Test and Running Experience with HAMAMATSU R5600-03 PMTs

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1 Initial tests

1.1 Test setup

After the 70 PMTs were received from the manufacture, they were put through a series of performance tests. Fig. 1 shows a schematic view of the test setup. The PMTs are placed inside a totally light tight box(referred as the Dark Box). A yellowish LED (Hewlett Packard(HP) HLMA-DL00 Amber LED, λ=592 nm) is put in front of the PMTS to inject light. A square pulse with an amplitude of $\sim$ 3 V, and width of $\sim$ 10ns from a HP pulse generator is used to fire the LED.

A computer controlled Cockroft-Walton type HV power supply, which is designed and built at NIKHEF, is used. The voltage division among the dynodes are 1/2:1:1:1:1:1:1:1 which is done inside the HV supply itself. The divided voltages is sent to the PMT base through a flat cable.

The PMT output signal is either sent to a LeCroy 2249A ADC or a discreminator depending on the purpose of the test.

For the PMT gain measurement, the signal is sent to the ADC which integrates the charge from the PMT. We used the trigger output signal of the pulse generator to generate an 120ns wide gate. The gate proceeds the pulse by about 45ns. The ADC data are read out with a VME based OS9 system. Some software for data acquisition was developed to accumulate and save the ADC counts on event by event base at each HV settings tested.

For rate test, the PMT signal goes to a discriminator with a threshold of 160mV. The discriminator output is sent to a NIM scalar.

For the quality control of the test, we always have two PMTs inside the Dark Box. One PMT is kept there all the time as a reference while all other PMTs were tested.

1.2 PMT gain measurement

The PMT output charge versus high-voltage curve was determined for each tube from 600V to 950V in 50V steps with 5000 events per point for the same LED light source. The curves are parameterized with Eq. 1.

$$Q = 10^a \times V^b \tag{1}$$

where Q is the total charge measured with the ADC, V is the HV applied, a and b are the characteristics parameters for each PMT.

The absolute gain of PMTs are also measured based on the assumption that the signal spread is totally due to the photostaticstical fluctuation. Then we have the following equations.

$$Q_{anode} = N_{photoelect.} \times e \times G \tag{2}$$

$$\sigma_Q = \sqrt{N_{photoelec.}} \times e \times G \tag{3}$$

where Q_{anode} is the charge collected at the anode of the phototube, $N_{photoelect.}$ is the number of photoelectrons produced at the cathode of the photomultiplier by incoming photons, and e is the electron charge, G is Ratio of charge collected at the anode of the photomultiplier tube to charge produced at the cathode, and σ_Q is the RMS of the charge distribution from the ADC. From Eq. 2 and Eq.3, we get the absolute gain G as in Eq.4.

$$G = \frac{\sigma^2}{Q_{anode}} \tag{4}$$

The distributions of the characteristics parameters a and b of the 70 PMTs tested and the absolute gain curves are shown in Figs. 2 to 4.

1.3 PMT signal shape study on scope

The general behavior of the tubes at different voltages was studied on a scope. Only an $1 \sim 2$mV noise, which is constituent with the noise of the scope system, is observed for all PMTs when HV is below 450V. When the HV applied is more than 700V, some PMTs give pulse with a typical rise time of 2ns, falling time of 2ns and a total base width around 5ns in the absence of any light source , i.e., inside the Dark Box and when the LED is off. The pulse amplitude varies from a few mV to 100mV. The rate is from a few Hertz to a few hundred Hertz. We shall refer this as the '*dark pulse*'.

Having observed the presence of significant dark pulses in some of the tubes, we registered dark pulse amplitudes and frequencies at 700V, 800V and 900V as seen on the scope. The rate for a selected sample was measured with a discreminator and a visual scalar.

All tubes are put in three classes according to the dark pulse measurement and the Gain measurement. The cretieria are as follows.

- **Class C: 'bad tubes'** i) The parameters of the PMT gains, Fig.2, at 700V are systematically away from others. There are four PMTs. The serial numbers are 4l22ee, 4k25ek, 4m06eq, 4k18ep. or. ii) Gives a dark pulse which is more than 10mV at 700V(the rate is from a few Hertz to a few hundred Hertz) and more than 80mV at 900V. Thirteen PMTs belong to this type. The serial numbers are 4k25ac, 4l22eg, 4l22eq, 4l29al, 4m06ec, 4m06ee, 4m06ef, 4m06en, 4l22ed, 4m06ep, 4m06ek, 4m06eh, 4m08ba. It is interesting to notice that the PMTs with serial number starting with 4m06 are mostly bad in this respect.

- **Class B:** The dark pulse at 900V is at the order 20 to 80mV. There are fifteen PMTs. Their serial numbers are 4l22ea, 4k25ae, 4k25ad, 4m06ej, 4m06eg, 4m06el, 4m06eb, 4l30eq, 4l29am, 4l29ak, 4l29aj, 4l11af, 4k18el, 4l22ab, and 4l24fa.

- **Class A: 'Good tubes'** The rest of the 38 PMTs. There is no dark pulses at 700V, and up to 20mV dark pulses at 900V.

The 4 tubes in Class C which showed far more severe dark pulses were sent back to HAMAMATSU (see enclosed remarks on these tubes. The serial numbers are 4m06ee, 4m06ep, 4m06en, 4k18ep. We later received replacement for them. The serial number of the four new PMTs are 5a25en, 5b01ah, 5a23ef, 5b01ak. They belong to Class A according to the above classification.)

The transit time variations respect to high voltage applied were measured on a subset of tubes. We found reasonablely good agreement with the manufacture specification.

We also looked at the stability over a period of 20 days for four tubes under a HV of 900V in a totally dark box. Some of them show serious dark pulses since the beginning. A daily check was done and no significant change on the noise level was seen.

2 Running experience

2.1 The PMT environment inside the BPC

The Beam Pipe Calorimeter(BPC) at the ZEUS experiment is mounted next to an evacuated beam pipe in which high energetic positron (27.5 GeV) and protons (820 GeV) are collided about 3 m away at the nominal interaction point. The radiation background from synchrotron radiation and other energetic particles is fairly high near the beam pipe, i.e. a few kilo Gray per month. However, the radiation background is much lower at the location where the PMTs are installed, i.e. less than one gray per month.

The external magnetic field at the PMT locations was measured to be around 500 Gauss. In order to provide enough shielding to the magnetic field, the PMTs and their bases are housed inside an Armco magnetic-iron block with some 2mm thick PVC covers for the PMT and some 0.5mm-thick PVC-tube for the base. The magnetic field inside the shielding material has been measured to be less than ? Gauss. The HV setup is the same as in the initial test setup described in Section 1.

The light guides or wavelength shifters from the scintillating materials of the BPC are wrapped by an $25\mu m$-thick aluminum foil. The wavelength shifters extend into the Armco magnetic-iron tubess to about 25mm and touching the PMT surfaces. The distance between the photomultiplier and the aluminum foil is about 15mm. There is also a clear light fiber, which is used to inject LED or Laser light to the PMTs, touching the PMT surface.

2.2 Summary of the PMT performance

The total number of photomultipliers being currently used in the BPC is 62. After they are installed and powered under constant HV (about 700V) for about four months, we tested their performance in-situ with scope and a Digital Voltage Meter(DVM). All of the following tests were done while the PMTs are inside the above total light tight environment.

The first systematic check concentrated on measuring the trigger level with a LeCroy Digital Scope at which dark pulses appear at a rate of about 1 Hz. This was done with a 50 Ω termination on the scope. The second check was done with a 1 MΩ termination to account for possible DC-offsets. Finally, the output current as well as possible DC-offsets were monitored with a DVM which has a 5 MΩ input resistor in the voltage mode.

According to the above systematic checks we choose the following classification to the describe PMT performances. The classification of all the tubes here will be compared with their initial classifications.

- **Class 1** i).Less than 1 Hertz dark pulse at 10mV threshold with 50Ω termination and no DC offset with 1MΩ termination; and ii).The DC current is 10nA(the limit of DVM measurement) or less and the DC offset is less than 1mV. There are 38 PMTs.

- **Class 2** i). at least 1 Hertz dark pulse with 10mV threshold with 50Ω termination and the DC offset is more than 1mV with 1 MΩ termination on scope; ii) The DC current is more than 10nA and DC offset is more than 1mV with a DVM. There are 15 PMTs.

- **Class 3** We also observed very large dark pulses for a few PMTs on scope. With 50 Ω termination, the pulse width of one big dark pulse is ranging from 20μs to 200 μs and the amplitude is about 20mV. The rate is typically at a few Hertz. We called them 'discharge' effect. We observed this effect on five of the PMTs.

The discharge effect of three PMTs from Class 3 had been measured to show the discharge characteristics as in the Table 2.2.

We also measured the output current as a function of the applied HV for two of the PMTs which showed server discharge effect. The steep rise from a certain HV on is clearly apparent, i.e. Fig. 1.

channel ID	scope		DVM	
	Pulse Width	Height	DC Voltage	DC Current
sx10	20–100μs	20mV		10–50nA
sy6	20-200μs	20mV	400-500mV	80-170nA
sy16	5-20μs	10mV	65-100mV	10-30nA

Table 1: Voltage and current characteristics of the discharging PMTs.

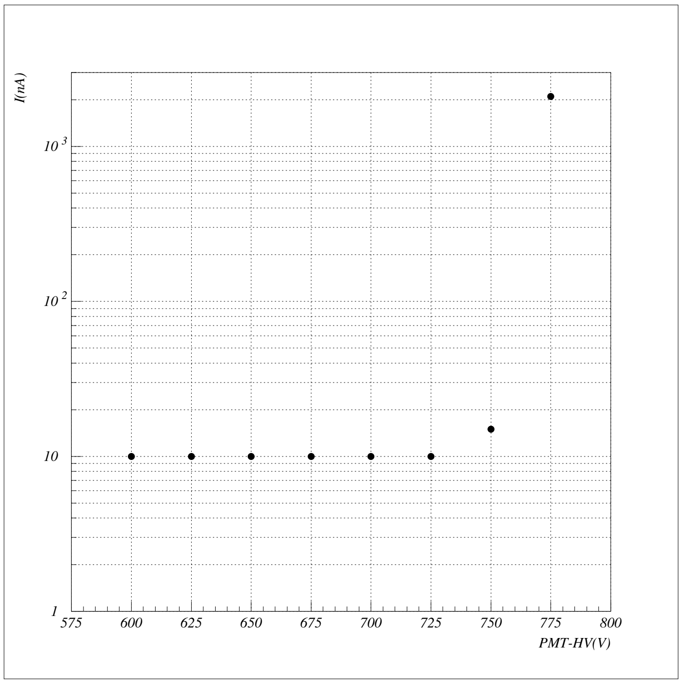

Figure 1: The PMT current as a function of the HV applied for one of the PMT which showed *Spark*.

Figure 2: The stability of LED signal of the PMTs used in the BPC.

The discharge effect was also investigated on the bench on one of the PMT just after it's taken out off the BPC. The PMT was put into the Dark Box with the same kind base. But the HV supply is done with resistive divider instead of Cockroft-Walton type. Discharges were seen but at a higher HV than inside BPC. The discharge effect was seen at 767V inside BPC. We start to see discharge effect from 840V on the bench test. The width seen on the bench were also smaller.

3 Performance comparison between initial test and in-situ test

The following table listed the classification of all PMTs with the two classifications. One readily notices that the tubes which are good ones, i.e., Class A, stay good, i.e. Class 1, after four month running. The 'bad' tubes, i.e. in Class C, degraded quickly. One thing worth mentioning is that the 'discharge' effect wasn't observed in the initial test for any of the tubes. We'll continue to monitor the PMTs inside the BPC. But the mechanism of the dark pulse and discharge effect can only be understood and solved by the manufacture.

BPC Channel	PMT Nr.	Initial Test	Classification on 10.08.95
NX1	4L16AM	A	1
NX2	4K25AM	A	1
NX3	4L16AN	A	1
NX4	4L29AH	A	1
NX5	4L11AC	A	1
NX6	4L11AB	A	1
NX7	4L30EJ	A	1
NX8	4K18EJ	A	1
NX9	4L11AA	A	1
NX10	4K04EF	A	1
NX11	4L22EA	B	2
NX12	4M06EQ	C	1
NX13	4L22AB	B	1
NX14	4K25AC	C	1
NX15	4L29AL	C	1
NY1	4K25EK	C	1
NY2	4K25AD	B	1
NY3	4K25AE	B	1
NY4	4L29AN	A	1
NY5	4K25AG	A	1
NY6	4M06EA	A	1
NY7	4L22EH	A	1
NY8	4L29AE	A	1
NY9	4L29AC	A	1
NY10	4L11AD	A	1
NY11	4K25AA	A	1
NY12	4L22AA	A	1
NY13	4J21EK	A	1
NY14	4L11AG	A	2
NY15	4M06EJ	B	1
NY16	4L22EG	C	3
NVETO1	4J21EH	A	1
NVETO1	4L16AP	A	1

Table 2: The Comparison of the PMT classifications for BPC North

BPC Channel	PMT Nr.	Initial Classification	Classification in 10.08.95
SX1	4L11AE	A	1
SX2	4K25AJ	A	1
SX3	4L11AH	A	1
SX4	4L29AB	A	1
SX5	4K25AF	A	1
SX6	4M06EL	B	1
SX7	5A23EF	A	1
SX8	4L29AK	B	1
SX9	4M06EC	C	1
SX10	4L22EE	C	3
SX11	4L22ED	C	3
SY1	4L22EN	A	2
SY2	5B01AH	A	1
SY3	4L29AF	A	2
SY4	4L11AF	C	2
SY5	4L29AJ	B	2
SY6	4l24FA	B	3
SY7	4M08BB	A	2
SY8	4L30AN	A	2
SY9	4M06EG	B	2
SY10	4M06EB	B	2
SY11	4J21ED	A	1
SY12	4L30EK	A	2
SY13	5A25EN	A	2
SY14	4L30EQ	B	2
SY15	4L22EQ	C	3
SY16	4M06EH	C	2
SVETO1	4L29AM	B	1
SVETO1	4K25EM	A	1

Table 3: The Comparison of the PMT classifications for BPC South