HOWTO measure the number of photo electrons per MeV for the detectors of the Neutron Wall

Johan Nyberg

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1 Introduction

The number of created photo electrons per MeV of deposited energy is an important parameter of a scintillator detector. It is a measure of how well the complete detector (scintillator light yield, light collection, photo cathode of the PMT, etc.) can convert the deposited energy into an output signal of the photo-multiplier tube (PMT). The number of photo electrons per MeV, N_{phe}, is usually measured by comparing the size of the signal from the energy deposited in the detector by a γ ray from radioactive source, with the size of the single photo-electron signal, which is visible as a intense signal at very small amplitude. For liquid scintillator detectors a convenient radioactive source to use is ^{137}Cs ($E_\gamma = 661.6$ keV). The 661.6 keV γ rays give rise to a Compton distribution in the liquid scintillator detector (no or very small full energy peak), which has a Compton edge at 0.48 MeV. The energy of the Compton edge is used in the measurement of N_{phe}. The expression for the number of photo electrons per MeV is

$$N_{phe} = \frac{(P_{Ce} - P_{zo})}{(P_{sphe} - P_{zo})} \frac{G}{E}, \tag{1}$$

where P_{Ce} [ch] and P_{sphe} [ch] are the positions of the Compton edge and single photo-electron peak, respectively, in the measured spectra, and P_{zo} [ch] is to zero offset of the setup (see subsection 3.1). G is a factor used to correct for the change in amplification between the measurement of the single photo-electron peak and the Compton edge (see subsection 3.2). The value of G is typically 100. If a ^{137}Cs source is used, $E = 0.48$ MeV.

Typical values of the number of photo electrons for the Neutron Wall detectors are $N_{phe} = 300 - 800$ `phe`/MeV. Tables 1-3 show the results of measurements of N_{phe} for all 50 Neutron Wall detectors. The measurements were made in February 2003 just after the complete repair of all neutron detectors. The measurements shown in this table were made with the detectors standing on a table in the detector laboratory at IreS.

The average value of N_{phe} is 684, while it was well above 1000 before the big repair made during the time 2002 to Feb 2003. The reason for the reduction of the N_{phe} is not known. One possible reason could be the much thicker glass windows used now (5-8 mm) compared to before (about 3 mm) and/or that some of the windows are not fully transparent to the scintillation light (a few of them look yellow). It could also be that the white reflective paint inside the detector detector vessels is not as efficient as before, which would give a smaller light output.

2 What you need

The following equipment is needed for the measurement of the number of photo-electrons per MeV:

- A ^{137}Cs source with an activity $0.1 - 1$ MBq, placed somewhere in front of each detector segment, e.g. in the target position, which is located about 51 cm from the front face of the detector segments. The strength of the source is not sensitive. Only make sure it is gives a reasonable count rate in the detector, well above the background rate, but not larger than about 10 kHz.
- A standard shaping amplifier (sometimes called spectroscopy amplifier) of the type which is commonly used in HPGe or scintillator detector energy measurements. The shaping time of the amplifier should be set to something between 1 and 6 μsec, typically 1 or 2 μsec.
- A multichannel analyzer (MCA) or any DAQ system with a peak-sensitive ADC.
- A precision tail pulse generator.
- A standard oscilloscope (optional).

3 How to measure

3.1 Finding the zero offset

If there is a large zero offset, due to a DC offset somewhere in the signal path, the extracted value of N_{phe} would be wrong if this is not corrected for. The anode signal from the PMT, which is used in the measurement, has a negligible DC offset (AC coupled), but the shaping amplifier (if the unipolar output is used; use the bipolar output to avoid a DC offset from the amplifier) and the ADC might have an offset.

Use the precision pulse generator to investigate if there is a non-negligible offset. The zero offset is best obtained by changing the amplitude of the pulse generator signal in a few (at least two) precisely known steps, say by attenuating the signal by a factor of $A = 1$, 0.5, 0.1, which gives peaks distributed over a large portion of the channel numbers in the measured spectrum. A precision pulse generator often has accurately defined attenuation switches which can be used for the attenuation. By fitting a straight line to the measured peak positions as a function of the attenuation factor A, the zero offset, P_{zo} [ch], can be obtained.

Correct for any non-negligible offset either in the hardware, adjusting if possible the zero offset to be as close as possible to 0 ch both for the amplifier and for the ADC, or do the correction in the analysis. If the correction is done in the analysis, the obtained zero offset, P_{zo} [ch], should be subtracted from the measured values of P_{Ce} [ch] and P_{sphe} [ch] before N_{phe} is evaluated.

3.2 Finding the G factor

It is usually not possible to see in the measured spectrum the single photo-electron peak and the Compton edge of ^{137}Cs using the same gain of the shaping amplifier. The reason for this is that the single photo-electron signal is so much smaller than the signal due to the ^{137}Cs Compton edge. One must therefore change the amplification of the shaping amplifier between the two measurements by a factor G, which typically is 100. This can be done simple by changing the course gain on the amplifier for example from 5 to 500 (or whatever settings it has). Most amplifiers have accurate enough course gain settings, which means that by changing the coarse gain, e.g. from 5 to 500, really leads to a change of the gain by a number that is very close to $G = 100$ (close enough for our needs). But if this is not be the case, the extraction of N_{phe} would be wrong. To determine the factor G experimentally one can do the following.

- Set the amplifier to its high gain state, i.e. to the one that will be used for the measurement of the spe spectrum.
- Feed a signal from the pulse generator into the input of the amplifier and connect the output of the amplifier to the ADC input.
- Adjust the amplitude of the pulse generator so that the peak is located in the upper end of the spectrum measured by the MCA or DAQ.
- Note the position of the peak = P_{hg} (hg = high gain)
- Change the coarse gain of the amplifier to its low gain state, i.e. to the one that will be used for the measurement of the ^{137}Cs spectrum.
- Note the position of the peak = P_{lg} (lg = low gain)
- Determine the G factor as $G = P_{hg}/P_{lg}$. Note: if there is a DC offset in the setup (see previous subsection) this must be corrected for in order to get a correct value of G.

3.3 Measuring the single photo-electron spectrum

1) Apply a suitable HV value to the PMT if not already done. The standard HV values used during experiments are ok.
2) Connect the anode signal from the PMT to the negative input of the shaping amplifier.
3) Set the shaping time of the amplifier to about 2 μsec.
4) Connect the bipolar or unipolar output of the shaping amplifier to the ADC.
5) Set the amplifier to its high gain state.
6) Remove any sources from the vicinity of the detector.
7) Measure a spectrum with reasonable statistics. The spectrum should look like the lower spectrum shown in figure 1.
8) Save the spectrum for further analysis.

3.4 Measuring the ^{137}Cs spectrum

1) Items 1-4 are the same as in the previous subsection.
2) Set the amplifier to its low gain state.
3) Put the ^{137}Cs source in front of the detector.
4) Measure a spectrum with reasonable statistics. The spectrum should look like the upper spectrum shown in figure 1
5) Save the spectrum for further analysis.

4 How to analyze

From the measured spectra get P_{Ce} [ch], the position of the Compton edge in the ^{137}Cs spectrum, and P_{sphe} [ch], the position of the single photo-electron peak. The location of these positions are indicated in the spectra shown in figure 1. The number of photo electrons per MeV can then be calculated using equation 1.

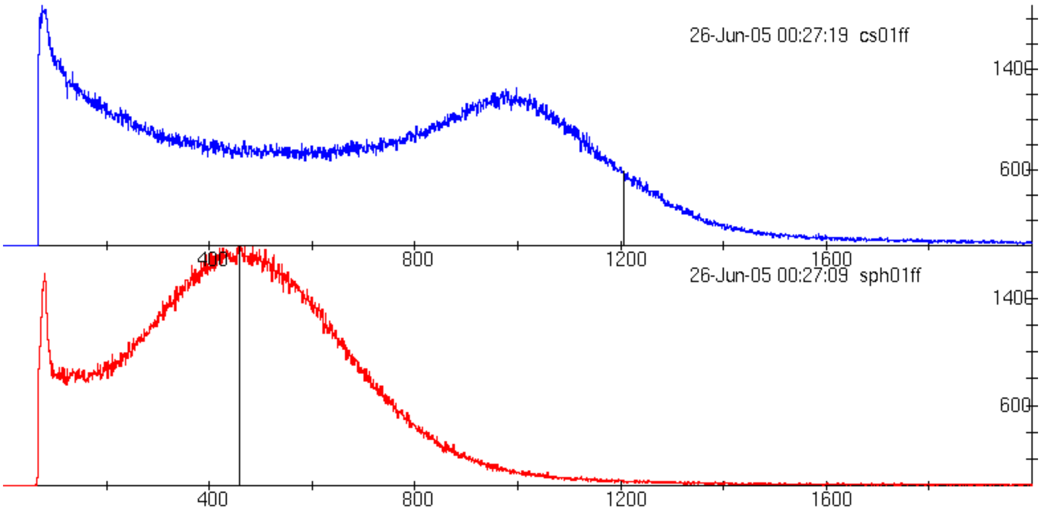

Figure 1: Spectra measured in Feb 2003 for detector segment `01FF`, which was mounted as detector number 01 in the 2003 EUROBALL + Neutron Wall campaign. Upper: Compton distribution and Compton edge of ^{137}Cs. Lower: Single photo-electron peak. The gain of the shaping amplifier was increased by a factor $G = 100.0$ in the lower spectrum compared to the upper one. The vertical lines show the positions $P_{Ce} = 1206$ ch and $P_{sphe} = 457$ ch in the upper and lower spectrum, respectively.

Hexagonal detector segments of type H1

Segment ID	Detector ID	PMT ID	PMT high voltage [V]	P_{Ce} [ch]	P_{sphe} [ch]	N_{phe} [phe/MeV]
01BB	00	9335	1510	1258	434	604
01DD	02	9351	1400	1244	419	618
01FF	01	9312	1155	1206	457	550
02BB	05	9346	1260	1190	328	756
02DD	07	9334	1105	1208	281	896
02FF	06	9333	960	1276	330	806
03BB	10	9342	1390	1257	328	798
03DD	12	9289	1170	1233	369	696
03FF	11	9328	1265	1188	280	884
04BB	15	9320	1086	1228	404	633
04DD	17	9313	1020	1200	363	689
04FF	16	9340	1640	1230	452	567
05BB	20	9301	1270	1249	368	707
05DD	22	9349	1360	1220	286	889
05FF	21	9285	1190	1210	299	843
06BB	36	9339	1345	1158	390	619
06DD	25	9321	1030	1194	327	761
06FF	35	9299	1300	1235	424	607
07BB	38	9290	1570	1239	456	566
07DD	27	9350	1390	1203	678	370
07FF	37	9324	1305	1203	383	654
08BB	40	9306	1200	1226	315	811
08DD	29	9330	1240	1199	363	688
08FF	39	9293	1320	1202	329	761
09BB	42	9284	1225	1213	377	670
09DD	31	9286	1330	1242	350	739
09FF	41	9295	1270	1180	403	610
10BB	44	9323	1430	1321	1092	252
10DD	33	9319	1050	1241	428	604
10FF	43	9307	1170	1229	404	634
COUNT	30	30	30	30	30	30
AVG			1271	1220	377	699
STDEV			163	26	82	123

Table 1: Number of photo electrons per MeV for the Neutron Wall hexagonal detectors of type H1. The second column gives the detector ID as numbered during the 2003 EUROBALL + Neutron Wall campaign. The last three columns are: P_{Ce} = position of the 0.48 MeV Compton edge for ^{137}Cs, P_{sphe} = position of the single photo-electron peak, N_{phe} = number of photo electrons per MeV calculated by using equation 1. For these measurements $E = 0.48$ MeV, $P_{zo} = 0$ ch, and $G = 100.0$ were used.

Hexagonal detector segments of type H2

Segment ID	Detector ID	PMT ID	PMT high voltage [V]	P_{Ce} [ch]	P_{sphe} [ch]	N_{phe} [phe/MeV]
11AF	04	9318	1155	1218	288	881
11BC	03	9303	1070	1195	326	764
11DE	26	9305	1000	1186	332	744
12AF	09	9337	1200	1189	317	781
12BC	08	9343	1180	1210	347	726
12DE	28	9327	1210	1203	300	835
13AF	14	9294	1090	1176	318	770
13BC	13	9341	1230	1182	298	826
13DE	30	9304	1145	1196	320	779
14AF	19	9338	1300	1198	302	826
14BC	18	9345	1375	1231	296	866
14DE	32	9288	1010	1198	328	761
15AF	24	9300	1080	1200	356	702
15BC	23	9314	1140	1232	353	727
15DE	34	9352	1330	1218	370	686
COUNT	15	15	15	15	15	15
AVG			1168	1202	323	778
STDEV			111	17	25	58

Table 2: Number of photo electrons per MeV for the Neutron Wall hexagonal detectors of type H2. See table 1 for further details.

Pentagonal detector segments

Segment ID	Detector ID	PMT ID	PMT high voltage [V]	P_{Ce} [ch]	P_{sphe} [ch]	N_{phe} [phe/MeV]
PEAB	49	5977	1965	1135	411	575
PEBC	48	5967	2090	1187	655	378
PECD	47	6039	2190	1185	603	409
PEDE	46	0603	2080	1213	607	416
PEAE	45	6030	2115	1162	521	465
COUNT	5	5	5	5	5	5
AVG			2088	1176	559	449
STDEV			81	29	96	77

All detector segments

Segment number	Detector number	PMT number	PMT high voltage [V]	P_{Ce} [ch]	P_{sphe} [ch]	N_{phe} [phe/MeV]
COUNT	50	50	50	50	50	50
AVG			1318	1212	395	684
STDEV			297	31	137	148

Table 3: Number of photo electrons per MeV for the Neutron Wall hexagonal detectors of type H2. See table 1 for further details. The average and the standard deviation for all 50 detector segments are given in the last two rows.