Version 2.0
July 20, 2006

Developing Large-area Psec Timing: The MCP Return-Path Problem and a Proposed Solution

Timothy Credo, Henry Frisch, Harold Sanders, and Fukun Tang
Enrico Fermi Institute, University of Chicago
Karen Byrum and Gary Drake
Argonne National Laboratory

Abstract

One limiting factor in the speed of a $2'' \times 2''$ MCP is the inductance in the path that charge has to flow from the anode back to the source of the charge, the micro-channel plate output. In this note we propose a solution to the MCP problem that uses a grid in the anode plane and a small MCP-OUT physical gap to provide a fast capacitative return path. We provide the physical dimensions and a specification of the anode we would like implemented in an MCP optimized for timing, hopefully the next MCP of the four we have ordered from Burle/Photonis.

1 Introduction

Our goal is to build a Time-of-flight (TOF) detector that has resolution of a picosecond, which corresponds to a distance of 300 microns at the speed of light. The goal of a psec is set by the application in High Energy Physics for particle identification by velocity measurement [1]; high-resolution applications also exist in many fields, including radiology and nuclear physics.

The basic design principles we have chosen are described in Reference [2]. The fundamental principle is that the characteristic lengths describing the signal path, whether it be light or electrical current, have to have variations small compared to 300 microns (1 psec). This has implications on the source of the light, the light collection, the path of the charge in the optical detector, and the electrical path of charge collection and digitization.

We use Cherenkov light as the source, as it is intrinsically fast, without any characteristic decay time like in a scintillator. The Cherenkov light goes directly onto the phototube cathode so that variations in the optical path of the light are small in this design, as there are no bounces. We plan to use a microchannel plate with small pore size (10 microns or less) as the amplifier- these devices have transit times spreads in the tens of picoseconds, and with the large number of Cherenkov photons generated in our geometry the statistical fluctuation on the leading edge is reduced by $\sqrt{N}$.

Lastly, we have designed a solution to the problem of differential time spread on the anode collection by using equal-time transition lines to collect the charge to the input to the amplifier [2]. This is necessary to retain the time resolution while limiting the number of electronics channels in a large system.

We have used a Monte Carlo (MC) simulation of the process up to the photocathode, to show that the jitter in the arrival times of the MCP cascade electrons at the anode are less than a picosecond (first results give 0.86 ps), assuming a single-photon transit-time spread (TTS) for the MCP of 25 psec.

This note is organized as follows. Section 2 describes the problem of the long (and hence inductive and slow) return path for charge emitted at MCP-OUT, arriving at the anode, and completing the circuit back to the potential of MCP-OUT Section 3 describes what we would like to see in the next MCP of our series of four that we have ordered (the changes could be spread over several tubes). These tubes would require a custom anode and other changes to the structure.

The individual elements of the solution are described in turn: Subsection 3.1 states the request for a reduced MCP-OUT to anode gap. Subsection 3.2 describes the custom anode pixel structure. Subsection 3.3 describes the equal-time transmission charge collection. The anode grid and capacitive coupling return path are described in Subsection 3.4. Subsection 3.5 describes the method of physically mounting the psec TDC chip we are developing, which goes directly on the back of the anode.

Section 4 gives details and specs for the anode. We see this as the 'hard part', in that it requires a custom anode integrated directly into the tube (and not just tacked on the back as we have been discussing for the tube we have already received.) Section 5 describes preliminary results of simulating the grid and capacitive return scheme. The electrical circuit and coupling to the TDC are described in Section 6

Lastly, to aid in the discussion of what the next steps should be, Appendix I summarizes our requests for the features of an optimized MCP-PMT for picosecond timing.

2 The Current Return-Path Problem

The TTS of a small-diameter MCP can be this small. However, for the large area MCP modules we will need to build a large area array, the anode and the return path back to MCP-OUT have physical dimensions of an inch (when at the center of the MCP), much larger than 300 microns (1 psec). In existing $2'' \times 2''$ MCP modules the path that current has to follow goes across the anode, up the side of the MCP, and back across the MCP-OUT plane to the pores that are the source of the charge. Such a path, several inches long, will have a large inductance. Considering the generation of the signal and its return path as a circuit, the inductance dominates the rise-time of the signal, and hence the time resolution.

Figure 1 shows a photograph of the 'Mark-0' Burle 85011 $2'' \times 2''$ MCP-PMT, the first MCP-PMT of 4 we have ordered that we have received from Burle/Photonis. This tube has 64 outputs in an 8-by-8 array, each with its own pin.

Figure 2 is a sketch of a side view of the Burle 85011 $2'' \times 2''$ MCP-PMT, giving typical voltage drops across the device (from Paul Hink [3]).

The return-path problem is shown schematically in Figure 3. The current return path is outlined in red. For a large-diameter MCP, the path is long, and the path impedance will fatally degrade the signal time characteristics.

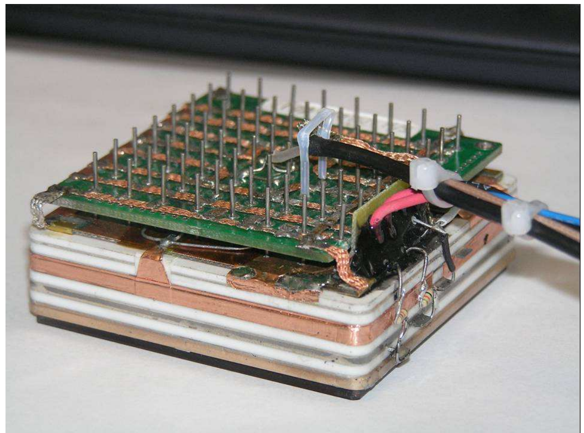

Figure 1: A photograph of the 'Mark-0' Burle 85011 2″ × 2″ MCP-PMT.

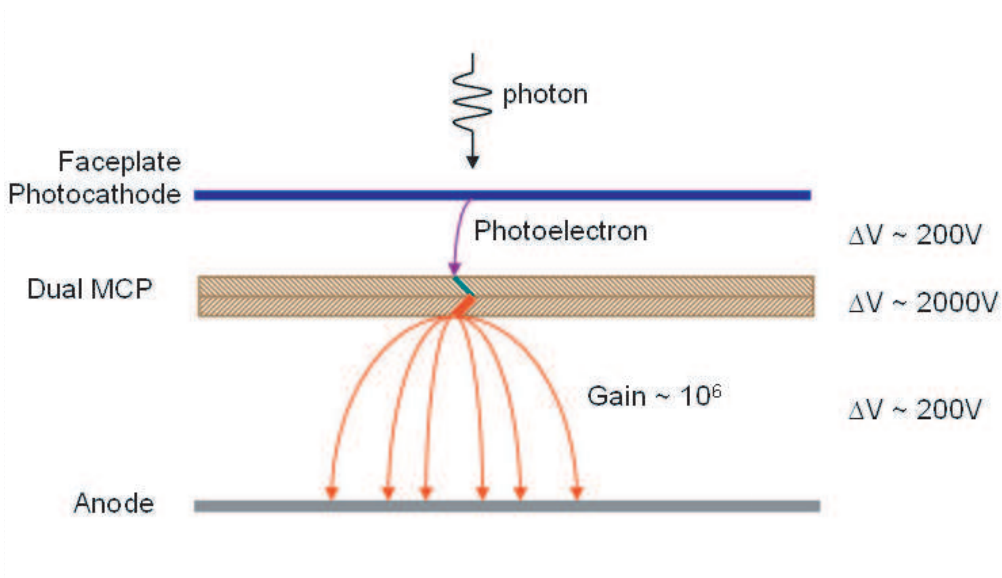

Figure 2: A sketch of a side view of the Burle 85011 2″ × 2″ MCP-PMT, giving typical voltage drops across the device (from Paul Hink [3]).

3 A Proposed Solution: Bypassing the Long Return Path

The anode and the return path back to MCP-OUT is the part of the circuit that has physical dimensions much larger than 300 microns (1 psec). The anode and return must therefore be specially designed so that the electrical properties preserve the advantages of the fast timing of the Cherenkov light, and the small pores and short electron shower path lengths in the MCP. We have chosen the features listed in the subsections below to preserve the arrival time precision to 300 μm even given the scale of inches of the anode and the return path:

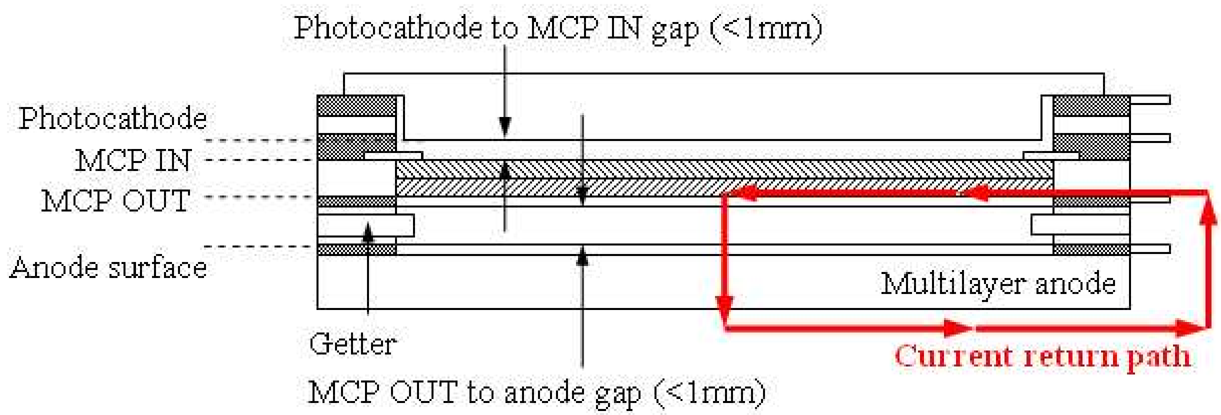

Figure 3: A sketch of a side view of the MCP-PMT, showing the long (several hundred psec) return path of the current on the surfaces of the anode and MCP-OUT.

3.1 MCP-OUT to Anode Gap

A reduced distance between MCP-OUT and the anode plane (see Figure 3) to create a capacitive return path back to MCP-OUT.

3.2 Custom Anode with Pads Organized into Pixels

A multi-anode structure of 8-by-8 pads (this is a standard option from Burle), organized into 4 readout channels[1].

3.3 Equal-Time Transmission Line Charge Collection

Equal-time transmission lines from each of the 16 anode pads in a quadrant connect to a common collection point. The transmission lines are constructed with two traces on separate layers. In each transmission line the conductor that connects to the pad is called T, and its twin, the conductor that connects to 'ground', is called $\bar{T}$ (see Figure 6). The 16 transmission lines all are 'OR'ed together; there is consequently an impedance mismatch which causes ringing on the lines, but since we are interested only in the leading edge, and the rate of a given pixel is low, the ringing does not affect the timing.

3.4 Anode Grid and Capacitive Coupling Return Path

A grid structure in the anode plane that connects to the $\bar{T}$ side of each transmission line near the pad connected to its corresponding T. The grid capacitively couples to the anode and provides the AC return path. The grid is AC-coupled to the input to the TDC chip so that it can be held at some fraction of the potential of MCP-OUT [2] by a divider on the HV chain.

[1] Each channel is a quadrant of the anode, giving 4 $1'' \times 1''$ 'pixels per MCP module (see Figure 5).

[2] The default will be the same potential as MCP-OUT.

3.5 Sub-Psec TDC Anode-Mounted per Pixel

Each TDC chip, one per $1'' \times 1''$ pixel, is surface-mounted on the back of the anode. The input to the chip is differential , one side (S) being the OR of the pad side of the 16 transmission lines (the T lines) and the other ($\bar{S}$) the OR of the respective grid lines (the $\bar{T}$ lines). (See Figure 10).

4 Proposed Anode Construction

The anode is a multi-layer ceramic board. The layer structure and tabular description are shown in Figure 4.

Anode Board (B2588) Specifications (2)

Board Materials	FR4
Board Dimension	24.6 x 24.6 mm
Board Materials	FR4
Total Board Thickness	40 mils
Total Stack-up Layers	4
Copper Thickness Before Plating	1 oz. Copper
Trace Width/Gap Width	5 mils / 5 mils
Total Through Hole Vias	144
Through Hole Via Drill Size	10 mils
Total Buried Via (layer3-Layer4)	4
Buried Via Drill Size	10 mils

Figure 4: Left: The layers of the anode PC board. Right: A table of parameters for the construction of the first version of the anode prototype.

The layout of the top layer of the anode, which has the signal pads and the 'ground' grid of the anode, is shown in Figure 5. The grid is connected to the HV distribution string and is held at a voltage between ground and that of MCP-OUT ($\sim$ 200 Volts); it is AC-coupled to signal ground. The signal pads and signal ground are connected on internal layers to the input to the TDC chip.

5 Electrical Simulation

To test the idea of capacitively coupling the return back to MCP-OUT we have made a simple equivalent circuit, shown in Figure 7, so that we can simulate the behaviour. Input pulses are made with the detector simulation that starts with a relativistic particle traversing the window of the tube [2]. The detector simulation takes into account the Cherenkov radiation spectrum, absorption in the window, path length of the photons to the photocathode, the photo-cathode response, the transit-time spread of the MCP[3], and the footprint of the charge on the anode pads.

[3]The TTS is taken as a Gaussian for now. We would like to be able to fully simulate the MCP response in the future.

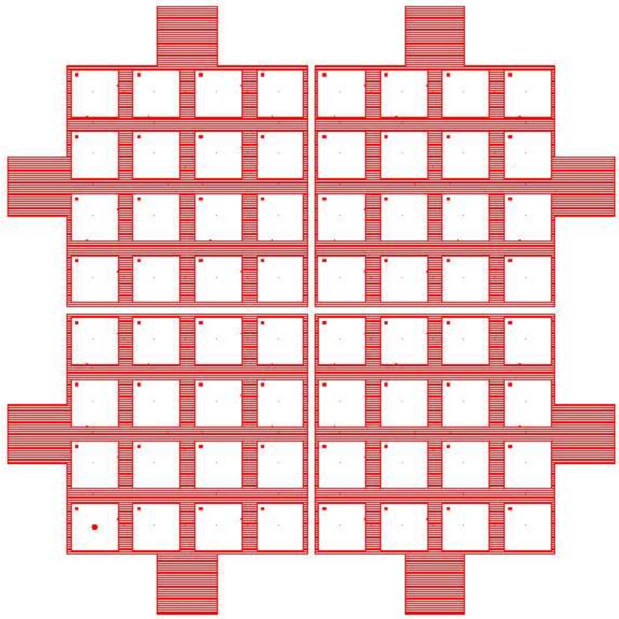

Figure 5: A 'head-on' view of the anode, showing the pads embedded in the grid structure. Each pad feeds the T side of a transmission line formed by a pair of traces on neighboring layers of the anode board; the $\bar{T}$ trace is directly underneath the T trace. The 16 transmission lines in each quadrant end at the signal (S) and its signal ground ($\bar{S}$). The grid has a large capacitance to MCP-OUT; it is this capacitance that shunts the inductive path and provides a fast AC return path.

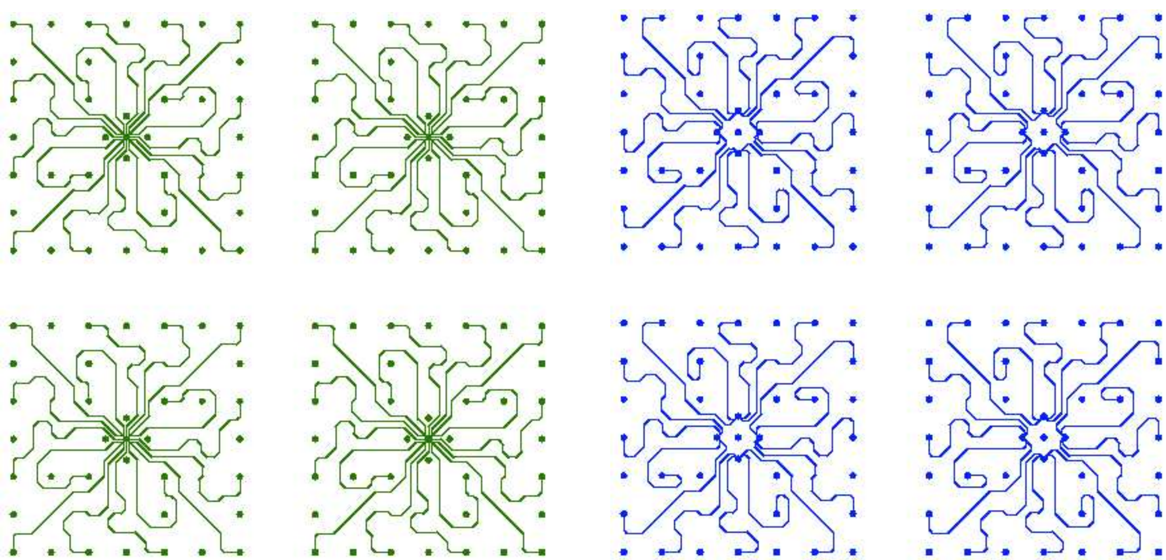

Figure 6: The layout of the equal-time transmission lines on two neighboring layers of the multi-layer anode. Each pad feeds the T side of a transmission line formed by a pair of traces on neighboring layers of the anode board; the $\bar{T}$ trace is directly underneath the T trace. The 16 transmission lines in each quadrant end at the signal (S) and its signal ground ($\bar{S}$).

6 Coupling to the TDC Chip and the Capacitive-Return Circuit

Because the input to the TDC chip is differential and the $\bar{T}$ line will be held at some potential between ground and the MCP-OUT potential, the T and $\bar{T}$ lines need to be AC-coupled into

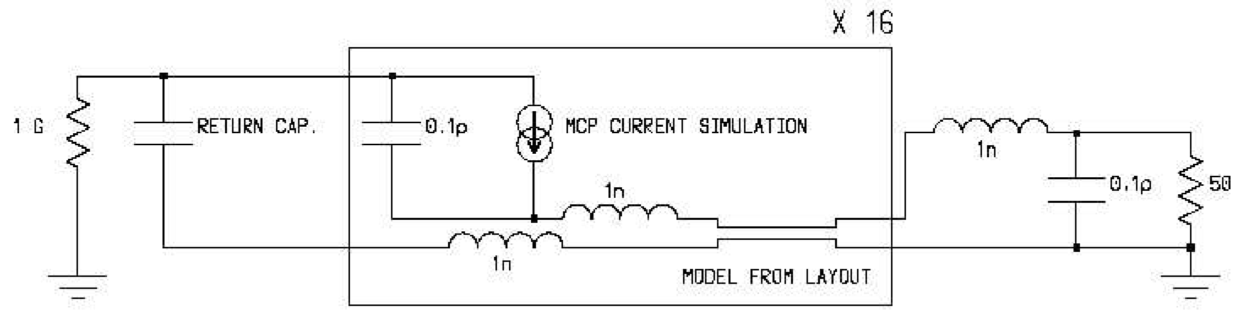

Figure 7: The schematic of the equivalent circuit for the return current path. This is the circuit used in the simulation.

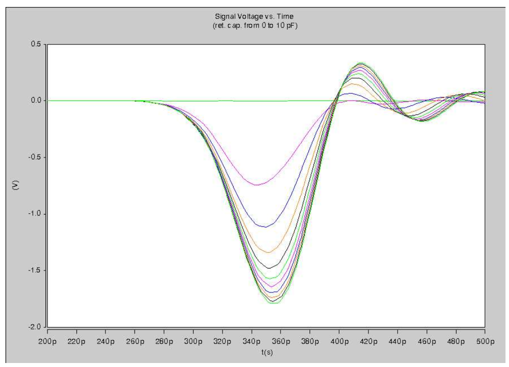

Figure 8: The simulated pulse output from the equivalent of Figure 7 as the capacitance between MCP-OUT and the grid is varied from 0 to 10 pf in 1 pf steps.

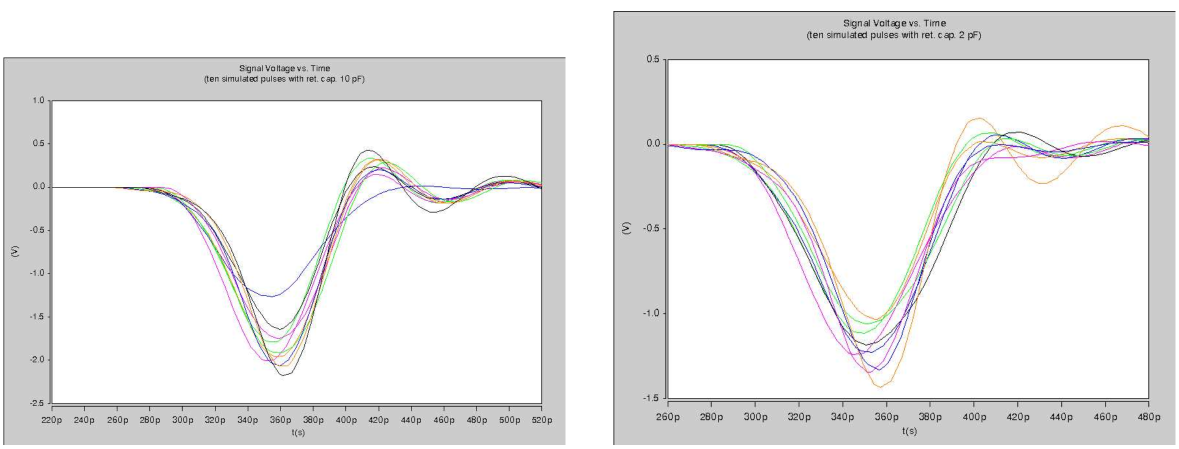

Figure 9: Left: The simulated output for 10 particles incident on the MCP-PMT window from the equivalent circuit of Figure 7 for a fixed grid to MCP-OUT capacitance of 10 pf. Right: The same for a grid to MCP-OUT capacitance of 2 pf

the chip. Figure 10 shows the scheme.

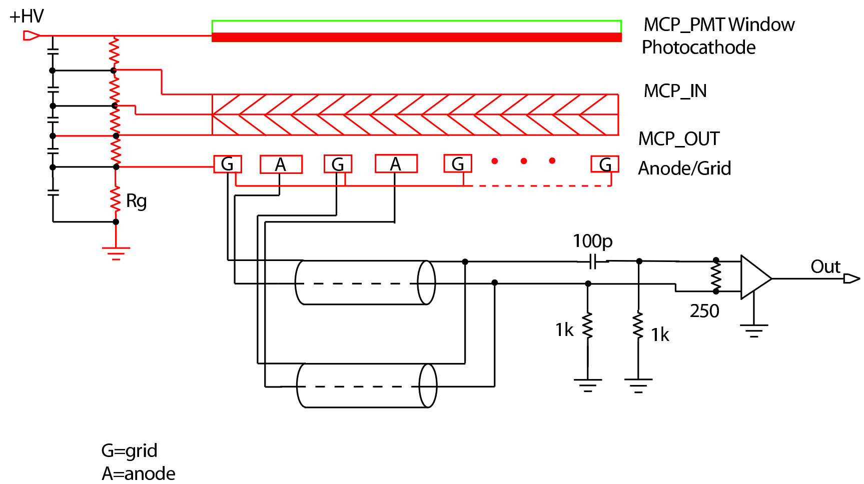

Figure 10: A description of the complete signal circuit showing the grid and its biasing network, the anode signal pads, and the transmission lines to the front-end electronics.

7 Acknowledgments

We thank Paul Hink, Pascal LaVoute, Paul Mitchell, Scott Moulzoff, and Jerry Vavra for discussions of the problem. We especially thank the Burle/Photonis group for the 'Mark-0' 85012 MCP-PMT modified by Paul Mitchell to investigate the effect of grounds on signal shape (this is the first of the 4 we have ordered).

8 Appendix I: Spec for the Mark-I Picosecond MCP-PMT Tube

The Picosecond MCP tubes would have 64 anode pads in a multilayer custom anode board, as described above. We envision making a series of these with improved timing, learning as we go.

At the Arlington workshop Paul Hink presented ways to speed up an MCP-PMT [3]. We discussed with Paul and Jerry Vavra what we would like, and agreed to write down a request.

Table 8 gives the specifications for an MCP with some of the features for optimization for speed, in particular the capacitive return-current path[4]

It's understood that not all these things are equally feasible or doable on a reasonable schedule; hence this is a draft, to be worked out mutually with Burle/Photonis. We hope that features that can't be done for MK-I could be done for a later tube in the series.

DRAFT MCP-PMT General Specifications (to be worked out)					
Characteristic	Importance	85012 Value	MkI Preferred	Min	Max
MCP-OUT-Anode Gap	5	5 mm	? mm	? mm	? mm
Pore size	5	25 μm	10 μm	—	10 μm
Tolerance on					
MCP-OUT-Anode Gap	5	μm	10% μm	- μm	- μm
PC-MCP-IN gap	3	? 6-7mm	6-7 mm	?	?
MCP-OUT plating	3	Ni	Au	—	—
MCP-IN pore doping	3	No	Yes	—	? —
MCP-OUT pore plating	3	No	Yes	—	? —
Photocathode Material	?	BiAlkali	MultiAlkali?		
Anode Specifications					
Anode Pad Size	5	?	?	?	?
Anode Grid Line Width	5	NA	?	?	?
Transmission Line Imped	5	NA	50 Ω	50 Ω	100 Ω

Table 1: Draft Specification for the next tube for testing (we call it the Mark-I Picosecond MCP-PMT). A custom anode is necessary, and so is assumed. Importance runs from 0 (less) to 5 (more). The entry 'MCP-IN pore doping' refers to Paul Hink's discussion of increasing the multiplication of the first few collisions by adding a low work-function surface to the input of the pores. The entry 'MCP-OUT pore plating' refers to Paul's mention of extending the metalization of MCP-OUT into the output side of the pores . The entry 'NA' means 'Not Applicable'. We are hoping we can work together on filling in this table to get a spec.

[4]We call this the 'Mark-I' design, just to give it a name. The one we have now we call 'Mark-0'.

References

[1] H. Frisch, *Visions of Experimental Particle Physics– Where Are We Going?*, Aspen Winter Conference, Aspen Co., Jan. 26, 2003 (http:hep.uchicago.edu: frisch)

[2] H. Frisch; http://indico.cern.ch/conferenceDisplay.py?confId=2846; T. Credo, H. Frisch, H. Sanders, R. Schroll, and F. Tang; *Picosecond Time-of-Flight Measurement for Colliders Using Cherenkov Light*; proceedings of the IEEE, Rome, Italy, Oct. 2004;

[3] P. Hink, *Burle Update* http://indico.cern.ch/conferenceDisplay.py?confId=2846