M13 Muon Beam Development for $\mathcal{TWIST}$

Proposal for measurements in Fall 2000

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1 Introduction

In order to take advantage of the existing and potential capabilities of the M13 muon beam, and to control and assess different sources of systematic effects, it is important to learn about the behavior of the beam as a function of almost anything that we can control or that can change with time. Much of this can be done with simulation, but using reliable data to test and verify the simulation results is essential.

There may be an opportunity to add to our understanding of the muon beam in the fall of 2000, in parallel with the many activities of construction, instrumentation, and first operation of the $\mathcal{TWIST}$ detectors in the solenoid. It is proposed to do this with an independent and easily changed set of detectors mounted between the end of the M13 vacuum pipe and the front face of the magnet yoke, perhaps extending into the beam hole in the yoke face. Different beam properties can be determined with different detector arrangements and strategies. This note contains a summary of the properties that we may wish to measure, and why, along with proposals about how the measurements might be accomplished. Much of this information is available in various documents posted to the $\mathcal{TWIST}$ Beams Study Group bulletin board at http://stoney.phys.ualberta.ca/~e614/Projects/E614-S2/.

2 Beam properties to be assessed

The ideal measurement of beam properties consists of determinations of the total intensity for the beam of interest (surface muons, in our case), as well as the particle momentum and factors of the four dimensional emittance, namely x, y (position) and dx, dy (divergence), for individual particles. A direct and precise momentum measurement requires a spectrometer, and we do not propose to attempt it here; however, some inferences may be made via other means where necessary. Due to limitations imposed by multiple scattering of muons at surface muon momenta, direct measurements of divergence with two separated x, y wire chambers are imprecise. While some beam properties can quite usefully be measured at higher momenta, *e.g.*, 90 MeV/c, where scattering is not a significant hindrance, others are unique to the surface muon production mechanism and have to be measured near 29 MeV/c. In this case, beam size can be measured by accounting for the effects of multiple scattering. We hope that a collimator array will provide us with some idea of surface muon beam divergence as well. Other strategies have been considered but would rely on hardware which is not available at this time.

2.1 High momentum measurements

We first describe measurements which can be made with a higher momentum. The detector arrangement consists of a tracking system of two separated x, y chambers followed by scintillators for particle identification. More detailed descriptions of how the measurements are to be made, for both surface muon and higher momenta, are in a later section.

Beam tune strategy

As has been demonstrated in E614 Technical Notes and discussed at some length in group meetings, the beam properties while passing through the $\mathcal{TWIST}$ solenoid fringe field are critical to the maintenance of polarization at the stopping target. Most recently, J. Doornbos has examined the effect of different M13 tuning strategies[1]. His findings are summarized in a separate document[2]. It is first necessary to establish a base tune from which we can work, and this is expected to take a significant amount of the beam study time available in the upcoming running period. It can be done initially with pions at higher momenta, where divergence measurements are more precise. Beam profile, emittance, and intensity (with particle identification via time of flight) should be determined.

Beam element settings

Once the base tune is established, the dependence of the beam properties for variations in the settings of the elements can be investigated. By adjusting each element in turn by plus and minus a fixed amount (*e.g.*, 0.5% for dipoles and 5% for quadrupoles) the sensitivity can be found.

Beam emittance

The dependence of the emittance in x and y ($\pi(x \cdot dx)$ and $\pi(y \cdot dy)$ respectively) on the settings of the horizontal and vertical jaws (located between the production target and the first bend, M13B1, which limit the channel acceptance) can also be measured at higher momenta with two x, y chambers.

Momentum acceptance

Without a spectrometer of some kind to measure muon momentum to better than 1% accuracy, the only way to find the momentum distribution of the beam is to scan the channel momentum across a step in the distribution of beam particles *vs* momentum. There are two such steps in the M13 momentum range. One step is the surface muon edge at 29.79 MeV/c, and the other is the positron edge from muons stopped near the surface of the target, near 53 MeV/c. In either case, the momentum acceptance can be inferred from the width of the derivative of the number of particles as a function of momentum. Particle identification is important, for example to distinguish the positrons arising from muon decays the target from others such as those from π^0 decay.

2.2 Surface muon measurements

The following properties are specific to surface muons and must therefore be measured near 29.79 MeV/c. In these cases, due to multiple scattering, at most one wire chamber can be utilized, along with scintillators for particle identification and timing.

Cloud muon properties, including polarization

Because cloud muons do not have the "perfect" polarization of surface muons, it is essential for $\mathcal{TWIST}$ polarization measurements to correct for beam contamination by cloud muons. We therefore want to measure how many cloud muons are in the beam, and what their polarization is. The number can be determined from a short extrapolation of the muon rate as a function of momentum measured at momenta higher than the surface muon edge. It can also be confirmed by careful analysis of the time of flight with respect to the RF. The TOF of surface muons shows the 26 ns lifetime of pions stopped in the production target, whereas cloud muons are more distinctly correlated to the RF. The TOF spectrum for cloud muons can be observed at momenta higher than the surface muon edge, which is useful in fitting different components of a TOF spectrum. Polarization can be determined to some precision by μSR in a transverse field. R. MacDonald has designed a small magnet and scintillator detector system to do this. It is planned that it will be placed inside the solenoid volume, with the primary $\mathcal{TWIST}$ detector array removed and the solenoidal field off.

BL1A proton beam steering sentitivity

There are four monitor plates in front of the 1AT1 target which are used to determine the horizontal and vertical halo of the proton beam, collectively known as the T1 Protect Monitor. Proton beam steering can be measured via this device, the operation and stability of which has been examined by T.A. Porcelli. We want to measure the change in the M13 muon beam properties as the beam is steered, in order to determine how stable the proton beam must be, as measured by the T1 Protect Monitor, to assure a given stability of the surface muon beam.

Effect of solenoid fringe field

If possible, we want to confirm the change in the beam properties in the presence of the solenoid fringe field. This may be limited to fields consistent with proper operation of our scintillators and chambers. Within the precision of measurements, however, there is no reason to believe that the properties would be inconsistent with calculations, assuming that we understand the properties with the solenoid field off.

Production target differences

We expect to be able to use a 10 mm graphite production target at 1AT1, at least with a lower proton current in the range of 100 μA. The muon beam can be compared to that from the stainless steel jacketed 12 mm beryllium target. Results from μSR measurements indicate a significant ($\sim 50\%$) increase in surface muon rate from the graphite target surface, especially if the proton beam properties (shape and position) are optimized for M13. It will be interesting to see the effects on the beam profile and divergence as well.

3 Detector arrangements

TRIUMF has developed[3] fast wire chambers which are suited to our needs. Each chamber has x and y anodes, each with an independent pair of cathode foil (CF) planes, with additional gas envelope (GE) foils on each side (arranged as, e.g., GE, XCF, XA, XCF, YCF, YA, YCF, GE). The gas envelope foils should be impervious to He. The thicknesses of all foils is presumed to be 6.35 μm. The anode spacing is 0.030" (0.762 mm) and the anode-cathode spacing is 1/32" (0.0313", 0.794 mm). There are two types available, one with 96 wires (dimension $\sim$ 7 cm, one only) and one with 64 wires (dimension $\sim$ 5 cm) in each of x and y. The preferred chamber gas is CF_4 (80%) and isobutane (20%). The chambers are mounted in frames which have a smooth surface and threaded holes so that in principle a gas-tight He-containing pipe can be placed between the M13 beam window and the first chamber, and in between the two chambers. The thickness of the frame assembly is 57 mm, with the GE foils inset by about 13.5 mm on each side, so the distance between the two GE foils is about 30 mm.

It is proposed to construct adapter flanges with the minimum thickness required to adapt both sides of one 7 cm and one 5 cm chamber to the TRIUMF standard 6" diameter beam tube flange, with gas fittings so that helium can be maintained between the chambers and between the beam line vacuum exit window (probably 75 μm) and the first chamber. In this way, the distance of the chamber(s) along the beam axis can be varied easily, by insertion of different lengths of standard beam tube.

The device arrangement for high momentum measurements is two fast wire chambers, separated by some distance, each with x and y readout and capable of at least a significant fraction of the full intensity from M13. Scintillators following the chambers allow for particle identification via time of flight. An example arrangement is shown in Fig. 1.

GEANT simulations were made at three momenta for a "perfect" beam (zero size and divergence) passing through a realistic set of materials. The materials are:

- 76.2 μm mylar
- 10 cm He
- fast chamber (FC)with
  - 30 mm CF_4/isobutane (80/20)

  - 6 mylar foils, each 6.35 μm thickness
  - 2 anode planes (x and y), each of 12.7 μm diameter W wires, 0.762 mm spacing

- 50 cm He

This roughly represents the growth of the beam at the entrance to a second wire chamber, which would be used to determine a second pair of coordinates for constructing emittance plots. Table 1 shows the results for three momenta. The conclusion is that the beam growth due to scattering is prohibitively large for surface muons for this method to be useful. However, at three times this momentum (near 90 MeV/c) the scattering is small enough that the emittance can be determined. By separating the particles via TOF with respect to the RF signal, the emittances of pions produced in the target, muons from the pion decay in flight (cloud muons), and positrons are distinguished.

Figure 2 compares simulations of x and dx distributions for two similar beams, each with horizontal and vertical emittances of 80π mm $\cdot$ mrad, but sizes differing by 20%. The GEANT simulations (for muons only) used the detector geometry of Fig. 1. Even with a small event sample, a significant difference is clear for both x and dx.

For low momentum measurements, a plate with an array of holes (a sieve collimator) can be placed at the focus position, and the distribution of particles passing through the holes could be analyzed to determine beam size and divergence. In this case, one or two thin (250 μm) scintillators identify muons, while thicker scintillators tag positrons from the beam and from muon decay in the collimator and elsewhere. An example arrangement is shown in Fig. 3. The collimator in this case consists of a 5×5 square array of 25 holes of diameter 1 mm, with centers separated by 4 mm, bored through a 2 mm thickness stainless steel plate. It is placed in the beam line vacuum 5 cm in front of a 75 μm thickness, 12 cm diameter mylar window. After the window is 4 cm of helium at atmospheric pressure, followed by a 96 wire fast chamber and finally the scintillators.

Optimization of the sieve collimator characteristics involves some compromises which have not yet been fully studied. In order to quantify the requirements, consider a sieve collimator with hole separation s and hole diameter w, a distance l from the chamber. Take the beam to be described by rms size and divergence of σ_x and σ_{dx} respectively, at the focus (on the chamber). Neglect scattering. Clearly, one must have approximately $s \leq \sigma_x + l\sigma_{dx}$, so that more than one collimator hole is hit. The size of the beam of particles passing through one hole should also be smaller than the hole resolution at the wire chamber, so $w + 2l\sigma_{dx} \leq s$ (with a somewhat arbitrary factor of two to ensure that particles passing through one hole remain distinct at the chamber). Only a restricted set of parameters is permitted by this simple analysis. In general, the relation $l\sigma_{dx} \leq \sigma_x$ must be satisfied, leadint to the conclusion that different values of l and perhaps s would be required to determine a range of values of σ_x and σ_{dx} whose product is constant.

It is much more difficult to distiguish small variations in σ_x and σ_{dx} with a sieve collimator. With the arrangement of Fig. 3, and the beam focused on the sieve collimator, simulations were made for the two beam situations described in Fig. 2. The results are shown in Fig. 4. Note that the x distributions are narrower than the y distributions due to the extra scattering and beam growth between planes of the chamber.

If the analysis of the sieve collimator wire chamber distributions does not produce results for emittance estimates of sufficient accuracy, a more time consuming method of measuring the beam size at different positions along the beam direction can be attempted. Different lengths of vacuum beam tube in front of a beam window and chamber allows us to change the position, at least as much as will be allowed by the yoke of the solenoid.

A remotely controlled set of slits in vacuum a short distance in front of a wire chamber could be used for emittance measurements of surface muons, without all of the restrictions of the sieve collimator. So, too, could a time expansion chamber (TEC). Unfortunately, neither one is available to us at the time of this writing.

4 Summary

The characteristics and behavior of the M13 beam line can be measured or remeasured, within certain limitations, with an arrangement consisting of one or two existing wire chambers and a set of thin and thick scintillators. No particular arrangement will enable all of the measurements listed, so it is important that we are able to change from one setup to another without difficulty. Precise and direct measurement of surface muon emittances will presumably require much lower density position-sensitive detectors such as the time expansion chamber (TEC).

It is expected that a significant amount of beam time, perhaps as much as one week, will be required to establish a low emittance beam tune which has been proposed by J. Doornbos. Following that, the characterization of the tune and establishment of its stability, with respect to variables such as primary beam and magnet fluctuations, will take a similar period.

References

[1] Transparencies of talk by J. Doornbos, available in pdf format at http://stoney.phys.ualberta.ca/ e614/Projects/E614-S2/00012/index.html

[2] J. Doornbos, contributions to the $\mathcal{TWIST}$ collaboration meeting, August 2000.

[3] R. Henderson, W. Faszer, *et al.*, IEEE Trans. Nucl. Sc. **NS-34** (1987) 528. Reprint available in pdf format at http://stoney.phys.ualberta.ca/ e614/Projects/E614-S2/00015/index.html

Momentum (×29.79 MeV/c)	1.0	2.0	3.0
into FC1			
x (cm, rms)	0.256	0.07	0.04
dx (mr, rms)	26.5	7.4	4.1
exiting FC1			
x (cm, rms)	0.332	0.09	0.05
dx (mr, rms)	47.4	13.0	6.5
at 50 cm from FC1			
x (cm, rms)	2.49	0.70	0.37
dx (mr, rms)	48.1	13.2	6.8

Table 1: Simulation results for growth in size and emittance of muon beams passing through beam line materials and one fast chamber (FC1), for three different momenta. A second fast chamber at 50 cm from the first is used to measure beam divergence, but this is only practical at higher momenta.

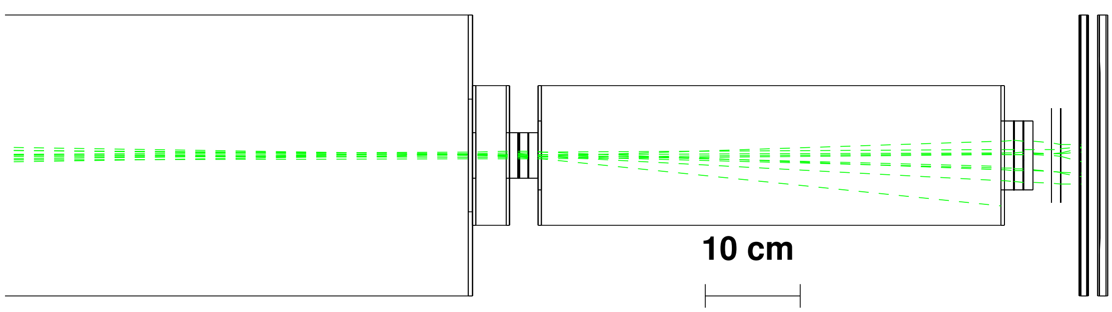

Figure 1: Possible arrangement for high momentum beam size and emittance estimation using two separated chambers (FC1 is 5 cm, FC2 is 7 cm) and scintillators for particle identification. The simulated tracks entering from the left demonstrate the significant multiple scattering of a surface muon beam with realistic emittance, focused at FC1.

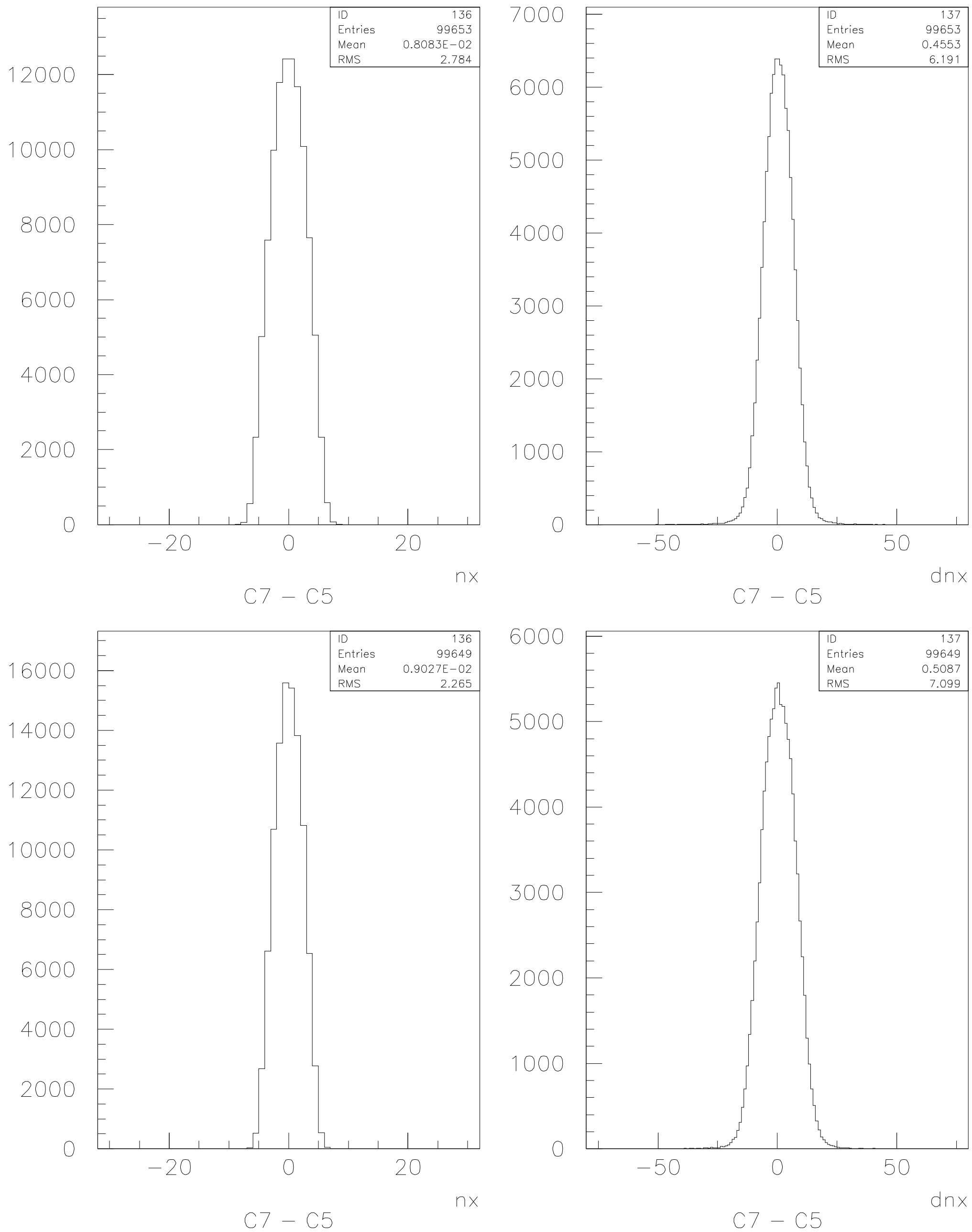

Figure 2: Comparison of fast chamber distributions for the setup of Fig. 1 at three times surface muon momentum. The top left is the x wire distribution in FC1 (64 wires, ~ 5 cm) and the top right is the wire location difference between FC2 (96 wires, ~ 7 cm) and FC1, which gives the beam divergence, for beam half widths of 5 mm and 16 mrad. The lower two pictures are equivalent measurements for beam half widths of 4 mm and 20 mrad.

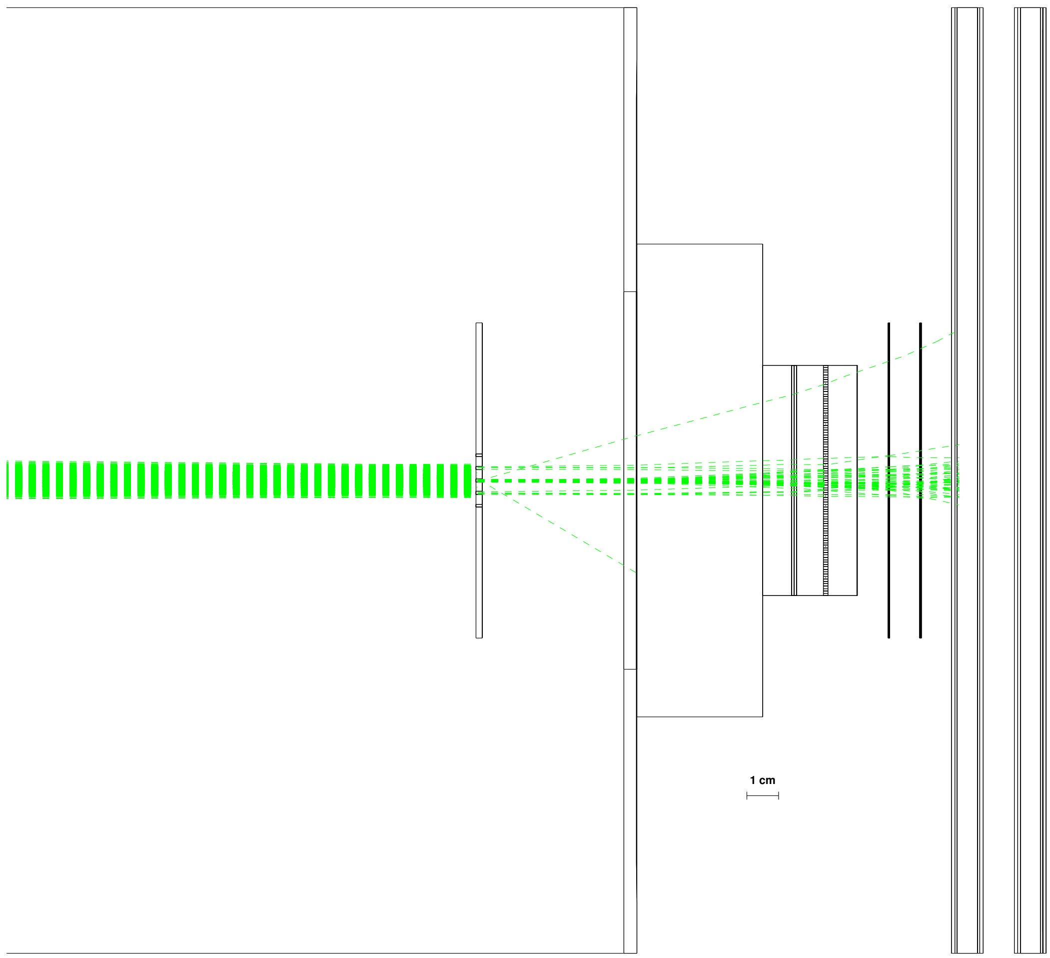

Figure 3: Possible arrangement for low momentum beam size and emittance estimation using a multiple-hole (sieve) collimator in vacuum, one fast wire chamber, and scintillators for particle identification.

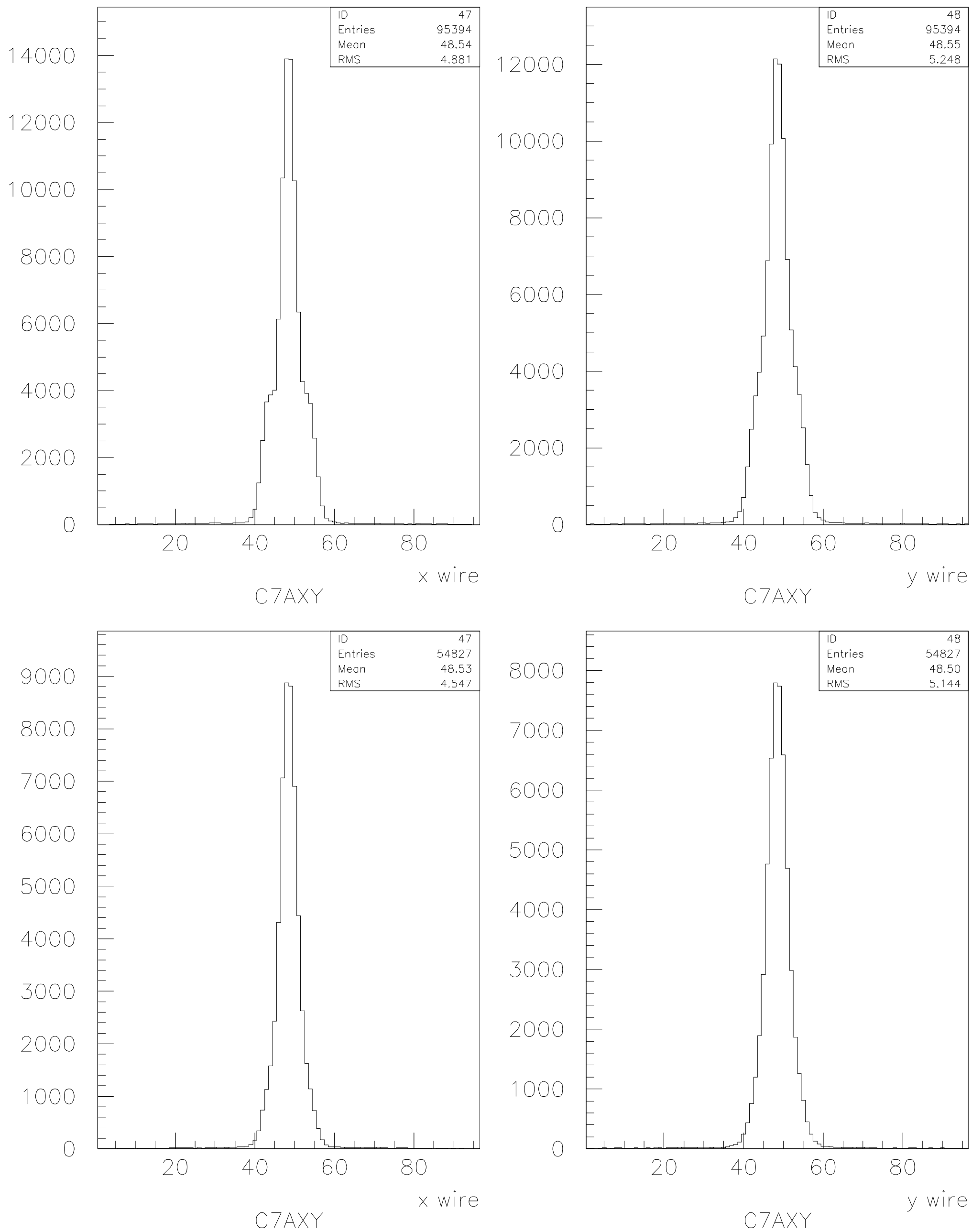

Figure 4: Comparison of fast chamber distributions for the setup of Fig. 3 at surface muon momentum. The top left is the x wire distribution in FC1 (64 wires, $\sim$ 5 cm) and the top right is the y distribution, for beam half widths of 5 mm and 16 mrad. The lower two pictures are equivalent measurements for beam half widths of 4 mm and 20 mrad, showing the differences to be expected in this measurement. In both cases, only the center and four nearest neighbor holes of the square array collimator are hit with the beam.