NPS Calorimeter Prototype

We are planning to build a small prototype of the NPS calorimeter and test it for the goal to finalize the best configuration, type and design of the real curing and monitoring systems.

The prototype will have effective area ~6×6 cm^2 and will consist of 9 $PbWO_4$ crystals (matrix 3×3) each with dimensions of 2.0×2.0×20.0 cm^3.

Light from the blocks will readout by 19 mm diameter R4125 Hamamatsu PMTs (such PMTs are used in the PrimEx calorimeter).

Assuming the NPS calorimeter will be shielded from all sides but the front side, notable radiation damage (after accumulated doses ~50 krad) is expected for only in the frontal 2-3 cm thick layer of the crystal. This must be relatively easy to remove with optical bleaching.

It is known that the blue light of ~400 nm is most effective in removing the radiation damage. It was estimated that the required light intensity is of an order of 1-2 mW/cm^2, thus for 2×2 cm^2 or 3×3 cm^2 crystals we need curing system with power ~5-10 mW/crystal at λ~400-600 nm.

With blue light, ~90% of the original amplitude can be restored within first 200 minutes with photon flux of ~10^{16} photon/s (delivered by 4 identical blue LEDs). This traditional method of curing with blue light will require turn OFF high voltage on the PMTs, Hall access, removal of the front panel of the temperature controlled box, and installation of the frame with curing lamps.

We are considering possibility to use infrared (IR) light for recovery (λ~900-1000 nm). But at longer wavelength a significant recovery is possible for a long time irradiation (by factor ~20 relative to blue light). This must be compensated by using intensity ~10^{17} photons/s per block.

The main benefit of using IR is that such curing can be performed continuously, even (hopefully) without turning OFF high voltage on the PMTs (since IR light is out of QE region of the phototubes). Illuminating crystals with infrared light ($\lambda \approx$940-1040 nm) in curse of experiment may keep its transmittance at good enough level due to continuous curing.

Figures below show details of assembly of the prototype and its LED curing system. (Note, this is not an engineering drawing and not to scale).

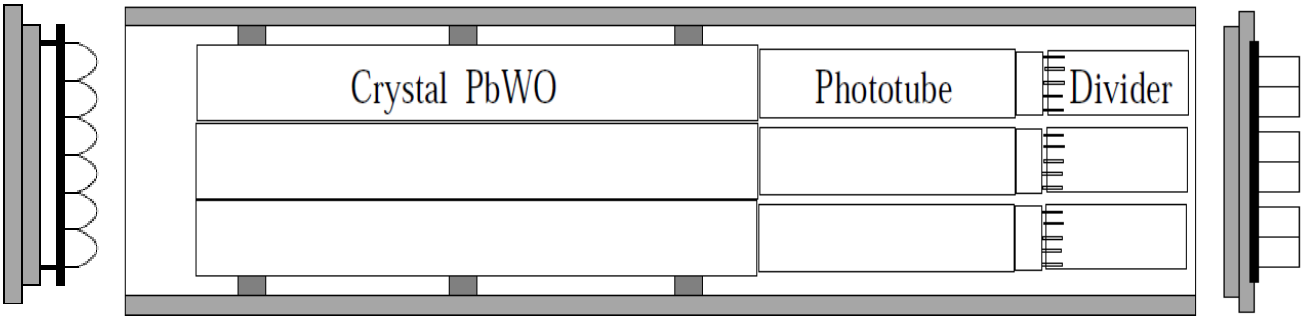

Fig.1 Schematic side-view of the prototype. The $PbWO_4$ blocks attached with PMTs and divider are shown inside of the cooling box. Front covering plate with LEDs assembling and back cover plate with connectors are removed.

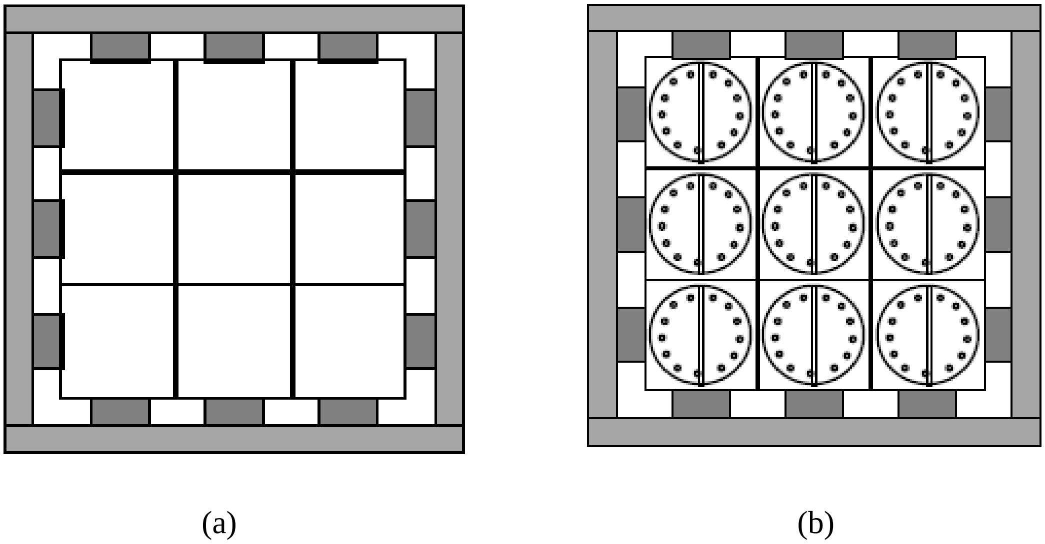

Fig.2 Frontal (a) and backward (b) view of the prototype without covers

For curing we will use permanently installed super bright Infra-Red LEDs. A set of LEDs (λ~940 nm) can be assembled on a special board and mounted on the frontal cover of the prototype box.

All the assembly of LEDs shall fit inside the prototype box and be easily assembled or taken out if needed. The box will have an additional socket for powering of the LED system.

Radiated heat of full assembly of LEDs, their power and amount must be adjusted to the capability of the temperature controlled frame.

Some possible candidates of Infra-Red LEDs are listed (very preliminary selection) in Table 1.

Type/Company	Emission Peak (nm)	Diameter or Dim. (mm)	Power W (mW)	Basic material	Proposed cost (USD)
Hamamatsu L6895-10	940±60	4.6×4.6	1.2		?
Osram LD274	950±55	5	165	GaAs	0.6
Kingbright L-53F3BT	940	5	30		0.6
Superbright/Adafruit	940	5	?		8.0 for 25
Hamamatsu L12170	840-900	5	80		?
EverLight IR333-A	940	5	150	GaAlAs	0.75
LTE-2871/Lite-On-Electronics Inc.	940+-50	5	90		1.0 for 3
Hamamatsu L9338	945+-60	4.2	15		
ThorLabs LED940E	940+-50	?	6.2	GaAs	11.0
ThorLabs LED1070E	1070+-50		~7.5	?	20.0
L2-0-IR5TH30-1 /Ledsupply com.	940	5	100		0.60

It is important to select LEDs which can withstand ~1 Mrad or more radiation doses without significant degradations (radiation hard LED). This strongly depends on the material used in LED production. Best radiation hardness show LEDs based on SiC, GaN and AlGaInP.

Radiation hardness of the LEDs has been tested with protons, neutrons and photons. It was shown that while for GaAs based LEDs the normalized light output drops by factor ~5 after radiation doses of $5\times10^{8} – 10^{10}$ p/cm^{2} caused by protons or neutrons, degradation effect from photons are ~100-1000 times lower. For the accumulated dose of ~1 kGy (~100 krad) from photons no any noticeable change in light output or timing characteristics of GaAs LEDs were observed.

In all the cases it would be preferable to use only fibers, glue, optical grease, electronic components and any other material, which can withstand ~10 Mrad or more radiation doses, specifically if they are planned to be used in the frontal side of the calorimeter.

In addition to curing system, we are planning to develop LED based monitoring system for the prototype to control status of the $PbWO_4$ blocks and the PMT gains in the curse of the experiment.

Light Monitoring system can be clone of LMS used in PrimEx.

Light will be generated by set of bright (high power) blue LEDs, mixed and distributed to multiple channels.

From the distribution box light to each individual block would be delivered by ~200 µm diameter silica fiber. The ends of fibers must be attached to crystals from the back, nearby to PMT.

Several fibers from the distribution box will be used to monitor light source stability by reference PMTs.

Possible candidates of blue LEDs which can be used in monitoring system are listed in Table 2.

Type/Company	Emission Peak (nm)	Diameter (mm)	Power W (mW)	Basic material	Proposed cost (USD)
Nichia NSPB500S	~470	5			~3.0
Nichia NSPB500AS	470	5	?		3.0
Nichia NCSB119	470	3.5×3.5	1160-2600		~3.0
Superbright COM-08860 /Sparkfun.com	465-470		180		1.50
Kingbright APHK1608PBC-Z	467	1.25×1.25,Surface mounted	120	InGaN	0.53
Blue, ultra bright/Tayda-Electronics com.	460-465				0.10
Super-bright MVL-914 MBC/allelectronics.com.		7.62×7.62	140	InGaN	1.0
Super bright Blue LED/ Flikto or Electroshop	465	5			8.0 for 25

List of proposed activities and studies before assembling of the Prototype:

- Measurements of light transmission efficiencies of the PbWO4 blocks;
- Assembling and test of the HV dividers for the PMTs
- Gain and relative quantum efficiency measurements of the PMTs;
- Development of drivers for the blue and Infra-red LEDs;
- Studies of samples of Blue and Infra-Red LEDs;
- Test sensitivity of the PMTs to IR light and measurements of anode current;

- Study of possibilities using IR cutoff filters (films) to reduce IR light impact;
- Develop necessary hardware and software for tests;
- Design, fabrication and assembling of the prototype, curing and monitoring systems.

List of proposed tests with full assembled Prototype:

- Test all assembly on light leak;
- Test light monitoring system;
- Test IR assembly and its ON/OFF effect on PMT anode current;
- Cosmic test and preliminary calibration/equalization of channels;
- Installation of the prototype in experimental area and test with the beam;

Current status:

- We have ordered 10 blocks of $PbWO_4$ crystals and delivery is expected before summer 2014;
- We have ordered 10 phototubes Hamamatsu R4125;
- Working on design, high voltage bases
- Looking for the blue and IR LEDs and their drivers.