Photon Emission from R1408 PMT. P.J. Harvey and H.B. Mak
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Gene reported earlier on data from LSND on possible photon emission from the dynodes of R1408 PMT when electrons strike the dynode surfaces. In particular, the data indicate that photon emission from the first dynode may be the most important. To study this effect, we looked at the coincidence spectrum between 2 R1408 PMTs. For this PMT, the photoelectron transit time from the photocathode to the first dynode is approximately 11ns and the electrons then take another 24ns or so to go through the dynode structure. Thus the coincidence between one PMT and the detection of the photons emitted from dynodes of this PMT by the other PMT will give two coincidence peaks. These peaks correspond to;

1. Photon emission from dynodes of PMT A due to electron bombardment, PMT B then detects one or more of these photons. The anode pulse from PMT B should be later than anode pulse from PMT A by at least 11ns.
2. Interchange the roles of PMT A and B; and the anode pulse of PMT A should be at least 11ns later than anode pulse from PMT B.

Thus the two coincidence peaks should be separated by approximately 22ns if the emission of photons from the first dynode dominates, and wider if the photons are from other dynodes. It should be noted that it is possible to have one of the coincidence peak to be much larger than the other coincidence peak because of higher photon emission probability in one PMT, and the coincidence spectrum may appear to have only one coincidence peak. However, if the absolute time scale can be established, such coincidence peak should always be delayed relative to simultaneous emission of photoelectrons in both PMTs.

We have done the following measurements.

1. Placed two R1408 PMT facing each other with a cerenkov source between them. Separation of front surface was about 1cm. Data accumulation time was varied to give good timing spectra. This determined the timing of the coincidence peak for simultaneous emission of photoelectrons in both PMTs.

2. The two PMTs were left in place and cerenkov source removed. Data accumulation time was 45 min. for different PMT combinations. This measured the random coincidences between PMT dark noise

pulses and coincidences between one PMT and the detection of photons emitted by the dynode of this PMT by the other PMT.

The above measurements were done for three R1408 PMTs;

1. Serial number CA226, Pyrex glass bulb. Total Weight = 771g. PMT base has no Sylgard.
2. Serial number CA229, Pyrex glass bulb. Total weight = 696g. PMT base has no Sylgard.
3. Serial number ZW535, Schott 8246 bulg. Total weight = 1068g. PMT base filled with approximately 150g of Sylgard.

Thre separate measurements were done with the following pairs;

1. PMTs CA226 and CA229 (spectra 1a and 1b)
2. PMTs CA226 and ZW535 (spectra 2a and 2b)
3. PMTs CA229 and ZW535 (spectra 3a and 3b)

The PMT-base combination is somewhat stupid, but we did not think ahead before we took data. Also spectra cannot be sent via bitnet.

Result.

For arrangement 1. There is a sharp coincidence peak in all three coincidence spectra. The timing peak distribution has a sigma of approximately 1.63ns. The timing resolution is good because the two PMTs were very close to each other and most likely only the central portion of the photocathode were used. There are late pulses in the timing spectra. These pulses can be from photons produced in the dynode which were absorbed by the same PMT producing a later pulse (in this case the primary pulse or electrons which produce the photons is below detection threshold) or from funny photoelectron trajectories.

For arrangement 2. Each of the 3 spectra has a sharp coincidence peak with a sigma of 2.4ns. on a flat background which are random coincidences from PMT dark noise pulses. The peak to background ratio is about 17:1. It is based on the presence of this peak that LSND suggested that there may be substantial photon emission from the first dynode when an electron strikes it and the photon is then detected by the other PMT, thus producing the sharp coincidence peak. The resolution of this timing distribution is consistent with folding the timig resolution of two R1408 PMTs (sigma of approximately 1.5-1.6ns). However, in all cases, the centroid of the coincidence peak is the same as in arrangement 1. This strongly suggests that the coincidence peak observed in arrangement 2 are from simultaneous emission of photoelectrons produced by a common light source, and not by photons emitted from the dynode due to electron bombardment. This hypothesis is supported by the fact that all three coincidence spetra are similar; each has only one peak and the peak counts are more or less the same to within 20%. If photon emission from dynode produces the coincidence peaks, we should expect at most two spectra to have one coincidence peak and the third to have two peaks. Moreover, the peaks would have very different counts.

Thus our data lead to the conclusion that there is a light source in the R1408 PMT which can cause simultaneous photoelectron emission from 2 such PMTs when they are placed facing (or near) each other. Possible light sources are

1. Cosmic ray producing Cerenkov light in PMT glass. LSND ruled that out by placing thick glass between two PMTs and did not observe a significant increase in the coincidence rate.

2. Th and U in PMT glass. LSND now thinks this is the problem. Data at Queen's is troublesome. The net coincidence peak counts for arrangement 2 are;
   a. CA226 and CA229 counts = 15000 in 45 minutes
      background = 670 in 45 minutes
   b. CA226 and ZW535 counts = 18000 in 45 minutes
      background = 1000 in 45 minutes
   c. CA229 and ZW535 counts = 17000 in 45 minutes
      background = 900 in 45 minutes

   We should expected counts in a to be higher than counts in b and c by a factor of 2 due to lower Th and U in Schott 8246 glass. This is not the case. It is certain that ZW535 has heavier (hence thicker) glass bulb; hence higher probability of producing Cerenkov photons by beta rays and gamma rays emitted by decays in the Th and U chains. The Th and U in the Sylgard may make matter worse. Difference in photon detection efficiency may also affect the coincidence rate. So may be we should not expect lower coincidence rate when ZW535 is one of the PMT used.

3. Other?

Conclusion:

When electrons with 100eV to 1000eV energy strike a dynode, we expect atomic excitations; hence a large number of photons (from visible to soft X-ray) will be produced. Some undoubtly will strike the photocathode producing late pulses and some will escape the PMT all together to be detected by another PMT. We seen late pulses from PMTs (within 100ns of the primary timing peak) by all 4 manufacturers;

PMT	Late Pulse Fraction
Burle C83601E	4%
EMI 9351KB	4.4%
Ham R1408 Mark 1	7.4%

Ham R1408 Mark 2	3.3%
Ham R3600	1.7%
Phil XP1802	7.1%

Ham R3600 is the 50cm PMT. Ham R1408 mark 1 is the older 20cm PMT, and mark 2 is the version in contract. The number of PMT samples studied is small, hence the numbers listed should not be taken too seriously. Also, the late pulses are extracted from timing spectra. If these late pulses are from photon produced at the dynode, then the primary electon pulse which produce the photons must be below detection threshold (so that the TDC does not see the earlier primary pulse and triggered by the late pulse). The other possible source of late pulses are funny photoelectron trajectories. Heavy ions come much later in time.

The coincidence between 1 R1048 PMT and another (R1408 or other type of PMT) observed by LSND is not likely to be due to photon emission from the dynode structure produced by electron bombardment, but rather from real light sources. One possible source is Cerenkov light produced in the glass by fast electrons (beta or photon interaction in glass). Cosmic rays may also contribute. There may be other sources.

It is possible to estimate the probability of detecting photons produced by electron bombardment of the dynode structure by another R1408 PMT placed 1cm away. The random coincidence rate between two PMT is

RAN = R1.R2.DT

Where R1 = dark noise rate of PMT 1
R2 = dark noise rate of PMT 2
DT = coincidence time duration

The coincidence rate of photon from dynode is

COINC = R1.P2 or R2.P1

where P1 is the probability of PMT 2 detecting photons from dynodes of PMT 1 and P2 is the probability of PMT 1 detecting photons from dynodes of PMT 2. By choosing different regions of the timing spectrum it is possible to deduce P1 and P2 separately.

In another measurement using CA226 and CA229, in 45 minutes

R1 = 6700Hz
R2 = 6500Hz
(The dark noise rate is high because PMTs were exposed to light just before measurement to increase statistic)

RAN = 840
COINC less than 200 (cannot see peak, use generous limit)

DT = 10ns

Hence P2 = COINC.R2.DT/RAN
less than 200x6500x0.00000001/850
less than 0.000015

So the probability of the dynode of a R1408 PMT producing photons when bombarded by electrons and the photon be detected by another R1408 PMT placed 1cm from its front face is less than 0.00002 per photoelectron. Thus this effect is not likely to affect the performance of SNO detector.