Summary of M13 Momentum Scans of Surface Muon Edge (*TWIST* Technote 52)

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8 March, 2001

Abstract

This document describes four momentum scans performed on the M13 channel—two with a beryllium 1AT1 target, and two with graphite. The scans were performed by Glen Marshall and Robert MacDonald.

The muon and positron rates were measured for a series of magnetic field settings of the first dipole magnet (B1) of the M13 channel. The B1 magnet selects the channel momentum, and the purpose of these scans was to calibrate the B1 magnetic field (according to an NMR probe) to the well-known surface-muon edge momentum (29.79 MeV/c). Since this edge should be very sharp, the measured width of the edge also gives the momentum bite of the channel for the chosen F1 slit setting.

Summary of the momentum scan results:

Beryllium target	**30 Oct.**	**5 Dec.**
B1 Field at Edge (Gauss)	879.6 ± 0.4	876.5 ± 0.4
Momentum bite	2.1%	1.3%
Graphite target	**13 Nov.**	**20 Nov.**
B1 Field at Edge (Gauss)	878.7 ± 0.4	877.8 ± 0.4
Momentum bite	1.6%	1.7%

The momentum bite results are in agreement with the (very rough) estimate of 2% momentum bite for the F1 horizontal slit setting of 25 mm.

1 About the Momentum Scans

The momentum scans were taken using two different targets at 1AT1. The beryllium target was in place for the 30 October and 5 December scans. The graphite target was in place for the 13 and 20 November scans. (All scans took place in 2000.) The scans were performed by Glen Marshal and/or Robert MacDonald.

An initial tune, at a momentum slightly below the surface muon edge, was chosen to be the "reference momentum." The channel momentum was scaled by percentages relative to this reference. The B1 and B2 bender magnets were scaled by their NMR readings; the quadrupoles were scaled by their DAC values.

About the November 13 scan: A coarse scan was performed, starting at the reference momentum and going up to 20% higher, in various step sizes. Additional points were then filled in on the surface muon edge, as well as points down to 10% below the reference momentum.

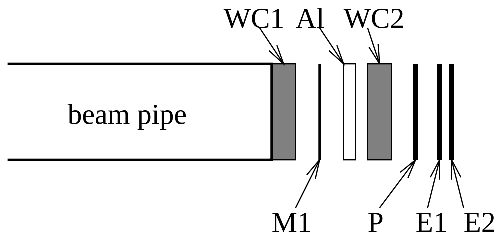

Figure 1: Schematic diagram of apparatus. M1, P, E1, and E2 are scintillators. WC1 and WC2 are wire chambers (WC1 is pushed against the end of the beam pipe). Al is a set of aluminum sheets. (Not to scale.)

The same scale percentages were used for the later two scans (20 Nov. and 5 Dec.) described here, but scaling monotonically from -10% to +20%. It was hoped this would reduce any hysteresis in the quadrupole magnets.

The first scan (30 Oct.) used different (slightly coarser) percentages, but was also done monotonically in an attempt to avoid hysteresis effects.

For all but the 30 Oct. scan, the detector at the end of the M13 channel consisted primarily of a set of scintillators and an aluminum target, arranged as shown in figure 1. $M1$ is a thin scintillator used for counting muons, and is relatively insensitive to positrons. Surface muons stop in the aluminum. For these reasons, $(M1 \cdot \bar{P})$ was used as a muon ID. Positrons pass through the entire setup undeterred, so a coincidence of $E \equiv (P \cdot E1 \cdot E2)$ is a good positron ID.

Two wire chambers were also part of the apparatus, but were used for other beam studies. They are included in the diagram for completeness.

The 30 Oct. scan used a similar apparatus, but without the wire chambers (the apparatus used was for the μSR studies).

The data was taken using visual scalers, set to accumulate over 10 second intervals. Scalers counted $M1$, "clean" muons $(M1 \cdot \bar{P})$, positrons, and the T1 ion chamber (which puts out pulses at a rate proportional to the proton current in the BL1A beamline). The rates were then normalized to proton current by dividing by the T1Ion scaler.

2 Muon Flux, Surface Muon Edge, and Momentum Bite

Figures 2 and 3 show the normalized muon flux as a function of the B1 NMR reading (in Gauss), for both scans on each target. The shape is approximately as predicted: the muon rate rises with momentum until it reaches the surface muon edge, at which point it falls sharply. It resumes rising, but more slowly, after the edge—at these momenta, the only muons are "cloud" muons.

The minima and maxima of these graphs are summarized in table 1. Of particular interest is the graphite (C) target data. The minima (mostly cloud muons) are roughly the same between the two scans, but the maxima (mostly surface muons) differ by a factor of almost two. The graphite target split in two during the November beam studies, and it is not known when this happened; the difference in surface muon flux may be due to this break.

The curves are not quite as smooth as expected. Some of the jitter in the November 13 data could be attributed to hysteresis (the data was not taken in order of momentum), but not so for the other scans. Moreover, the shape of these jitter "features" is reproduced in three of the four graphs (and the fourth—from 30 Oct.—was taken using different equipment).

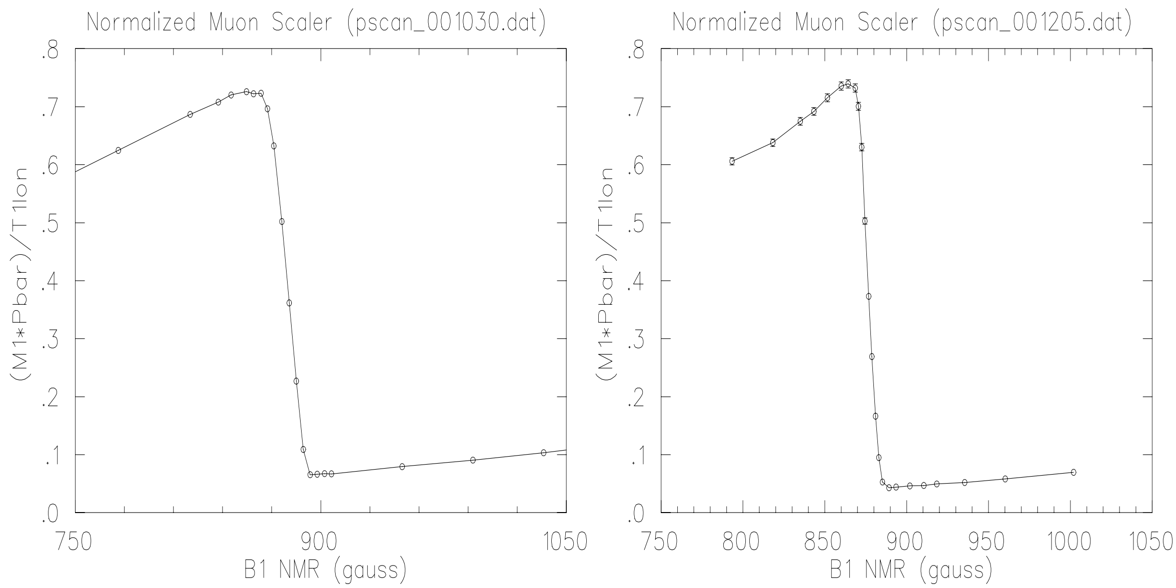

Figure 2: Normalized muon flux vs. B1 NMR reading, **Be target**. Left: October 30. Right: December 5. Muon flux is normalized against the T1 Ion Chamber rate, which is proportional to the BL1A proton rate.

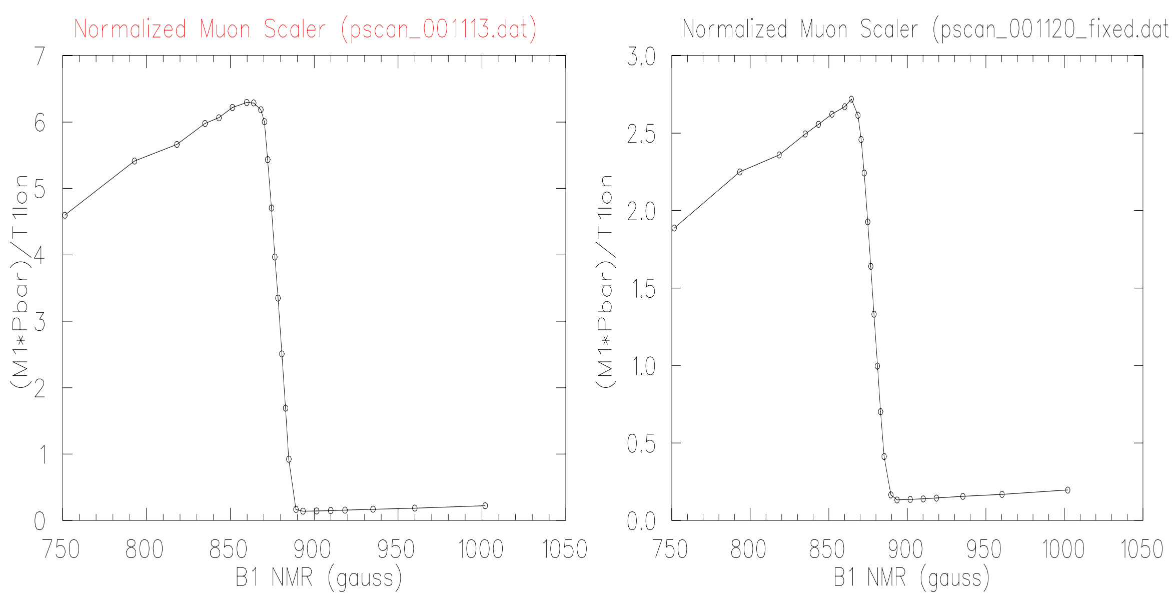

Figure 3: Normalized muon flux vs. B1 NMR reading, **C target**. Left: November 13. Right: November 20. Muon flux is normalized against the T1 Ion Chamber rate, which is proportional to the BL1A proton rate.

Date	Target	Min. Flux	Max. Flux
Oct. 30	Be	0.066	0.73
Dec. 5	Be	0.043	0.74
Nov. 13	C	0.14	6.3
Nov. 20	C	0.13	2.7

Table 1: Minima and maxima of normalized muon flux graphs from figures 2 and 3.

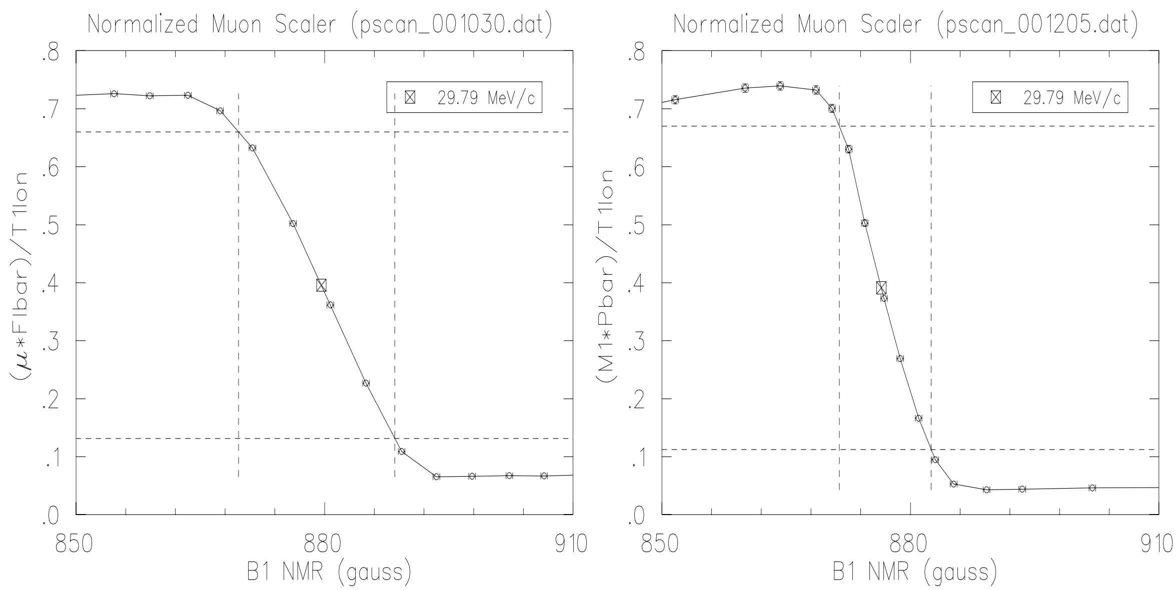

Figure 4: Closeup of surface muon edge, **Be target**. Normalized as in figure 2. The horizontal dashed lines show the 10% and 90% levels, and the vertical dashed lines show where the momentum scan crosses those levels. The boxed point shows the halfway-point between those levels, ie. the surface muon edge (at 879.6 ± 0.4 Gauss (left graph) and 876.5 ± 0.4 Gauss (right graph)).

Figures 4 and 5 show an expanded view of the surface muon edge for each scan. The "10%" and "90%" levels correspond to 10% and 90% of the range between the minimum and maximum muon fluxes.

Let B represent the magnetic field in B1 (that is, the B1 NMR). Then B_{10}, B_{50}, and B_{90} are the B values for the 10%, 50%, and 90% levels.

The 10% and 90% levels were chosen because the derivative of the edge shape should approximate a Gaussian curve. In this case, the B1 NMR values for the 10% and 90% levels should roughly correspond to the half-maximum points of the Gaussian's peak. Therefore, the difference $B_{90} - B_{10}$ should give the "width" of the edge, and B_{50} should occur at exactly the surface muon edge.

The 10% and 90% levels are shown as dashed horizontal lines in figures 4 and 5; the corresponding B1 NMR values are shown as dashed vertical lines. The boxed point shows the position of B_{50}—the surface muon edge of 29.79 MeV/c. This point occurs at the field values shown in table 2. (The uncertainty in the field values represents the precision to which the B1 magnet can be set, as limited by the coarseness of the power supply control (DAC). A detailed error analysis has not yet been done, so this may not be the only source of error on these points.) The fields for the graphite target momentum scans agree within error. The beryllium target results, however, vary

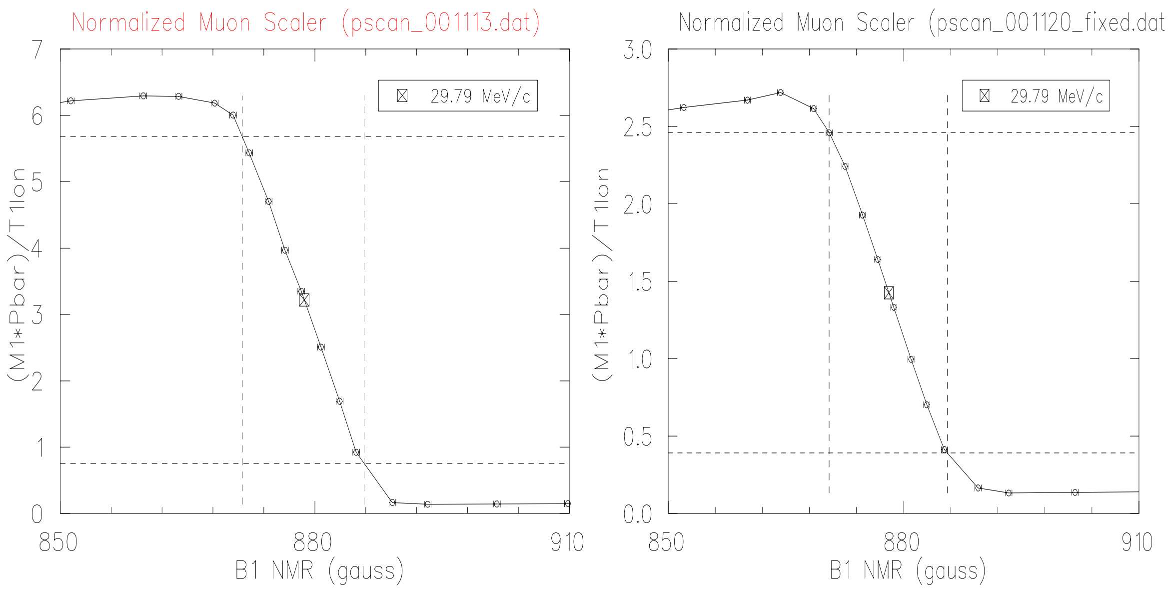

Figure 5: Closeup of surface muon edge, **C target**. Normalized as in figure 3. The horizontal dashed lines show the 10% and 90% levels, and the vertical dashed lines show where the momentum scan crosses those levels. The boxed point shows the halfway-point between those levels, ie. the surface muon edge (at 878.7 ± 0.4 Gauss (left graph) and 877.8 ± 0.4 Gauss (right graph)).

Beryllium target	**30 Oct.**	**5 Dec.**
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Table 2: Summary of momentum scan results, both targets.

significantly.

One possible explanation for the difference in beryllium target results is beam tuning: the 5 December scan was taken during beam tune studies, and the tune used was probably not exactly the same as that used for the other scans. (In fact, it was probably a better tune (closer to what $\mathcal{TWIST}$ will likely use).)

Figures 6 and 7 show plots of the "derivative" of the surface muon edge. The derivative was calculated as the difference in y positions (normalized flux) of adjacent points, divided by the difference in x positions (B1 NMR). They are plotted at the centres of their B1 NMR intervals. Vertical lines show the positions of B_{10}, B_{50}, and B_{90}. All of these plots are vaguely Gaussian, some moreso than others; with all curves, with both curves B_{10} and B_{90} occur near the half-max points of the curves, and B_{50} occurs roughly in the middle of the peak. Note that uncertainties in these "derivatives" were not calculated.

The magnetic field B should be directly proportional to the channel momentum p. Therefore

$$\frac{dB}{B} = \frac{dp}{p}. \tag{1}$$

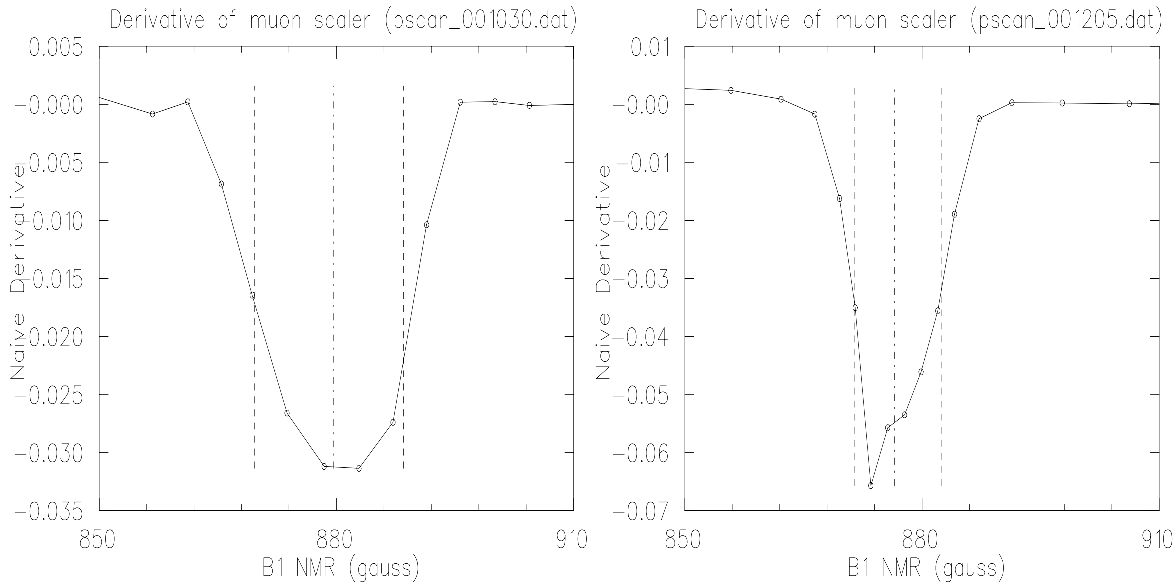

Figure 6: "Derivative" (slope of segments between data points) of surface muon edge, **Be target**. Vertical lines show B_{10}, B_{50}, and B_{90} (see text). These plots do not include uncertainties.

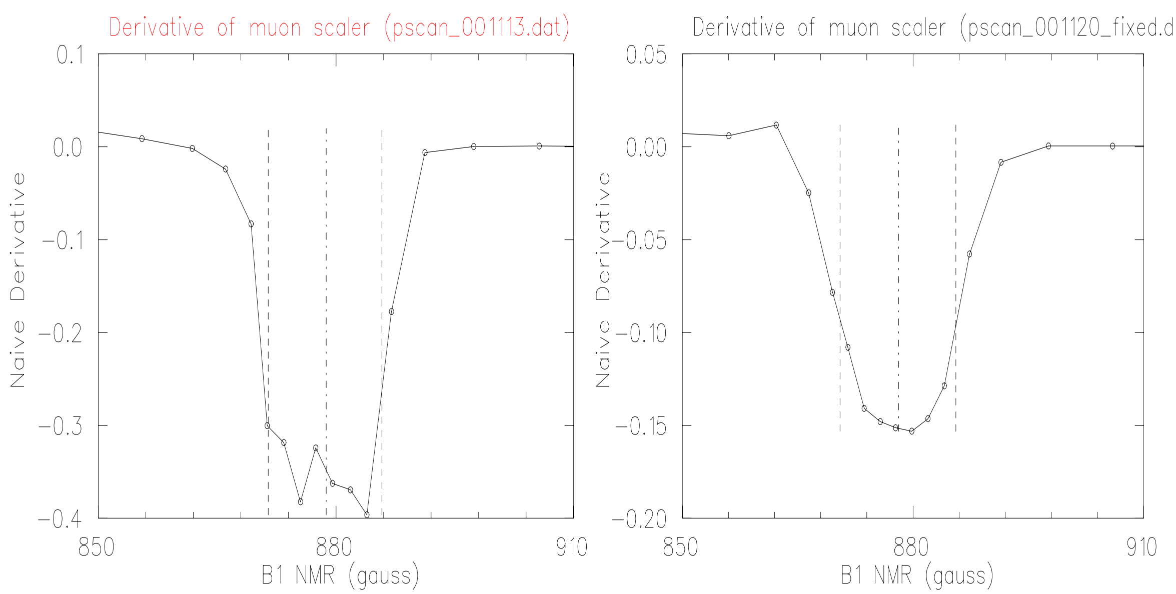

Figure 7: "Derivative" (slope of segments between data points) of surface muon edge, **C target**. Vertical lines show B_{10}, B_{50}, and B_{90} (see text). These plots do not include uncertainties.

Thus we can calculate the momentum bite dp/p from the width of the surface muon edge:

$$\frac{dp}{p} \approx \frac{|B_{10} - B_{90}|}{B_{50}} \tag{2}$$

The momentum bite results are listed in table 2. No error analysis has yet been done on momentum bite, but the results are in good agreement with the 2% momentum bite estimated by Jaap Doornbos. (The width of the F1 horizontal slit defines the momentum bite. Jaap Doornbos calculates a momentum bite of (very roughly) 1% per 1.25 cm slit width; the slit was set to 2.5 cm wide for these scans.)

3 Positron Flux

The surface muon edge should have little to no effect on the M13 positron flux—the flux should increase approximately linearly with momentum—so this flux can be used as a check. Figures 8 and 9 show the normalized positron flux as a function of B1 NMR. The flux was normalized against the T1 ion chamber as with the muon flux.

As the graphs show, the positron flux does seem to scale linearly with channel momentum. There are kinks in the curves, however. For the November 13 data, these may be due to some hysteresis in the quadrupoles, since the data points were not taken in a single series. (The dipole magnets B1 and B2 should not be subject to hysteresis, since the magnetic fields for those were set by NMR.)

The kinks in the other scans are probably not due to hysteresis, since the data was taken in order of momentum—any hysteresis should affect all points in roughly the same way. They could be due to some non-linearity or scaling problems in the quadrupoles.

It is worth noting that most of the features of these curves are in the same places on both graphs for a given target (though different for the different targets). This suggests that hysteresis is probably not the cause.

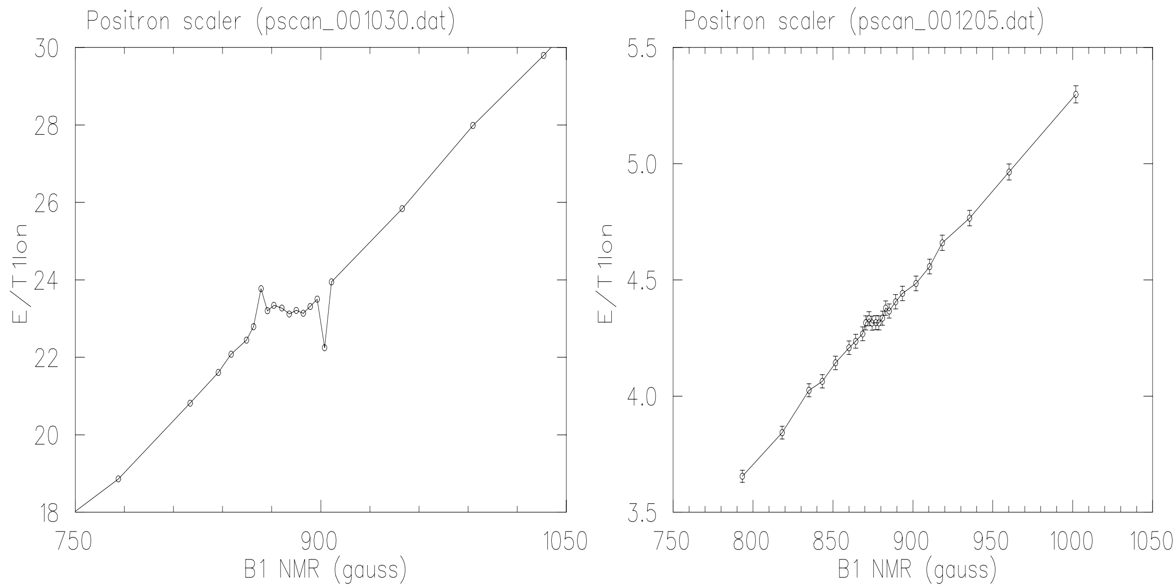

Figure 8: Normalized positron flux vs. B1 NMR reading, **Be target**. Positron flux is normalized against the T1 Ion Chamber rate, which is proportional to the BL1A proton rate.

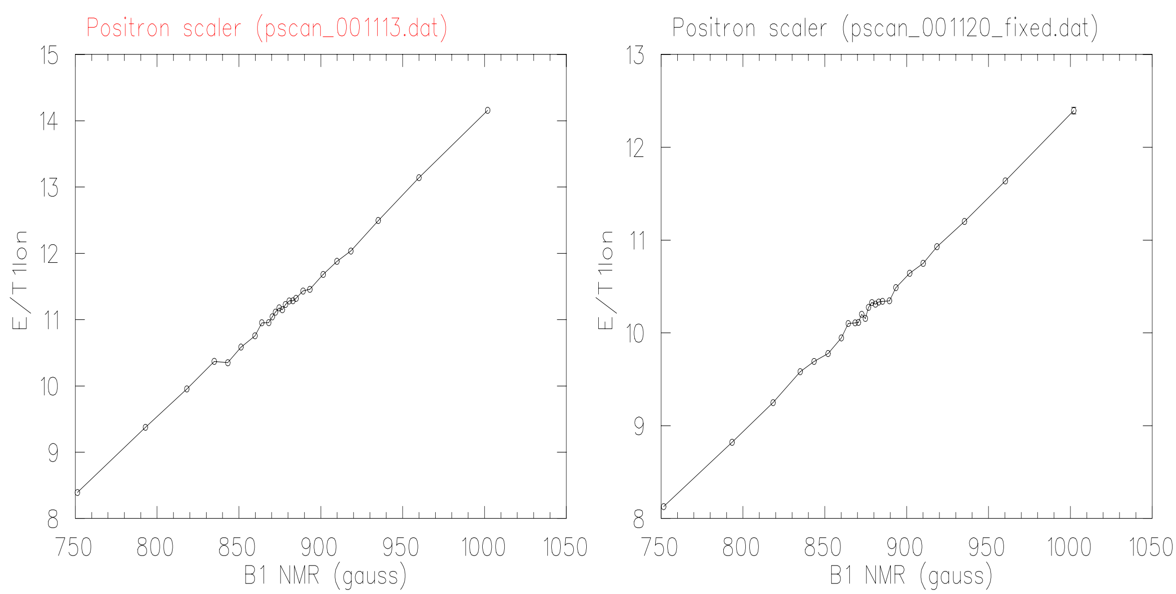

Figure 9: Normalized positron flux vs. B1 NMR reading, **C target**. Positron flux is normalized against the T1 Ion Chamber rate, which is proportional to the BL1A proton rate.