Study of Shashlyk calorimeter modules

(A progress report)

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Introduction

According to the guidelines of the previous report, a new Shashlyk study should give special attention to the following issues:

- **Increasing light output from the calorimeter module by improving of the scintillator quality, optimizing the spectral consistency of the scintillator-fiber pair, and improving mechanical and optical construction of the module and assembling procedure.**
- **Improving the uniformity of light collection from the calorimeter module by optimization of reflective characteristics of the scintillator surface coating, optimizing the WLS fiber layout.**
- **Selecting an optimum photo detector (PMT, vacuum triode or tetrode, PID and APD) considering quantum efficiency, uniformity of photosensitive area, and stability characteristics.**

This report describes the progress of that program thus far.

Light yield for new prototype modules

New Shashlyk modules of two types have been build and tested in a cosmic ray muon setup.

In all measurements of light yield for different modules with PMT readout the same photomultiplier was used. This photomultiplier was calibrated by a precision light source on the basis of Y11 fiber excited by the blue LED.

For PIN diode readout, the diode was calibrated with a 1.2 pF precision calibration capacitor built into the preamplifier circuit.

The experimental results of light output for various Shashlyk modules are shown in Table 1.

Based on these data and known characteristics of photo detectors (Photo Multiplier Tube with low gain, Vacuum Photo Tetrode, Silicon PIN Photodiode and Avalanche Photo Detector), new estimations of energy resolution for variants of Shashlyk modules have been calculated.

Results of these estimations are also presented in Table 1.

Energy resolution for new prototype modules

Three different type of Shashlyk modules have been tested at the X5 tagged photon beam at BNL NSLC.

The tagged photons were produced by backscattering laser light from the stored 2.80 GeV electron beam in the NSLS. The photon energies were determined (tagged) to ~ 5.4 MeV by detecting the scattered electrons in a 64-channel tagged spectrometer.

For our measurements, the lower tagging energy was 248 MeV, the higher energy was 360 MeV. Beam divergence was limited to 2 mrad. The cross section size of beam was ~ 2 cm diameter at the location of the detector.

For technical reasons only a high intensity, ~10^6 Hz, photon beam was available during our measurements. A low intensity, ~ 10^5 Hz, photon beam with energies of 250 MeV and 360 MeV was available only for very short runs for calibration of the energy scale. All measurements were performed during a 5-hour period.

The prototype of calorimeter (3×3 modules) was mounted on a platform that could be moved horizontally and vertically with respect to the beam line. As 90% of energy of a photon shower is deposited in the central module of our prototype Photon Calorimeter, only the central position of the Shashlyk nonet was reserved for modules under study.

Each module was individually calibrated using the 250 MeV high intensity photon beam passing the central region of the module at normal incidence.

The energy resolution of Gamma Calorimeter prototype was determined only for photons passing through the 2×2 cm^2 area in the center calorimeter as defined by the size of photon beam.

Typical distributions of signals in each module of Shashlyk nonet, for the 250 MeV high intensity photon beam, are shown in Fig.1.

The typical energy spectrum for a central module and the sum of eight surrounding modules of the calorimeter are shown in Fig. 2.

Distributions of the clump energy for different central modules prototypes at the photon energy of 250 MeV and intensity 850 kHz are shown in Fig. 3-5. As can be seen in these figures, all energy distributions have high-energy tails. We associate these tails with overlapping signals in high intensity beam and/or with the photon energy distribution of the beam. To reduce the effect of this tail an estimate of resolution and dispersion of the beam energy was calculated two ways:

a) By considering only the low side of the observed distribution ($-3\sigma \div +\sigma$),

b) Forming a two Gaussian fit where one Gaussian was associated with the calorimeter response.

Both methods gave consistent results with an accuracy of about 2%.

Distributions of the clump energy for one prototype at the photon energies of 250 MeV and 360 MeV, and low intensity 120 kHz are shown in Fig. 6-7. The energy resolution for low intensity beam is a bit worse than that for the high intensity beam. A possible explanation of this is effect is the need for PMT stabilization after any sharp change of the mean PMT current. Such a stabilization process requires at least of 20-30 minutes. But because of accelerator constraints we had no opportunity for such a time delay.

The experimental results of energy resolution for different prototypes of Shashlyk modules are shown in Table 2. The only correction to the observed energy resolution was a subtraction of the contribution due to the beam energy spread of 1.7%.

Photo readout

As our experimental data shows, a Shashlyk calorimeter with PMT readout satisfies requirements of the KOPIO experiment.

But it is necessary to point out that our test measurements were made in perfect conditions for PMT readout: short measuring runs, continuous photon beam, a good stability of beam intensity. These conditions do not correctly simulate those encountered in the KOPIO experimental environment.

A standard multi dynode PMT with gain $\geq 10^5$ is not a good candidate

- **Because of its large gain variation related to a changing anode current (Fig. 8),**
- **Because of hysteresis effects when a light source (beam) is interrupted and then re-applied (Fig. 9),**
- **Because of its large sensitivity to magnetic fields.**

Currently we are considering three candidates for the photo readout system of KOPIO calorimeter (decreasing in priority):

- **Avalanche Photo Diode (APD) with fast an amplifier. A candidate device is a 10×10 mm^2 APD (C30703F) made by EG&G Optoelectronics Canada. This detector offers a typical operating gain of 50, excellent green response (Q.E. ~75%), low capacitance ~100 pF and good uniformity over its active area. The quadrature sum of sampling and statistical terms in this case will be ~2.2%/√E (see Tab. 1). An expected noise term for the combination of APD and fast amplifier will be no more than 0.5\%/E (summed over the nonet). Unfortunately we have little information about the long-term stability of this device.**

- **Vacuum Photo Tetrode (VPT) with a fast amplifier. A candidate device is a 1" diameter VPT (R2149) with Q.E. ~ 16\% made by Hamamatsu. Even though it has low quantum efficiency when compared to the APD, in comparison with a standard PMT this device offers the advantages of higher stability and linearity, low sensitivity to magnetic fields, and practically no rate or hysteresis effects. It is also a well-understood device with good long-term stability. The quadrature sum of sampling and statistical terms in this case will be ~(2.5-2.7)%/√E (see Tab. 1). The noise term of the combined VPT and fast amplifier is expected to be ~ 0.6\%/E.**

- **Low gain (~10^4) PMT with a fast amplifier. A candidate device is a 30 mm diameter, 7 dynode stage PMT (EMI9106) made by Electron$ Tubes LTD. This PMT has a rubidium bialkali (RbCs) photocathode providing increased green response and an SbCs dynode system decreasing the rate effect by factor of ten (Fig.9). A combination of this PMT and fast amplifier (gain ~ 20) can perhaps solve the problems of rate and hysteresis effects. However, the problem of magnetic shielding would be present. The quadrature sum of sampling and statistical terms in this case should be ~ (2.5-2.7)%/√E (see Tab. 1). The expected noise term of PMT and amplifier will be small (~ 0.3%/E) summed over the nonet.**

Conclusion

The measured energy resolution for the studied Shashlyk modules is in good (~ 10%) agreement with results of our Monte Carlo simulations. Those simulations were normalized to the response of old modules (of types 1,2) to 0.5÷2.0 GeV electrons.

This indicates that our Monte Carlo model of Shashlyk modules is suitable for the study of Shashlyk Calorimeters whose resolution is 3÷3.5%/√E.

Agreement between Monte Carlo and data also increases our confidence in the possibility of building Shashlyk modules with resolution of about 3%/√E.

To actually achieve such a resolution for a 2,500 modules calorimeter with long-term stability, however, an improved photo detector readout system will be required.

We presently have three candidate photo readout devices that avoid most of the problems of phototubes. We are planning to study these devices in our continuing Shashlyk R&D program.