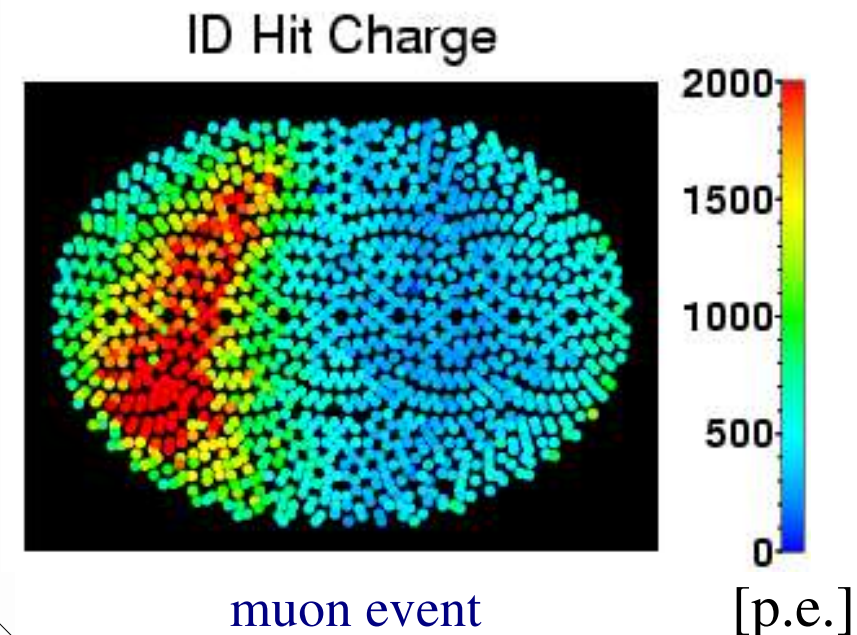
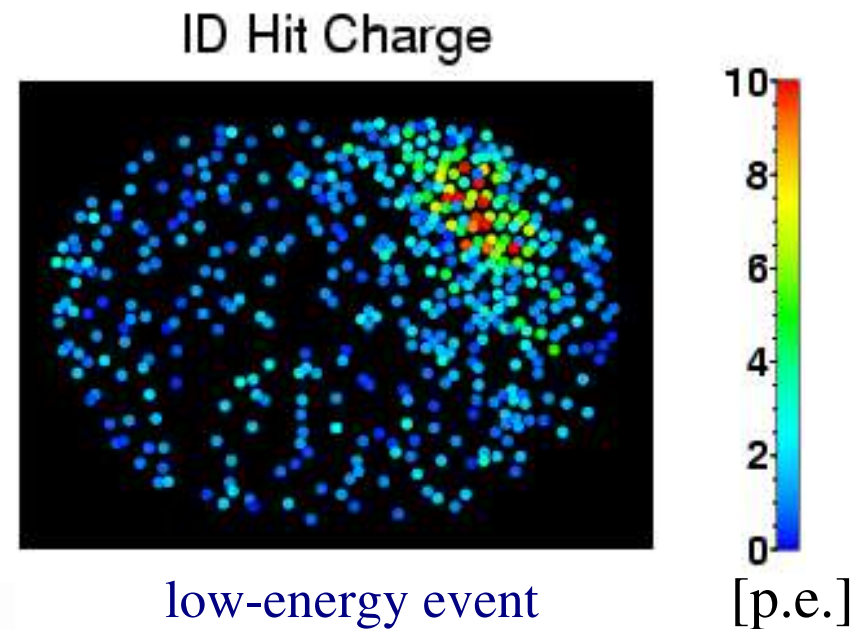
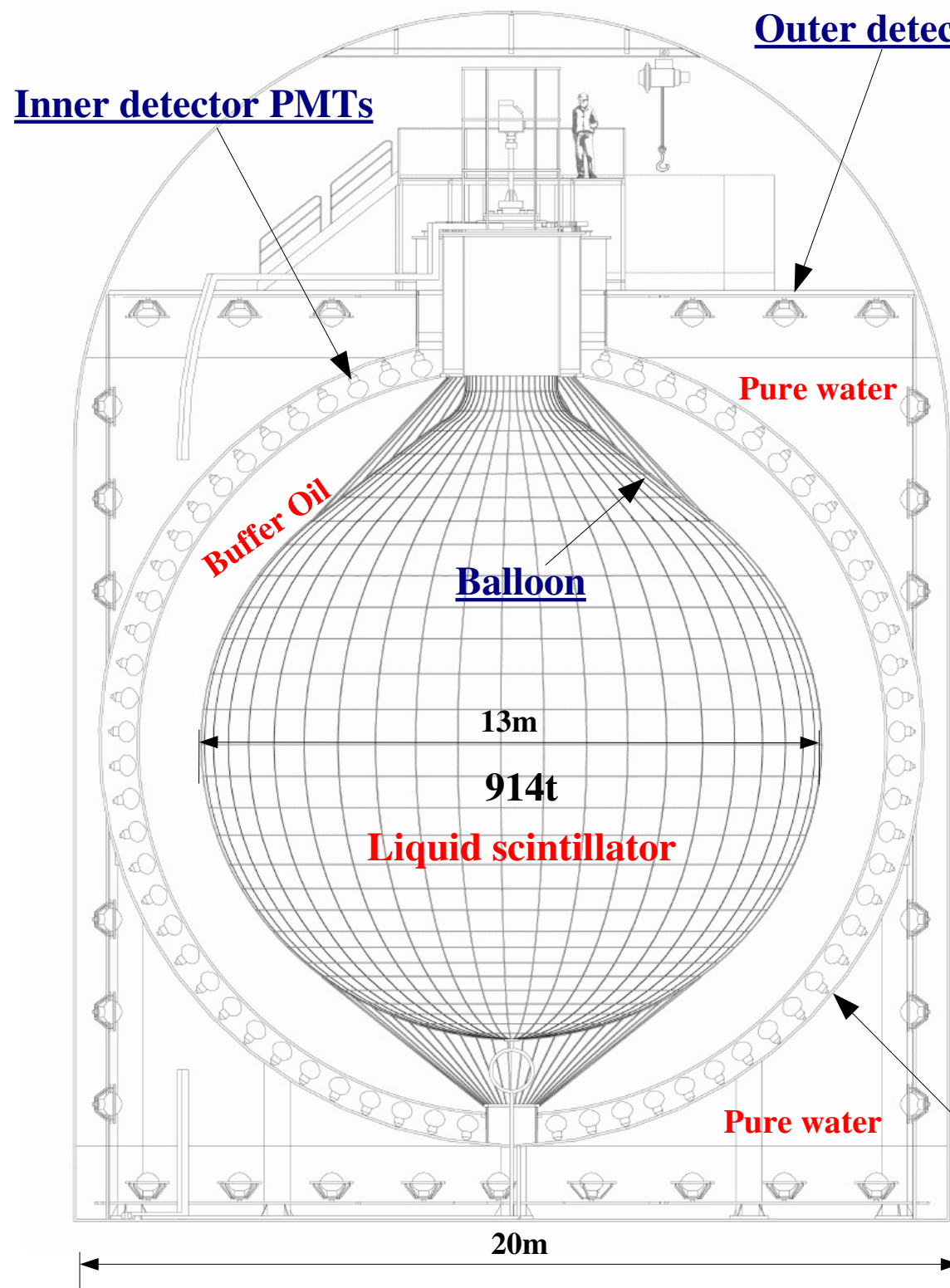




Unusual PMT behaviour in KamLAND

Alexandre Kozlov
Research Center for Neutrino Science
Tohoku University

International Workshop on new photon-detector June 27-29 Kobe University JAPAN



Stainless steel tank (Ø18m)

KamLAND 17-inch and 20-inch PMTs



Inner Detector (ID) 1325 17-inch PMTs (R 7250) were designed by Hamamatsu Photonics K.K. in cooperation with the RCNS group. ID also includes 554 older 20-inch PMTs (R 1449) developed and produced for the Kamiokande experiment (while the SuperK detector built using an improved 20-inch PMTs of the R 3600 type). In Outer Detector 225 20-inch PMTs (R 1449) are installed.

In 17-inch PMTs Venetian blind-type dynodes used in 20-inch PMTs were replaced by fast linear focusing and photo-cathode area was reduced to improve PMT transit time spread and peak-to-valley ratio.

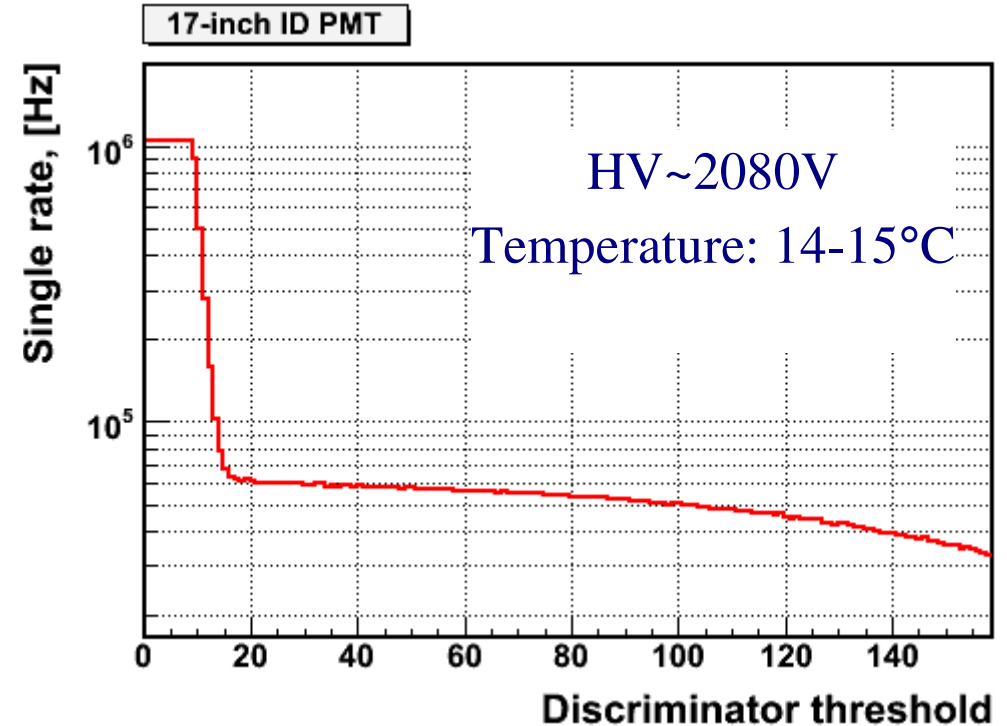
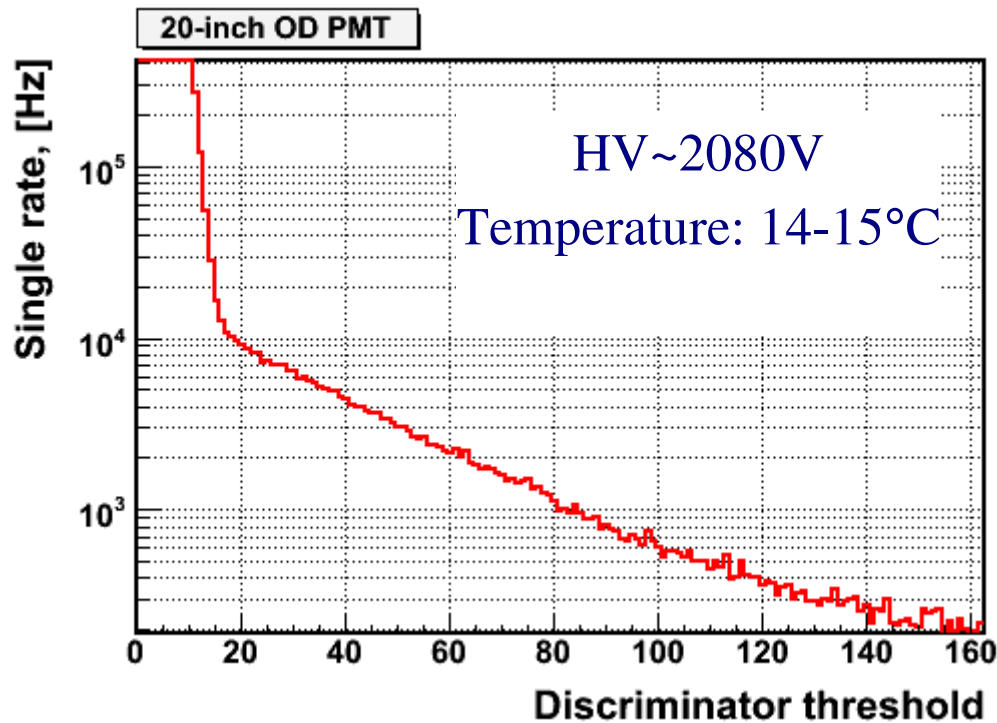
Historical overview of development of world's largest PMTs can be found here:

http://jp.hamamatsu.com/resources/products/etd/eng/html/pmt_005.html

History of KamLAND PMTs single rates “problem”

- Systematic studies of KamLAND 17-inch PMTs properties were conducted at RCNS at the beginning of KamLAND construction. For example, dark count rate test of 12 PMTs in year 1999 was performed for 1000 hours. During this test period single rates measured at $\frac{1}{4}$ photo-electron threshold were stable in the range between 4 and 7kHz depending on individual PMT.
- After KamLAND was filled with scintillator and buffer oil sharp increase in single rates was observed. Reason why single rates for the Inner Detector PMTs are much higher than expected is still unclear.

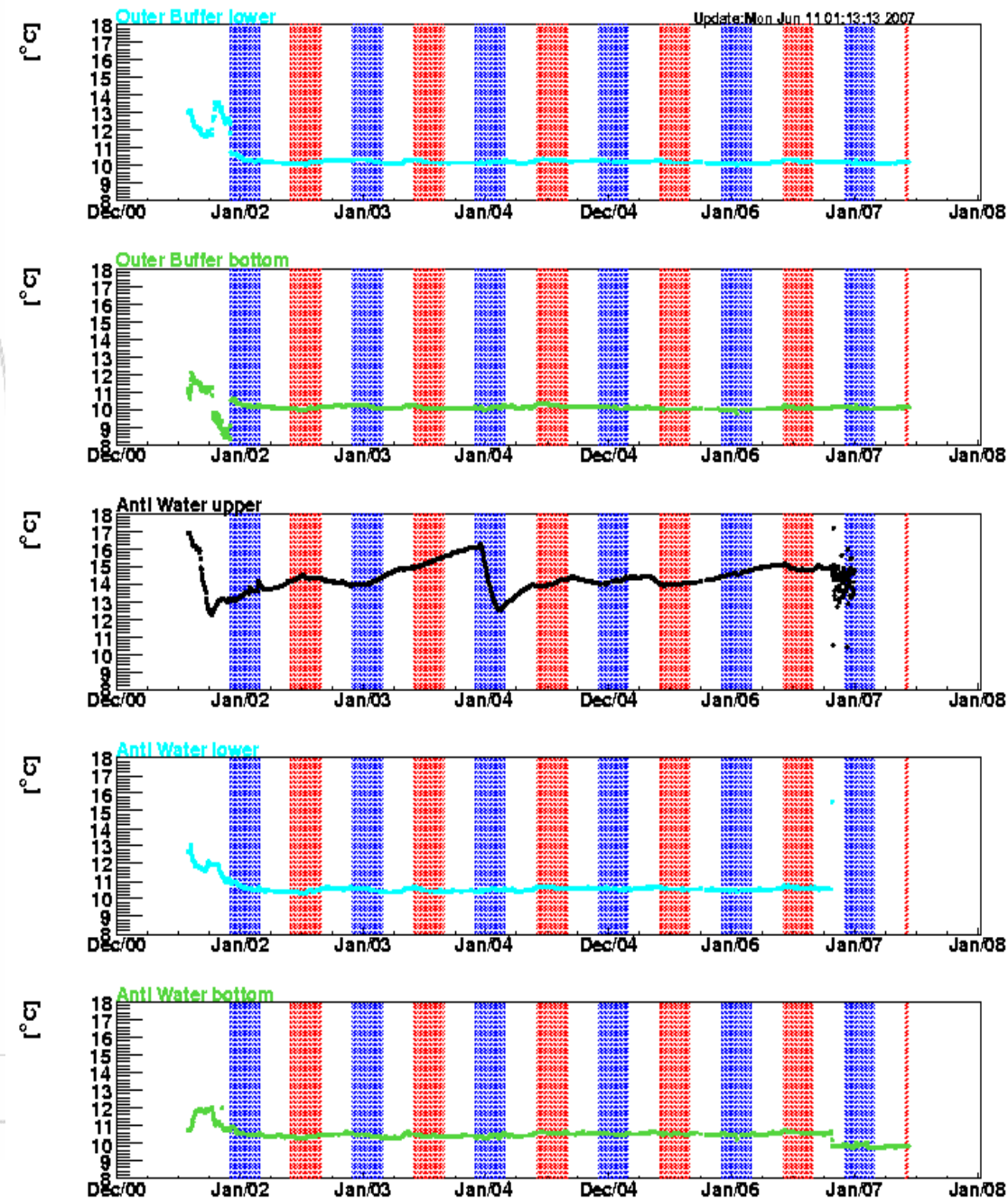
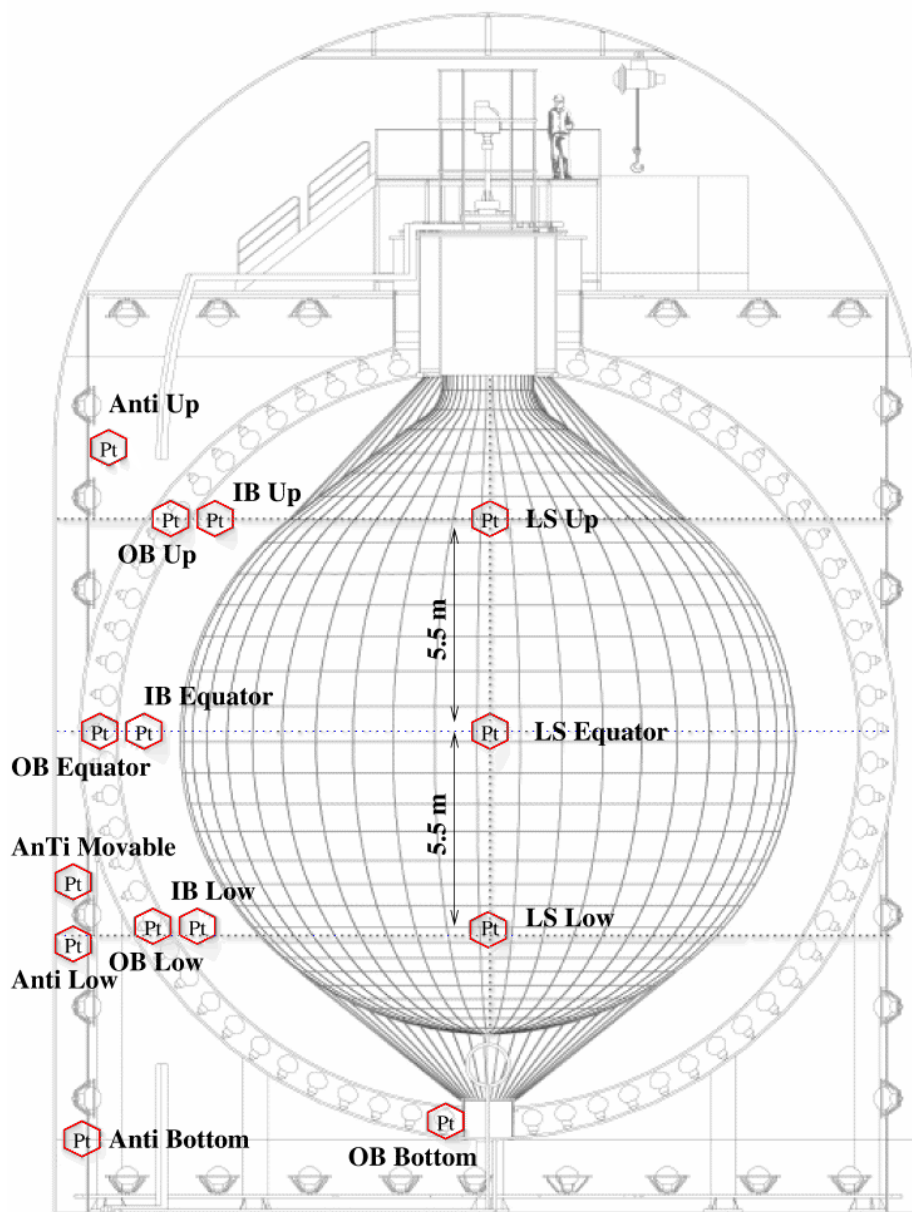
Result of discriminator threshold scan



Number PMT single hits is $N_{\text{total}} = N_{\text{PMT}} + N_{\text{photon}}$, where N_{PMT} number signals due to PMT itself (thermionic emission etc) and N_{photon} due to external light sources.

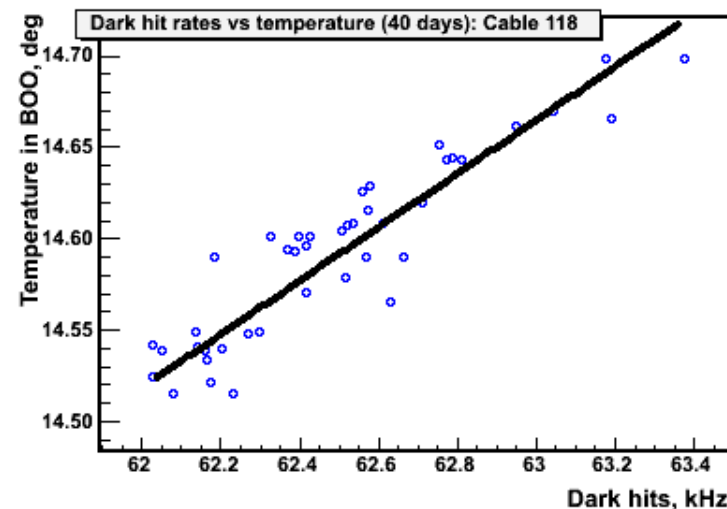
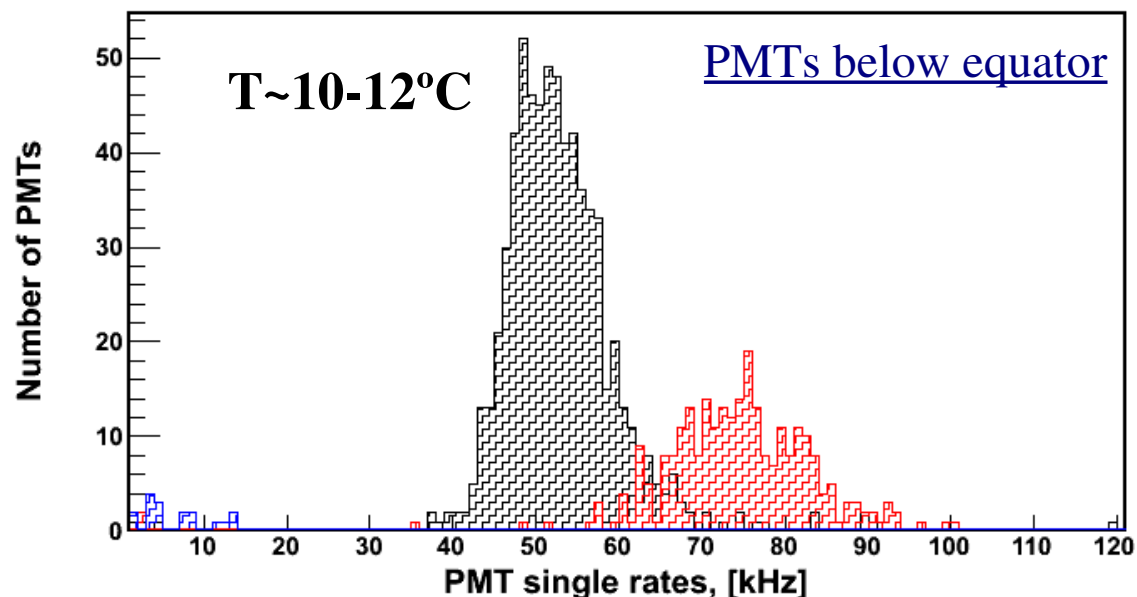
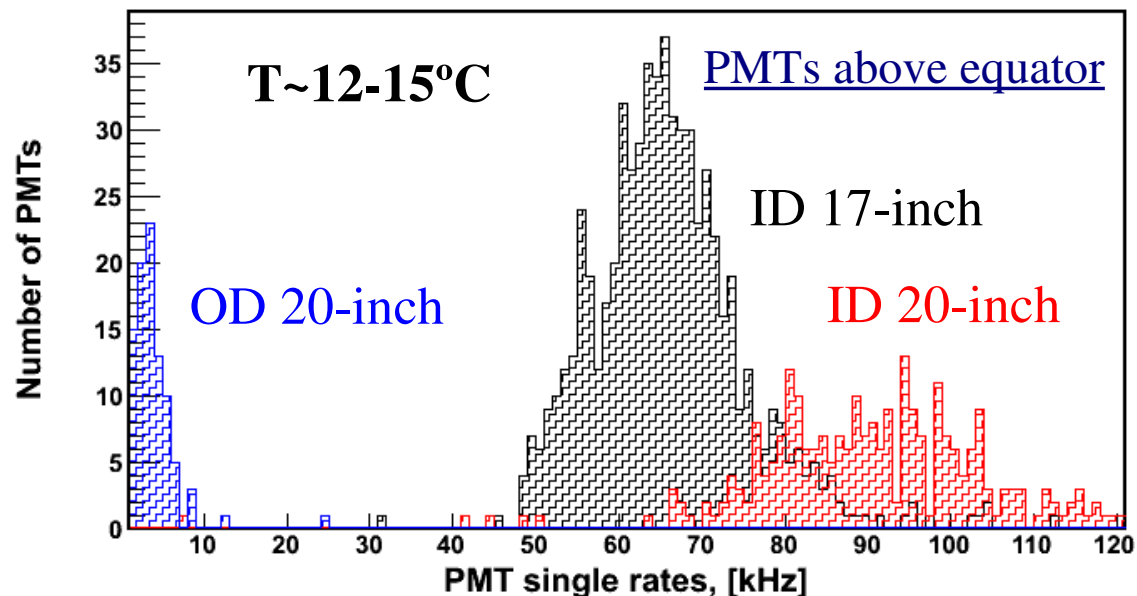
Plots show single rates as a function of threshold value for two PMTs operated under the same conditions (HV value, and temperature). Single rate value (taken at threshold 30) for the **Outer Detector** PMT is **6 kHz**, single rate for **Inner Detector** 17-inch PMTs is **60kHz**.

Temperature control in KamLAND



Heat from PMTs (~2kW) causes temperature gradient in KamLAND: bottom ~10°C, top ~15°C

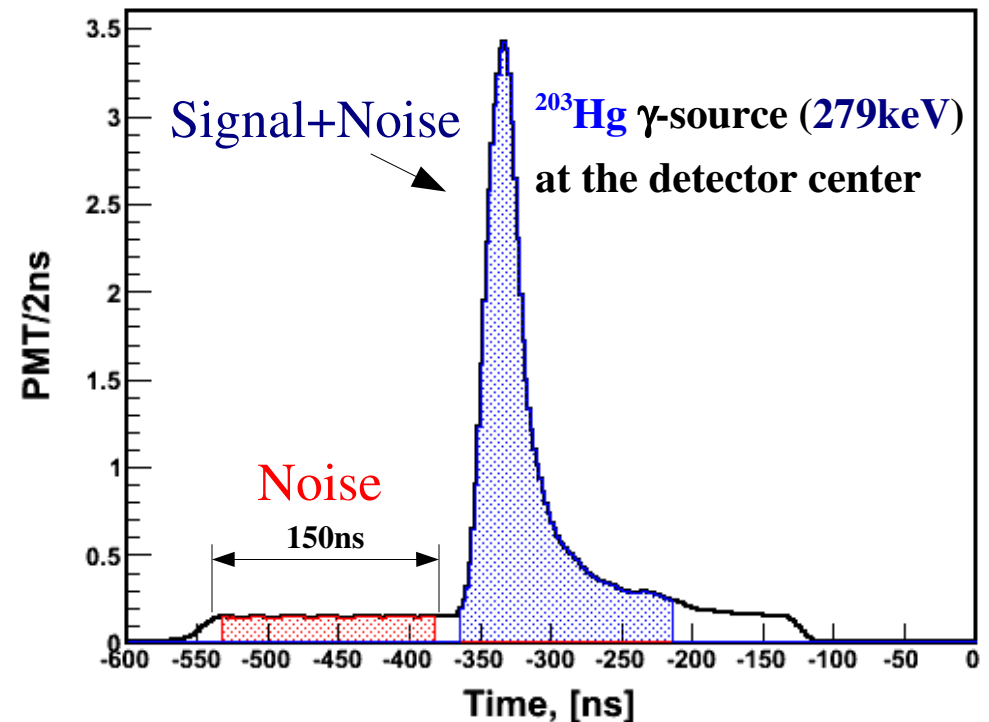
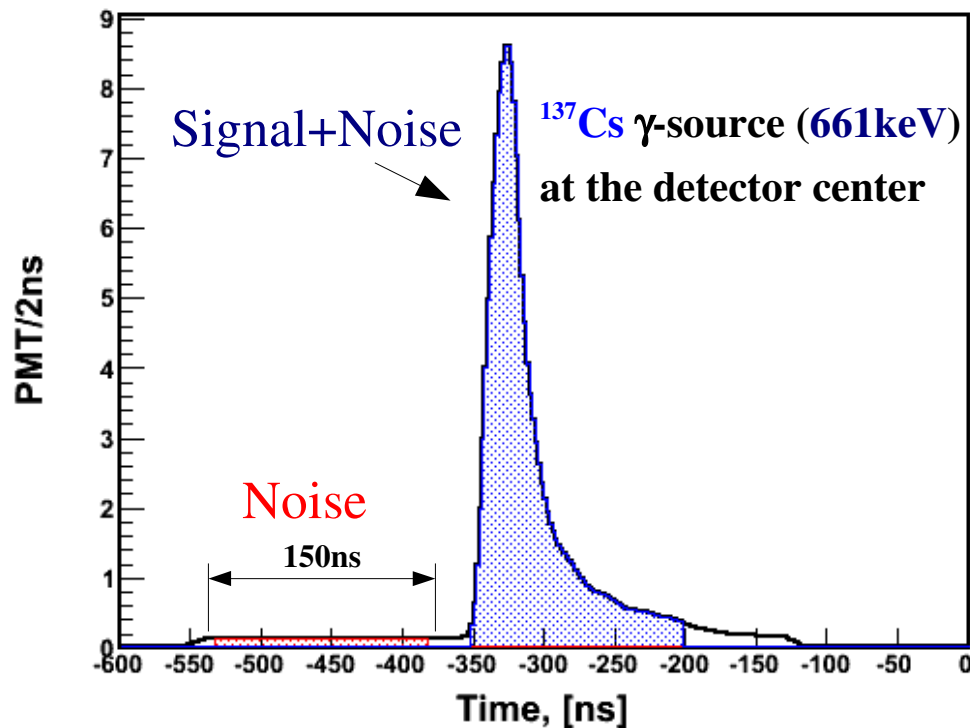
Single rates for all KamLAND PMTs



Temperature gradient is causing single rate ~20% variation in the vertical direction.

OD PMTs operated at the same temperature have single rates an order of magnitude lower than PMTs in Inner Detector.

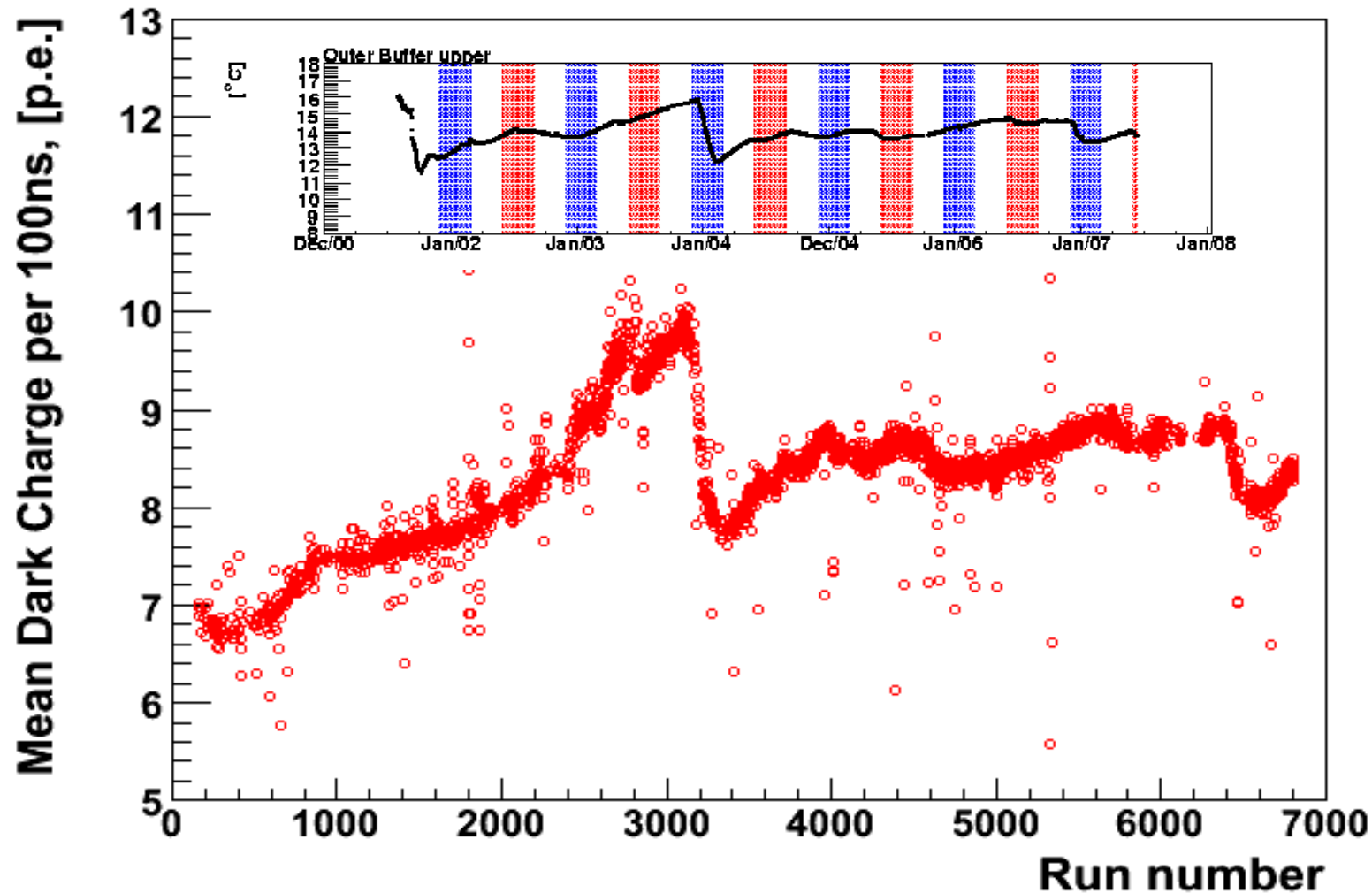
Single rate contribution to the KamLAND signal



In KamLAND data PMT single rates cause some **reduction** of events energy-and-position reconstruction resolution especially at low energies. For example, if for ^{137}Cs γ -ray event fraction of single hits in **150ns** timing window is **~6%**, for ^{203}Hg γ -ray it is already **~15%** if only 17-inch PMTs are used. With 20-inch PMTs single rate contribution is higher. Non-linear reduction of the light output for low energy γ -rays (“so-called “signal quenching”) also makes relative contribution from dark hits higher, and limits detector resolution. During event reconstruction energy is corrected for the **mean dark charge** contribution.

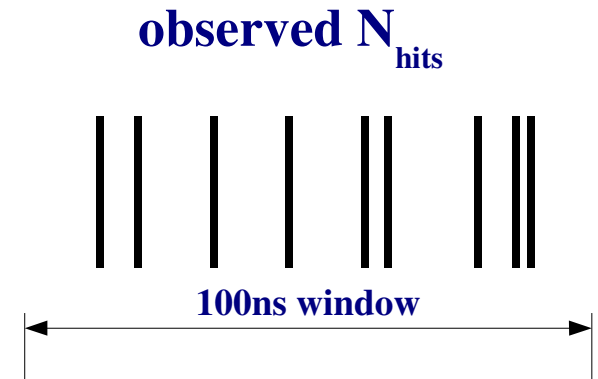
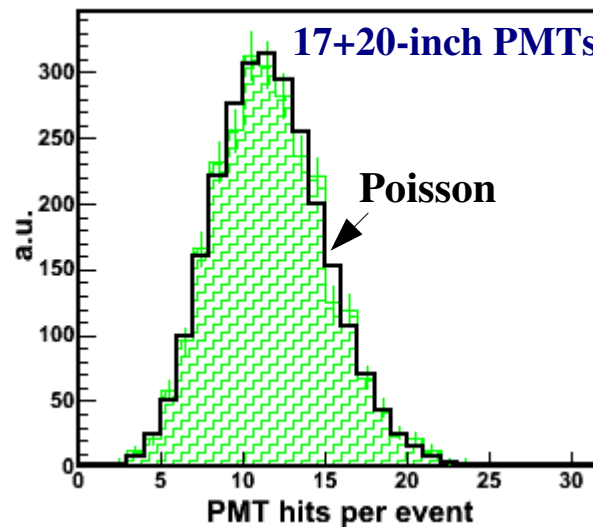
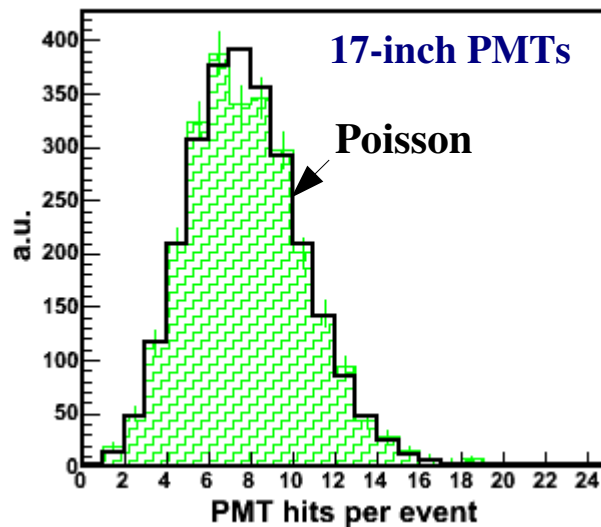
Time variations of single rates

Time Variation of Dark Charge in years 2002-2007

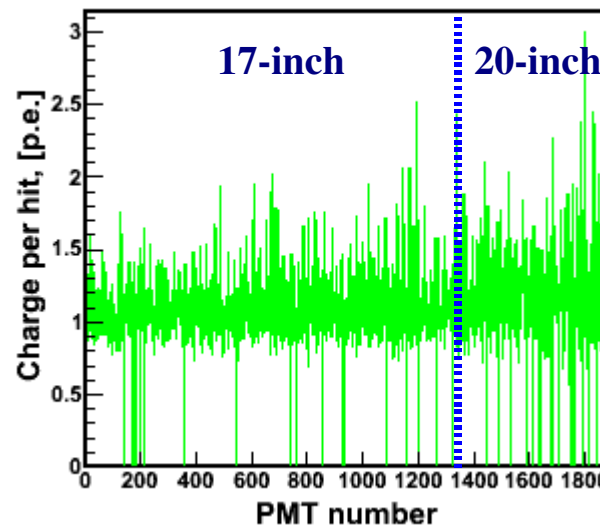
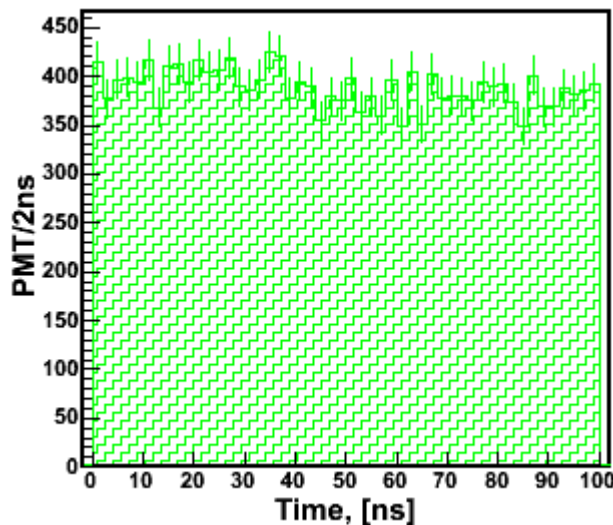


Mean charge from PMT single hits (shown for the 100ns window) changes as a function of time mostly due to detector temperature variations. In the process of data analysis mean charge value from single rates is estimated for every run and used to correct energy value.

Special trigger with no threshold



Wed Jun 13 16:13:43 2007



For 17-inch PMT:

$$\text{Mean single rate} = N_{\text{hits}} / (N_{\text{PMTs}} \times \text{Time})$$

$$= 7.3 / (1325 \times 100 \cdot 10^{-9} \text{ s}) \approx \mathbf{55 \text{ kHz}}$$

For 20-inch PMT:

$$\text{Mean single rate} = N_{\text{hits}} / (N_{\text{PMTs}} \times \text{Time})$$

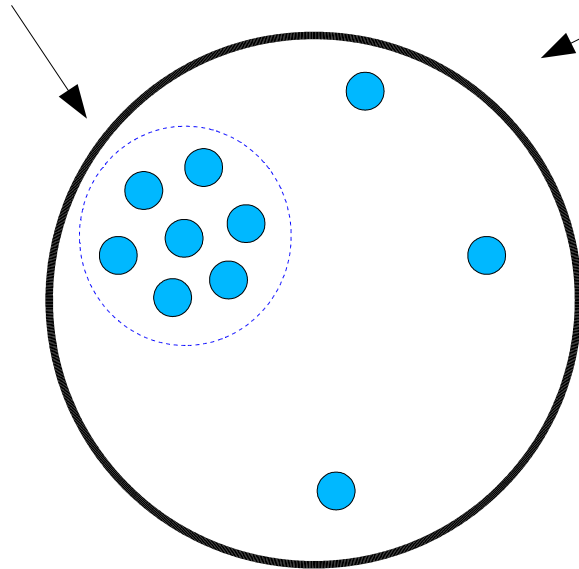
$$= 3.9 / (554 \times 100 \cdot 10^{-9} \text{ s}) \approx \mathbf{70 \text{ kHz}}$$

Single hit distribution of 17-inch PMTs (17+20-inch PMTs) in selected **100ns** window are equivalent to **Poisson** distribution with the Mean **7.3** (**11.2**) correspondingly. Each PMT charge is **> 0.3 p.e.**

The PMTs **timing distribution** has no structure and mean charge per PMT is about **1 photo-electron**.

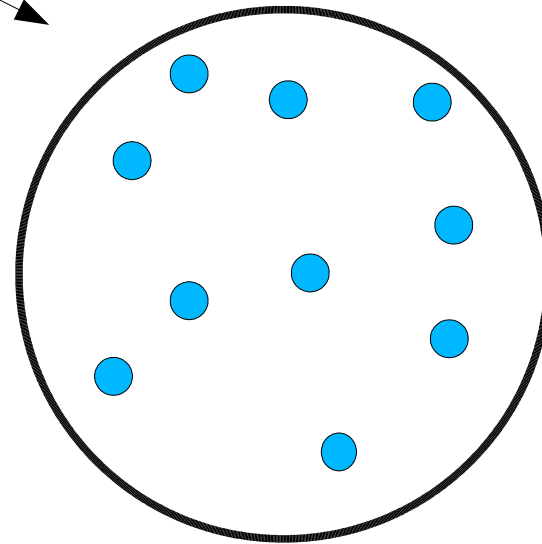
PMTs position correlation test

cluster of PMTs



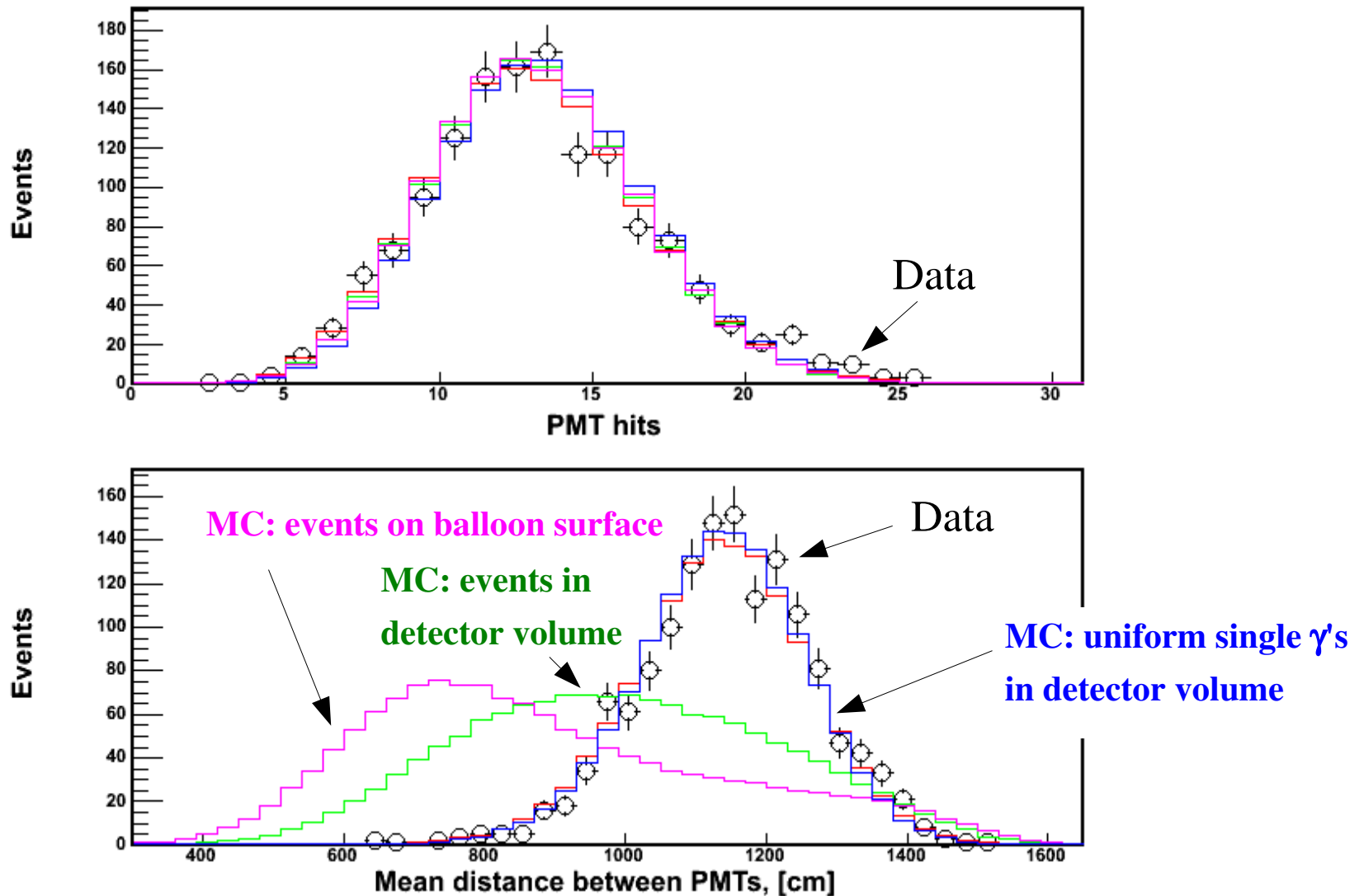
KamLAND

random PMT distribution



If single rates have a **component** originated from **very low energy radioactivity** events we would observe **clusters** of PMTs where mean distance between PMTs which have signals during the sampling time will be much shorter than for a purely random distribution.

PMTs position correlation test (data vs Monte-Carlo)

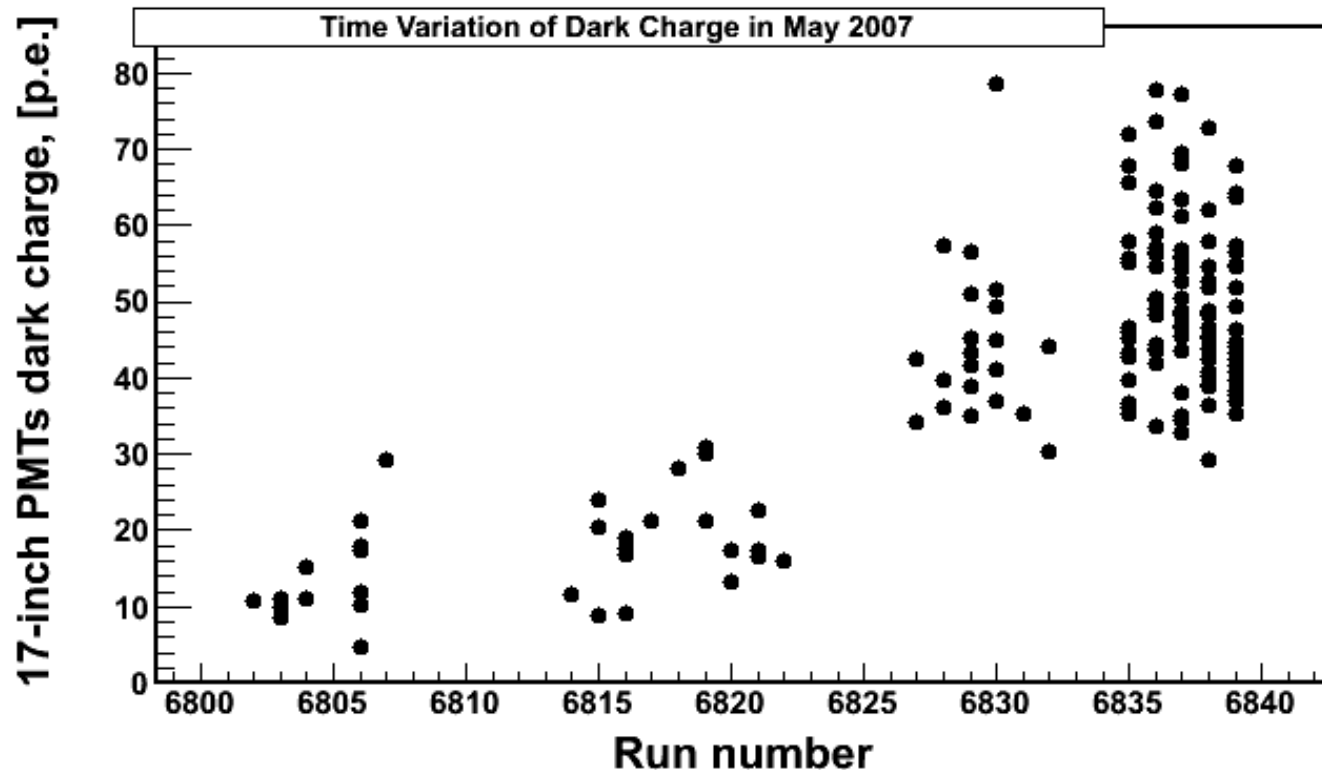


Data agrees with simulated random single rates of PMT (red) or detection of single photons uniformly emitted in scintillator volume (blue). Monte-Carlo for low energy radioactivity events with vertex in scintillator or balloon (green and magenta) is inconsistent with the data.

Hypothetical light sources excluded by tests

- **Low energy radioactivity** (main candidate was ^{14}C decay) excluded by shape of the PMT hit, time and position distributions
- Electronics noise is unlikely to be the cause. Waveforms from signals looks like **normal 1p.e.** Test data-taking with 1 PMT being **ON** while **all other KamLAND PMTs OFF** did not show any change in single rates of the operational PMT
- **Slow scintillation** of LS by activation excluded by measurements with radioactive source with a small scintillator sample
- **Static Balloon tension.** Stretching of a piece of KamLAND balloon in a small volume of LS did not affect PMT single rates
- **Scintillator oxidation.** Air bubbling through a small volume of LS has no effect on single rates

Jump in single rates during distillation



Recently KamLAND scintillator distillation process was started. Right after the beginning of KamLAND filling with distilled scintillator single rates increased by about **5 times** while **temperature of ID buffer oil** surrounding PMTs remained **not higher than 15°C**. This is probably indication that KamLAND high single rates may be related to the motion of the scintillator.

Summary

- KamLAND PMTs in the inner detector show significantly higher single rates compared to the same PMTs in outer detector operated at the same temperature.
- If single rates were due to the energy deposition in scintillator then $1325 \times 5 \cdot 10^4 \text{ p.e. /s} \approx 6.6 \cdot 10^7 \text{ p.e./s} / (300 \text{ p.e./MeV}) \approx 220 \text{ GeV/s}$ while energy deposition from cosmic ray muons is only $\sim 1 \text{ GeV/s}$
- High single rates may be caused by light emission from scintillator resulting from slow chemical reactions, or by **scintillator convection**
- Effect may become a serious obstacle in operation of liquid scintillator detectors with a larger than KamLAND volume (**LENA, HANO HANO**) especially in **low energy region**. R&D of these projects should consider KamLAND experience and study PMT single rate behaviour with detector prototypes.