- event digitization - hit times from each simulated event track in the 52 drift chamber planes are generated from a preliminary drift-distance-to-time table and read out in a format identical to that generated in the 1877 TDCs. A file of such events is then written out in YBOS format, just as in a real data run
- histogramming - HBOOK histograms are used.

Part IV

Systematics and tests:

Several sources of systematic errors have already been considered in other sections and will be summarized here. Experimental tests and additional Monte Carlo calculations are listed which are required to make accurate estimates of systematic error on the derived Michel parameters.

The complete list of corrections and errors that have been estimated for E614 (and the corresponding errors on these) are presented in table 2 (the notation used: $(1-P_\mu\xi)(10^{-5}) = 5\pm1$ means that the correction to $(1-P_\mu\xi)$ value would be $+5\cdot10^{-5}$ and that the error on this correction would be $\sigma(1-P_\mu\xi) = 1\cdot10^{-5}$).

Below are comments to the entries in table 2 and/or reference to the section where they were discussed.

1. The effect of Coulomb scattering of muons inside the production target and the modifications to 1AT1 and M13 required to achieve this level of accuracy have been described in section 7.1.

2. The admixture of particles in the M13 beam that are not surface muons has been measured for the existing 1AT1 target. The most pessimistic assumption is that the long tail of the cloud muon peak is the main source of any non-surface muon admixture. If this is the case $(1-P_\mu\xi) = (12\pm3)\cdot10^{-5}$. However estimates show that the shift of $(1-P_\mu\xi)$ will be smaller if a 1AT1 "pencil" target is used (the result for the existing target is given in table 2).

3. A vertical displacement of the proton beam on the 1AT1 target of $2mm$ will result in a $\Delta\theta = 2mrad$ change in the muon beam direction at the final focus. This directly corresponds to a $(1-P_\mu\xi)$ shift of $2\cdot10^{-6}$. It also leads to a $2mm$ transverse displacement of the muon beam in the fringe field area at the entrance to the solenoid and thus causes an additional increase of $(1-P_\mu\xi) = 5\cdot10^{-5}$. The present instrumentation in BL1A is sensitive to $0.5mm$ shifts in the position of the proton beam so that maintaining stability below $2mm$ is possible. For the existing 1AT1 target a $2mm$ proton beam shift in the horizontal plane not only adds to the fringe field depolarization as described above but may also change the mean value of the muon beam momentum. For a "pencil" target a horizontal shift will only affect the surface muon beam rate.

4. Any instability of the currents in the M13 bending magnets translates into changes in the momentum bite of the channel and thus, because of the Coulomb scattering in the 1AT1 target, changes in the average muon polarization(see section 7.1). Such drifts would also

Table 2: Correction and Error Estimates.

##	Source of Correction or/and Error	$(1-P_\mu\xi)$ (10^{-5})	$(0.75-\rho)$ (10^{-5})	$(0.75-\delta)$ (10^{-5})
1	Coulomb scattering of muons inside the production target	5 ± 1	–	–
2	Non-surface muon contamination	12 ± 3	–	–
3	Proton beam shift ($\pm 2mm$) on the existing production target	5 ± 1	–	–
4	Instability (10^{-3}) of current in M13 bending magnets	< 1	–	–
5	Fringe field depolarization of muon	9 ± 3	–	–
6	Muon depolarization due to muon stops in last PDC	7.5 ± 2	–	–
7	Muon scattering by unpolarized electrons	1.5 ± 0.5	–	–
8	The ratio $e^+/\mu^+ = 4$	$\ll 1$	–	–
9	Muon decay in flight	$\ll 1$	$\ll 1$	$\ll 1$
10	Depolarization of thermal muon in metal at $2T$	< 1	–	–
11	Deviation ($2\mu m$) of average distances in PDCs assembly	3 ± 1	5.2 ± 2	5.4 ± 2
12	Random errors ($20\mu m$) in sense wire positions	$\ll 1$	$\ll 1$	$\ll 1$
13	Wire sags ($< 1\mu m$) in PDCs	< 1	< 1	< 1
14	Misalignment ($< 0.1mrad$) of **B** with respect to the beam direction	< 1	–	–
15	PDCs' misalignment ($< 0.1mrad$) with respect to **B** direction	< 1	< 1	< 1
16	Deviation (10^{-4}) of magnetic field magnitude	± 2.5	± 2.6	± 2.7
17	Magnetic field inhomogeneity ($< 10^{-4}$)	$\ll 1$	$\ll 1$	$\ll 1$
18	Creation of thin ($\ll 20$Å) films on the surface of the stopping Al target	$\ll 1$	–	–
19	Drift chamber zero time	± 5	± 5	± 5
20	Non-uniformity of detector acceptance	< 1	< 1	< 1
21	Positron energy calibration	± 3	± 5.2	± 5.4
22	Response function	± 5.9	± 4.6	± 4.9
23	Statistical errors for 10^9 events	± 10	± 5	± 8

move the beam where it crosses the fringing field of the solenoid thus leading to further changes in the average polarization. A current change of order 10^{-3} would cause a shift of $1 - P_\mu\xi < 10^{-5}$. The M13 magnet power supply monitoring will be improved to assure better than 10^{-3} accuracy and NMR and Hall probes will be installed in the magnets. The PC's at the entrance to the detector will also provide a means for monitoring for such drifts.

5. Fringe field depolarization was discussed in section 7.3. Three PCs at the entrance to the PDC assembly (see Fig. 4) provide a way to monitor the muon beam transverse position and width with mean position accuracy of $0.1mm$ and width accuracy of $0.5mm$. These PCs also allow monitoring of all possible instabilities, for example any p-beam shift on 1AT1 or drift in current in M13 bending magnets.

6. The measured P_μ value for muons stopped in $CF_4(ISO)(80:20)$ gas at $B = 2T$ is $P_\mu > 0.985$. According to Monte Carlo calculations $5 \cdot 10^{-3}$ muons stop in the last PC(-1X) chamber. Thus the shift of $(1 - P_\mu\xi)$ is $(1 - 0.985) \times 5 \cdot 10^{-3} = 7.5 \cdot 10^{-5}$. The deposited energy of muons in both PC(-1X) and PC(-1Y) will be measured by ADCs. This will allow reliable identification of μ^+ stops in PC(-1X) and exclude such events from the analysis. GEANT calculations to check this option are in progress.

7. The depolarization of a muon when slowing from $p = 29.8MeV/c$ down to zero quoted here is a reproduction of what was calculated in [1].

8. The influence on the Michel spectrum of the $e^+/\mu^+ = 4$ ratio in the beam and how it is essentially eliminated by a TOF cut has been discussed in section 2.

9. The influence of muon decay in flight on the Michel spectrum has been estimated to be negligible since it can only be influential if that decay occurs in the stopping target where the probability is very small ($\approx 10^{-6}$) and will be reduced even further by the delay in opening the positron "gate".

10. All possible mechanisms of muon depolarization in the Al stopping target lead to depolarizations that are very small at $B = 2T$ if the admixture of ferromagnetic elements (Fe,Co,Ni) in Al is less than $10ppm$. Obviously the target material will be the highest grade Al possible.

11. The effect of systematic inaccuracies in the PDC assembly on the derived Michel parameters has been discussed in section 7.4.4. Direct measurement of each wire position in the PDC assembly will be made.

12. The effect of random errors of wire positions (not systematic inaccuracies) on the Michel spectrum has been calculated in section 7.4.4.

13. Wire sag in the PDC assembly can reach $1\mu m$ for PDC planes with wires strung horizontal (Y measuring planes) if $(WRe)Au$ wires are used. There is no sag for planes with vertical (X) wires. Estimates discussed in section 3.1 found $2\mu m$ errors of negligible importance so this $1\mu m$ sag should likewise be unimportant. The actual sag values will be measured together with wire positions.

14. The influence of a misalignment $\theta_{beam,B}$ between the muon beam axis and the magnetic field on $P_\mu\xi$ will be reduced to less than 10^{-5}. This will be accomplished by measuring the transverse component of muon polarization $P_\mu^t = \sin\theta_{beam,B}$ using ordinary μSR techniques at $B = 2T$ (muon precession period $3.5ns$) before the PDC assembly is inserted into the solenoid. To measure the misalignment and make the required corrections and check the result could require

substantial beam time, a reasonable estimate for a couple of iterations is 8 days on M13 at $p = 29.6 MeV/c$ at $100\mu A$.

15. A misalignment $\theta_{PDC,B}$ between the PDC assembly and the magnet axis will also distort the Michel spectrum. The Michel spectrum is independent of azimuthal angle ϕ, but such a misalignment $\theta_{PDC,B} \neq 0$ will introduce a ϕ dependence into the measured spectrum. With total statistics of 10^8 muon decays this artificial ϕ asymmetry can be measured to an angular accuracy of $0.1mrad$ and corrective adjustments will then be made. Shifts of Michel parameters because of a $0.1mrad$ misalignment are less than 10^{-5}. Again a measurement of the misalignment, making the required corrections and checking the result could require substantial beam time, a reasonable estimate for a couple of iterations is 8 days on M13 at $p = 29.6MeV/c$ at $100\mu A$.

16. A temporal instability of the spectrometer magnetic field was discussed in section 3 where the errors listed were explained. Monitoring and operational procedures will maintain the stability of the superconducting magnet during the time intervals required.

17. The magnetic field will be mapped to better than 2 Gauss(10^{-4}). Magnetic field distortions at this level will not distort the Michel spectrum significantly. The magnet will be shimmed if problems are found during the mapping.

18. Muon depolarization is possible in solid films which can be formed on the surface of the stopping target. In [24] the thickness of such a solid film on the surface of PC anode wires was measured after an accumulated charge $\approx 5C/cm$ which corresponds to more than 10^{12} detected particles per $1cm$ of sense wire. The mixture CF_4/ISO (80/20) was used as a drift gas. The thickness of the film was 20 Å. E614 will not detect more than 10^9 particles per sense wire. The number of muons which will stop in a film much thinner than 20 Å will be very small and thus a negligible influence on muon polarization. It is mentioned in many publications that CF_4/ISO gas mixture does not interact chemically with aluminum. The drift gas could permeate into pores and structure disturbances of the aluminum target foil which can lead to muon depolarization in these mixtures, this effect is also negligible.

19. The effect of jitter and shifts in the time zero used to convert drift chamber times to distances was discussed in section 7.4.3. It was determined that the influence of t_0 jitter will be negligible while a shift of $\approx 1ns$ will result in shifts on the Michel parameters of less than $\pm 5 \times 10^{-5}$.

20. The geometrical acceptance of the E614 detector has been studied in section 7.4. It was determined that the acceptance is unity and uniform within the range $0.3 < x < 1$ and $0.3 < \cos\theta < 1$ at the level better than 1 part in 10^4. A simple reconstruction routine failed for some of the geometrically accepted events to find a fit thus reducing the detector "acceptance". These reconstruction losses were primarily at the low energy end and/or at the extremes of the angular range. For these studies no assumption was made about the PDC efficiency. The effects of inefficiency are expected to be small because the detector has an abundance of planes. A sophisticated reconstruction routine will be developed to attempt to recover those events that do not have continuous high quality tracks. The excellent geometrical acceptance of the E614 detector simplifies the understanding of any losses to that of understanding of

physical effects such as energy loss, multiple scattering, etc. all of which will be included in the Monte Carlo and thus will have a negligible effect on the Michel parameter extraction.

There are several technical reasons why individual wires in the PDC's may have low efficiency. There are 26 planes through which the positron track passes (if no annihilation or other violent loss occurs, $\leq 10^{-5}$) and since far fewer points than this will be required to fit the positron helix modest inefficiencies can be tolerated and still result in an over-determination of the helix.

Inefficiencies may result for several reasons related to the passage of the incoming μ through the upstream chambers. The first problem arises because the energy deposited by a muon in a PDC cell can be $5 \div 20$ times larger than by a positron. This can result in a saturation of the preamps and hence - to a long recovery time. Tests using VTX preamps [25] (which have a gain of $1mV/fC$, a dynamic range of $400mV$ and a saturation output voltage of $1V$) made during the PDC test runs showed that the total gain (wire+preamp) was about $10mV/1e$. This means that even for a very efficient gas the muon will not saturate these preamps (about 60e for the 4mm gap). The second problem arises from the possibility of mistaking a muon hit for that of a decay positron that is going upstream. In offline analysis the introduction of a $500ns$ wait time after the muon arrival before any positron hits are analyzed will lower the probability of making this mistake by a factor of ≈ 20. The third problem arises because of the long dead time ($> 20\mu s$) of a sense wire due to the slow dissipation of the ion cloud around the hit sense wire. The dead zone along the sense wire is about $0.5mm$. The influence of this effect on track reconstruction has been estimated to be similar in magnitude to what was found above for inefficient wires.

A full analysis of the effect of inefficient wires, the $500ns$ wait time and ion cloud dissipation will be made using GEANT for muon track simulation, EGS4 for positron tracking and GARFIELD for PDC cell simulations. The equality of ρ measured in the backward direction with that for the forward direction for an unpolarized muon sample will provide the relative efficiency of the upstream/downstream PDC assembly. This measurement will take about 30 days at $150\mu A$.

21. The calibration of the detector will be contained within the measured Michel spectrum. It was demonstrated in section 7.4.4 using the *slide* fitting technique that the energy calibration of the Michel spectrum can be fit to provide an energy calibration with an accuracy of $\pm 2keV$. Conservatively assuming that this can provide an accuracy of $\pm 10keV$ results in the values of systematic errors for this factor in table 2.

22. The errors estimated for the response function contribution to the Michel parameters was calculated in section 7.4.4

In conclusion, we list final estimates for all of the above systematic and statistical errors:

$$\sigma(\rho) = [\pm 5(stat) \pm 9.2(syst)] \cdot 10^{-5}$$

$$\sigma(P_\mu \xi) = [\pm 10(stat) \pm 10(syst)] \cdot 10^{-5}$$

$$\sigma(\delta) = [\pm 8(stat) \pm 9.5(syst)] \cdot 10^{-5}$$