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**Studies of Electromagnetic Debris
Associated with a High Energy Muon
Passing Through Matter.***

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Summary

The performance of a drift tube prototype in a 0.5 TeV/c muon beam was studied. Presented is a comparison of experimental data with a GEANT simulation in order to determine the validity of the Monte Carlo in simulating the detector performance in the presence of the electromagnetic contamination associated with high energy muons. The Monte Carlo simulation generally was with few exceptions in 30% or better agreement with the data .

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1. Introduction.

An important consideration in the design of a muon spectrometer for LHC detectors [1] is the level of backgrounds from muon-induced showers. As an energetic muon transverses dense material (calorimeter, muon filter or material of muon chambers and support structures) it will lose energy giving rise to showers of particles accompanying the muon [2]. These showers will potentially obscure the muon resulting in measurement uncertainties and a degradation of the pattern recognition capabilities. As the energy of the muon increases, radiation losses (bremsstrahlung or pair production) increases rapidly and eventually dominates over ionization losses above a few hundred GeV. The amount and character of the muon-induced showers also depend on the atomic number Z and density of the material. These issues must be considered in the design of the muon spectrometer including the choice of materials and chamber placement.

Although the theory of the underlying processes is well understood and a number of Monte Carlo programs exist for simulation of the passage of energetic muons through matter, the application of the latter for simulation of detector performance has never been free of doubt. The problem is obvious: many detectors, such as gaseous detectors, give a normal signal even for a few electron or even single electron ionization deposited in the detector volume (e.g., wire chambers operating in limited streamer mode). A simulation of a shower development down to the few eV range is definitely unfeasible and would not be trustworthy. Nevertheless, a reliable simulation of muon associated backgrounds is needed to properly set many of the muon system design parameters and to compare various chamber technologies. The verification of the Monte Carlo against experimental data is, therefore, a very important step on the way of a detector design.

We conducted a small test experiment T819 [3] at Fermilab with the purpose of studying the spatial resolutions achievable in a drift chamber operated in limited streamer mode and in Iarocci-type [4] detectors with an external pick-up strip readout. The results on the resolutions obtained are reported elsewhere [5;6]. The measurements were performed in 0.5 TeV/c muon beam which allowed us to study not only the resolution, but also the electromagnetic debris which we studied by means of a special set of measurements with different absorbers in front of the drift chamber. Presented here is a comparison of the observed effects of the material on chamber performance (occupancies, pattern recognition and etc.) with the Monte Carlo simulation results.

2. Experimental Set-Up.

2.1. Apparatus.

The E665 Tevatron muon beam was tuned to a momentum of ~ 500 GeV/c with a typical momentum spread (FWHM) of around 120 GeV/c and a vertical beam divergence (sigma) ~ 0.5 mrad. We set up our apparatus downstream of the beam, far behind the E665 absorbers. The beam sizes (FWHM) at our spot were typically ~ 15 cm (horizontally) and ~ 7 cm (vertically). We requested special short runs with a low intensity beam as the normal beam intensity was too high for a drift chamber operating in a streamer mode. Then a typical rate in the maximum of a beam profile was ~ 350 cm $^{-2}$ s $^{-1}$.

The sketch of our experimental set-up is shown in fig.1. The upstream strip readout detector consisted of four Larocci-type detectors and was used for muon tagging. The active area was 6 cm (six 1 cm cells of the profiles had wires) by 7 cm (seven 1 cm strips were equipped with readout electronics). Strips ran horizontally and wires vertically. By analyzing pulse heights on the pick-up strips, we could reconstruct a muon coordinate (vertical) with an accuracy of 80 μ m per plane [6]. By making use of a small beam divergence, we could extrapolate the coordinate given by the strip detector to the drift detector with an accuracy of ~ 600 μ m (sigma).

We put bricks made of different materials in places marked M1 and M2 in fig.1. We had 5 different runs which will be further referred to by a short name:

Table 1. List of runs.

RUN name	M1	M2
"Nothing"	—	—
10 cm Al	—	two 5 cm thick Al bricks
10 cm Fe	—	two 5 cm thick Fe bricks
10 cm Pb	—	two 5 cm thick Pb bricks
10 cm Pb + 5 cm Al	5 cm thick Al brick	two 5 cm thick Pb bricks

Fig.2 shows the drift detector in detail. Cathodes were made of four Al U-shaped open profiles, each profile containing 4 cells, 2.5×2.5 cm 2 in cross-section. The two downstream profiles (left in fig.1) were Ni plated and the upstream profile was Cu plated. The two inner profiles were staggered by 2 mm with respect to the outer ones to allow solving left/right ambiguities. The front and back profiles were covered by G10 boards with 2.5 cm etched strips. The active length of the detector was about 60 cm. Anode wires (100 μ m gold plated tungsten) were supported by plastic bridges at the ends of the

profiles. The stack of profiles was placed in the gas tight Al box with 3.2 mm thick walls. At the trigger level we also required the first and fourth layers to have hits.

The drift chamber was filled with a standard gas mixture (Ar+Isobutane=1+3) and operated at 5.4 kV (~400 V above the knee of a singles rate curve). The limited streamer regime provided fast and high amplitude pulses (~50-100 mV/50 Ω , ~2 ns rise time, and about 100 ns pulse duration at base). The signals were directly fed into four-input LeCroy MVL407 discriminators with a threshold set to 15 mV (the board with a discriminator was mounted directly on the profile). The drift time digitization was performed by 11 bit TDC's (LeCroy 2229) set to 0.25 ns bin width. The start time was given by a four-fold coincidence of scintillators Sc1, Sc2, Sc4 and Sc5. The chamber spatial resolution was determined to be ~55 μ m [5]. We measured only the first arriving signal and any signal arriving later could not be detected with our single hit electronics.

Fig.3 presents an example of an event. One can see that the track was found in spite of extra hits. A possibility to trace/fit an extra track back to the material in front of chamber as shown in Fig.3 was not very typical. Most of the time, the extra hits did not form any obvious straight track.

2.2 Backgrounds and apparatus noise.

Special precautions were taken to suppress cross-talks. The maximal cross-talk occurred across cells within one profile and did not exceed 0.3% so that it could pass over the 15 mV discriminator threshold only for impractically high signals of 5 V. We also checked the data on any excess of time-correlated hits across a profile and did not find any detectable contributions (<0.05%).

We required only one track in the strip detector and the track angle had to be consistent with the beam parameters. A signal amplitude from a scintillator Sc3 was also analyzed. By suppressing too high amplitudes, we could further eliminate triggers containing a few incoming particles. This suppressed a background associated with a few incoming particles. From data we found that ~0.3% of triggers nevertheless had two beam muons. Those events were eliminated from the analysis and we estimate that the part associated with this background remaining in the data did not exceed 0.1%.

Other hall/beam background (uncorrelated with an actual triggered muon) would result in extra hits with a time distribution uniformly spread over full range of TDCs and beyond the maximal drift time T_{max} . Indeed, we did observe such tails in time distributions for hits in the rows not containing a muon. However, one must be cautious in interpretation of these tails: some part of them could result from electrons drifting from cell corners where the electric field is very weak so that it takes long time to drift from a

cell corner. Taking the entire tail and assuming it flat over the whole TDC range, we could estimate the upper limit on this background: ~25%, ~16%, ~8% and ~5% for the runs "Nothing", "10 cm Al", "10 cm Fe" and "10 cm Pb" respectively. With increasing the amount of material in front of the chamber, the number of the muon-induced hits increases and, as a consequence, the background fraction falls down. To avoid a possible artificial improving of the data by discarding any of these "maybe-background" hits, we preferred to leave them in the analysis.

3. Monte Carlo Simulation.

A Monte Carlo (MC) simulation of the experimental setup was performed using GEANT [7], version 3.15. For each absorber arrangement ("Nothing", 10 cm Al, 10 cm Fe, 10 cm Pb, and 10 cm Pb + 5 cm Al) a sample of 10,000 500 GeV muons was simulated with GEANT. All process flags within GEANT were set to 1 including BREM, LOSS, DRAY, PAIR, and MUNU. The automatic stepping in GEANT was switched off with a maximum step size set to 1 mm (STEMAX=0.1). The kinetic energy cutoffs for electrons and gammas were set to 10 KeV. Taking into account a single electron sensitivity of the chamber operating in the limited streamer mode (and well above the knee of an efficiency curve), any non-zero energy deposit left by a particle in a gas volume of a cell was considered to be sufficient to produce a signal, or hit, in that cell. The front and back layers of the LSDTs were required to have hits in order to compare with the data which required a readout from the strips. The closest distance of approach of a particle to the wire defined the hit position, or drift distance, for that particle in a cell. No noise was included in the simulation and no smearing of the position was done. The identification of all the charged particles, their momenta, and their hit position was recorded in the simulation.

4. Results.

4.1. Overall hit multiplicities.

After all cuts we applied to select single incoming muons, the typical statistics per run was about 2000 events. With this number of events we could get statistically significant fractions down to ~0.3-0.5%: any fraction below this level would have statistical errors comparable to the value itself.

Fig.4 presents the distributions of hit multiplicities in the drift chamber. The peak at 4 hits corresponds to events with a single row of cells containing all four hits. The 2-hit and 3-hit events mostly come from the geometrical inefficiency of the chamber: 2 mm thick walls and 2 mm staggering results in some number of events with hits in just 2 cells and also some number of event with only three hits.

In fig.4 one can see a drastic decrease of "clean" (4-hit) events as the amount of material in front of the chamber increases. The number of events with at least one extra hit (100% minus sum of 2-, 3- and 4-hit events) changes from $6\pm1\%$ for the run "Nothing" to $14\pm1\%$, $22\pm1\%$ and $27\pm1\%$ for the runs with the aluminum, iron and lead absorbers respectively. The Monte Carlo seems to agree with the data within around 30%, however, being slightly more optimistic. For example, the numbers corresponding to the ones given above would be as follows: 4.8%, 9.5%, 17.5% and 26.4%. The MC does also reproduce such peculiar details as bumps at 8 hits and a bump at 16 hits for the run "10 cm Pb".

4.2. Pattern recognition capabilities.

The next step in the analysis was an attempt to find the muon track among these hits (table 2). The procedure was as follows. For each event we examined all four rows of cells (a row is along the beam direction). If a row had all four hits, these hits were fitted to a straight line. If $\chi^2 < 13.0$ for the fit, we declared that a track in this row was found. Also, if the track parameters were consistent with predictions (coordinate and angle as measured in the strip detector), we assumed that we found the muon. It is worth mentioning that with the high accuracy of the chamber ($\sim 55 \mu\text{m}$) any single measurement with a residual exceeding $200 \mu\text{m}$ would result in an unacceptable χ^2 . Fig.5 shows the distribution of χ^2 . One can see that the results would not depend very much on a choice of χ^2 -cut. In other words, if there was a bad measurement, it usually was dramatically bad. If $\chi^2 > 13.0$, the fit was not considered successful (99.9% CL) and we tried to exclude one of the points and fit the remaining three. If we could exclude one of the points so that the remaining three would give a good fit, we assumed that we managed to find a track in spite of one spoiled measurement. Again, the parameters of the found track were compared with those measured in the strip detector. The freedom to exclude one of the hits was essential and allowed us to recover events with only one spoiled measurement (~ 11 -13% of statistics). Rows with 3 hits were also fitted and the parameters of a found track were compared with the expected ones.

After examining all four rows, we could end up with a few found track candidates (from 0 up to 4). If one of them was consistent with the expected track parameters, we

believed that the muon was found ("TRACK IS FOUND" in table 2). If we had one or more candidates and none of them was consistent with the predictions, we put these events in the category "Found track is WRONG". And certain number of events did not allow us to find a single straight line at all -- "NO track is found". The events with no more than two hits in a row were checked for consistency with geometrical losses. If an event looked like a track which went through cell walls (two hits must be in corresponding cells (2+3 or 1+4), the two measured drift distances had to be consistent with the other two missed ones, a consistency with the expected coordinate and angle was also required), then we put it in the "geometry losses" category.

The analysis showed that the four plane drift chamber did not have enough information for robust track reconstruction. Just four drift measurements (with left/right combinatorics) and the freedom to exclude one of them, sometimes, resulted in an accidentally good and self-consistent fit which was spurious (see table 2). Therefore, the comparison with the tight expected track parameters was essential for finding such false "tracks".

One can see the degradation of a capability to reconstruct a muon track with increase of material in front of the chamber. Also, it is worth noting that 5 cm of aluminum added behind of 10 cm of lead seems to bring more trouble, rather than to shield upstream lead.

4.3. Analysis of hits in the cells containing a muon.

To make a straight comparison between the data and MC, we analyzed data without fitting. As was mentioned above, the muon coordinate in the drift detector could be predicted from the measurements in the strip detector with an accuracy of $\sim 600 \mu\text{m}$. Fig.6 shows a histogram of all residuals $\Delta R = R_{\text{drift}} - R_{\text{predicted}}$. One can see a peak at zero with a width corresponding to $\sim 600 \mu\text{m}$ resolution, and a left hand tail corresponding to spoiled measurements. The tail for runs with material in front of the chamber is much higher. And as expected, there is not any right hand tail. One can also see that the condition $|\Delta R| > 2 \text{ mm}$ means that a measurement is definitely compromised. Using this definition of a "bad" measurement ($|\Delta R| > 2 \text{ mm}$), we obtained probabilities to have certain numbers of "good" and "bad" measurements along a muon track (table 3). Note that the "good", as defined above, is far from being really good, or consistent with an intrinsic resolution of $\sim 55 \mu\text{m}$. However, this definition was very useful for a straight comparison (unbiased by fitting procedures) of the data with MC. The numbers in the table reveals a reasonable agreement: most of them are within 30-50% agreement and just a few disagree by a factor of two.

4.4. Analysis of hits in the cells not containing a muon.

The hits in the cells not containing a muon are of special interest since they are not mixed up with a muon track. In a certain sense, these hits are all "bad", and one needs not bother with finding a criteria for distinguishing whether the hit was produced by a muon itself or was due to electromagnetic radiation. Let us define the row adjacent to the row with a muon track as the *adjacent* row and the next one as the *second* row.

Fig.7 shows the distribution of number of hits in the adjacent row for two runs ("Nothing" and "10 cm Pb"). The content of each bin is printed at the top of a bin and the MC results are given at the very top of the graph. One can see that the predictions are in 20% or better agreement with the data. An average number of hits in the each of the adjacent and second rows for each run is presented in table 4 and reveals the same 10-20% agreement between data and Monte Carlo.

Next, we selected events with two-three hits in either adjacent or second rows and studied how often these two or three hits appeared all next to each other as if they were due to a penetrating electron. One can easily calculate that the probability would be 50%, if there were not any correlation. As one can see in table 5, the multiple hits do have a strong tendency to correlate and, also, the Monte Carlo seems to reproduce this effect. The probabilities do not depend very much on a row (e.g., in the case of the run with the lead absorber the numbers were 76% and 78% for the adjacent and second rows) and we summed up statistics in all rows not containing the muon.

Also relevant to the discussion on correlations and independence is whether the hits tend to appear in any particular cells. The data for the run with the lead absorber had the maximal statistics of secondary hits and were used for the analysis. To decrease statistical fluctuations, we also summed up the adjacent and second rows. Probabilities for different patterns are given in table 6. One can see that the triples tended to appear in front cells of the chamber. On the other hand, single hits had no tendency to appear in the front part of the chamber -- the cells turned out to be not equivalent in a different way: they were more frequent in the first and last cells. This is most likely connected with a presence of G10 boards in front of these layers and the Monte Carlo seems to reproduce this feature as well. We analyzed the MC events with doubles appeared in the rear end of the chamber. We found that about 50% of them are due to gamma-conversions in the chamber walls (mostly in the wall between the second and third profiles) resulted in an electron penetrating the both rear profiles. Another 30% were caused by electrons emitted from the lead absorber and entered the chamber in the neighboring row of cells and then scattered into the last two cells of the row under consideration. The remaining 20% of the

doubles in the rear end of the chamber were caused by two independent electrons mostly due to gamma-conversions of two photons in the chamber profiles.

4.5. Hit drift distances in the cells not containing a muon.

Given that a cell was hit (but not by a muon), we analyzed the distribution of the closest approach of that track to the anode wire. Fig.8 shows the distributions of drift distances for hits in all three neighboring rows (the fourth row contains the muon). One can see that for the runs with nothing or the aluminum absorber in front of the chamber, the distributions are rather flat (up to the maximum drift distance ~ 11 mm). However, there is an excess of hits with small drift distances in the runs with the iron and, especially, with the lead absorber. To understand better what is going on, we made two more plots. The first one contained only rows with a single hit (fig.9), while the second set contained events with all 16 cells hit (fig.10). One can see that if a row of cells has only one hit, the drift distance distribution for that hit is rather flat, while the distributions for extreme multiplicity events are peaking around zero. The latter feature is exactly what one might expect assuming that these events associated with heavy showers resulting in a number of tracks per cell*. It is quite striking that the Monte Carlo again very well reproduced "amplitudes" and shapes of all these distributions.

5. Conclusions.

A drift chamber based on limited streamer drift tubes was tested in 500 GeV/c muon beam. Different absorbers were placed in front of the chamber in order to study electromagnetic debris associated with a high energy muon and their influence on pattern recognition capabilities of the drift chamber. A detailed comparison of the results with GEANT simulation was performed to validate the Monte Carlo predictions. We found that the Monte Carlo reproduced all the essential features and many details of the chamber performance in the presence of contamination induced by muon radiation. We studied hit multiplicities, their patterns and correlations, and the distributions of drift distances between anode wires and contaminating tracks. The agreement between the data and the Monte Carlo simulation was typically good to 30% or better, with a few exceptions where the difference was of a factor of two. The backgrounds we have discussed in a section 2.2 may be partially responsible for some of the discrepancies,

* Each track has a flat distribution, but a superposition of a few tracks should result in a distribution with a typical shape $p(x)=N \cdot (1-x)^{N-1}$.

especially in the runs with small amounts of material in front of the chamber. Based on these results, we conclude that the GEANT can be used in evaluating a muon chamber performance and simulates sufficiently accurately the presence of electromagnetic debris induced by high energy muons passing through matter.

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Table 1. List of runs.

RUN name	M1	M2
"Nothing"	—	—
10 cm Al	—	two 5 cm thick Al bricks
10 cm Fe	—	two 5 cm thick Fe bricks
10 cm Pb	—	two 5 cm thick Pb bricks
10 cm Pb + 5 cm Al	5 cm thick Al brick	two 5 cm thick Pb bricks

Table 2. Probabilities (%) to find a muon track.

	"Nothing"	10 cm Al	10 cm Fe	10 cm Pb	10 cm Pb +5 cm Al
TRACK IS FOUND	90.4 ± 0.9	85.9 ± 1.1	83.2 ± 1.2	82.4 ± 1.2	79.6 ± 1.6
a single candidate	89.9 ± 1.0	83.8 ± 1.2	80.4 ± 1.3	79.0 ± 1.3	76.0 ± 1.7
among a few candidates	0.5 ± 0.2	2.1 ± 0.5	2.8 ± 0.5	3.4 ± 0.6	3.1 ± 0.7
Found track is WRONG	3.5 ± 0.6	7.6 ± 0.8	10.4 ± 1.0	10.0 ± 0.9	12.9 ± 1.3
NO track is found	3.8 ± 0.6	4.2 ± 0.6	4.4 ± 0.6	6.7 ± 0.8	4.8 ± 0.9
geometry losses	2.7 ± 0.5	1.8 ± 0.4	1.7 ± 0.4	1.4 ± 0.4	2.6 ± 0.6

Table 3. Number (%) of "bad" and "good" cells (cell is "bad" if error exceeds 2.0 mm - see text for details). Top numbers are data, bottom numbers in *Italic* font represent Monte Carlo.

	"Nothing"	10 cm Al	10 cm Fe	10 cm Pb	10 cm Pb +5 cm Al
4 "GOOD" + 0 "BAD"	90.6 ± 0.9 <i>93.1 ± 0.3</i>	86.7 ± 1.1 <i>92.0 ± 0.3</i>	84.4 ± 1.2 <i>88.9 ± 0.4</i>	84.1 ± 1.2 <i>86.0 ± 0.4</i>	81.5 ± 1.6 <i>86.4 ± 0.4</i>
3 "GOOD" + 1 "BAD"	7.1 ± 0.8 <i>6.0 ± 0.3</i>	8.5 ± 0.9 <i>6.1 ± 0.3</i>	8.7 ± 0.9 <i>7.2 ± 0.3</i>	8.7 ± 0.9 <i>8.4 ± 0.3</i>	10.9 ± 1.3 <i>7.7 ± 0.3</i>
2 "GOOD" + 2 "BAD"	1.6 ± 0.4 <i>0.6 ± 0.1</i>	2.8 ± 0.5 <i>1.0 ± 0.1</i>	3.2 ± 0.6 <i>1.7 ± 0.2</i>	3.6 ± 0.6 <i>2.3 ± 0.2</i>	3.1 ± 0.7 <i>2.8 ± 0.2</i>
1 "GOOD" + 3 "BAD"	0.3 ± 0.2 <i>0.14 ± 0.04</i>	0.5 ± 0.2 <i>0.3 ± 0.1</i>	1.2 ± 0.4 <i>0.8 ± 0.1</i>	1.3 ± 0.4 <i>1.1 ± 0.1</i>	1.7 ± 0.5 <i>1.2 ± 0.1</i>
0 "GOOD" + 4 "BAD"	0.4 ± 0.2 <i>0.17 ± 0.03</i>	1.3 ± 0.4 <i>0.6 ± 0.1</i>	2.4 ± 0.5 <i>1.5 ± 0.1</i>	2.4 ± 0.5 <i>2.2 ± 0.2</i>	2.8 ± 0.6 <i>2.0 ± 0.2</i>

Table 4. Average number of hits in the adjacent and second rows. Monte Carlo numbers are given in *Italic* font.

	"Nothing"	10 cm Al	10 cm Fe	10 cm Pb	10 cm Pb +5 cm Al
Adjacent Row	.04 .06	.14 .12	.31 .28	.43 .44	.45 .42
Second Row	.04 .04	.08 .07	.20 .21	.33 .33	.31 .29

Table 5. Probabilities for double and triple hits in a row to be next to each other (normalized on overall number of two- and three-hit rows). Top numbers are data, bottom numbers in *Italic* font represent Monte Carlo.

	"Nothing"	10 cm Al	10 cm Fe	10 cm Pb	10 cm Pb +5 cm Al
DOUBLE HITS <div> <div>■ ■ □ □</div> <div>or □ ■ ■ □</div> <div>or □ □ ■ ■</div> </div>	90±5%	79±5%	88±3%	77±4%	83±6%
	<i>97±2%</i>	<i>97±1%</i>	<i>88±2%</i>	<i>83±2%</i>	<i>85±2%</i>
TRIPLE HITS <div> <div>■ ■ ■ □</div> <div>or □ ■ ■ ■</div> </div>	100±4%	83±7%	79±5%	83±4%	78±6%
	<i>100%</i>	<i>91±3%</i>	<i>89±2%</i>	<i>84±2%</i>	<i>84±2%</i>

Table 6. Relative probabilities for different hit patterns in the cell rows not containing a muon. Direction of incoming muons is indicated by arrows, hit cells are shown as black squares, and empty cells as open squares.

		DATA	Monte Carlo
Single hits	■ □ □ □ ←	31±2%	31±3%
	□ ■ □ □ ←	23±2%	17±3%
	□ □ ■ □ ←	15±2%	17±3%
	□ □ □ ■ ←	32±2%	35±3%
Doubles	■ ■ □ □ ←	37±2%	33±4%
	□ ■ ■ □ ←	18±2%	19±4%
	□ □ ■ ■ ←	45±2%	48±4%
Triples	■ ■ ■ □ ←	31±3%	38±5%
	□ ■ ■ ■ ←	69±3%	62±5%

Fig.1. A schematic drawing of the experimental set-up (not to scale). Sc1 and Sc5 are finger-type scintillators (2.5 cm wide). Sc4 is $10 \times 10 \text{ cm}^2$. Sc2 and Sc3 are long paddle-scintillators covering all active length of the drift chamber. The muon beam is coming from the right. The absorber material is placed in locations indicated as M1 and M2.

Fig.2. A schematic drawing of the drift chamber. The muon beam is coming from the right.

Run: New-Is02
Event: 343

Fig.3. A typical event. One can see that in spite of some extra activity in the drift chamber, the track was found and it matched the muon track tagged by the strip detector.

Fig.4. Hit multiplicity in the drift chamber for different absorbers in front. The data are shown as a solid line histogram, and the Monte Carlo is presented by dots.

Fig.5. An experimental χ^2 -distribution for all events with one 4-hit row (run "Nothing"). An expected distribution (χ^2 for 2 degrees of freedom) for given number of events is presented by a line. The agreement indicates that the drift chamber resolution was reconstructed correctly, while the tail collected in the last bin shows that sometimes the measurements were dramatically spoiled.

Fig.6(a). Residuals ($\Delta R = R_{\text{drift}} - R_{\text{predicted}}$) for the run "Nothing". $R_{\text{predicted}}$ is an expected drift distance in a cell as predicted from the measurements in the strip detector, and R_{drift} is an actual drift distance in that cell. The accuracy of a prediction was $\sim 600 \mu\text{m}$.

Fig.6(b). Residuals ($\Delta R = R_{\text{drift}} - R_{\text{predicted}}$) for the run "10 cm Pb".

Fig.7. A probabilities to get 0, 1, 2, 3, 4 hits in a row adjacent to the one containing a muon for two different runs: "Nothing" and "10 cm Pb".

Fig.8. Distributions of drift distances R_{drift} in cells with hits, but not containing a muon track. The histograms are normalized on the total number of events (muon tracks). Data are presented by a solid line and the Monte Carlo by dots.

Fig.9. Distributions of drift distances R_{drift} for single hit rows. Data from all runs are summed up in this histogram. The Monte Carlo was scaled to give the same number of entries. Data are presented by a solid line and the Monte Carlo by dots.

Fig.10. Distributions of drift distances R_{drift} in cells not containing a muon for events with all 16 cells having hits. The histograms are normalized on the total number of events (muon tracks), i.e. the normalization is the same as in fig.8. Data are presented by a solid line and the Monte Carlo by dots.