NPS Calorimeter Prototype:
Status 17 April 2014

PMT and HV Dividers

- R4125 PMT HV dividers:
  - 12 HV dividers have been assembled by JLab electronic groups (thanks to Chris Cuevas and Armen Stepanyan).
  - One of the newly assembled dividers was tested and a problem was found: ***the output signal amplitude was nearly zero***. Three possible sources may cause such problem:
    - mistake in schematics of the new divider (the new version of the divider was slightly was modified compared to the version from 2013),
    - mistake in board drawing, or
    - technical mistake during assembling of the divider.
  - We gave Vladimir Popov one of the newly assembled dividers along with the 2013 prototype and asked him to find out problem.
  - Vladimir found a mistake in the electronic version of his schematic drawings which propagated into the mechanical assembly of the boards: One transistor legs need to be swapped. It looks like this will be relatively easy to fix. He already fixed this on one of the new assembled divider and our test showed that the output signals from the phototube with the 2013 divider (prototype) and the new one are similar. We have asked the electronics group to fix the 11 remaining dividers and gave them the corrected example divider and drawing. By the way, Vladimir is very unhappy to contact and work with us without official agreement with his supervisor.
  - Still looking for the PMT R4125 and dividers taken in 2013 by collaborators for the various tests. On 07 March I sent another email to FIU (Pete and Joerg) asking them to return one PMT R4125 with divider. More than three weeks ago Pete and Joerg replied that they will send the PMT and divider. Finally one R4125 PMT with its active divider has been delivered.

LEDs and testing

- Recently we have ordered additional new samples of IR and Blue LEDs:
  - Infrared LEDs: Vishay TSAL7400, λ ~940 nm, have been delivered;
  - Waiting for Osram LD271, λ ~940 nm and SFH4547, λ ~950 nm;
  - Blue LEDs RL5-B5515 and RL5-B4630, λ~460 nm are delivered

- We already have on hand one type of blue LED (SLA580BCT3F) and two types of Infrared LEDs (OSRAM SFH4233 and LD274-3).
- Our goal is to measure parameters (intensity, emission spectrum) for several types IR and Blue LEDs and select most acceptable for the prototype monitoring and curing systems.

Infrared LED tests

- We made absolute ***intensity measurements of the two infrared LEDs LD-274-3 and TSAL7400*** using Carl Zorn's setup in ARC. Some details of the setup are shown in Fig.1. Infrared LED (seen on the left) is mounted on a special support structure. The calibrated Photodiode S2281 (seen on right) with an effective area of 100 mm^2 and quantum efficiency of ~67% (at λ~950 nm) measures the intensity of the emitted light (its current is nearly linearly proportional to LED intensity) . The distance between LED and Photodiode can be varied from 0.5 cm to 20 cm. The LED driving current is measured by a FLUKE multimeter and the Photodiode current is measured by high accuracy KEITHLEY picoamperemeter.

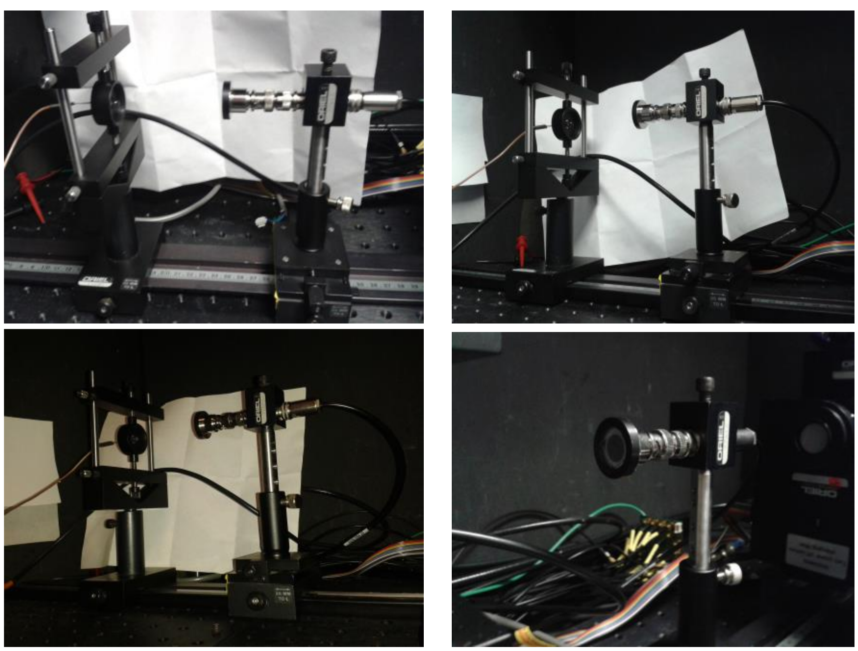

Fig.1 Carl Zorn's LED test setup in ARC. Infrared LED (on the left) is mounted on a special support structure, Calibrated Photodiode S2281 (on right) with an

effective area of 100 mm^2 measures the intensity of the emitted light. The distance between LED and Photodiode can be varied from 0.5 cm to 20 cm.

- All equipment is installed in a mini-dark-room. With closed doors the photodiode dark current with LED OFF was on the level of ~0.001 nA. With the doors open the dark current value jumped to 1.1 μA (about 1000 times higher). Though all LED studies were done with closed doors, this value of dark current is so negligible that we could do measurements with the doors open.

- The electronic circuit which was used to drive the LED is shown in Fig.2. At fixed 5.0 V of the power supply the value of the LED driving current was changed in the range from 0 to 100 mA by changing the value of the resistor in range 0-1 kΩ. The driving current was measured using a FLUKE multimeter.

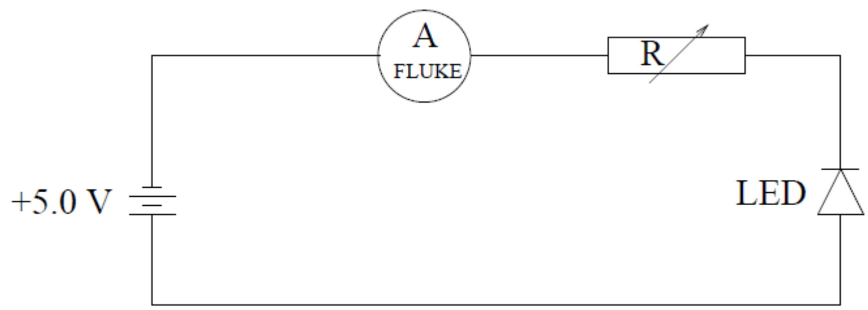

Fig.2 The LED driving electronic circuit. R is a variable resistor (0-1 kΩ); the LED is a Light Emitted Diode; FLUKE multimeter was used to measure the LED driving current.

- We have measured the LED emission intensity versus the driving current when the photodiode was located at distances of ~3 cm and ~7 cm from the LED. Results for both LEDs are shown in Fig.3

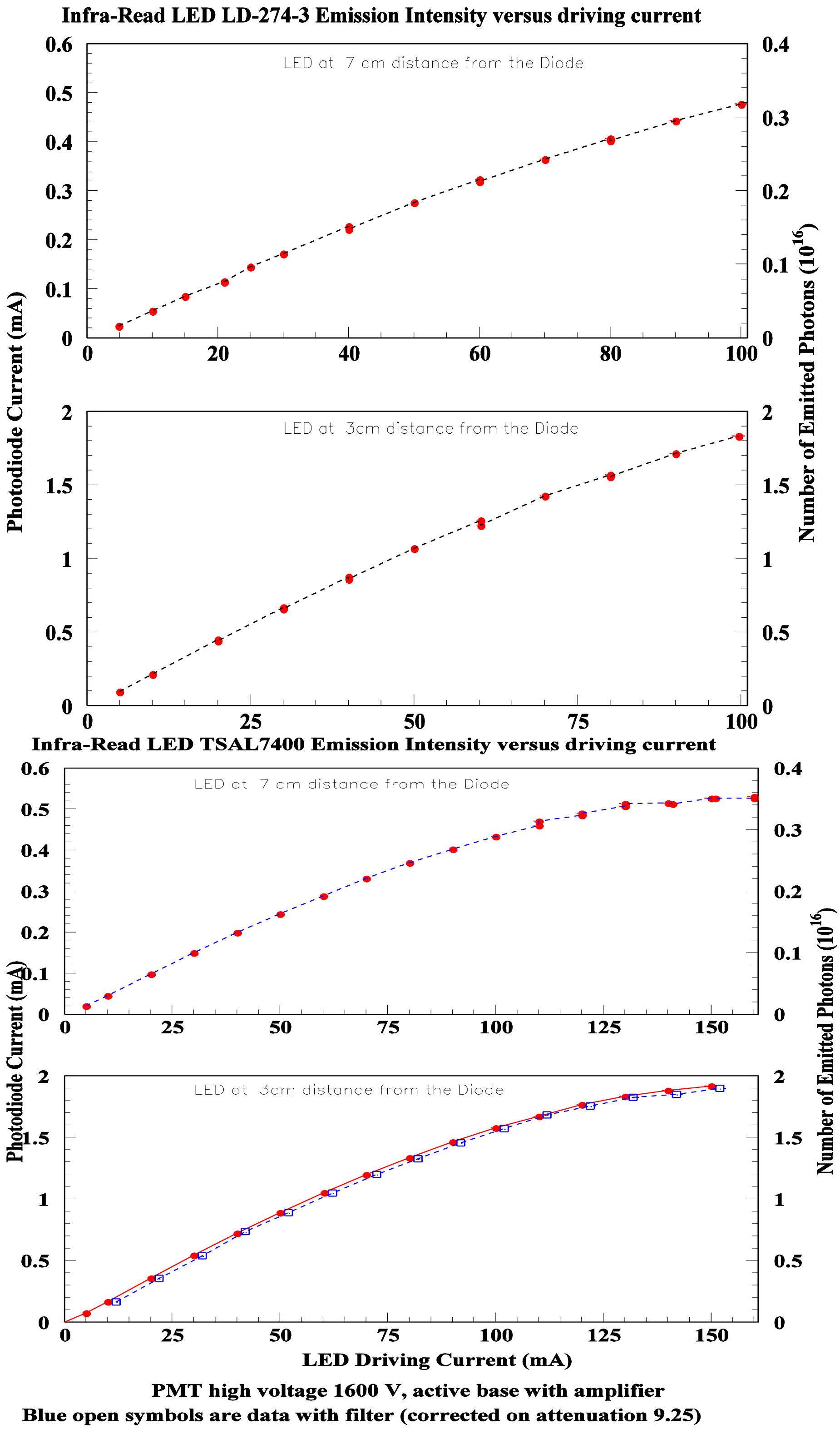

Fig.3 Emission intensity of the Infrared LED LD-274-3 (right) and TSAL7400 (right) versus driving current at distance 7 cm (top) and 3 cm (bottom).

- The peak wavelengths are 950 nm for LD-274-3 and 940 nm for TSAL7400.
- Using this number as an average to estimate the energy of the photons:
  $E_\gamma = h\times\nu = h\times c/\lambda = (6.63\times10^{-34}\ m^2\cdot kg/s\times3\times10^{8}\ m/s)/(950\times10^{-9}\ m) =$
  $= 0.0209\times10^{-17}\ m^2\cdot kg/s^2$ ➔ **1.31 eV**
  ($1\ J = 1\ kg\cdot m^2/s^2 = 6.24\times10^{18}\ eV$; $1\ eV = 1.602\times10^{-19}\ J$).
- At a distance of ~3 cm, where the LED fully illuminates the calibrated photodiode (with an effective area of 100.0 mm^2) the energy output is equivalent to **2×10^{16} photons per second** (for area 1 cm^2 or 2×10^{16} $\gamma/s/cm^2$) .
- Flux of photons $N_\gamma = 2 \times 10^{16}$ will deposit power of energy
  $P_\gamma = N_\gamma\times E_\gamma = 2 \times 10^{16}\times1.31$ eV/sec ≈**4.2 mW/cm^2**
  (at a mean wavelength of 950 nm and at the nominal maximum current of 100 mA driving the LED, as listed in the Osram data sheet).

- Fig.4 shows the ***LED driving current*** (~100 mA) measured by the FLUKE multimeter and the corresponding 0.447 mA current of the Photodiode when the distance between LED LD-274-3 and Photodiode was 7 cm. The flux of photons is $N_\gamma \approx 0.4 \times 10^{16}$ γ/sec

Fig.4 LED driving current (~100 mA) measured by FLUKE and corresponding 0.447 mA current of the Photodiode when distance between LED LD-274-3and Photodiode was 7 cm.

- These data show that the ***output is almost linear with driving current***. Beyond 60 mA, the output begins to curve slightly indicating the onset of saturation.
- We have checked that this saturation is not related to Photodiode. We did additional measurements with attenuation of the LED’s output light intensity (installed neutral density filter with attenuation factor 9.25 on the front of the LED). As one can see in Fig.3 (bottom plot, bottom panel), the data without filter (red solid symbols) and with filter (blue open symbols) when scaled by attenuation factor are in a good agreement.

Blue LED tests

- Arshak also did ***intensity measurements for Blue LED RL5-5515, RL5-4630 and SLA-580BCT***. The emission peak of these LEDs at ~470 nm. The LEDs were located at distance of 3 cm from the photodiode. Results are shown in Fig.5

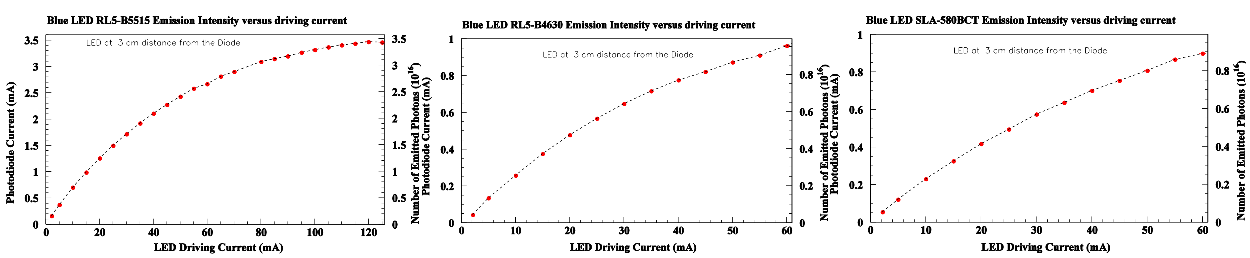

Fig.5 Emission intensity of the Blue LED RL5-B5515 (left), RL5-B4630 (center) and SLA-580BCT (right) versus driving current at distance 3 cm.

Test of the R4125 phototube sensitivity to Infrared light

- Possibility to perform continuous curing of the crystal using Infrared light of wavelength $\lambda > 900$ nm when PMT high voltage is ON will depends on its quantum sensitivity
- Using Carl Zorn’s setup we have measured the R4125 phototube sensitivity to infrared light. In this case the phototube R4125 was installed on the front of the LED. The measurements were done at different driving currents of the LED (from 0 up to 100 mA), at distances 0.5 cm and 16 cm (18 cm), with

and without the PbF_2 ($PbWO_4$) block on the front and PMT, and at different gain (high voltage) of the PMT.

- Note, that during these measurements we have used on of the prototypes of the active divider with build-in amplifiers for the PMT (assembled in 2013). First, using our PMT test setup in EEL we have measured single electron peak and gain of R4125. At HV 1600, 1700 and 1750 V we found gain values: 3.8×10^7; 7.6×10^7 and 1.0×10^8. These values are much higher than those listed in the Hamamatsu data sheet (at 1500 V they expect gain 10^5) due to the active divider.
- Doing the PMT sensitivity test to infrared light (actually this is a PMT quantum efficiency measurement at wavelength far beyond the sensitivity range shown in any of Hamamatsu data sheets) the output signal was sent to an ADC, and Carl Zorn's Lab-VIEW system with a simple DAQ was used.
- The ADC gate width was150 nsec, and 1 channel equivalent to 100 fC. Data for each setting were taken for 5 min (300 sec) with a frequency of ~200-300 Hz. Amplitude distributions of the signals detected at different values of the LED driving currents (at different intensity of the IR light) are shown in Fig.6 (left for the LED LD-274-3, and right for the LED TSAL7400).

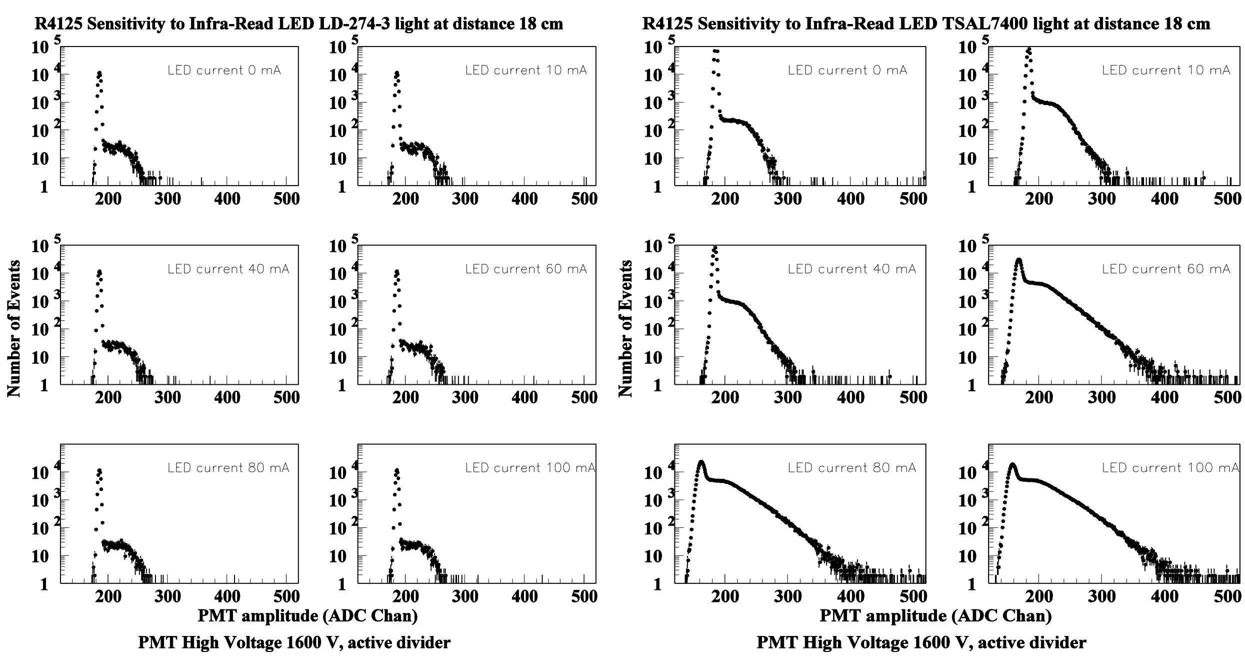

Fig.6 Amplitude distributions of the signals detected by PMT R4125 at different values of the infrared LEDs driving currents (left for LD-274-3 and right for TSAL7400).

- We did similar measurements when ~18 cm crystal (PbF_2 & $PbWO_4$) were installed between the LED and PMT. Fig.7 shows the amplitude distributions of the signals detected by PMT R4125 at 100 mA driving current of the infrared LED LD-274-3, when PbF_2 (top) and $PbWO_4$ (bottom) crystals are installed between LED and PMT.

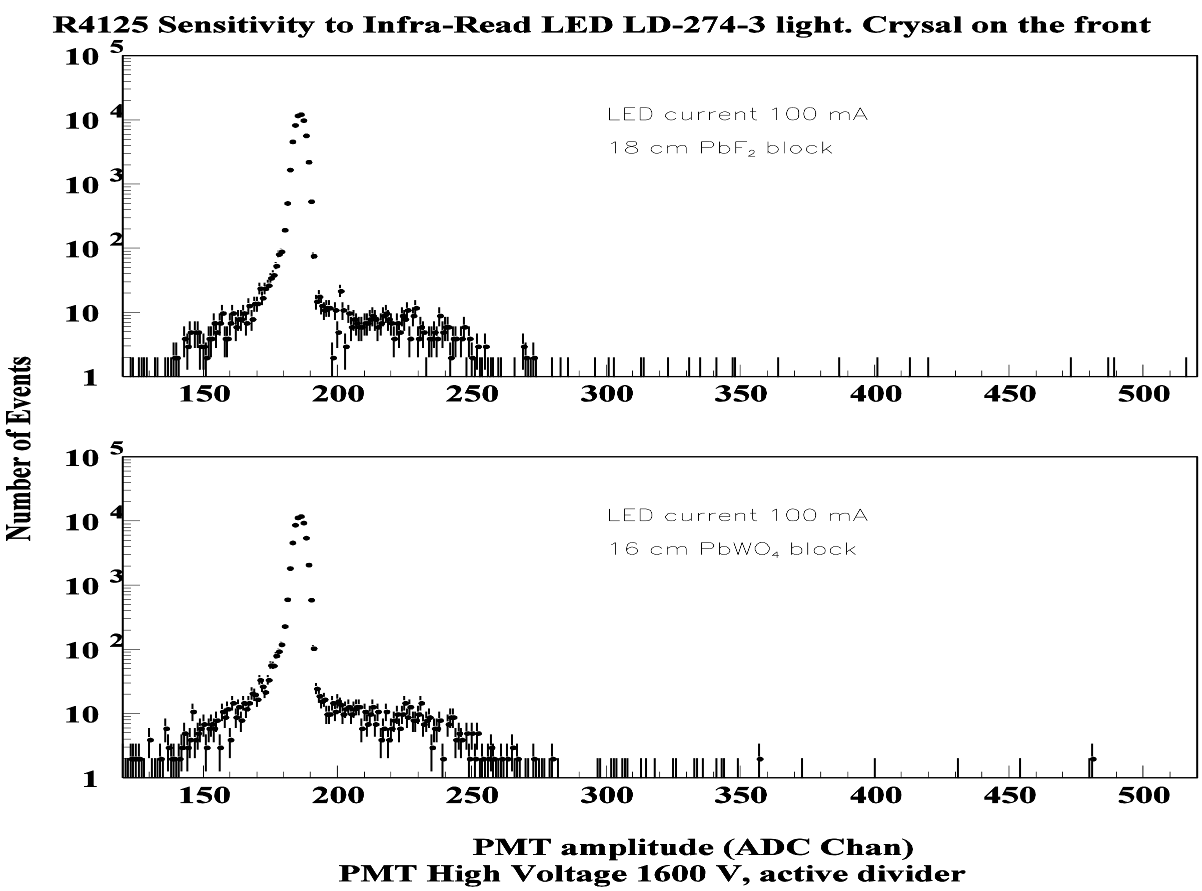

Fig.7 Amplitude distributions of the signals detected by PMT R4125 at 100 mA driving current of the infrared LED LD-274-3, when PbF_2 (top) and $PbWO_4$ (bottom) crystals are installed between LED and PMT.

- Fig.8 shows the experimental setup with which the sensitivity measurements were performed when the PbF2 block was installed between the LED and the phototube.

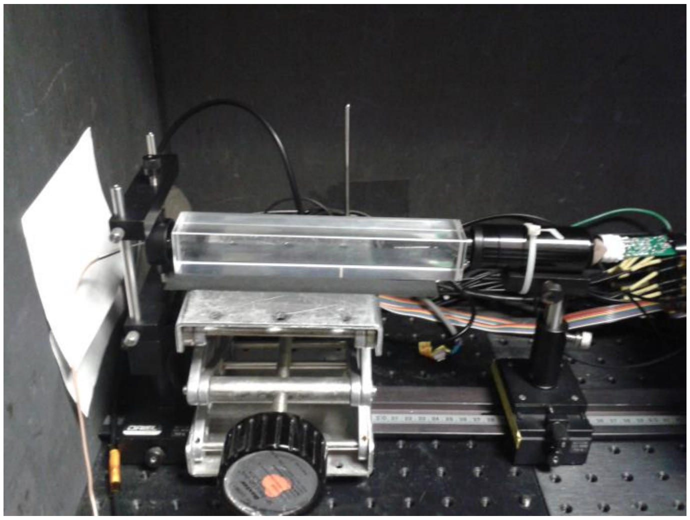

Fig.8 Carl Zorn's experimental setup for PMT's sensitivity measurements to infrared LED light. The 20 cm PbF2 crystal is installed between PMT and LED.

- Our data show that PMT R4125 have very low, but not negligible, efficiency relative to infrared light.
- We have checked that this sensitivity is not due to contamination of short wavelength light in the emission spectrum of Infrared LEDs.
- For the infrared LED LD-274-3 at distance of 3 cm from the Phototube, and driving current values of 0, 10, 20, 30, 40 and 50 mA we have measured PMT amplitude spectrum with and without 900 nm long-pass filter. (Note, this filter cut out all light with a wavelength below 900 nm). No differences between these two sets of measurements was found

<u>Conclusion:</u>* R4125 PMT actually have very low, but non-zero, efficiency relative to the light with wavelength λ>900 nm. Will this damage the PMT or not during long term operation ? More studies are needed to answer this question ! We also may look for the LEDs with emission spectrum >1000 nm.

Prototype construction design considerations (use Al or Cu for the frame ?)

- Several aspects (weight, price, thermal properties and residual radiation activity) have been considered to choose the material for the frame. We came to the conclusion to **use Cu for the construction of the prototype frame.**
- The JLab Machine shop started fabrication based on our schematic drawings. But we need to finalize type of the connector for the LEDs and monitoring fibers.

Common light source in the monitoring system for the $PbWO_4$ and PbF_2:

- One of the open questions was "*could we use same primary light source for the hybrid calorimeter consisting of $PbWO_4$ and PbF_2 blocks*"?

- Arshak did ***transmission measurements for one $PbWO_4$ crystal (from Hall C photon detector) and for one PbF2 (provided by Charles Hyde)*** using Carl Zorn's setup in the ARC (shown in Fig.9)

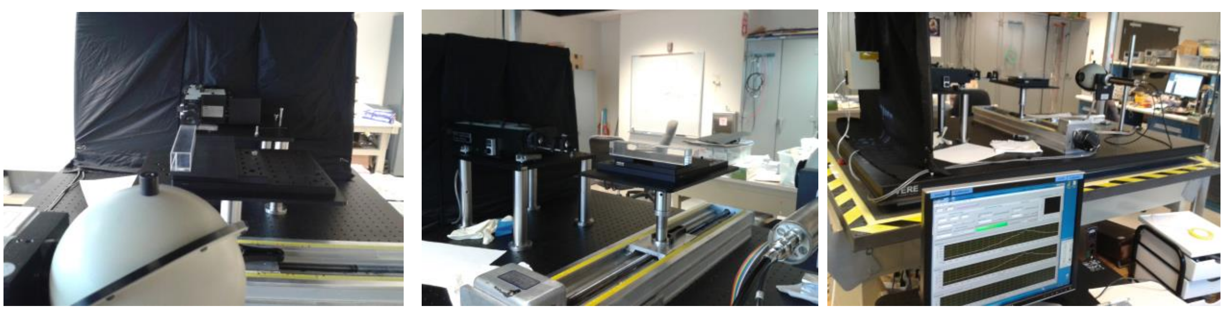

Fig.9 Carl Zorn's setup in the ARC for the transmission measurements. (Monochromonator , crystal with support table, and integrating sphere can be seen)

- The transmission efficiencies for the $PbWO_4$ crystal (not from PrimEx, but type of the Hall C photon detector crystals) and for one PbF_2 (from Hall A DVCS calorimeter) are shown in Fig.10

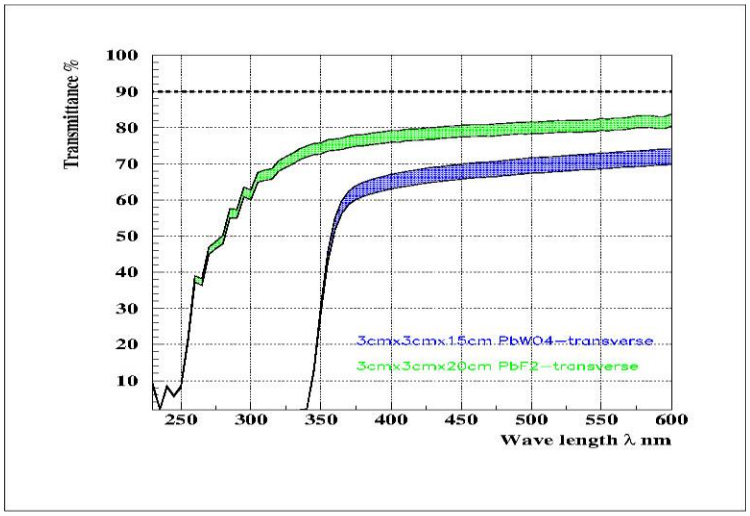

Fig.10 Light Transmission efficiencies of the PbF2 (green) and $PbWO_4$ (blue) crystals (3. 0 cm thickness) versus the wave length. Color band for each case represents the spread between the data measured at different points of the crystals.

- Comparison of Transmittance efficiency curves show that $PbWO_4$ and PbF_2 crystals transparencies are very different in the short wavelength region (λ~250-350 nm), but for both type of crystals the transparency is reached to its maximum value above λ~400 nm)

Conclusion: The blue light with a λ~470 nm should be acceptable for both types of crystals as a common light source for the monitoring system

Radiation studies of $PbWO_4$:

- Arshak also did transmission measurements for the four small piece of the PbWO4 rectangular crystals (thickness 2.0 cm) which we are planning to give RadCon for radiation.
    - Unfortunately this is not exact type of PrimEx crystals, but will help to understand efficiency of curing with blue and infrared light
    - We are planning to give RadCon three of these pieces and ask to put ~20 krad doses

- The “not-radiated” crystal will use as reference during all future measurements. One of radiated crystals we will use to study its spontaneous recovery with time, two others will be used for studies curing efficiencies with blue and infrared lights.

<u>The output pulse timing and shape for $PbWO_4$ and PbF_2 crystals</u>

- Alternative version of the NPS calorimeter will combine $PbWO_4$ and PbF_2 crystals. For $PbWO_4$ crystal the light generation mechanism is pre-dominantly scintillation light, while it is pure Cherenkov for PbF_2. As we have discussed on 06 March meeting, these will require special studies:
- The output signal timing properties and pulse shape are different then it may require a different digital filtering for the $PbWO_4$ and PbF_2.
- In addition, the active bases used for R4125 PMTs will change the shape of signals from the $PbWO_4$. It is necessary to take this into account.

<u>Proposed activities in near future</u>

There are several jobs which can and needs to be done before construction of the calorimeter prototype. The list of these jobs includes:

- Fix mistake in assembled high voltage dividers for the PMTs R4125
- Test all dividers with PMT and be sure that they are good
- Look for the other types of IR LED with a wavelength >1000 nm
- Measurement absolute intensity of the LED’s with λ>1000 nm
- Check sensitivity of the PMT R4125 relative to the light λ>1000 nm
- Test negative impact of Infrared LED with >900 nm on R4125
- Study the timing properties and shape of the signals generated by blue LED in $PbWO_4$ crystal when using active high voltage divider (with amplifier)
- Finalize mechanical part and driving scheme of the prototype curing LEDs
- Develop fiber connection scheme of the monitoring system
- Assembling prototype of the curing systems (with blue and Infrared LEDs)