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Conceptual Design for a UV Laser-based Calibration System for the TOF Scintillators

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This document describes a conceptual design for a system to calibrate the TOF system. The primary emphasis is on timing and should be capable of achieving better than 100 ps resolution. Fifty picoseconds should be achievable at high light levels. The system should also be able to vary the amount of light in a determined way so that time-slewing corrections can be measured. The basic concept is to use 337 nm UV light from a nitrogen laser coupled to optical fibers to distribute the UV light to the center of the TOF scintillator bars.

1. Nitrogen laser

A laser is desirable since it has very good timing properties. It is a triggerable device that produces a short (2 ns, typical), intense burst of UV light. UV light is preferable to blue light since it excites the fluor just as a charged particle would. The resulting (and wave-shifted) light is isotropic and includes all the timing and geometric (save one) properties of the light produced by charged particles. The following table lists the important specifications for the laser and, as an example, the value of these specs for the Oriel laser used in the preliminary tests at Penn.

Specification	Oriel value	Comments
Pulse width	600 ps	Should be < few ns and stable
Pulse energy	100 μJ(10^{13} photons)	Amount of light
Beam size	1 mm x 2 mm	Determines lens aperture
Beam divergence	1 mrad x 2 mrad	
Pulse jitter	500 ps	Needs a timing reference
Max rep rate	50 Hz	

The laser will presumably be located on the First floor counting room so that it is accessible for maintenance. One problem that we noticed with the Oriel laser is that when the thyratron fires the laser, it generates a lot of RF noise so the laser should be in a shielded enclosure (probably required for safety anyway).

2. Long optical fiber

The laser light is carried from the first floor to the detector with an optical fiber. We have preliminarily selected a fiber with a 600 micron core, 30 micron thick cladding, and 25 micron thick polyimide coating (overall diameter = 710 microns). The attenuation of the fiber is approximately 200 db/km at 337 nm so that about 4% of the light captured by the fiber from the laser is transmitted to the detector. The pulse dispersion is negligible at 70 m.

It is desirable to fill the phase space of the fiber when matching the laser output to the fiber acceptance. The fiber has a numerical aperture of 0.22, which translates to an acceptance cone of half-angle about 13 degrees. Since the angular divergence of the laser is very small, the light should be coupled to the fiber with a focussing lens. Using the Oriel laser as an example, the lens should have an aperture of at least 2 mm and an ideal focal length of 4.5 mm. To keep attenuation small, the lens should be made of fused silica.

For convenience in handling, the 70 m fiber should have connectors at both ends. An inexpensive SMA connector should suffice.

3. The 1-216 coupler/splitter

After the 70 m fiber terminates on the detector, it must be fanned out to the 216 fibers that go to the individual scintillator bars. In the tests at Penn, this device was problematical. When we used a diffusive reflector as the coupling, the light uniformity to the 216 fibers should be very good but the amount of light was marginal. With a Tyvek reflector, we could achieve no better than about twice the average amount of light from a cosmic trigger after we took into account the attenuation from the 70 m fiber. We would prefer at least 20 times minimum for the reasons mentioned above. Better matching of the laser to the fiber could improve the total amount of light by perhaps a factor of 3-4. With a “direct” (i.e., the fibers were facing each other but not in direct contact) coupling, we could achieve 22 times the light from a cosmic trigger but uniformity of the coupling into the 216 fibers would be a concern.

The proposed solution is to take advantage of the fact that the focussing lens from the laser fills the phase space of the fiber. That, plus mixing in the fiber from the inevitable bending radii from the 70 m cable run, causes the light at the coupler/splitter to emerge uniformly in a cone of half-angle 13 degrees. We have chosen fibers with an OD of 125 microns for the 216 outputs of the splitter (see next section for details of these fibers). Assuming a packing fraction of 70%, the bundle of 216 fibers will have a diameter of 2.2 mm. If the separation of the 600 micron fiber and the face of the 125 micron fiber bundle is about 5mm, the light cone emerging from the 600 micron fiber just fills the 216 fiber output bundle. In practice, the separation will be adjustable (with screw threads) for uniformity and light ouptut.

4. Output 216 fiber bundle

In the preliminary design, we have chosen fused silica fibers with 100 micron core, 5 micron thick cladding, and 7.5 micron polyimide coating, for an overall OD of 125 microns. Since we want an isochronous system, all 216 fibers should have the same length and we specify this to ± 2mm. The length of the fibers is approximately 10 meters depending on exactly where on the detector the 1-216 splitter is located The first 5 meters of the fiber bundle should have a jacket for protection in the 30 degree slot. After emerging from the slot, the jacket terminates and the 216 fibers are loose for distribution to the scintillators.

5. Fiber mounted to the scintillator bar

For the fiber attached to the middle of the scintillator bar, we choose the same 100 micron core fiber as the splitter output. The 125 micron OD is small enough that it has no significant infringement on spatial tolerances and should not require a milled slot in the PMT housing. In principal, the amount of light entering the scintillator could depend on exactly how the fiber was oriented. In practice, this turned out not to be the case. Simply laying the fiber along the bar was adequate and the exact orientation did not appear to matter. This might be understood by the large angular divergence of the light emerging from the fiber. A Monte Carlo simulation indicated that the light enters (either directly or after 1-2 bounces off the Tyvek wrapping) within a few mm of the end of the fiber. In addition, the pulse shape from the UV-induced light might be different from that for particles. The UV is strongly absorbed and amounts to essentially a point source of light. By contrast, particles cause light emission from a line source. In practice, we found very little difference. The rise time of the UV light (5.15 ns, 10% - 90%) is somewhat smaller than that for cosmics (7.76 ns).

We envision that a fiber pigtail of about 10-20 cm be left for each bar.

6. Connector from bar pigtail to the splitter output fiber

This connector is a cost concern since standard industrial connectors (such as SMA) cost $30-50 each and we need 216 of them. The cheapest solution is to use a capillary tube ferrule connector. We tried a sample tube that had an 810 micron OD and 129 micron ID. It seems to function well as a coupler (i.e., holds the concentricity of the fibers to a few percent) but is extremely hard to use. It is hard to imagine inserting a 125 micron fiber into a 129 micron hole 216 times while standing inside the solenoid. Our preferred solution is to use a ferrule with a tapered opening to guide the fiber on insertion. The cost is not known at this time but should be affordable. An alternative should the tapered ferrule not work out is to design an insertion tool to guide the fiber into the tube. We have not yet explored an insertion tool.

7. Dressing the 216 fiber bundle on the inside of the solenoid

This bundle must accommodate the fact that we are using an isochronous system so that we must store the excess fiber length. The worst case is for the scintillator bar nearest the 30 degree slot where the 216 fiber bundle emerges. In this case, we must store about 5 meters of excess fiber. To solve this problem, we have experimented with a fiber “cable tray” consisting of a 2 inch wide strip of velcro. Velcro works by having an array of tiny plastic hooks on one strip that engage wooly loops of fiber on the mating strip. When an optical fiber is pressed below the plane of the hooks, the hooks are very effective at holding the fiber in place. Once the optical fiber is engaged by the hooks, the mating strip of velcro can be attached and removed without damaging (or even disturbing) the optical fibers. The velcro strip can come with an adhesive backing for attaching to the inner surface of the cryostat.

Since we know the exact geometry of the system, we envision dressing the 216 fibers into the velcro cable tray ahead of installation time in a clean and comfortable (compared to standing inside the solenoid) environment. At installation time, the jacket portion of the 216 fiber bundle is first dressing into the 30 degree slot and then the velcro cable tray is attached to the inner cylinder of the cryostat. Finally, each fiber must then be connected to the scintillator bar pigtail.

8. Prototype system

Before committing to production of a full system, we would like to purchase a prototype that would test the essential features of the system. We envision a prototype that would consist of:

- Focussing lens to couple laser to the long fiber
- Full length (approx. 70 meter) 600 micron core fiber, SMA connector on each end
- 1/20 splitter that includes adjustable distance between 600 micron fiber and 20-fiber bundle.
- 10 meter long bundle of 20 fibers, each fiber with 100 micron core.
- 20 tapered ferrule connectors

This system would allow us to measure the laser-lens-fiber coupling efficiency, the attenuation in the long fiber, the efficiency of coupling to the 100 micron fibers, and some idea of the uniformity of the 20 output fibers.

9. Some cost considerations/options for the prototype system

Option 1: The prototype system becomes a secondary calibration system

In this scheme (assuming the prototype works), we install the prototype system as a secondary calibration system for 20 "reference bars." We imagine coupling the 20 fibers to the bars at an intermediary distance along the bar—perhaps at the 25%/75% point of the bar length. This would allow us to monitor the attenuation length and propagation velocity for these 20 bars using relative measurements only. (Of course, the same information could be extracted from absolute measurements on tracks.) Moreover, this would give us some redundancy should any of the fibers (especially the 600 micron fiber) break.

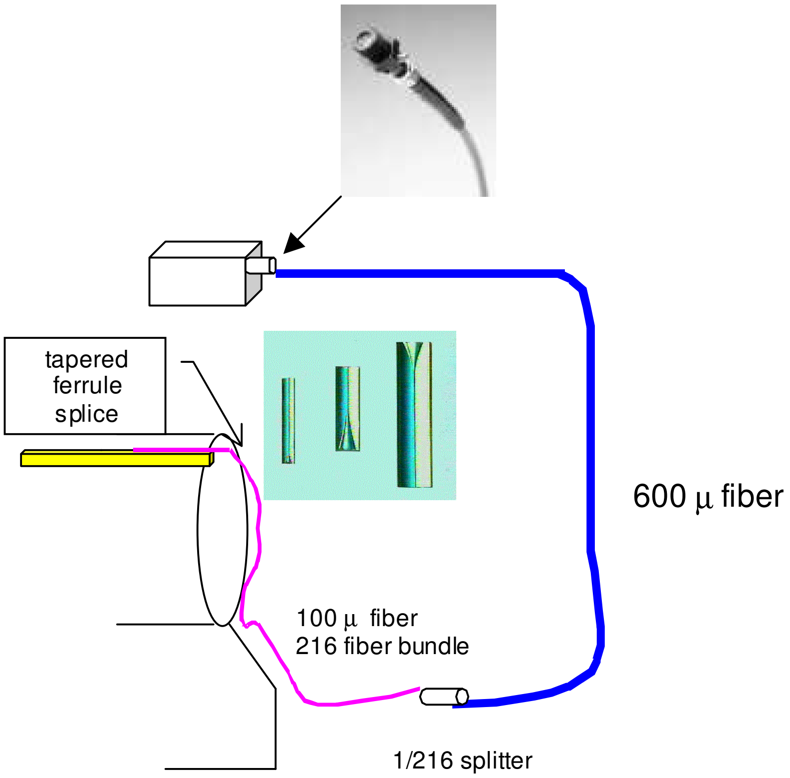
Option 2: We save money by re-using prototype components in the production system

The 600 micron long fiber should certainly be re-usable and is a significant cost savings. We might be able to re-use portions of the splitter as well, though this is less clear.

10. Other possibilities for cost optimization

As we begin to receive vendor quotes, we should be alert for other potential savings. For example, PTI indicated that they would probably make the prototype mechanical components for the 1-20 splitter identical to a 1-216 splitter. That is, they would make the 20 fiber bundle be part of a 216 fiber bundle with 196 dummy fibers. In that case, it may make sense to produce parts for two splitters at the same time since much of the machining costs are in setup.

In the final production system, we may well choose to have approximately 10% spares by making an output bundle of 240 fibers instead of exactly 216.



SILICA/SILICA Optical Fiber

FV

Fibers

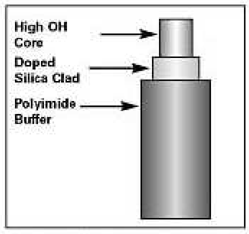
- High OH
- UV Enhanced

Characteristics

- Step Index
- Numerical Aperture: 0.22 ± 0.02
  Full Acceptance Cone: 25.4 degrees
- UV-Vis-NIR Transmission, 180nm to 1,150nm
- Superior Radiation Resistant
- High Laser Damage Threshold
- Sterilizable
- Bio-compatible Materials – USP Class VI
- High OH Silica Core, Doped Silica Clad
- Polyimide Buffer Standard; Silicone, Acrylate, Fluoropolymer, Aluminum & dual buffers also available
- Polyimide Concentricity ± 3µm
- Sizes for Bundling
- Tighter Tolerances Available
- Temperature: Operating –65°C to +300°C
  Intermittent, up to 400°C
- Proof Tested to 100kpsi

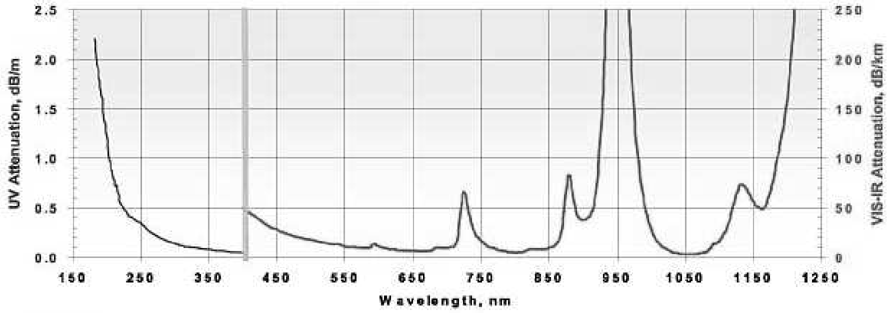
Product Descriptor	Core (µm)	Clad (µm)	Buffer (µm)
FVP050055065*	50 ± 5	55 ± 5	65 ± 5
FVP100110125**	100 ± 7	110 ± 5	125 ± 5
FVP150165195	150 ± 7	165 ± 5	195 ± 5
FVP200220240	200 ± 8	220 ± 5	240 ± 5
FVP300330370	300 ± 14	330 ± 10	370 ± 10
FVP400440480	400 ± 17	440 ± 10	480 ± 10
FVP500550590	500 ± 20	550 ± 12	590 ± 12
FVP600660710	600 ± 25	660 ± 15	710 ± 15
FVA8008801100***	800 ± 20	880 ± 15	1100 ± 30
FVP100120140	100 ± 7	120 ± 5	140 ± 5
FVP200240280	200 ± 8	240 ± 5	280 ± 5
FVP320385415	320 ± 14	385 ± 10	415 ± 10
FVA100010501250***	1000 ± 30	1050 ± 15	1250 ± 50

* Recommended for UV wavelengths only. Availability varies.
** Not recommended for wavelengths greater than 1000nm.
*** Acrylate buffer



Note: The items listed in this table are standard configurations and sizes. Other configurations may be available on request. Please let us know what we can do to help satisfy your project requirements.

Typical Attenuation



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