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Time Of Flight for MTest

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A time of flight system was installed in 2014-5 to provide particle ID for the second MINERvA testbeam effort in MTest. It was later modified slightly to be a permanent facility for subsequent MTest users. The device provides excellent separation of protons from lighter particles up to about 8 GeV. This document covers the physical description of the device and shows some early results from its use. A simple description of the beamline is in Appendix A.

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I. Overview

The MTest beam, particularly at lower energies like 1GeV, will be mostly electrons (even when the lead sheet, MT4PB, is in the beam) but the hadrons also in the beam will have some non-negligible p/π ratio. Electrons are easily tagged with the Chernkov system (try N_2 at 2psia), but to tell protons from pions, we have a time of flight (ToF) system. The ToF system consists of a START station in MT3-4 located at the old MT5SC location, a STOP station in MT6.1 and readout via NIM/CAMAC electronics was installed in MTest.

The START station (Figure 1) was constructed for an earlier edition of a Time-of-Flight facility for the MTest beamline, and was rebuilt for this rendition. This station contains 4 fast PMT tubes all looking at a single 20mm thick[1] piece of polyvinyltolune based scintillator (Bicron 400). The scintillator is approximately an octagon of 10cm side-to-opposing-side. It is located just upstream of the vertical bend magnet MT5VT1, and is supported with Unistrut that is bolted to the floor, to ease removal and replacement. The PMTs are 2 inch diameter “fast” (1.3ns with a jitter of about 0.3ns), see below) Ampex model PM2106 PMTs. Probably.

The START station is located at $(x, y) = (30266.92, 32111.74)$ m in the survey group’s FSCS coordinate system.

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[1] Perhaps. There was some claim that it is actually more like 5mm thick.

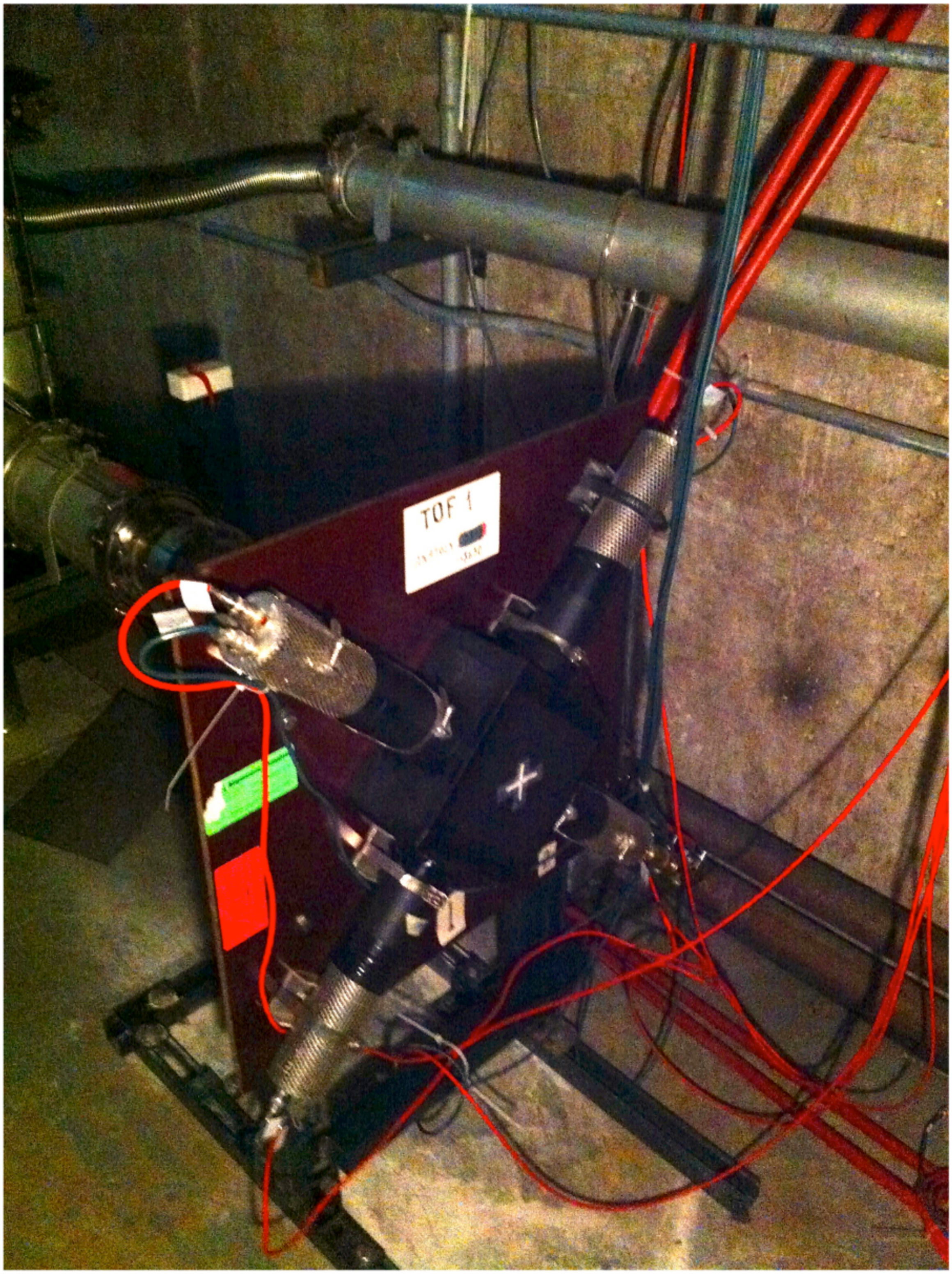

Figure 1. The installed START station in MT3-4.

The STOP station (Figure 2) is located in MT6.1, downstream of the MT6.1 hut and upstream of the muon absorbers. This station contains 4 fast PMT tubes, all looking at a single 12.5mm thick piece of Eljin Technology EJ-200 polyvinyltoluene based scintillator. The scintillator is a 173 x 173mm square with the corners cut to make an octagon. As with the START station, the PMTs face are connected to the scintillator through the corners of the octagon. The active area is designed to to completely cover the span of the “Fenker” MWPC tracker MT6PWC2 which is about 10.5 inches upstream of the STOP station. The PMTs are Hamamatsu model R1828-01 units; also 2 inch diameters and using E2979-500 bases. Their spec’d rise time is 1.3ns, with a jitter of about 0.3ns.

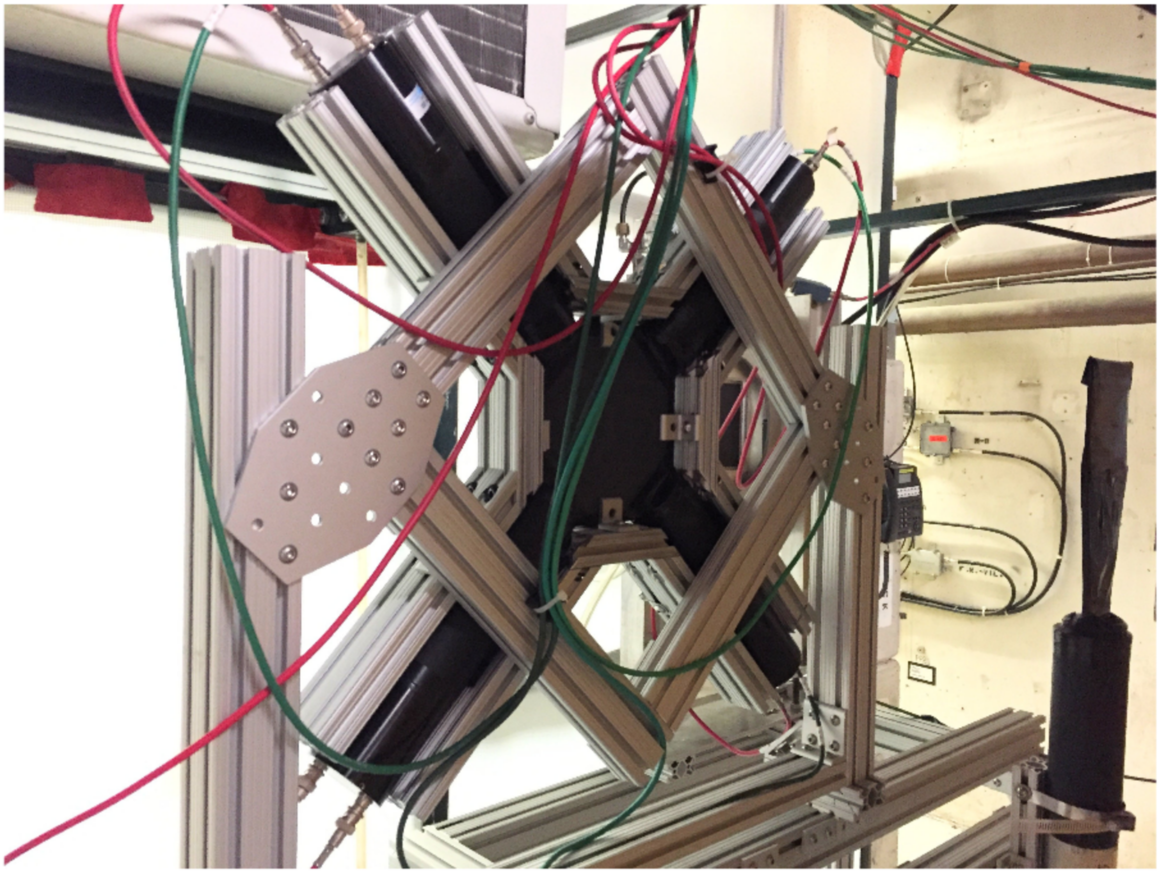

Figure 2. The STOP station, installed in MT6.1. The view is from the east side, downstream of the device; MT6PWC2, which is seen by the beam directly before the STOP station, can be glimpsed through the supporting frame of the STOP station between PMTs 1 (bottom right) and 2 (top left).

The STOP station is located at (x, y) =(30249.37, 32193.66) m in the survey group's FSCS coordinate system. This puts it 83.78m from the START station; additional throw arm from curvature in the beamline due to the sweeper magnets is negligible.

The rise time of the PMTs is useful for setting the delay of the Constant Fraction Discriminators (CFDs); the measurement desired for that use is the time from when the pulse reaches 20% of its maximum amplitude to the time when it reaches 100% of its maximum amplitude. The 100% point is difficult to find easily with a scope, but the 20% – 80% rise time can be found almost automatically. The average reading on 50 samples was 1.57ns on the START station PMTs (with a scatter of 0.26ns). Scaling the numbers by (100–20%)/(80–20%) and subtracting 0.7ns from the rise time (but not the scatter) gives the values listed above.

In the START station, PMTs are numbered 1–4 in a counter clockwise direction starting from the 2nd quadrant as one faces the device in the beamwise (i.e. from upstream to downstream) direction. In the STOP station the PMTs are numbered 1–4 in a clockwise direction starting from the 3rd quadrant as one faces the device in the beamwise direction.

II. HV settings, discriminator thresholds, cable loss

The PMTs are run at moderately high HV values – the typical charge delivered for a good pulse is on the order of 100pC. As of 14 June 2018, the settings are as given in Table 1. Users are advised to take some data and determine if one PMT is failing to provide data noticeable more frequently than the others; the voltage on that tube might be reasonably increased 20V.

PMT1	2260V
PMT2	2000V
PMT3	1900V
PMT4	2240V
PMT5	1640V
PMT6	1620V
PMT7	1660V
PMT8	1620V

Table 1. HV settings as of 14 Jun 2018.

The advantage of a large pulse is that one may run relatively long cables from the START station, which is in an Oxygen Deficiency Hazard zone to MT6.1 where a CFD may be easily accessed. These RG-58 cables are 82.4 ±0.1m in length, and have an attenuation of pulse voltage of 0.101 dB/m. Their index of refraction is 1.50. Accordingly, discriminator thresholds of 96mV are applied to the START counter pulses and thresholds of 250mV are applied to the STOP counter pulses.

With these settings, the START counter will fire more than 99% of the time with a 6GeV beam, which is mostly electrons. The STOP counter also has a high efficiency – over 97% of time, all 4 counters will fire. In 120GeV protons, the scattering loss is low – one should be able to retain 99% of the beam if the voltages are set correctly.

III. CFD, delays and TDC

The CFDs used are ORTEC model 934 NIM units. They have 4 settings. The first, the threshold that an incoming pulse must be for the CFD to produce an output, was discussed in Section II. The second, the “Z” setting, defines the voltage (near zero) where the upward crossing of the “M” signal will produce an output from the unit. In principle, this value can be adjusted to provide optimal time resolution. It has not however been adjusted so far and is near 0V. The third, the width of the output pulse, is set to 25ns. That number is not critical of course; the information is all in the rising edge and the TDC will recognize any pulse of more than 10ns. The final setting is the amount of delay, as selected by the length of cable plugged into the 2 “DELAY” inputs of the CFDs. With regard for what is known of the pulse rise times, 1ns cables are used for the delay.

The STOP station, by virtue of being so much closer to the counting house than the START station, produces pulses for input to the Time to Digital Converter (TDC) much sooner than the START station. A 200ns cable delay box, borrowed from Burak Bilki of the University of Iowa (Iowa City) is placed after the CFD. Logical fanout units (LRS429) and fixed value discriminators are used to revive NIM pulses that have been tuckered out by long cable runs. Figure 3 shows the overall cable/CFD layout; Section V contains detailed cable layout information.

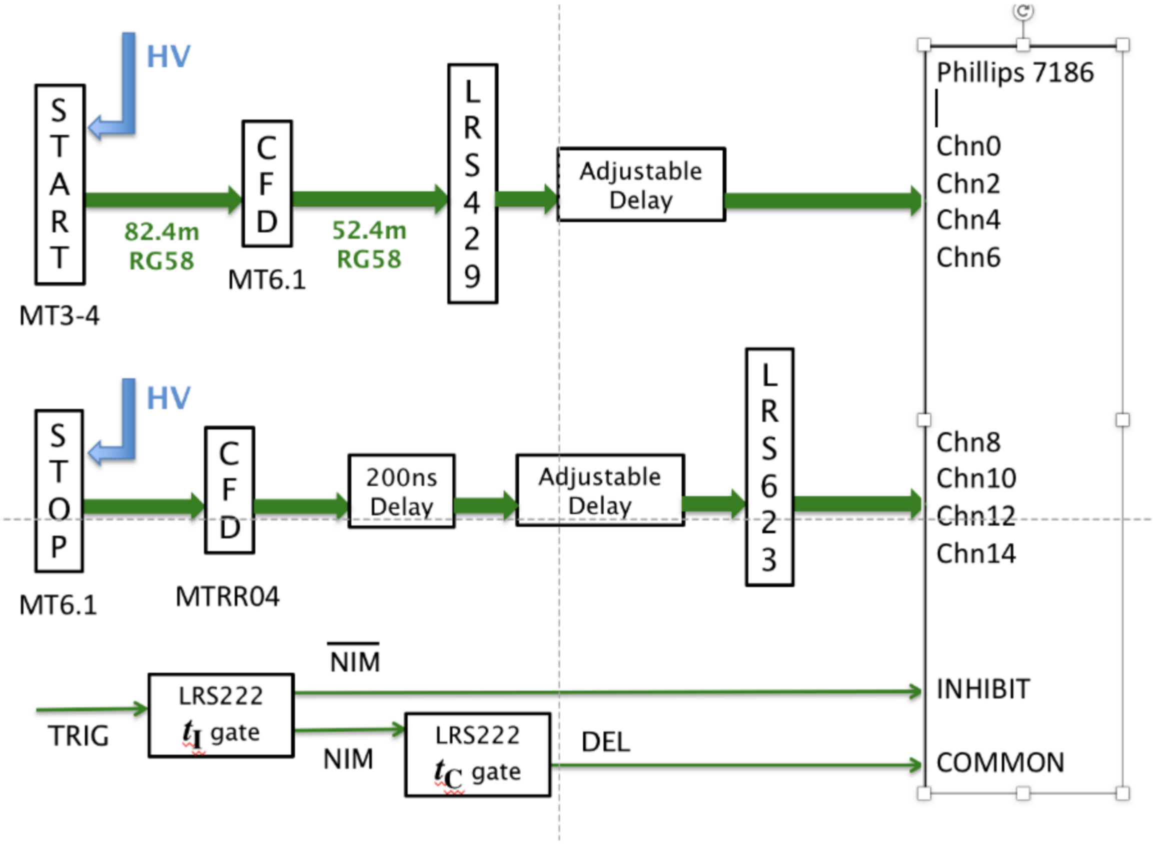

Figure 3. Schematic electronics layout.

To understand Figure 3 one must realize that, unlike situations involving the police, STOP does not actually mean STOP. COMMON means STOP; STOP is the same as START. As a result, one cannot use the appearance of a START & STOP coincidence as any kind of a trigger element. On the contrary, the whole design is based around the supposition that you already have a trigger signal and will use the appearance of that signal to know when to take a measurement.

The other thing to know is that Chn1 (counting from 0) on the module has some sort of failure and produces plausible yet incorrect values. A second module is around here somewhere, although it is still in the box it was shipped to us in.

The Phillips 7186 TDC is run with a 100ns range and in common stop mode. This means that each of the channels will start their internal stopwatches (so to speak) when a signal appears at the corresponding input; all the stopwatches are stopped at the same time, when a pulse appears at the COMMON input. In this way, the behavior of each individual PMT can be easily picked out of the data stream, and different algorithms to determine the time of flight can be used for different cases where one or more PMTs fail to see light, or produce light at spurious times.

To prevent measurement outside the interesting times, the INHIBIT signal is raised for a bit over 100ns as a result of a TRIG input which indicates the presence of a particle to be measured in the beamline. The MWPC input trigger, made from `MT6SC1 && MT6SC2 && MT6SC3 && SPILL` can easily be used to form TRIG. The times for which the INHIBIT is lowered, and the time of the appearance of the COMMON stop, t_I and t_C, are 130ns and 106ns respectively.

When timing-in the system for a different experiment, keep several things in mind:

1. LeCroy 365 logic units have been known to fire on 60Hz noise, at least in this crate. Fortunately, this doesn't usually mess with the rest of the system.
2. Be sure to leave t_I at 130ns and t_C at 106ns. Although the Phillips 7186 documentation does not exactly say so, $t_I - t_C$ has to greater than 10ns, at least on the 100ns range.
3. You must adjust the delays, and any appropriate external trigger delay, so that all 8 Chn inputs *always* appear at the front of the TDC well within 100ns before the COMMON is presented to the TDC. As you are (probably) working with low energy beams, it is useful to examine the inputs as presented to the TDC with high persistence settings on an oscilloscope, so that you will see different traces for different velocity particles.
4. You might be expecting that the slower particles will appear later in time as seen on the STOP counters. You might be wrong. You are probably going to trigger the oscilloscope on TRIG, INHIBIT or COMMON. These signals appear when the particle goes into MT6 and will have a relatively fixed time relationship vs. STOP, and the pulses that will appear at a different time relative to TRIG are the START pulses, not the STOP pulses.
5. Be careful with the switches on the adjustable delays. They must be flipped with vigor and determination, or they will be left in some intermediate position that will create impedance mismatches and reflections in the delay box. It is prudent to watch the pulse shape going into the TDC directly on an oscilloscope to verify that there are no reflections in the adjustable delay box.
6. There are small variations in the lengths of the cables for each module and in offsets for each channel. As a result, readings for even particles at $\beta = 1$ will appear at times that differ by a few ns in

each of the 8 channels. It is usually convenient to take some 120GeV proton data to find the corresponding offsets that need to be subtracted from each channel.

Because the trigger is formed using fixed value discriminators, the spread in the distribution of the readings for any given channel will be larger than the spread in the distributions of START-STOP values. "START – STOP values?" you say. "Not STOP – START values?". Right. The quantity returned by the TDC is the time from the input at the Chn input to the time of the COMMON input. As a result, a later input to Chn produces a smaller output value; the stopwatches in the TDC run backwards in time.

Section IIX is an example of a minimal readout code in python for use with a Wiener CC-USB CAMAC crate controller. The basic approach is to poll for LAM, which is raised whenever COMMON occurs in the absence of an INHIBIT.

The TDC provides for fast CLEARs and sparsification; these are not used in this application.

We do not know really the behavior of the TDC when 2 pulses are placed in the same input within the same 100ns window.

VI. Performance

The resolution of the TDC itself was measured by feeding the same square NIM pulse into both a Chn and the COMMON input; the average resolution for all channel but Chn1 was 18.4ps. This was measured in the middle of the range (i.e. with about 45ns between the Chn and the COMMON). The digitization uncertainty is (25ps/bit) over $\sqrt{12}$, so there is something on the order of an additional 16.9ps in the electronics that generated the test pulses. The advertised linearity of the TDC is "Less than 4 counts over 10% to 90% of range".

By using the sum of all 4 PMTs, averaged, for each of the 2 stations, jitter due to transit time variation caused by beam spread over the active surface of the stations is removed.

In the MINERvA testbeam II version of the system, the resolution in measured time of flight was on the order of 200ps minimum. However! This width is derived from fitting the central core of the Δt distribution for 4GeV electrons. There will be tails to the distribution, and the observed width will depend not just on the system's time resolution, but also upon the momentum bite of the collimators MT4CH1 and MT4CH2.

Users need to be aware of the subsequent bucket problem. Beam is delivered to the switchyard and then to MTest in buckets that are 18.831ns apart. If a particle appears delayed by 18.831ns, the user needs to figure out if this is because of the mass of the particle or because the particle is from a subsequent bucket. For certain specific beam momenta, it is in principle impossible to tell a proton from a subsequent bucket pion. Similarly, a situation where one can not tell a proton from a subsequent bucket electron occurs, but the user will probably be clever enough to trigger on the Cherenkov counter to suppress or select electrons.

These evil momenta are, in principle, 1.016, 1.183, 1.388, 1.727 and 2.484 GeV. There is another evil momentum at infinite GeV, and an infinity of evil momenta below 1 GeV. In practice, only the listed ones can occur within plausible operating conditions of the MTest beam. In practice, the fraction of particle-containing buckets with is a particle in a subsequent bucket is not large. These occupancies can change with running conditions. Therefore, the user may well want to measure this occupancy, as well as monitoring for multiple particles in the interesting bucket.

A spreadsheet is available to do the Time-of-Flight calculation with appropriate values for this system already initialized. The spreadsheet also deals with the subsequent-bucket problem.

VII. Material Assay

START Station:

Two titanium alloy windows, of thickness 0.002 inches and X_0 of 3.70cm; that is 2.7×10^{-3} radiation lengths.

Air gap in MT5: 115cm and X_0 of 30050cm; that is $\sim 3.8 \times 10^{-3}$ radiation lengths.

5mm of polyvinyltoluene based scintillator, with X_0 of 42.6cm; that is 11.7×10^{-3} radiation lengths.

Some light-tight black paper, no assay available. If it is 2 x 0.3mm of cellulose equivalent, it is 0.7×10^{-3} radiation lengths.

STOP Station:

12.5mm polyvinyltoluene based scintillator, with X_0 of 42.6cm; that is 29.3×10^{-3} radiation lengths.

Some light-tight black paper and light tight tape, no assay available. If it is 2 x 0.3mm, it is 0.7×10^{-3} radiation lengths.

VIII. Cable plant

From the START station, there are 5 signal and 5 HV lines (1 spare each) that are run to the relay rack in MT6.1 just downstream of the Cherenkov counter.

The HV lines, labeled “Upstream ToF PMT# HV” run into the patch panel labeled “To MS4 RR7” and thence to relay rack RR7 in MS4 where the HV is supplied from. The lines are in sockets 7-10 on that patch panel, which are connected to cables labeled SHV TB-07 through SHV TB-10 going to the HV supply in the bottom of that rack. On the HV supply, channels 1-4 are used.

The signal cables, labeled “Upstream ToF PMT# SIG”, run into an ORTEC 934 Constant Fraction Discriminator in the far right side of the NIM bin in this relay rack. The output of the CFD, labeled “MT3-4 ToF DSIG#” runs over the huts of MT6.1 and through the cable tray penetration into MT6.2 where they feed to the 2A patch panel. At the 2A patch panel, the signals are fed into the plugs 2A-11 to 2A-14 whence they are fed to the corresponding patch panel in the MTest counting house and thence to MTRR04.

From the STOP station, there are 4 signal and 4 HV lines that are run to the patch panel in the MT6.1B hut. The signals go to sockets 6.1-ER-01 through 6.1-ER-04; HV lines go to sockets 6.1-ER-001 through 6.1-ER-004. All these lines appear in the corresponding patch panel in the MTest counting house.

The STOP station HV is, along with the NIM bin, in MTRR04. Channel 1 of the Zener divider circuit (a.k.a. the cow) sets the HV for PMT1, and similarly for channel and PMT2. Channel 3 is nonfunctional, so channels 4 & 5 drive PMTs 3 & 4.

Cabling in the NIM crate: The user’s trigger (which might perhaps be just the MWPC trigger of `MT6SC1 && MT6SC2 && MT6SC3 && SPILL` is fed into the upper gate of the LeCroy 222 gate generator in slot 8 of the NIM crate[2]. The STOP counter’s CFDs are in slot 9, and slot 12 has the gate generators to produce the INHIBIT and COMMON stop signals. The Phillips model 7186 TDC is in the CAMAC crate to the immediate right of this NIM crate.

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[2] I count the slots from 1, starting left and going right. Slot 12 is the far right hand slot.

IIX. Simple sample code

Here is an example Python script to illustrate the required CAMAC commands to read out the Phillips 7186 TDC. It is to be executed on that machine in FTBF which is connected to the MTRR05 CAMAC crate via a Wiener CC-USB interface, and uses the library developed as the `ccusb` package. So you had better `setup ccusb` first!

The basic approach is to poll for LAM, which is raised whenever COMMON occurs in the absence of an INHIBIT.

```
#! /bin/env python
#
# Filename : daq.py
# Created  : 12-Oct-2012
# Author   : Geoff Savage
# Hacked Up: Leo Bellantoni
#
#
# Readout Phillips 7186.
#
#
# Is crate on?
# lsusb | grep CC
# Bus 001 Device 008: ID 16dc:0001 Wiener, Plein & Baus CC
# To run:
# setup ccusb
# ./<filename>.py
#
import time, sys, math
from CamacSystem import *
from CcusbCrate import *
from Phillips7186 import *


s = CamacSystem()
c = CcusbCrate('CC0208')
s.addCrate(c)
s.open()

tdcModule = Phillips7186(c,1)
tdcModule.addAllChannels()
c.addModule(tdcModule)
ps_per_bit = 25

s.configure()

s.z()  #Initialize, clear crate, remove inhibit
s.c()
s.i(0) #I think this was also done at s.open()

tdcModule.clearModule()          #Clear module; disables LAM, peds, thresholds
#print 'control register =', tdcModule.readControlRegister()

starting = time.time()
event  = 0
Nevent = 100000
while event < Nevent:
      tdcModule.enableAcq()      #Clears tdcModule's data, re-enables LAM.
      lam = tdcModule.testLam()
```

```
        while lam < 1:
                lam = tdcModule.testLam()
                #print 'lam =', lam
                #time.sleep(0.1)
                #print 'chan %d = %d ps (%d counts)' % (i, data*ps_per_bit, data)

        PMT1 = tdcModule.readChannel(0) & 0xFFF
        PMT2 = tdcModule.readChannel(2) & 0xFFF
        PMT3 = tdcModule.readChannel(4) & 0xFFF
        PMT4 = tdcModule.readChannel(6) & 0xFFF
        PMT5 = tdcModule.readChannel(8) & 0xFFF
        PMT6 = tdcModule.readChannel(10) & 0xFFF
        PMT7 = tdcModule.readChannel(12) & 0xFFF
        PMT8 = tdcModule.readChannel(13) & 0xFFF


        print event, PMT1,PMT2,PMT3,PMT4, PMT5,PMT6,PMT7,PMT8
        event += 1

s.close()
```

Appendix: Description of the beamline

The MTest secondary beamline is sketched in a very simplified form in Figure 4; a table of information about the ACNET devices that monitor and control the beam is in Table 2.

120GeV protons are delivered from the Main Injector (MI) to a ½” x ½” x 12” Al target in MT4. The MI is not operated exactly at 120GeV; it runs at 119.7GeV, and this number is known to within “closer to 100 MeV”[3]. The bunch spacing at 120GeV is a bit shorter than it is at injection; the correct spacing is 18.831nsec. Also in M01 is a SEM, a calibrated device to measure beam intensity. At a distance of 1.22m upstream of the target, MT4PWC monitors the position of the beam from the MI. This proportional wire chamber has a 2mm wire pitch in both x and y; the position of the beam is determined in real time by fitting a normal distribution to the accumulated hit profiles.

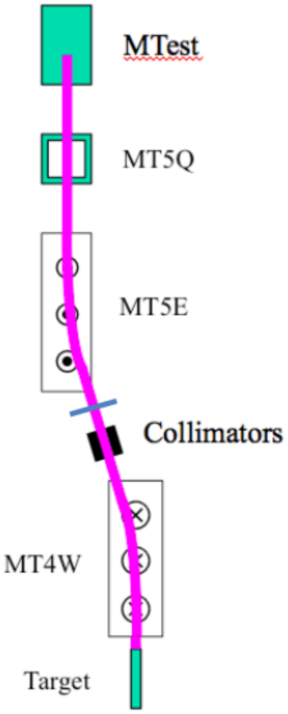

Figure 4. Simplified sketch of the MTest secondary beamline.

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[3] Ioanis Kourbanis, private communication, 27 May 2015

Device Name	**Logged at**	**Comment**
F:MW1SEM	Swyd e36+200	Calibrated measurement of primary beam intensity
F:PMT4HM F:PMT4HS	FixTr e34+0	Last beam monitor before target; HM is the fitted horizontal mean from fit to Gaussian, HS is fitted sigma
F:PMT4VM F:PMT4VS	FixTr e34+0	Last beam monitor before target; VM is vertical mean from fit to Gaussian, VS is sigma
F_MT4WL	Sets Client	Power for MT4W (Low). The readback current is F:MT4WL, which is logged at FixTr e35+0
F:MT4WH	FixTr 1min	Hall probe for MT4W
F:MT4Q2H	FixTr 1min	The other MT4W Hall probe
F:MT4CH1 F:MT4CH2 F:MT4CV1 F:MT4CV2	FixTr 1min	Collimators
F|MT4PB	FixTr 1min	Pb sheet
F_MT5EL	Sets Client	Power for MT5E (Low). The readback current is F:MT5EL, which is logged at FixTr e35+0
F:MT5EH	FixTr 1min	Hall probe for MT5E
F:MT4Q6H	FixTr 1min	The other MT5E Hall probe
F:MT4HT F:MT4HT2	FixTr e35+0	Horizontal trim magnets
F:MT6SC1 F:MT6SC2	Swyd e36+200	Trigger scintillators in MT6.1
F:MT6SC3	Swyd e36+200	Trigger scintillator in MT6.2

Table 1. List of ACNET elements important for this study.

Shortly after the target, the beam enters a low quality vacuum line which reduces multiple scattering to enable operation at secondary energies as low as 1 GeV.

The first element after the target which is important for users is the "momentum selection" dipole magnet, MT4W[4]. This is actually 2 magnets of the type EPB in series. The bend angle is nominally 16mrad. The transfer constant $\int B_y \cdot d\ell / L$ is 1.031 T/kA and saturation begins to set in at about a kA of current. During "pion" mode running, currents are well below this limit. When transporting 120 GeV proton beam into MTest, saturation can be an effect. MT4W has 2 current supplies; a low-current supply for lower momenta beams and a high-current supply for 120 GeV proton running. The magnets are run DC; they are not ramped off to save power in the off-spill.

Iron core magnets are subject to hysteresis; the actual value of $\int B \cdot d\ell$ will depend on both the current passing through the magnet's coil and the recent history of the magnet's operation. The cure for this problem is to place a Hall effect probe near the ends of the magnets, outside but near the vacuum of the beamline to measure the magnitude of the magnetic field in some specified direction at some specific point in the magnet's field. The direction and relative strengths of the magnetic field has a complicated structure, but as long as the magnetic permeability of all the materials in the structure is a scalar rather than a tensor quantity, $\int B \cdot d\ell$ is proportional to the magnetic field measured at the Hall probe. The technique then is to regulate the actual current to obtained the desired Hall probe reading.

The scatter in a set of readings taken in Feb 2016 with 3 GeV beam indicates either that there is an unidentified uncertainty in each reading, or that there an instability in the beam energy at this level. These shifts are about ±12.5 MeV, which is not significant for most users.

The probes will saturate. When the secondary beam energy is over 30 GeV or so, or when primary 120GeV beam is run through the beamline, the field at the probe goes over the 3000Gauss maximum range of the devices. When this happens, the meter will continue to read, producing a low value most of the time but periodically producing a reading on the order of 10^2 Gauss. After each of these "hiccups", the device will fail to read out for some minutes. The frequency, amplitude and perhaps dead time of these hiccups has some as of yet uninvestigated dependence on how strong the field actually is.

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[4] In the name "MT4W", MT4 is of course the location of the device; W means that if the power supply is turned on with the "normal polarity", the magnet will bend a positively charged beam to the west. As the beam direction is northerly, that means the magnetic field points into the earth.

The Hall probe in MT4W is the primary means of determining the beam momentum. The key equation is:

$$\int B \cdot d\ell \propto (MT4WH + O_W) = SP_{BEAM} \,. \tag{1}$$

The bending strength of the magnet is proportional to the field strength measured at one specific point in the field of the magnet by the Hall probe; the probe has a DC bias offset, O_W, given in Gauss[5]. The bending strength of the magnet is also proportional to the momentum of particles in the beam following the beamline design centerline. The scaling factor, S was found to be 57.92 Gauss/GeV by Chuck Brown and Rick Coleman[6], with a 2% uncertainty.

After MT4W, there are two collimators in the vertical direction and two collimators in the horizontal direction; the latter, in conjunction with MT4W, are intended to perform momentum selection.

Following the collimators, there is an air gap in the vacuum line of about 115cm length. In this section there is the upstream station for the ToF system, and a lead sheet (MT4PB) which is ¼" thick. For "electron" running, users will typically remove the Pb sheet and require a hit in the Cherenkov counter (when run at 2psia of N_2) to trigger. For "hadron" running, users will typically insert the Pb sheet and vetoed on the Cherenkov counter in the trigger. At lower beam momenta, even the hadron running conditions will have a very large electron content, so the use of the Chernkov to tag hadrons is important.

Then there is a chain of 5 EPB magnets in series form the "sweeper magnet" MT5E. The first function of this magnet system is to remove neutral or off-shell particles that have been produced upstream of MT5E. The second function is to help cancel the dispersion of the beam. If a single west-bending magnet is used with a collimator, particles appearing on the east side of the beam will have a substantially higher momentum than those on the west side of the beam. This variation of P_{BEAM} across the aperture is called dispersion, and MT5E reduces it.

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[5] A similar offset, O_E exists for the Hall probe in MT5E but it is not large and has little impact on the analyses presented here.

[6] Private communication "Notes on MTest Energy Scale and Hall Probes", R. Coleman, 3 Oct 2014. That note actually gives a value of 57.937; but 57.92 is what is actually in use in MCR. The difference is much less than the precision of the number, and it is probably true that the 57.92 number is the result of an undocumented reanalysis of the data of Brown and Coleman. 57.92 is used throughout this study.

The bend angle between the MT5W magnets is nominally 8.9mrad. There are 2 Hall probes, MT5EH and MT4Q6H, in this magnet system.

The last beam element of importance here is MT5Q1, a quadruple magnet after MT5E. If the horizontal collimators are left open, MT5Q1 appears to be the momentum-slice defining aperture. The aperture is 3 inches.

For nearly all MTest users, a trigger is formed with the scintillation counters MT6SC1, MT6SC2 and MT6SC3. These counters are 10 x 10cm; the first of them is in the upstream side of MT6.1 and the last is at the upstream side of MT6.2. These counters would then form the effective limiting aperture.

The beamline also has 5 trim magnets. In principle, F:MT4HT and F:MT5HT2 could affect the beam momentum.