PAUL SCHERRER INSTITUT

Memorandum

Date: 22 Mar 2002

From: T. Prokscha
Phone: 42 75
Room: WLGA / B15
E-mail: Thomas.Prokscha@psi.ch

To: LEM group

cc:

Energy loss of μ^+ and p in the C-foil of the LEM TD, Run12 (Run2001 preliminary)

In run 12 (autumn 1999) a C-foil with a nominal thickness of 2.2 μg/cm^2 was used in the trigger detector (TD) of the LEM apparatus. The runs 2064 – 2095 had the purpose to determine the energy loss ΔE of protons and μ^+ simultaneously by measuring the time-of-flight (TOF) between TD and the MCP2 detector at the end of the LEM beam line. The measurements were performed with different HV settings at the moderator between 2.5 kV and 20 kV. The runs 2064 – 2079 used a s-N_2 moderator whereas the runs 2080 – 2095 used s-Ar and HV's below 7.5 kV. For the latter, severe problems with the DAQ system led to several crashes. I did not use them for the present analysis. The L3 and RA were set to 0 kV, thus allowing to use — besides the muonium (Mu) and hydrogen (H) TOF peak — the μ^+ and p peak (and H^- if observable) as well to determine the energy loss in the foil.

The drift distance $d_{TD-MCP2}$ from the C-foil of the trigger detector to MCP2 is not exactly known. Its nominal value is 1164 mm. However, we can use the TOF measurements at different HV settings to determine $d_{TD-MCP2}$ consistently. The method is the following:

1. Determine the time zero t_0 for the TOF measurement:

   $$t_0 = t_{PP} - t_{FE} - t_c,$$

   where t_{PP} is the position of the prompt γ peak, t_{FE} is the TOF of the foil electrons from the C-foil to MCP3 and can be determined from the time difference of the two prompt peaks in the μ^+ decay spectra, and t_c is the TOF of a particle with $v = c$ from TD to MCP2. For Run12 I obtain

   $$t_0 = 316 - 13.5 - 3.9 = 298.6.$$

2. Determine the peak positions t_P of the μ^+ , Mu, p and H (H^-) peaks by fitting a gaussian to the TOF peaks.
3. Calculate the mean TOF t_{TOF}:

   $$t_{TOF} = t_P - t_0.$$

4. Choose a length $d_{TD-MCP2}$ and calculate the energy of the neutral particles (Mu and H). This can be done using the PAW macro tof_td[1].

[1] Enter tof_td -h at PAW prompt for online help

5. We have now the energy of particles at the exit of the C-foil. Use tof_td to calculate the TOF for μ^+ and p (H^-).
6. Repeat 4. and 5. for different $d_{TD-MCP2}$ (see Appendix for an example).
7. For the correct drift $d_{TD-MCP2}$ the measured t_{TOF} for the charged particles must agree with the calculated t_{TOF} from steps 4. and 5.
8. Repeat the procedure for the different HV settings.

This analysis yields $d_{TD-MCP2}$ = 1157 mm instead of 1164 mm. The energy losses for $d_{TD-MCP2}$ = 1157 mm are summarized in Fig. 1 and in Tab. 1. This method should work as well to determine the

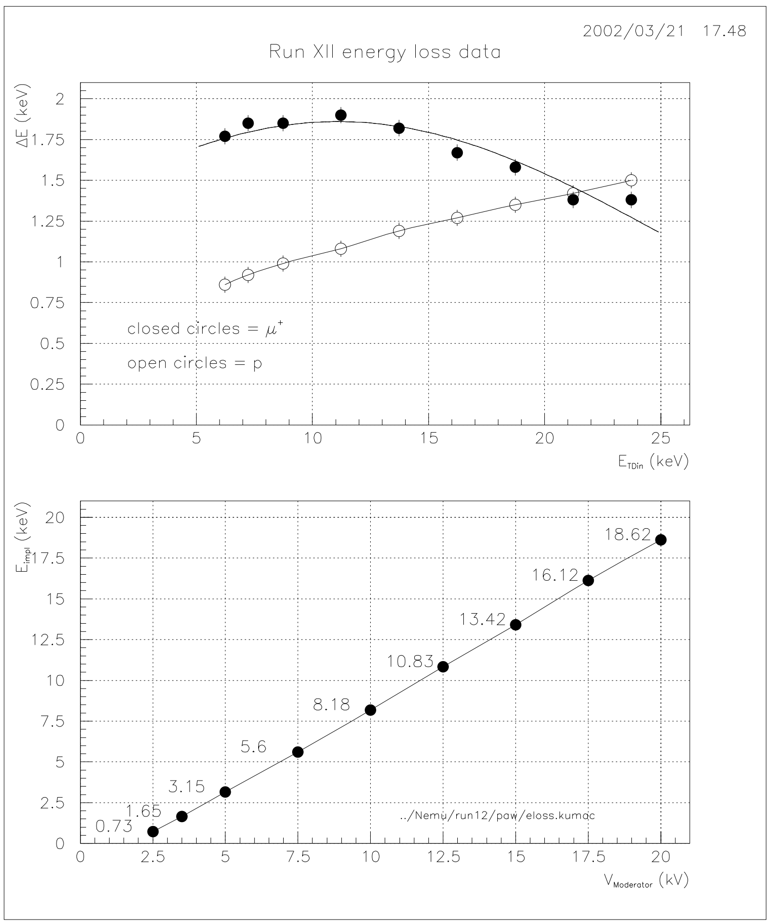

Figure 1: Top: energy loss of μ^+ and p in a 2.2 μg/cm^2 C-foil, Run12 data, $d_{TD-MCP2}$ =1157 mm. The solid line are guides to the eye. Bottom: μ^+ implantation energies at sample (V=0 kV).

energy losses for Run2001, where we had a C-foil with a nominal thickness of 2.2 μg/cm^2, but the energy loss is about 1 keV less than for Run12. We can start do this offline with protons generated by the QMS, and measure for completeness μ^+ and p simultaneously in April, when Run2002 will have been started.

$V_{Moderator}$ [kV]	E_{C-foil} [keV]	E_{Sample} [keV]	$\Delta E(\mu^+)$ [keV]	$\Delta E(p)$ [keV]
2.5	6.23	0.73	1.77	0.86
3.5	7.23	1.65	1.85	0.92
5.0	8.73	3.15	1.85	0.99
7.5	11.23	5.60	1.90	1.08
10.0	13.73	8.18	1.82	1.19
12.5	16.23	10.83	1.67	1.27
15.0	18.73	13.42	1.58	1.35
17.5	21.23	16.12	1.38	1.42
20.0	23.73	18.62	1.38	1.50

Table 1: Energy loss ΔE for μ^+ and p in the 2.2 μg/cm^2 C-foil, Run12 data. Shown are also the μ^+ energies E_{C-foil} and E_{Sample} when impinging on the foil and the sample ($V_{Sample} = 0$), respectively.

Appendix A: Analysis of TOF spectra

The TOF spectra for 12.5 kV settings of μ^+ and p are shown in Fig. 2. The muon spectra were generated by cutting on the decay positrons and the M3S1 TOF to get rid of a large background peak in the TOF distribution. The energy of the neutral particles was calculated for various drift distances $d_{TD-MCP2}$. Taking these energies the TOF for the charged particles was calculated using the PAW macro tof_td that takes into account the acceleration/deceleration in the trigger detector. The front plate of the MCP2 detector was at zero potential (for Run2001,it was set to negative potential) thus introducing no additional acceleration for the charged particles. Table 2 summarizes the analysis for the 12.5 kV settings with different $d_{TD-MCP2}$.

particle	t_{TOF} [ns]		1164 mm	1159 mm	1157 mm	1154 mm	1149 mm
Mu	233.1	$\Longrightarrow E_{out} =$	14.74 keV	14.62 keV	14.56 keV	14.48 keV	14.36 keV
			$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$
μ^+	266.1		265.6 ns	265.9 ns	266.1 ns	266.4 ns	266.7 ns
H	683.6	$\Longrightarrow E_{out} =$	15.14 keV	15.01 keV	14.96 keV	14.88 keV	14.76 keV
			$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$
p	779.1		777.8 ns	778.7 ns	779.1 ns	779.7 ns	780.7 ns

Table 2: Energy E_{out} at the exit of the C-foil of neutral particles for various $d_{TD-MCP2}$, 12.5 kV settings. The TOF for the charged particles is calculated according to E_{out}. For $d_{TD-MCP2}$ =1157 mm the calculated t_{TOF} of μ^+ and p agrees with the measured TOF.

Assuming that the distance between TD and MCP2 did not change in Run2001 the energy losses as shown in Tab. 3 are obtained from the measured Run2001 Mu peak positions.

$V_{Moderator}$ [kV]	E_{C-foil} [keV]	E_{Sample} [keV]	$\Delta E(\mu^+)$ [keV]
10.0	13.73	9.21	0.79
12.0	15.73	11.30	0.70
15.0	18.73	14.43	0.57
18.0	21.73	17.48	0.52
20.0	23.73	19.58	0.42

Table 3: Energy loss ΔE for μ^+ for the first 2.2 μg/cm^2 C-foil in Run2001, assuming $d_{TD-MCP2}$ = 1157 mm. Shown are also the μ^+ energies E_{C-foil} and E_{Sample} when impinging on the foil and the sample ($V_{Sample} = 0$), respectively.

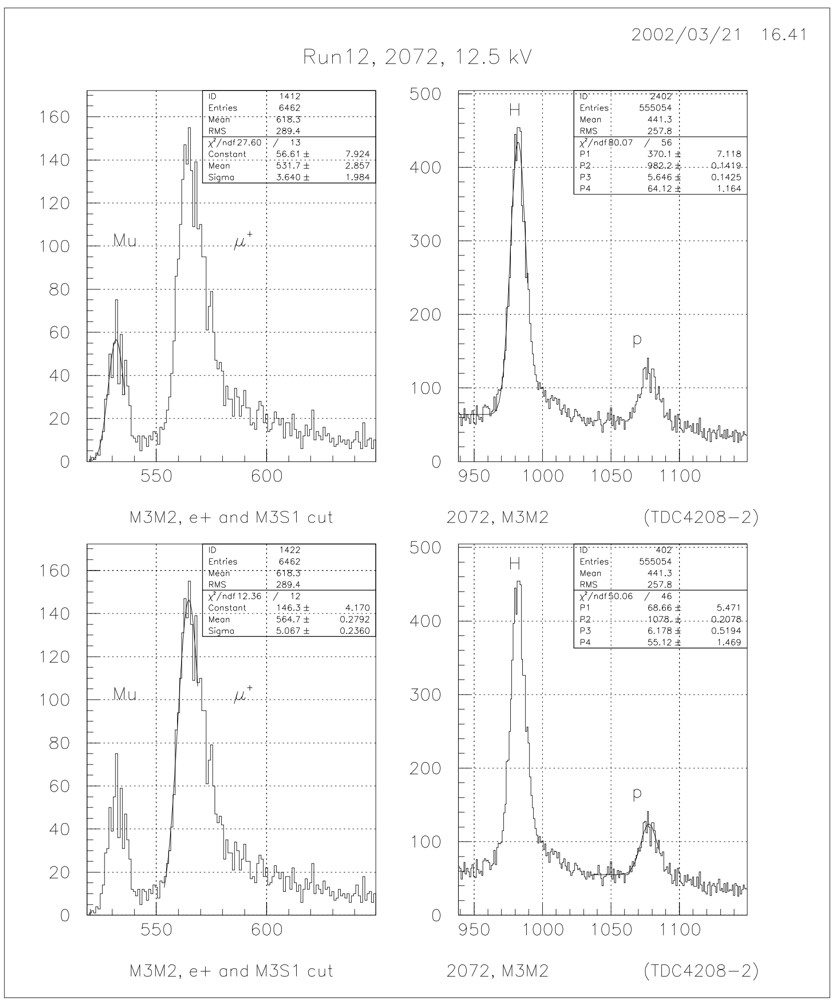

Figure 2: The TOF spectra of μ^+ , Mu, p and H for 12.5 kV settings. The solid lines represent gaussian fits to the TOF peaks. The time zero t_0 is at channel 298.6, 1 ns/ch.

Appendix B: Calculation of the TOF through TD up to MCP2

The PAW macro tof_td calculates the time-of-flight (TOF) for the drift $d_{TD-MCP2}$ from the C-foil to MCP2 for a particle with energy E_{out} at the exit of the C-foil. Particle type, $d_{TD-MCP2}$ and E_{out} are input parameters of the macro. The electric potentials V_C, V_F and V_R (at C-foil, front and rear "triangles") are set to -3.73, -3.54 and -3.95 kV, respectively. The drift lengths $d_1 - d_5$ (see Fig. 3) on the beam axis are taken from the technical drawings. For the charged particles the acceleration in the TD is calculated according to particle mass, the potentials V_C, V_F, V_R and the drift distances $d_1 - d_5$. The non-relativistic equations of motion are for the separate drift lenghts:

$$d_1 = \frac{1}{2}a_1 t_1^2 + v_1 t_1 \qquad v_1 = \sqrt{\frac{2E_1}{m}}c \qquad \Delta V_1 = (V_C - V_F) \qquad a_1 = \frac{e}{m}\frac{\Delta V_1}{d_1}c^2 \tag{1}$$

$$d_2 = v_2 t_2 \qquad v_2 = \sqrt{\frac{2E_2}{m}}c \qquad E_2 = E_1 + \text{sign}(e)\Delta V_1 \qquad a_2 = 0 \tag{2}$$

$$d_3 = \frac{1}{2}a_3 t_3^2 + v_3 t_3 \qquad v_3 = v_2 \qquad \Delta V_3 = (V_F - V_R) \qquad a_3 = \frac{e}{m}\frac{\Delta V_3}{d_3}c^2 \tag{3}$$

$$d_4 = v_4 t_4 \qquad v_4 = \sqrt{\frac{2E_4}{m}}c \qquad E_4 = E_2 + \text{sign}(e)\Delta V_3 \qquad a_4 = 0 \tag{4}$$

$$d_5 = \frac{1}{2}a_5 t_5^2 + v_5 t_5 \qquad v_5 = v_4 \qquad \Delta V_5 = (V_R - 0) \qquad a_5 = \frac{e}{m}\frac{\Delta V_5}{d_5}c^2. \tag{5}$$

Here, the mass m is given in eV. The a_i, v_i and t_i denote the acceleration, initial velocity and TOF in the 5 sections of the TD, E_1 is the energy at the exit of the C-foil. The t_i can be written as

$$t_i = \frac{d_i}{v_i} \qquad \text{for } a_i = 0 \tag{6}$$

$$t_i = -\frac{v_i}{a_i} + \text{sign}(a_i)\sqrt{(\frac{v_i}{a_i})^2 + \frac{2d_i}{a_i}}, \tag{7}$$

and the total TOF t_{TD} through the trigger detector is finally given by the sum

$$t_{TD} = \sum_{i=1}^{i=5} t_i. \tag{8}$$

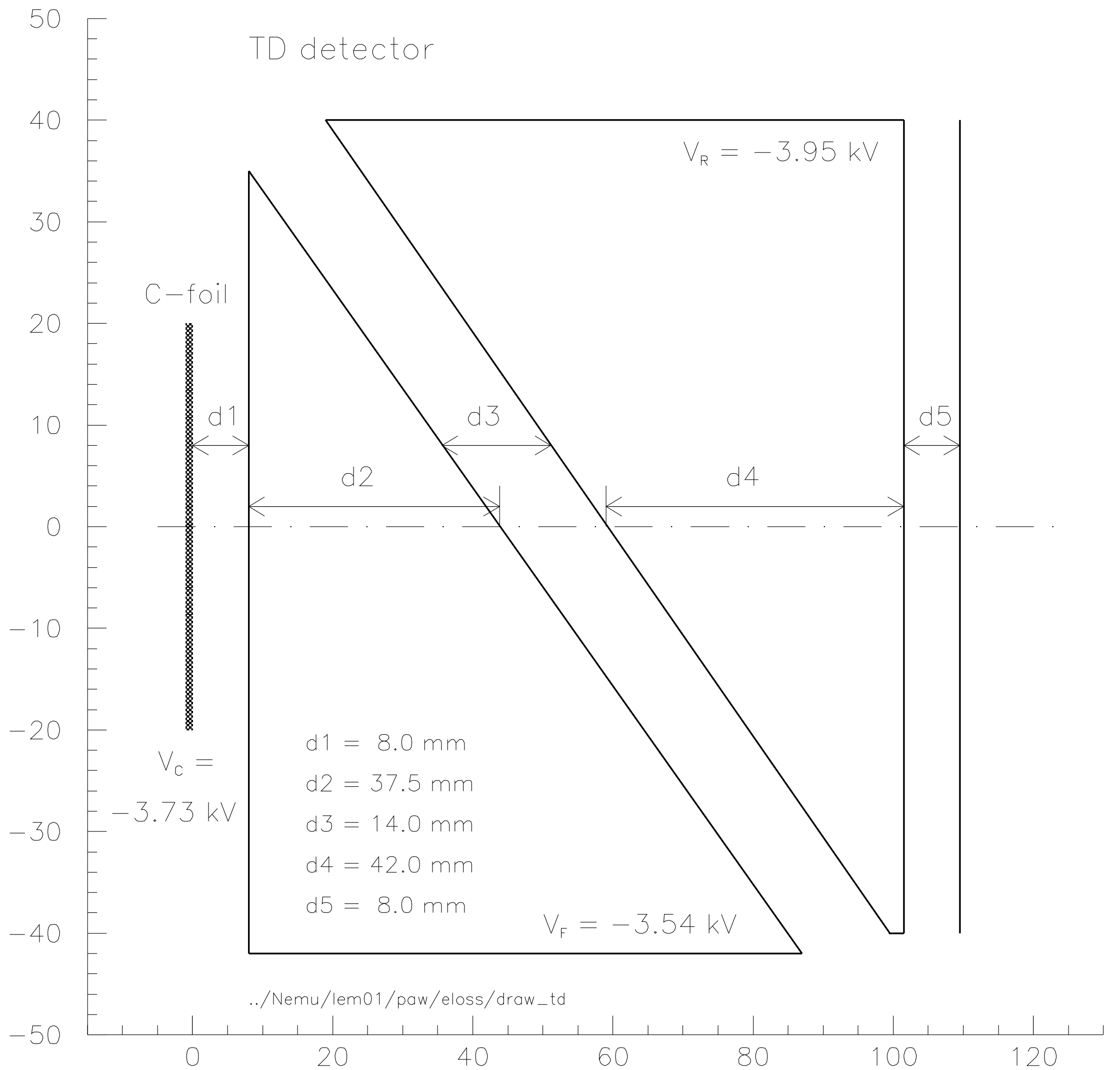

Figure 3: Trigger Detector.