Dark Current induced trigger in MEMPHYS*

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July 18, 2006

Abstract

Blabla

1 Motivations

On 5th of July, J. Bouchez had demonstrated the need to investigate deeper than expected the dark current induced trigger for a MEMPHYS tank. As a matter of fact, a 3 MeV reactor neutrino produce around 15 p.e, so basically 15 PMTs on a Cerenkov cone are hit, while in the same time at 2 kHz dark current noise per PMT in a 400 ns time window one can expect around 160 PMT hit randomly distributed. Although, it may be not a problem (not yet proved) to recover the PMTs of the signal, the main concern is the trigger. J. Bouchez has made a preliminary numerical analysis to show that the question is relevant. A long this line, I have investigated a toy MC and analytical analysis.

2 A toy MC

The toy MC consists simply of the generation of dark current random noise on each PMT baseline, then it simulates a digital sum of all the PMT baselines, and applies a threshold on a total number of PMT hit during a sliding window. This toy MC can be adapted according to:

```
NumberOfPMT  = 81,000 for MEMPHYS
DarkCurrentRate = 6.0*kHz  more likely for 12"
TriggerSlidingGate = 425.0*ns for MEMPHYS
PulseWidth = 5.0*ns this is the time quantum (a pulse width equivalent)
TimeDurationOfExp = 6000.0*micros (+TriggerSlidingGate)
                    as a total time for investigation
CountThreshold = number of PMTs at least to be fired in a TriggerSlidingGate to
                 produce a Trigger
```

*Preliminary

2.1 Dark current generation

According to the fact that dark current is a random noise, if ones make the assumption that there is no correlation between two noise hit (at least on the scale of `TriggerSlidingGate`), then the time interval between two hit δt follow an exponential probability with parameter $\tau = 1/\texttt{DarkCurrentRate}$. So, the probability to get 1 hit in the time window $[t_0, t_0 + \Delta t]$ reads:

$$\begin{aligned} P(1; [t_0, t_0 + \Delta t]) &= \int_{t_0}^{t_0+\Delta t} e^{(t-t_0)/\tau} \frac{dt}{\tau} \\ &= 1 - e^{-\Delta t/\tau} = \frac{\Delta t}{\tau} - \frac{1}{2}\left(\frac{\Delta t}{\tau}\right)^2 \ldots \end{aligned} \tag{1}$$

and is independent of t_0.

If one piles up N PMTs and if $\Delta t/\tau \to 0$, then it is well known that the probability to get n PMTs hit in a time window of Δt tends to a Poisson distribution:

$$P(n|N; [t, t + \Delta t]) \stackrel{\Delta t/\tau \to 0}{\longrightarrow} \text{Poisson}(n; N\Delta t/\tau) \tag{2}$$

One can see these properties reproduced by the toy MC on Fig. 1 for some parameters values used on purpose.

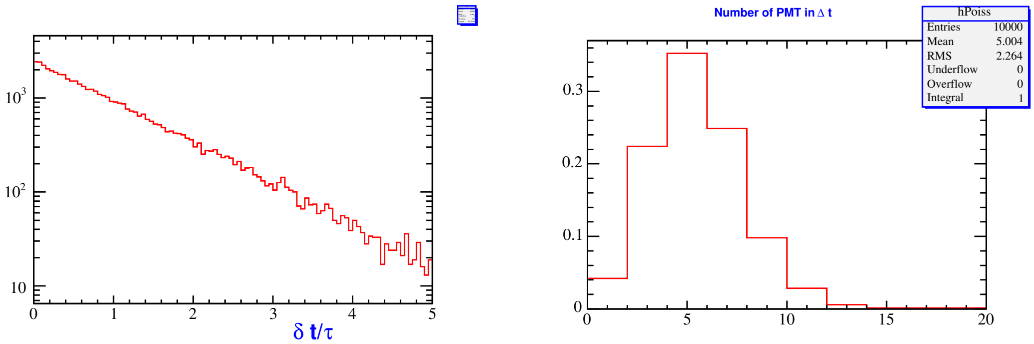

Figure 1: *left panel*: exponential generation of δt with $1/\tau = 1$ MHz dark current noise; *right panel*: number of PMTs fired among 50 PMTs, per $\Delta t = 100$ ns windows. One expects a Poisson distribution with a mean of $N\Delta t/\tau = 5$ as it is shown.

In fact, as it is mentioned, the Poisson distribution is an asymptotic distribution. The real probability to get exactly n PMTs fired among a collection of N PMTs in a Δt time window, with the hypothesis that each PMT dark current rate has a $1/\tau$ frequency, reads (using Eq. 1):

$$\begin{aligned} P(n|N; [t, t + \Delta t]) &= C_N^n P(1; [t, t + \Delta t])^n \left(1 - P(1; [t, t + \Delta t])\right)^{N-n} \\ &= \text{Binomial}(n, N; P(1, [t, t + \Delta t])) \end{aligned} \tag{3}$$

2.2 Trigger simulation

One may wish to know the occurrence of "how many times per second, n_{Th} PMTs are fired among N PMTs?". In fact, J. Bouchez noticed that this question is not complete as one may trigger only if the number of PMTs fired in a Δt sliding windows just exceeds n_{Th}. That is to say, one should consider the stepping function of the number of PMTs fired in the sliding window Δt examined at t, noted $n(t)$, and consider as "trigger" the passage $n(t) = n_{Th} \rightarrow n(t + dt) = n_{Th} + 1$ in an infinitesimal time duration dt. In fact, looking at Fig. 2, where is displayed the digital sum of $N = 81,000$ PMts with 6 kHz dark current noise rate in sliding window of 425 ns (computed every $dt = 5$ ns), one notices that it is true that the threshold[1] at 250 is reached by steps, but one may also specify that if there is a trigger at t_1, before to re-trigger the $n(t > t_1)$ function may pass through a sequence $n(t) = n_{Th} + 1 \rightarrow n(t + dt) = n_{Th}$.

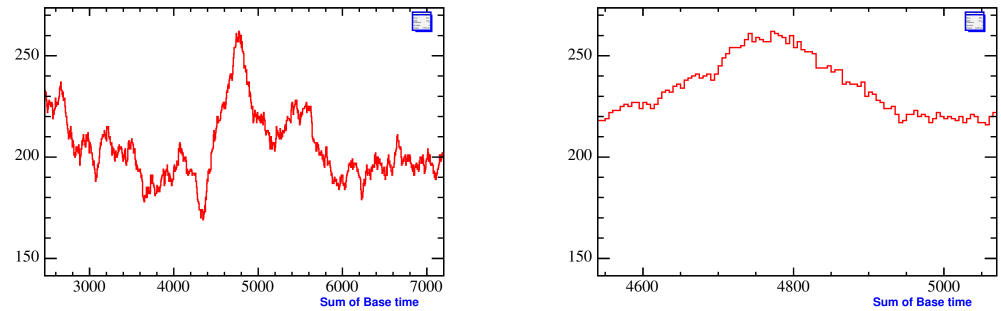

Figure 2: *left panel*: Digital sum of the time evolution of $N = 81,000$ PMTs with a dark current of 6 kHz, computed for a time sliding window of 425 ns every 5 ns; *right panel*: zoom around the location of a trigger threshold at 250 PMTs.

So in practice, one considers as a trigger the passage $n(t) = n_{Th} \rightarrow n(t+dt) = n_{Th}+1$ and groups together the following $n(t)$ values contiguous in time for which $n(t) >= n_{Th}$. Using this definition, one gets the results for one MEMPHYS tank (Tab.1): $N = 81,000$ PMTs, a sliding window of 425 ns which corresponds to the maximum time of flight of Čerenkov light in the $\phi : 65$ m $\times$ $H : 65$ m cylinder water volume ($v = 22,6$ cm/ns).

[1] mean number of PMTS is 206 and the threshold is set 3 sigma above

DC per PMT (kHz)	Mean of PMTs fired	Threshold (at 3σ)	Trigger (kHz)
1	34	52	325
2	69	93	378
3	103	133	198
4	138	172	378
5	172	211	268
6	206	249	416
DC per PMT (kHz)	Mean of PMTs fired	Threshold (nσ)	Trigger (kHz)
1	34	40 (1)	
1	34	46 (2)	

Table 1: Mean number of PMTs (m)fired among $N = 81,000$ PMTs on a time sliding window of $\Delta t = 425$ ns corresponding to the dark current (DC) rate (f) per PMT (this is $N\Delta t * f$). Then, setting a threshold to $m + 3\sqrt{m}$, one reads the trigger rate (see text for the definition of a trigger).