

# Measurement of the MASS detectors parameters with *mass* program

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## 1 Introduction

In the measurement of a scintillation indices, the variance of the registered signal is determined not only by fluctuations of the light intensity  $F$ , but also by photon noise. Ideally, the photon noise is Poisson noise and its contribution to the normalised variance  $\text{Var}[F]/\text{E}^2[F]$  is equal to  $1/\text{E}[F]$ , where  $\text{E}[F]$  is the mean (expectation) value of the flux of the pulses registered by the detector. That is, having the mean value, we can account for the contribution of the photon noise.

However, there are the effects which complicate this simple expression in the real detectors. Two main factors of them are

1. General non-linearity of detector. In the photon counting method, the non-linearity is described with help of dead time of the counter and arises both in PMT and in processing electronics.
2. After-pulses — false pulses arising with a certain probability  $q \ll 1$  after real pulses generated by the detected photons. Part of the after-pulses occur in the PMT, another part may appear in the counter electronics.

An effect of these factors on the signal associated with fluctuation of the light intensity and on the contribution of the photon noise has been considered in detail in [1, 2]. For a constant radiation  $F$ , we have the following relationship in the linear approximation:

$$\frac{\text{Var}[F]}{\text{E}[F]} = p(1 - 2\tau \text{E}[F]). \quad (1)$$

This formula is the basis for determination of the non-poissonity parameter  $p$  and the non-linearity parameter  $\tau$ . Non-poissonity parameter is connected [2] with after-pulse probability  $q$  by relation  $p = 1 + 2q$ .

Before determinating these parameters, we need to find an operating point of PMT for each channel of the MASS instrument.

## 2 Measurement of PMTs counting characteristics and selection of operating point

To select the operating point of the PMT, that is the optimal values of the high voltage supply and pulse discrimination threshold, the command `run counting=hv.value` is provided in the program *mass*.

In contrary to the *Turbina* program, where a special complex procedures is implemented to perform dual loop for the sets of high voltages and thresholds in the configuration file, the *mass* program performs a single measurement. Level of control light is used according to the value of `Tests/CountingLight` and discrimination thresholds in the channels are controlled by `Bicounter 1/DiscriminationA`, `Bicounter 1/DiscriminationB`, `Bicounter 2/DiscriminationA` and `Bicounter 2/DiscriminationB`. Duration of the measurement is defined by the parameter `Normal mode/AccumTime`.

The command `run counting=660` runs the appropriate mode `Counting` measurement. In the output file *\*-mass.stm* this is reflected in the lines

```
# 2014-11-28 19:03:15 Light=0.07 Voltage=660
M 2014-11-28 19:03:20 Counting measurement
```

followed by the measurement results.

The necessary changes in the configuration file can be made during the *mass* program execution, not terminating it, but it is needed to issue the command `park` and then `init` after editing the configuration file in order to make these changes actual. It does not take a lot of time and is reflected in the output file, for example,

```
P 2014-11-27 21:07:14 Devices/Bicounter 1/DiscriminationA = 0.4
P 2014-11-27 21:07:14 Devices/Bicounter 1/DiscriminationB = 0.4
P 2014-11-27 21:07:14 Devices/Bicounter 2/DiscriminationA = 0.4
P 2014-11-27 21:07:14 Devices/Bicounter 2/DiscriminationB = 0.4
```

Measurements, to obtain the set of counting characteristics for each channel at different values of the discrimination, can be organised in the following process.

1. First of all, a level of the control light should be adjusted. It does not have to be bright in order not to affect the output results by detector non-linearity and we could assume that  $p$  is directly equal to  $\text{Var}[F]/E[F]$ . We can consider the light is optimal when fluxes in the channels are between 200 and 600 counts per micro-exposure for operating point specified in the configuration file. The specific value of `Tests/CountingLight` depends on device, but it is typically 0.1. For the fitting one can use the `run dtest`, in this case the light level is regulated by the parameter `Tests/DetectorLight`.
2. Set the required discrimination threshold, for example, 0.4 mV in the configuration file for all channels. Do not forget to submit the command `park` and `init` to reload the configuration file into the program. Starting with the minimum voltage (say  $\approx 550$  V) run command `run counting=550` for the measurement execution. After measurement, the answer `OK STATUS=READY` will come in. For the counting characteristic curve, the voltage step 50 V is enough. However, in practice we prefer to spend a little more time and use the voltage step equals 25 V. Do not exceed the voltage of 850 V, in spite of the limiting supply voltage for the PMT P7100 is 900 V.
3. After completing the measurement with the specified threshold, change its value in all channels, for example, to 0.6 mV, and perform new measurement cycle. It is recommended to take measurements for the set of values of 0.4, 0.6, 0.8, 1.0. This is due to the fact that part of the MASS devices have been programmed with inverse setting of discrimination level, when the set level of 0.4 corresponds to a real threshold of about 1.0 mV, and vice versa, the set up of 1.0 leads to a real threshold of 0.4 mV.

The measurement results are stored in the output file in the form:

```
c 2014-11-28 18:47:17 29.94 64.74 149.0 29.44 0.03288 0.01613 \\
0.01614 0.03798 0.9844 1.0442 2.4048 1.1181
```

for each measurement of the `Normal mode/BaseTime` and for the accumulated average `Normal mode/AccumTime` in the string

```
C 2014-11-28 18:48:16 30.46 65.83 150.9 30.02 0.03339 0.01598 \\
0.01607 0.03549 1.0169 1.0521 2.4240 1.0653
```

The format of these lines is the same, both individual estimates and average values can be used to plot dependencies. After the prefix “C” and the time-stamp, in the fields 4 through 7 the mean fluxes are presented; in the fields from 8 to 11 the flux variances are shown, and in

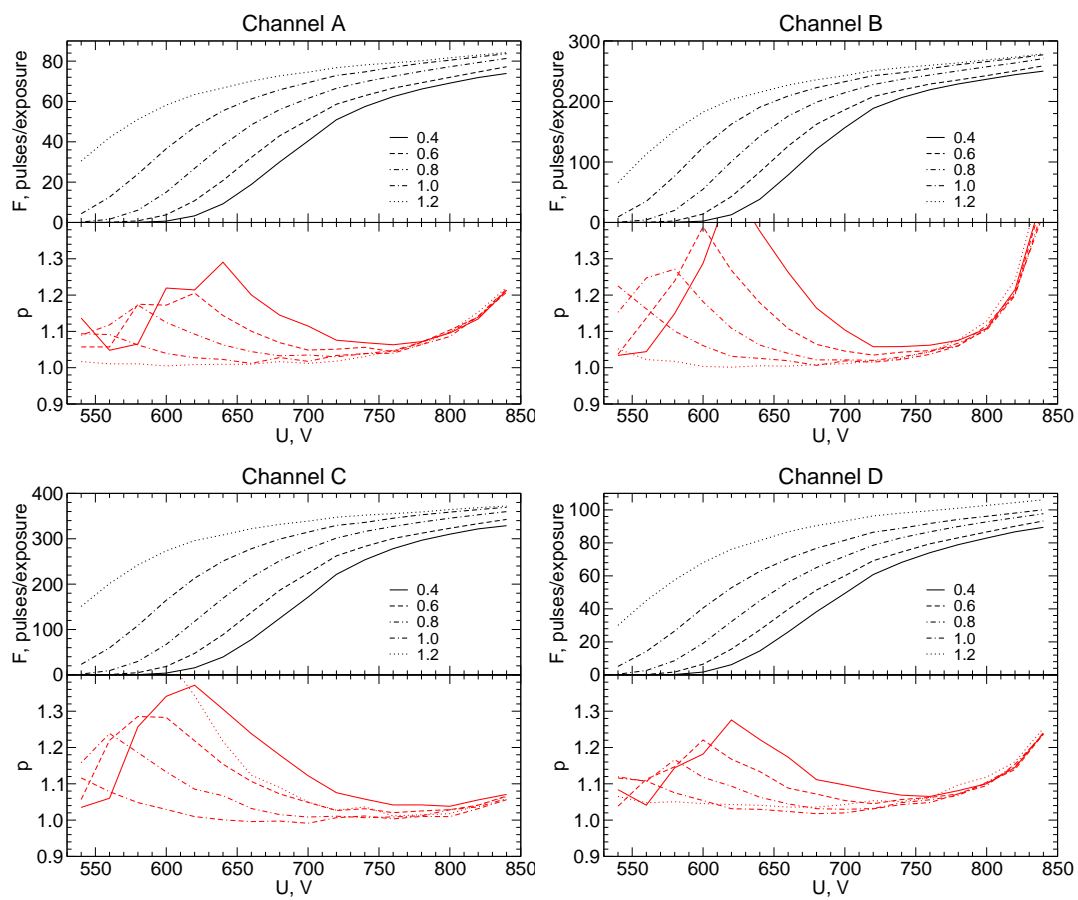


Figure 1: Example of counting characteristics measured with MASS/DIMM device MD09 for all detector channels and for five discrimination thresholds.

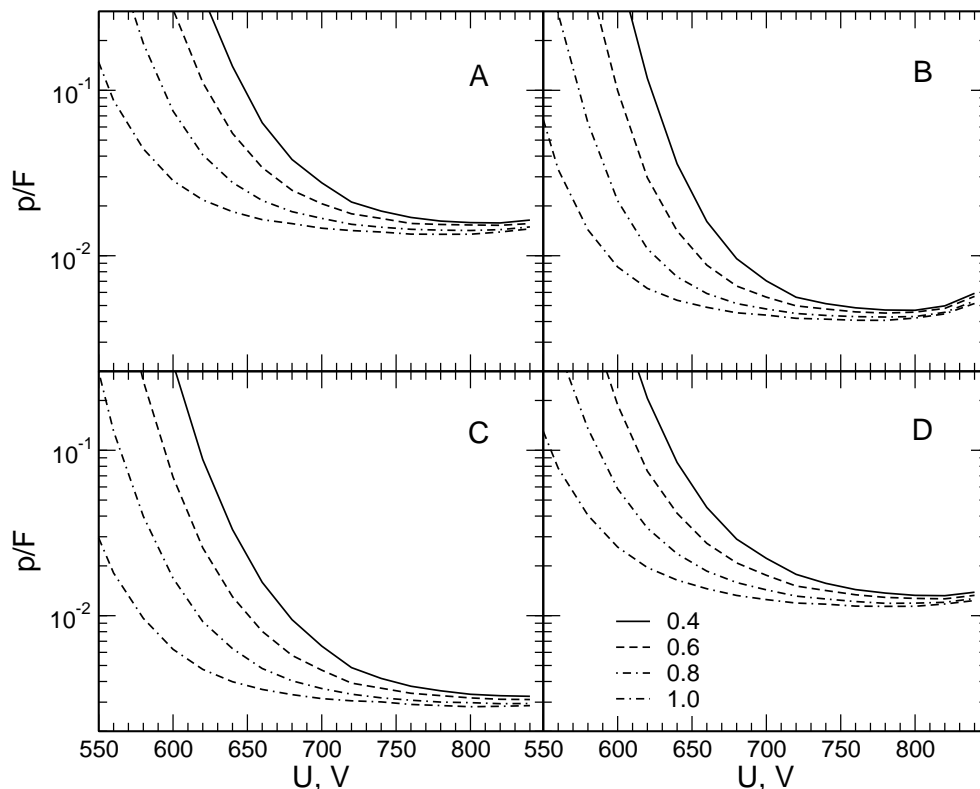


Figure 2: Example of the dependencies  $p/F$  versus high voltage supply for four discrimination levels calculated with measurement data plotted on Fig. 1.

the fields from 12 to 15 the non-poisson parameters  $p$  are presented for channels A, B, C and D, respectively.

Further, the data are converted into a table with the supply voltage as an argument by using a simple script, and presented in the form of graphs to analyse the behaviour of characteristic curves and to select the operating point. An example of such curves constructed from measurements of 27 and 28 November 2014 with the MD09 device is shown in Fig. 1. The measurements were performed remotely at night time under closed dome. The temperature of the device was from  $-1$  to  $+1^\circ\text{C}$ .

One can see that in our device the effect of the threshold is inverted. Counting curve is shifted toward higher voltages for formally installed threshold  $0.4$  mV. Conversely, the shape of the curves for the formal discrimination level  $1.2$  says that really the threshold is very low. We checked out the *mass* code and MASS counters microcode and found that the devices equipped by modified electronics contain inverse setting of the threshold. In this case the relation  $U_r = 1.4 - U_f$  can be applied. To avoid confusion on the figures we show threshold formal value of  $U_f$  which written in the configuration file.

Since the contribution of Poisson noise depends on the counting rate of pulses, conclusion on the operating point should be done on the basis of Fig. 2 where the value  $p/F$  as a function of the supply voltage is plotted, i.e. these curves characterise the contribution of the photon noise for case of some fixed light. The absolute value depends on the intensity of this light so it is necessary to look at the relative behaviour in the vicinity of the minimums. It can be seen that

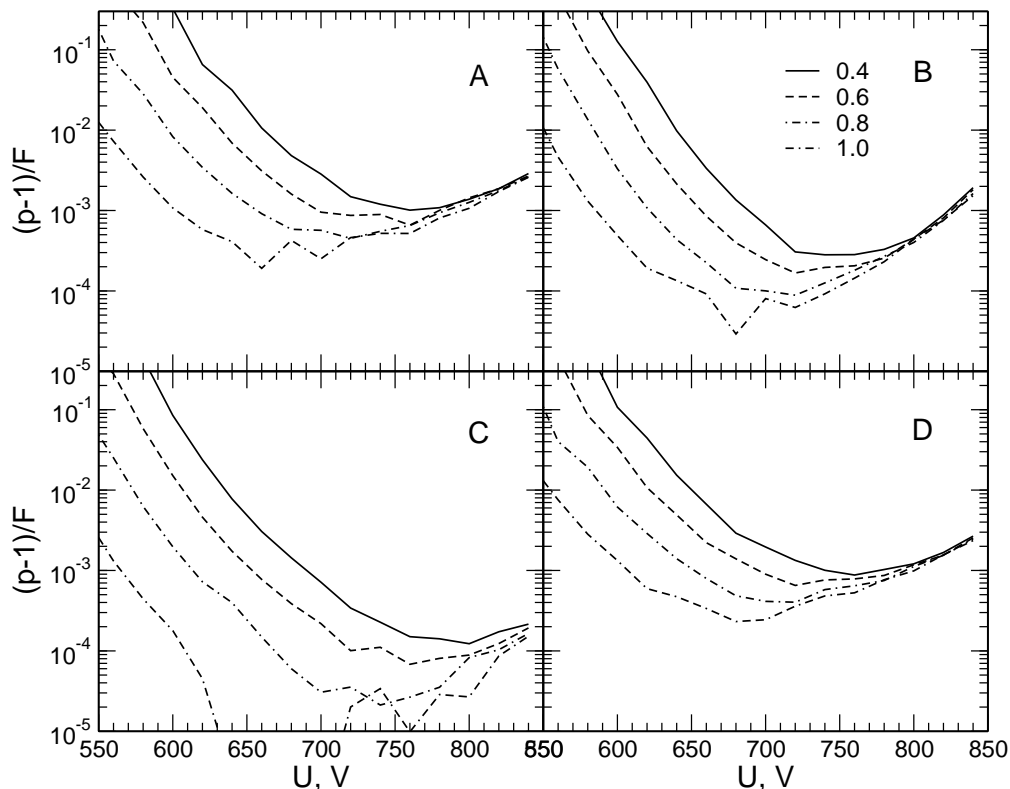


Figure 3: Example of the dependencies  $(p - 1)/F$  versus high voltage supply for four discrimination levels calculated with measurement data plotted on Fig. 1.

the minimums are very wide, especially for low thresholds, and occupy a range of 770 – 800 V.

Since the main reason for distinction the parameter  $p$  from unity, is the presence of after-pulses in PMT what induces mainly an uncertainty in measurements, because of its quite strong dependence on temperature and other external conditions. The after-pulses probability is proportional to  $p - 1$  (see Introduction). To determine the operating point on the basis of these considerations, the curves of  $(p - 1)/F$  was plotted in Fig. 3. It is clear that the relative accuracy of the determination of the  $p - 1$  value is significantly worse than for the  $p$ , therefore the curves are not quite smooth. But one can safely conclude that by reducing the supply voltage up to 700 V, we can significantly increase the stability of output results.

Considering both of these factors are equally important, we have chosen supply voltage of 750 V and discrimination thresholds of 1.0 mV (real threshold 0.4 mV).

### 3 Determination of the parameters of non-linearity and non-Poissonity

The values discussed in the previous section are burdened, though weakly, by the effects of non-linearity inherent to photon counting method. The final value of the parameter  $p$  and non-linearity parameter  $\tau$ , which should be used for measured statistics correction, must be determined from other measurements. First of all, set above selected value of supply voltage and discrimination threshold in the configuration file.

To measure the statistical dependence  $p$  as function of incoming flux of pulses  $\langle F \rangle$ , use the command `run stat=light_value`. This command sets the level of the control light, i.e.

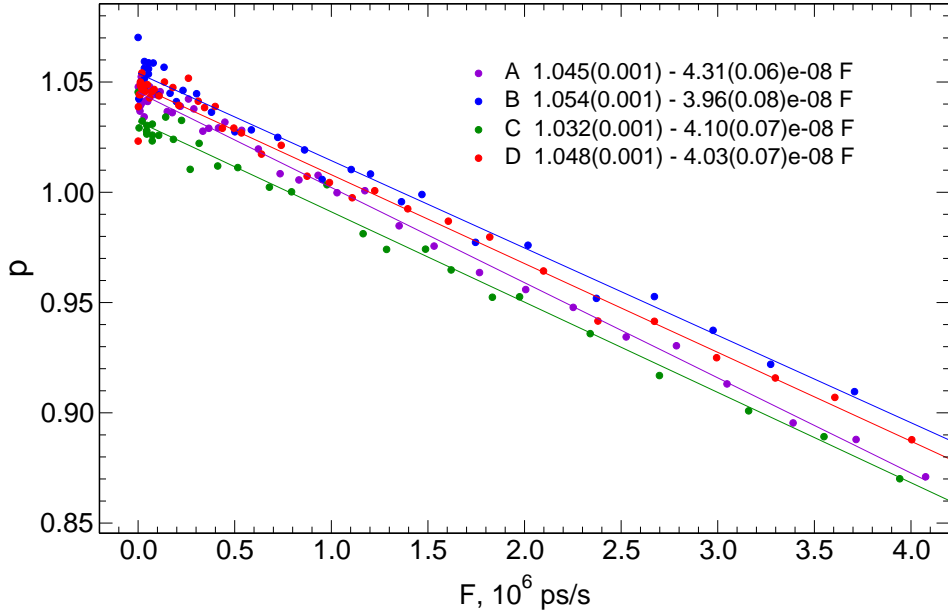


Figure 4: Example of statistical dependence of  $\frac{\text{Var}[F]}{\text{E}[F]^2}$  from flux obtained for device MD09.

the input photon flux and consequently pulses flux, and launches operational mode `Statistic measurement`. It reflects in the output file as

```
# 2014-11-28 20:00:40 Light=0.005
M 2014-11-28 20:00:45 Statistic measurement
```

The results will be written in the same form as in the case of `Counting measurement` as the “c” lines for `Normal mode/BaseTime` and `Normal mode/AccumTime`. Unlike the counting characteristics measurement in the configuration file anything does not need to be changed.

The initial part of the measurement should be done with minimal step 0.005–0.01 in `Light` value because pulse flux increases rapidly, while we should have a lot of points for small fluxes to fasten the value of  $p$ . Then the step in control light may be increased to a reasonable level. The maximum value of the intensity depends on the instrument, but to determine non-linearity reliably is sufficient to achieve the pulse flux of about  $3 \cdot 10^6$  per sec (3000 in 1 ms micro-exposure). Of course, we have to be guided by the channel with the minimal flux.

The measurement (one can even use individual dots) should be plotted. An example of such measurements is shown in Fig. 4. The initial linear portion of these dependencies should be approximated by a linear function. From the formula (1), it follows that the slope of the curve is uniquely related to the non-linearity parameter  $\tau$ , and the constant is equal to  $p$ . Our measurements were performed with a micro-exposure (`Normal mode/Exposition`) 0.5 ms and scaled for 1 s. From calculated slope coefficients (they are shown on the graph) we determined the non-linearity parameter for channels A, B, C and D as  $21.6 \pm 0.3$ ,  $19.8 \pm 0.4$ ,  $20.5 \pm 0.4$  and  $20.2 \pm 0.4$  ns. These values are recorded in the configuration file in nanosec.

## 4 Conclusion

Although the control of non-Poisson parameter can be carried out on the base real measurements of scintillation indices, namely from measurements of the sky background, it is preferably to

measure the parameters of the PMT as described every year. An important factor is that PMTs used in all MASS instruments have already fulfilled the warranty period. For example, photo-multipliers mounted in our device in 2003 exhibit a certain degradation in the increasing of fraction of after-pulses, especially at high supply voltages.

It is possible to measure counting and statistical dependences using simple command line sripts. For example you can fill needed voltage levels in file *hv\_list* and enter

```
for l in `cat hv_list`; do echo "14 run counting=${l}; echo "14 run counting=${l} |
netcat -w 82 -i 82 hostname 16201 ; sleep 83; done
```

Here *hostname* is the machine where *mass* is run. The port number 16201 is the default port to connect with *mass* program. The time intervals are adopted for Normal mode/*AccumTime* equals 60 s.

After start the script you will see at console

```
14 run counting=540
14 OK WAIT=80
14 OK STATUS=READY
14 run counting=560
14 OK WAIT=80
14 OK STATUS=READY
14 run counting=580
14 OK WAIT=80
14 OK STATUS=READY
.....
.....
```

Similarly, to measure statistics you can form file, e.g., *light\_list* with needed light levels and run

```
for l in `cat hv_list`; do echo "14 run stat=${l}; echo "14 run stat=${l} |
netcat -w 67 -i 67 hostname 16201 ; sleep 68; done
```



# Bibliography

- [1] Kornilov, V., A statistical description of the non-linearity of photon counts, *Astronomy Report*, **52**, 70, 2008
- [2] Kornilov, V., Effects of dead time and afterpulses in photon detector on measured statistics of stochastic radiation, *JOSAA*, **31**, Issue 1, 7, 2014