Pileup in ^{203}Hg Calibration

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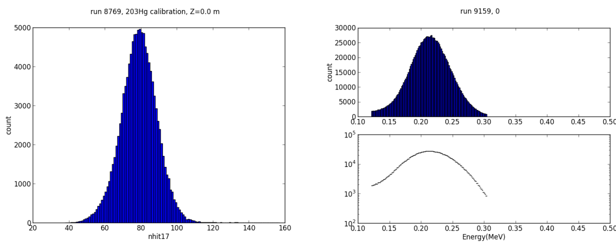
In this KamLAND internal note(KIN2013b), the algorithm used for ^{85}Kr coincidence analysis is applied to ^{203}Hg Calibrations.

Validity of the algorithm is checked. Accidental rate of pileup of ^{203}Hg is compared to that of single events.



(a) Nhit17 distribution (b) energy spectrum

I. INTRODUCTION

Pileup events due the high intensity of ^{203}Hg source in calibration are expected and serves one of the cause of high energy tail in ^{203}Hg spectrum[1]. We, however, still do not have a direct look at those pileup events. It would be useful to confirm such study by actually getting the pileup events out and see how exactly it contributes to the high energy tail.

In the study of delayed coincidence of ^{85}Kr minor decay branch, an algorithm is developed to extract two physics events from one FBE event[2]. It is hard to estimate the efficiency and energy scale of the algorithm. Simulation is hard, as we would have to cope with effects of frontend electronics which has not been implemented yet. Using the method on real ^{203}Hg calibration data will help improve the algorithm, especially energy scale thanks to the almost monochromatic γ radiation from the ^{203}Hg source.

II. ALGORITHM

The algorithm is the same as that of ^{85}Kr[2], the *hit range* was selected to be (100, 400). This range is based on the fact that a normal event of ^{203}Hg γ has a hit distribution centered at about 80(Fig. 1(a)).

III. DATASET

5 ^{203}Hg calibrations 8769, 9020, 9050, 9159, 9260 carried out in late 2009 and early 2010 are used (Table I). *Runtime* is multipled by ratios of prescale trigger to give *livetime* [3].

TABLE I. Hg Calibration Runs

Run	Runtime(s)	Livetime(s)	Date
8769	792	8	2009-07-19
9020	1548	44	2009-10-07
9050	1780	47	2009-10-15
9159	27066	717	2009-12-02
9260	21547	880	2010-01-21

IV. RESULTS

A. Spectrums

Applying the algorithm of ^{85}Kr pileup, the delayed conincidence result is plotted in Fig. 2.

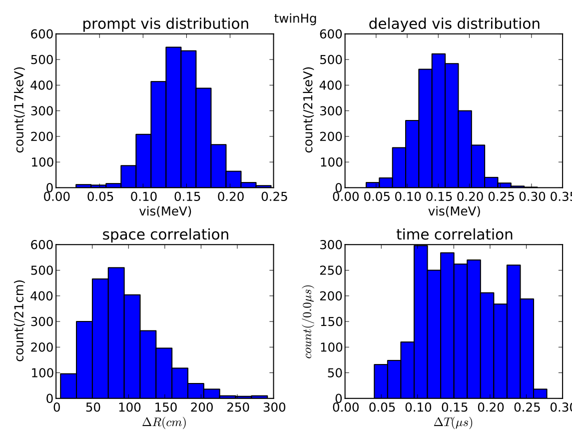


FIG. 2. several spectrums of a delayed coincidence study

The peak of prompt event is centered at 0.14 MeV, while that of delayed being 0.15 MeV. These are lower than the peak of single events as 0.19 MeV(Fig. 1(b)).

The space correlation looks normal and is further investigated with QQplots.

B. QQplots

QQplots are produced to check if radius and energy distribution of prompt, delayeda and single are the same. Radius are essentially the same(Fig. 3 (a)(b)). However, energy distributions have shift trends(Fig. 3 (c)(d)). The cause may be dark charge substraction which assumes a full time window of an FBE event, which is not the case for each subevent. It indicates that energy scale is mostly unexplored, only relative energy information can be drawn.

E_{prompt} and $E_{delayed}$ are both lower than E_{single}, if we add the two together, the combined energy gets larger than E_{single}(Fig. 3(e)). This excludes the possibility that a single event is wrongly splitted into two.

C. Channel Occupation

Usually in each event, any PMT is hit by 0 or 1 photoelectron (p.e.). For pileup, there is an additional chance to have 2 p.e. We can calculate the expectation of NhitID (sum of Nhit from 17 and 20 PMTs) of a pileup event, which is the sum of expectation of 1 p.e. and 2 p.e. channels.

Let h be expectation of NhitID for a normal event (non-pileup), N be the number of PMTs (bad channels excluded). The ratio of occupation is then $r := \frac{h}{N}$. For pileup events, we can expand the ratio as,

$$1 = [(1-r)+r]^2 = (1-r)^2 + 2r(1-r) + r^2,$$

where the three terms are ratios of 0, 1 and 2 p.e. channels, repectively. Then expectation of hits of a pileup N_h is $N(r^2 + 2r(1-r)) = 2h - \frac{h^2}{N}$.

This model is verified against the Hg calibrations. In reality, we need to consider *dark hit*, which is noise mimicing p.e. signal originating from unknown sources. In KamLAND, we infer rate of dark hit for each run, by averaging null light curves preceeding that of p.e. [4, p. 78]. The results are available in csv format and called *dark table*. In the calculation given in Table II, h is subtracted from *dark*. h and N_h are averages of each run.

TABLE II. Channel Occupation of Pileup Events

run	N	h	dark	expected N_h	N_h
8769	1823	108	18.12	193.45	185.5
9020	1839	108	16.75	194.72	192
9050	1838	107.75	16.49	194.48	189
9159	1839	107	15.97	193.52	192
9260	1840	107.25	16.31	193.70	194

As shown in Table II, the calucation confirms our hypothesis: Pileup events are two independent Hg events which accidentally falls into a single FBE event time window.

D. Event Rate

Rate (r_p) as well as half life (τ_p) of pileup event is related to that of single (r_s and τ_s). $r_p = \Delta T r_s^2$, where ΔT is time window of the delayed coincidence of two sub Hg events(Fig. 2). To cross check with ^{85}Kr[2], we use the same time window of 50-200ns, therefore $\Delta T = 150ns$.

The expected number of pileup events N_p is then $Lr_p\epsilon_{dip}$, where L is the *livetime* of each run (Table I), $\epsilon_{\rm dip}$ is the efficiency of pileup event identification as in ^{85}Kr[2]. Here we treat $\epsilon_{\rm fit}$ as 1, because the energy of ^{203}Hg is high enough to be reconstructed correctly. Table III gives a comparason between observed and expected pileup events. *Single Rate* is normal event rate of ^{203}Hg calculated by Kyohei([3]).

TABLE III. observed and expected pileup events in Hg calibration runs

run	Single Rate (kHz)	expected(pairs)	observed(pairs)	ratio
8769	15.1	273.61	210	0.77
9020	4.6	139.66	129	0.92
9050	4.1	118.51	95	0.80
9159	2.0	430.20	417	0.97
9260	0.9	106.92	119	1.11

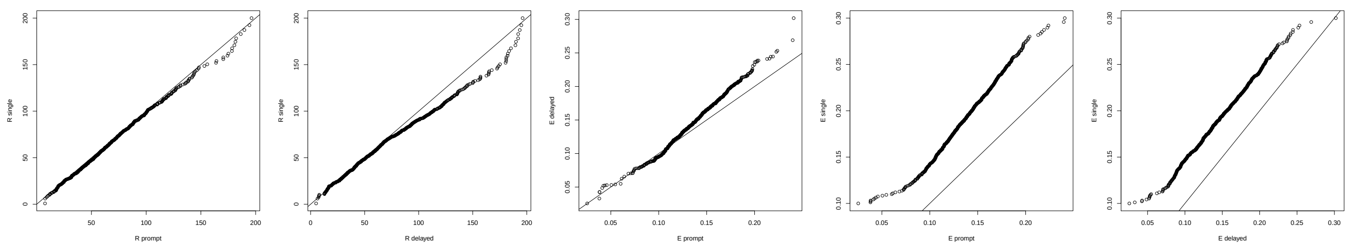
The ratio of observed over expected being larger than 1 in run 9260 indicates there are notable systematic uncertainties involved. Single rate of ^{203}Hg is itself a rough calculation as spectrum of ^{203}Hg exposes a heavy-tailed shape that deviates from guassian, making it hard to count against backgroud. The background events manifest themselves when the source gets weaker in run 9260. At the same time, miss fit ratio at this energy region, though assigned to 0 for simplicity, is largely unknown. Based on those points, we just infer that $\epsilon_{\rm dip}$ is 70%~100%.

r_p also decays along with r_s, with a doubled decay rate. Therefore $\tau_p = \frac{1}{2}\tau_s$. This is verified by an exponential fitting (Fig. 4).

V. CONCLUSION

The vertex fitter works reliably, while energy fitter has a large uncertainty and exposes a shift. The former relies on timing information, which is not affected much in pileup events. But the latter exploits charge information, which is affected by the validity of dark charge estimation. It would help if we fit two events simultaneously.

Occupancy model works, and confirms the nature of accidental coincidence. It can be exploited further to estimate performance of *waveform analysis* algorithms,



(a) $\mathrm{R}_{prompt} - R_{single}$ (b) $\mathrm{R}_{delayed} - R_{single}$ (c) $\mathrm{E}_{prompt} - E_{delayed}$ (d) $\mathrm{E}_{prompt} - E_{single}$ (e) $\mathrm{E}_{combined} - E_{single}$

FIG. 3. examples of different types of events in KamLAND

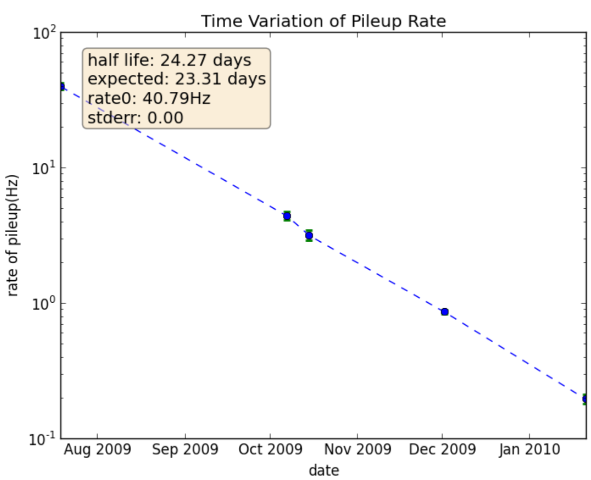


FIG. 4. Event pair rate goes exponential decrease

which reconstruct time-charge information from waveforms from PMT.

Agreement of half life is pilup event gives us confidence on this pileup reconstruction algorithm.

ϵ_{dip} is estimated to be 70%˜100%, this serves as a cross check to ^{85}Kr result[2]. They agrees at least within one order of magnitude.

[1] C. Grant, "Hg203 calibration source analysis," (2010), kamLAND Collaboration Meeting at Amsterdam, `http://kamland.lbl.gov/twiki/pub/Main/CollaborationMeetingLBNL2010/MeetingAgenda/KamLAND_Collaboration_Meeting_203Hg_Source_Analysis_March2010.ppt`.

[2] B. Xu, "Pileup reconstruction," (2013), kamLAND Internal Note 2013c.

[3] K. Nakajima, "Be-7 solar neutrino analysis," (2010), kamLAND Collaboration Meeting at Berkeley, `http://kamland.lbl.gov/twiki/pub/Main/CollaborationMeetingLBNL2010/MeetingAgenda/Be7_solar_neutrino_analysis_Mar_2010.pdf`.

[4] K. Nakajima, *First Results from ^{7}Be Solar Neutrino Observation with KamLAND*, Ph.D. thesis, Tohoku University (2010).