra after the cuts applied on muon position and angles after traversing the shield are presented in Figures 5–6 for two magnet configurations. The split magnet configuration with a 1 m air gap provides better a cutoff of the low energy part of the cosmic muon spectrum. Figures 7–8 shows the selected muon spectra for two possible configurations of unmagnetized iron. Without magnet field the selected muon spectra has more low energy muons than in case of magnetized iron.

The right part of the Figures 5–8 are obtained using a 2σ cut on bending angle for a 10 GeV muon (Figure 4).

4 Off-line Selection of Cosmic Ray Muons in TTR

To achieve high precision in an overall track fit that involves several technologies one need to harden muon cosmic ray spectra further. The TTR Iarocci chambers will provide data for an off-line selection of cosmic ray spectra. To optimize the selection algorithm we made a GEANT MC study of the TTR. In this study realistic cosmic ray spectrum [3] were used. The positions of Iarocci chambers in TTR geometry are not yet determined. Values used in our GEANT MC study are shown in Table 2.

Figure 9 presents an example of the selected spectra for some set of cuts based on Iarocci chambers. To reduce multiple scattering effects one can impose stronger selection cuts. Stronger cuts harden selected spectra, but make muon rate lower. The value to be optimized in a selection algorithm is the mean value of $1/p^2$. This value is proportional to the magnitude of multiple scattering effects, $(\sigma_\theta^{m.s.})^2$, for the selected spectra. Figure 10 plots the muon rate in the upper layer of the TTR Iarocci chambers versus $< 1/p^2 >$. Figure 10 shows that the TTR will provide effective selection of the cosmic ray spectra up to $< 1/p^2 >^{-1/2} \approx 8GeV$. Figure 11 shows the selection efficiency for muons traversing the upper layer of TTR Iarocci chambers. The muon efficiency at high momenta limited by geometrical efficiency, which is determined by magnet area. We assumed perfect efficiency for muon detection in Iarocci chambers in this analysis. Figure 11 shows that off-line analysis will provide up to a 10^{-5} rejection of the low energy cosmic ray muons.

Table 2: TTR Geometry used in GEANT MC studies

Element	Position, cm	X×Y, cm	Thickness, cm
Scintillator 1	495	120×270	2.5
Scintillator 2	485	120×270	2.5
Iarocci tubes 1	450	400×192	1.5
Iarocci tubes 2	240	400×192	1.5
Magnet	166.5	380×110	101.6
Iarocci tubes 3	95	400×192	1.5
Scintillator 3	25	120×270	2.5
Scintillator 4	10	120×270	2.5
Iarocci tubes 4	5	400×192	1.5

5 Conclusions

To test the performance of different muon chamber technologies proposed for the GEM experiment at the SSC the Texas Test Rig (TTR) will be established at the SSC Laboratory. The results of GEANT Monte Carlo studies of the TTR are:

- the 1.5 GeV cutoff of the cosmic muon spectrum provided by 1 m of unmagnetized iron is sufficient to make multiple scattering effects less than the intrinsic position resolution of the chambers,
- to have additional control over the muon cosmic ray spectrum the iron shield at the TTR will be magnetized,
- the TTR provides up to a 10^{-5} rejection (in off-line) of low energy cosmic ray muons.

6 Acknowledgements

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References

[1] GEM Collaboration, GEM Letter of Intent, SSC-LOI004.

[2] F.Taylor, private communication.

[3] Allkofer and Greider, in Cosmic Rays on Earth, Physics Data, Fachinformationszentrum Energie, Physik, 1984 (Table 2.2.4, p. 242).

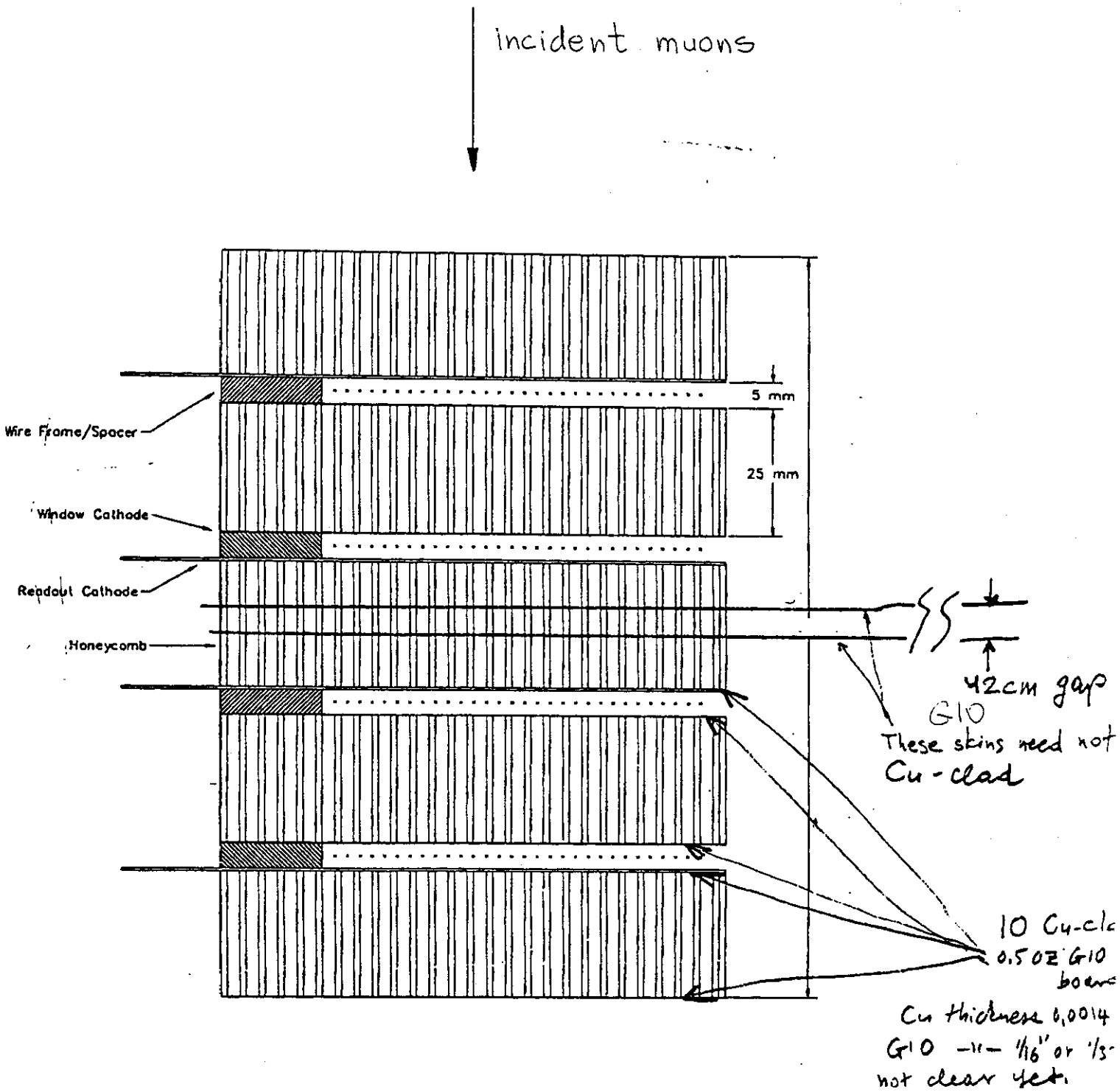

Figure 1: The layout of the Cathode Strip Chambers

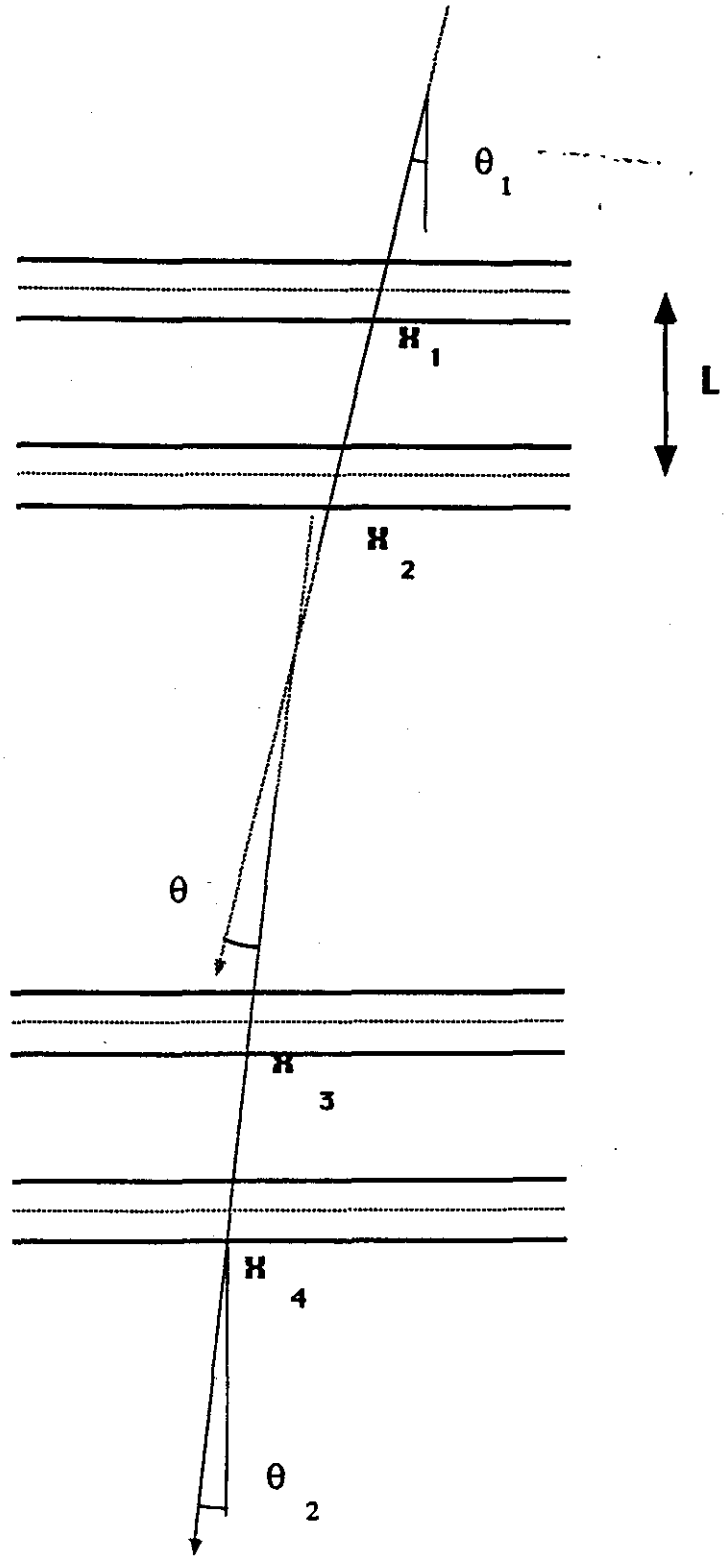

Figure 2: Incident angles measured in the upper and the lower part of the Cathode Strip Chambers are relevant to CSC's position resolution.

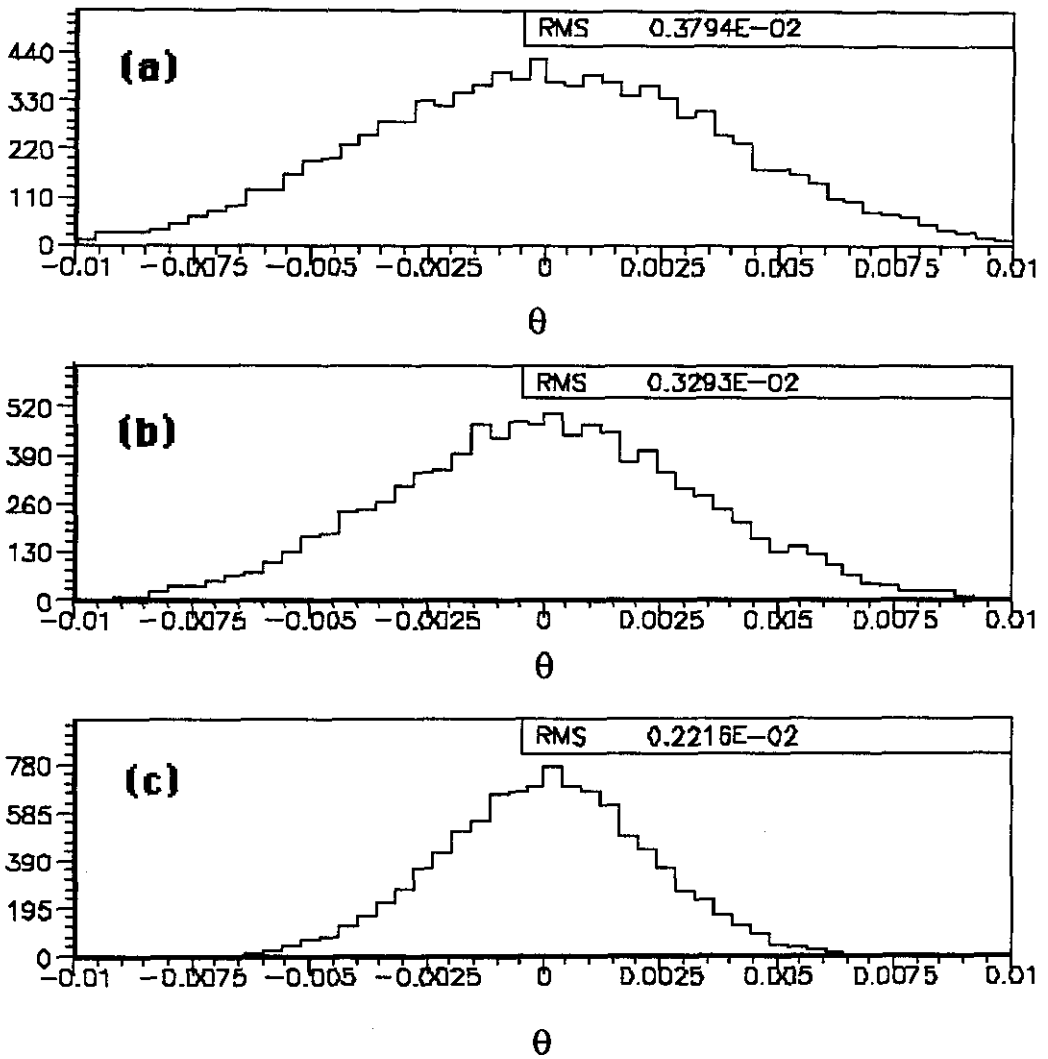

Figure 3: Position resolution in CSC reflected by $\theta = \theta_1 - \theta_2$ (as shown in Figure 2): (a) Multiple scattering plus intrinsic position resolution errors; (b) intrinsic position resolution errors only; (c) multiple scattering only.

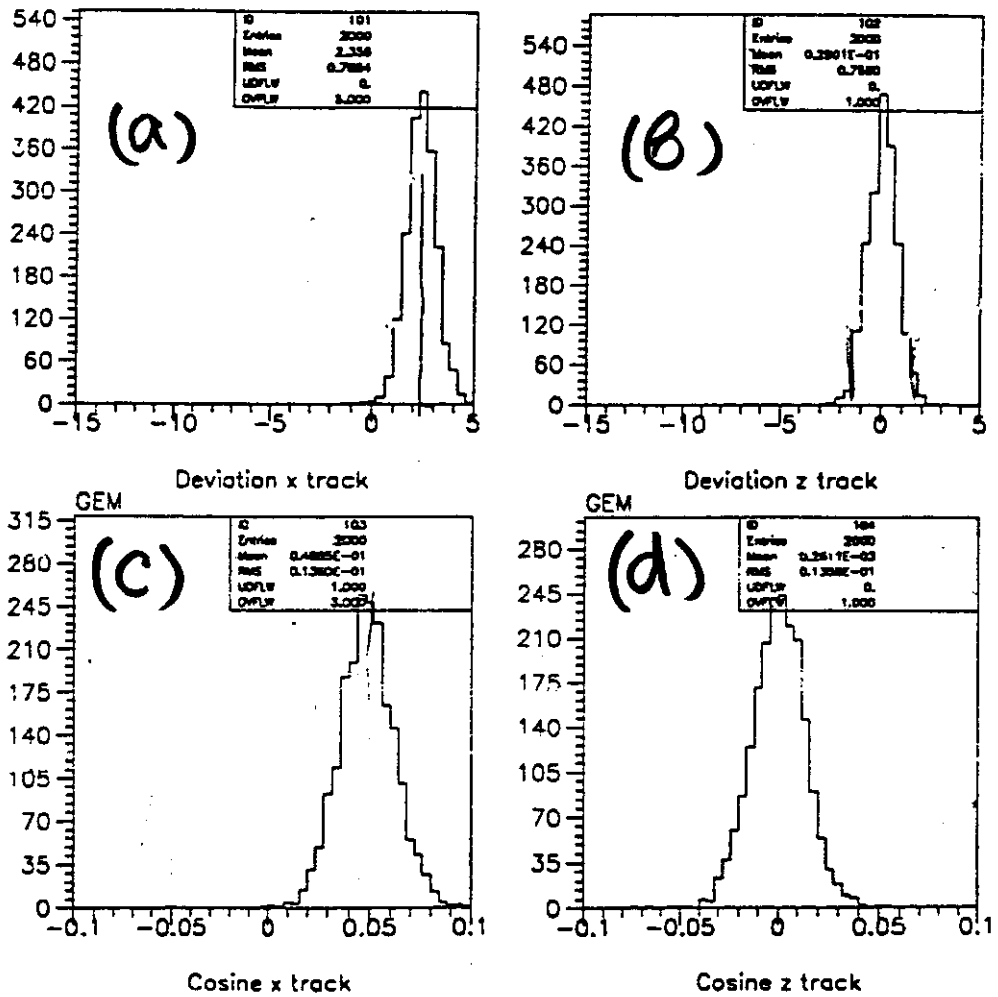

Figure 4: Distribution of the outgoing coordinates and angles of a 10 GeV muon track after traversing 1 m of magnetized iron: (a) distribution of the outgoing coordinate in the bending plane of the magnet; (b) distribution of the outgoing coordinate in the non-bending plane; (c) distribution of the outgoing angle in the bending plane of the magnet; (d) distribution of the outgoing angle in the non-bending plane.

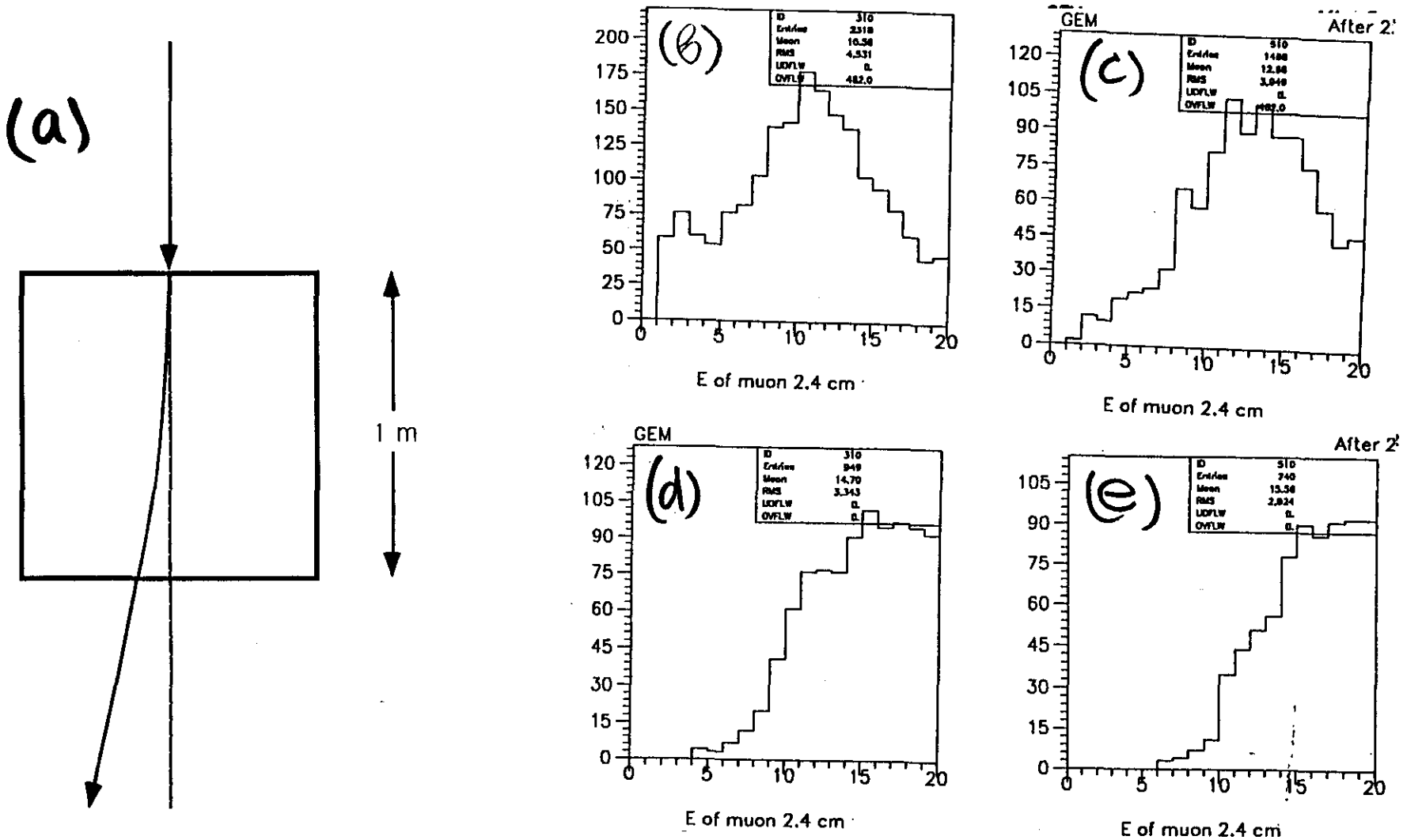

Figure 5: Muon Spectra for a 1 m Fe magnet with a 1.5 T field: (a) Layout of the 1 m magnet configuration; (b) Muon energy spectrum after a cut of 2.4 cm on track deviation in the magnet; (c) same as in (b) with the 2σ cut on deviation in another plane is applied; (d) Efficiency of the cut in (b) versus muon energy; (e) same as in (d) with the 2σ cut on deviation in another plane applied.

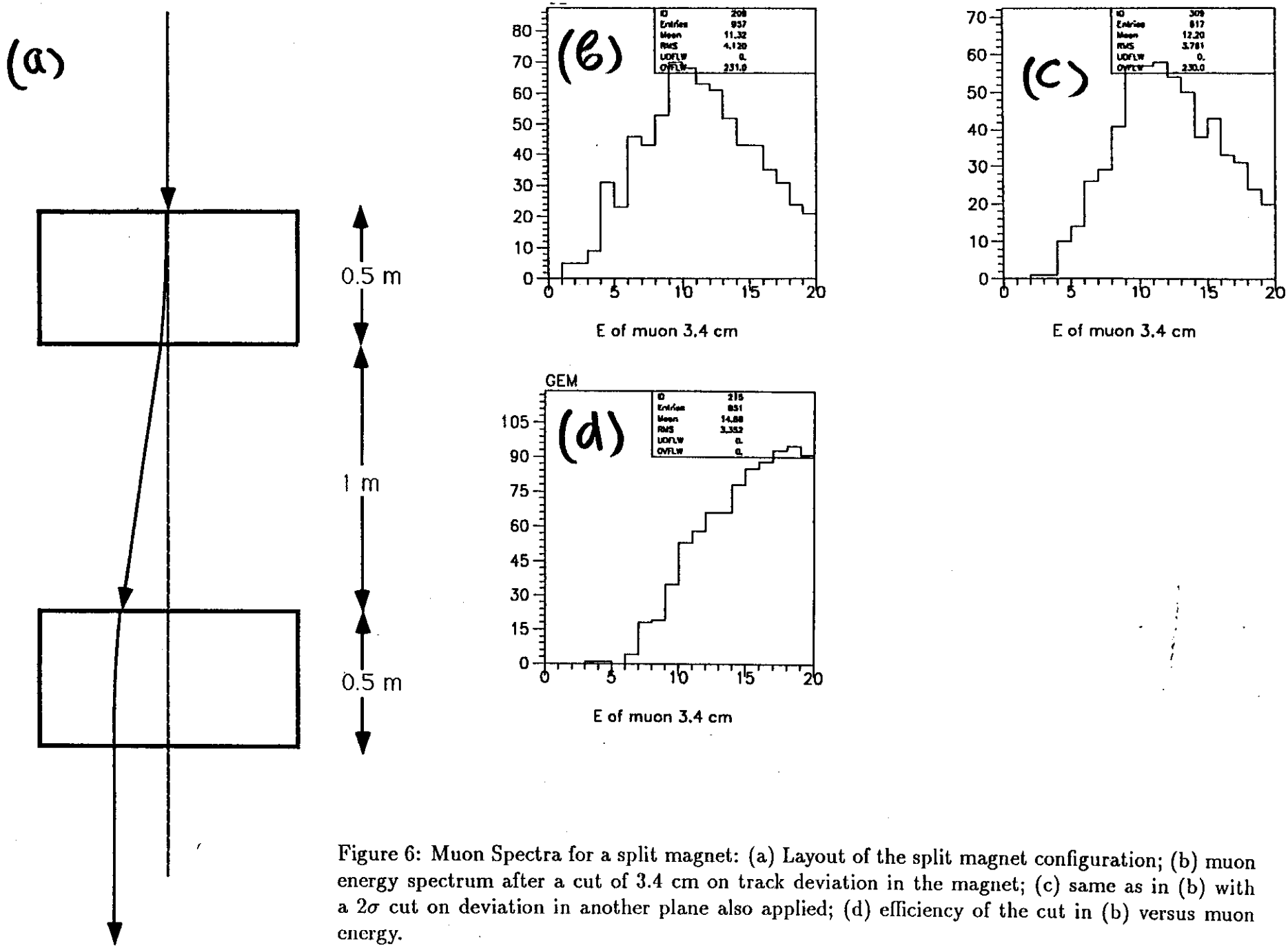

Figure 6: Muon Spectra for a split magnet: (a) Layout of the split magnet configuration; (b) muon energy spectrum after a cut of 3.4 cm on track deviation in the magnet; (c) same as in (b) with a 2σ cut on deviation in another plane also applied; (d) efficiency of the cut in (b) versus muon energy.

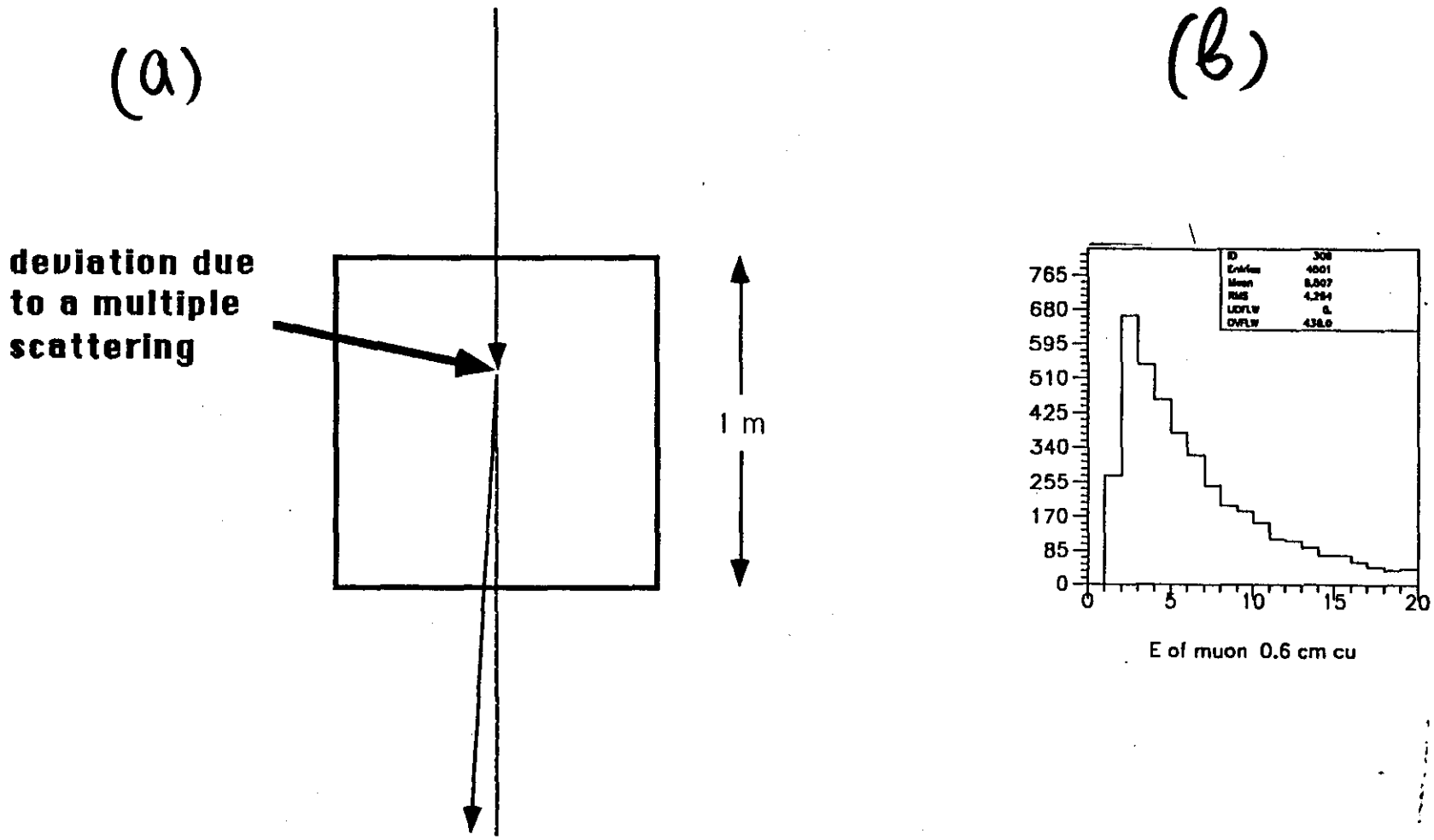

Figure 7: Muon Spectra after traversing 1 m block of an unmagnetized iron: (a) layout of the unmagnetized iron configuration; (b) muon energy spectrum after a 0.8 σ cut on track deviation in the iron.

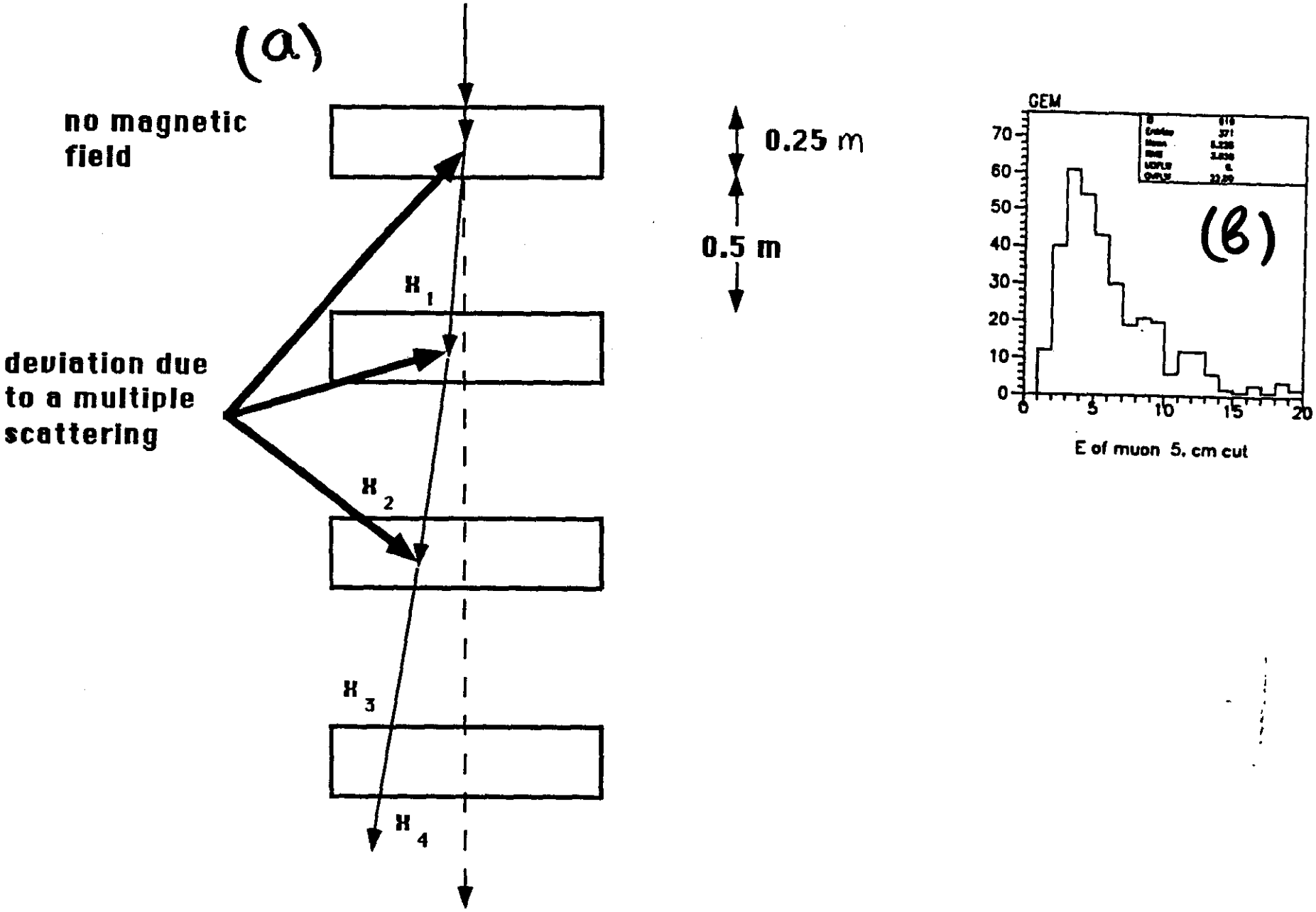

Figure 8: Muon Spectra after traversing 1 m of split iron: (a) layout of the unmagnetized iron configuration (to use multiple scattering effects more efficiently the coordinates of the track are measured in each air gap); (b) muon energy spectrum after a 2 σ cut on track deviations measured in all four chambers applied.

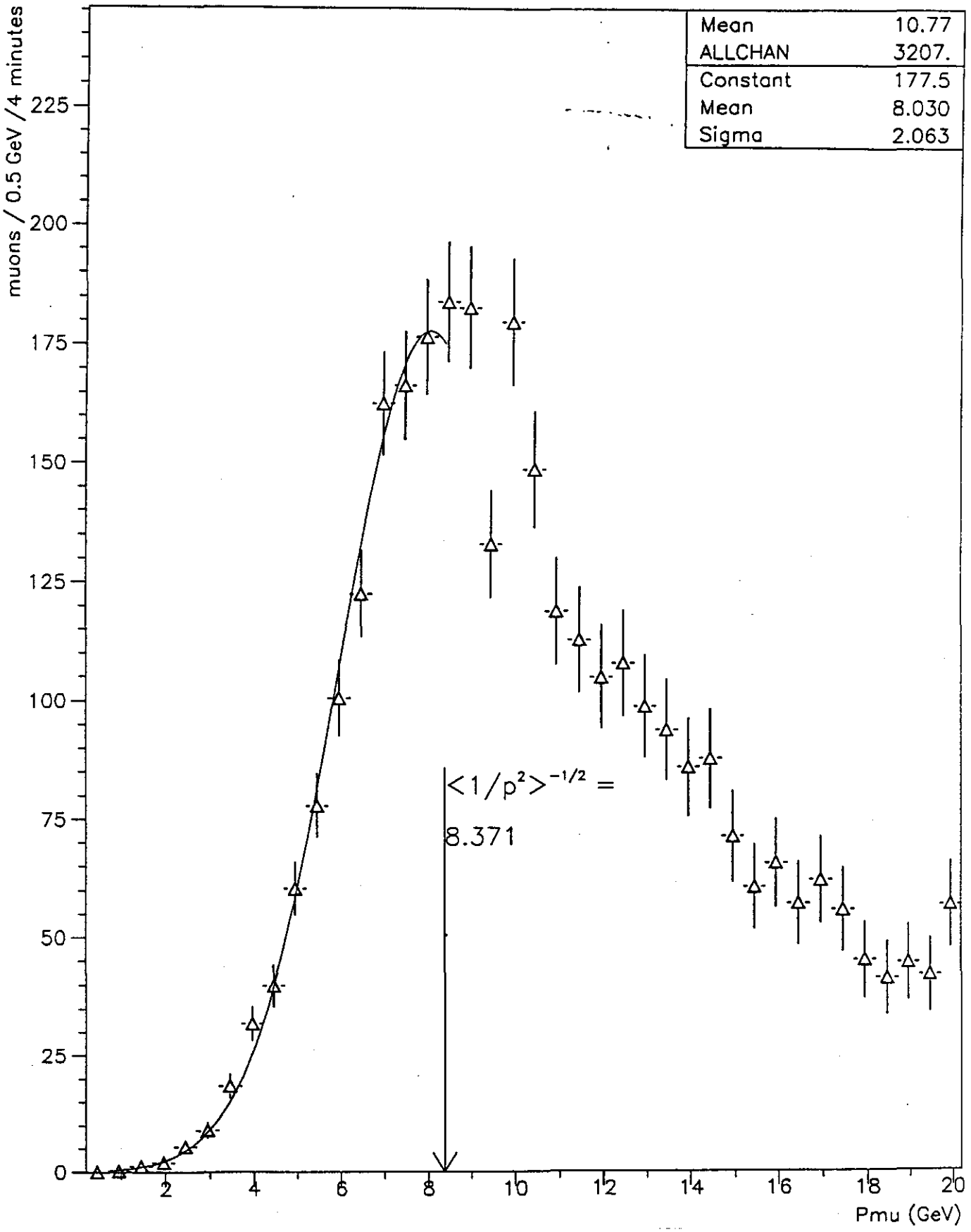

Figure 9: Muon spectrum after off-line selection (1 m 1.5 T magnet).

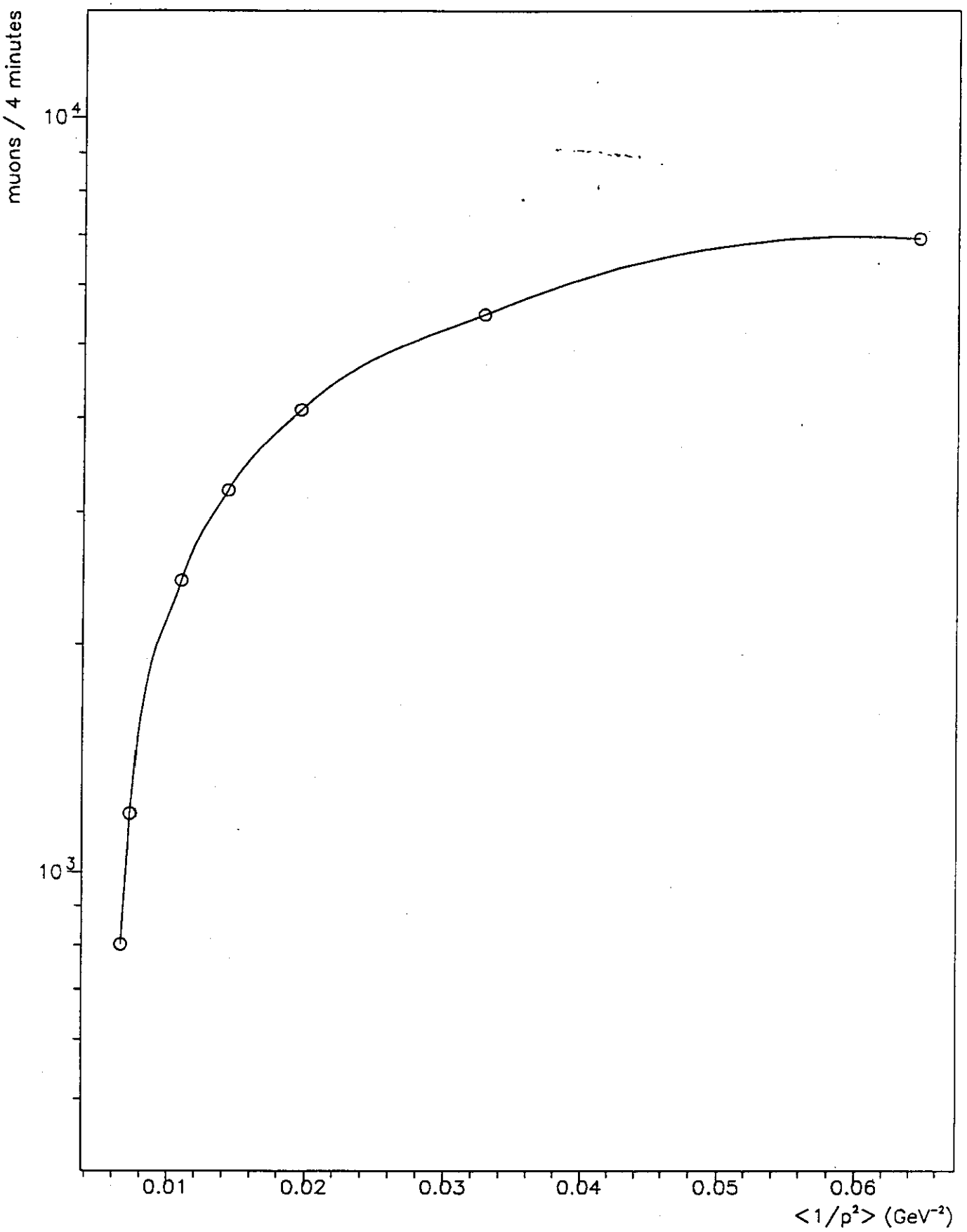

Figure 10: Rate of muons in the upper layer of the TTR Iarocci chambers versus $< 1/p^2 >$ for the selected spectra.

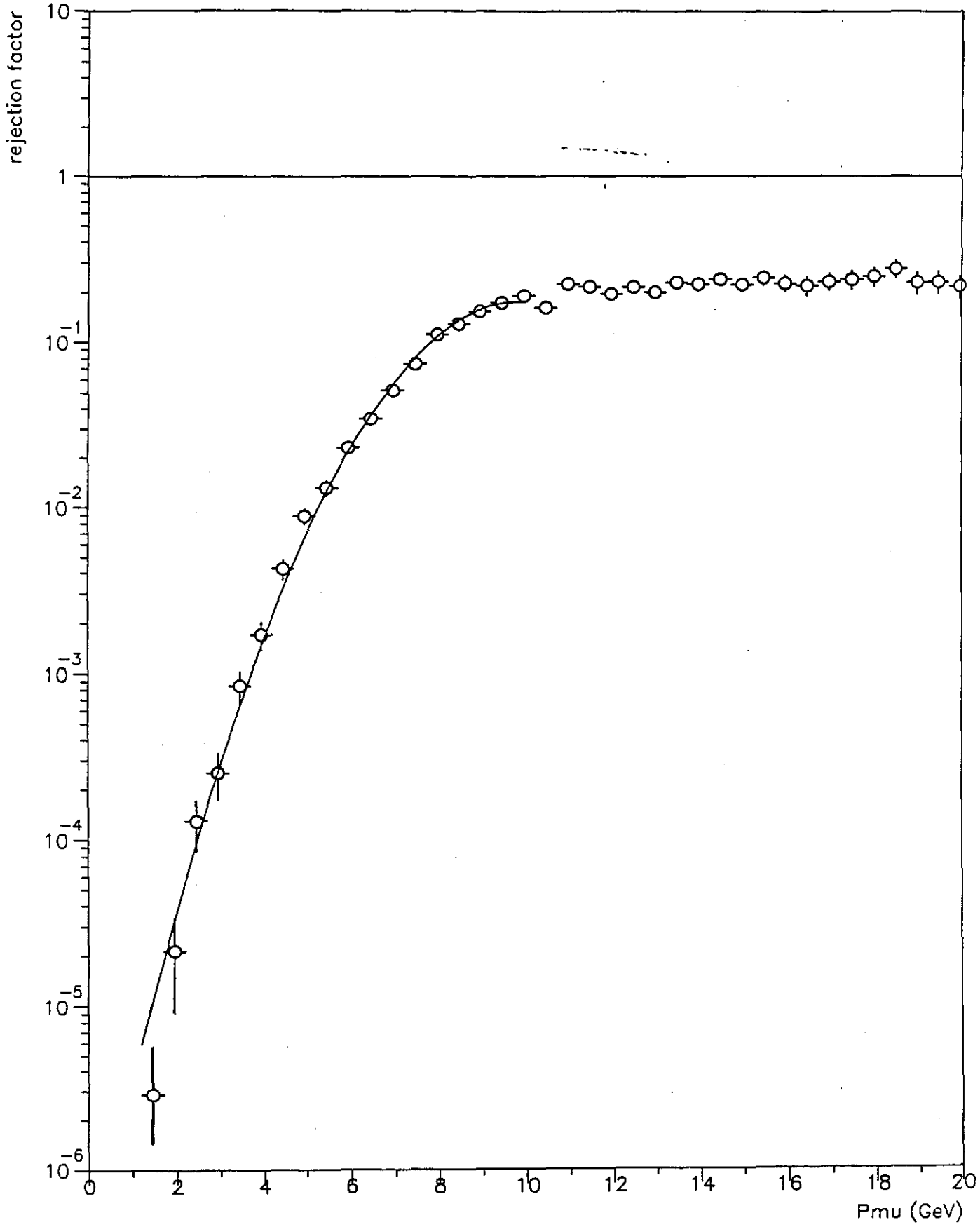

Figure 11: Efficiency of the off-line muon selection in TTR.