Testing PMTs for XENON1T

requirements, measurement techniques and results

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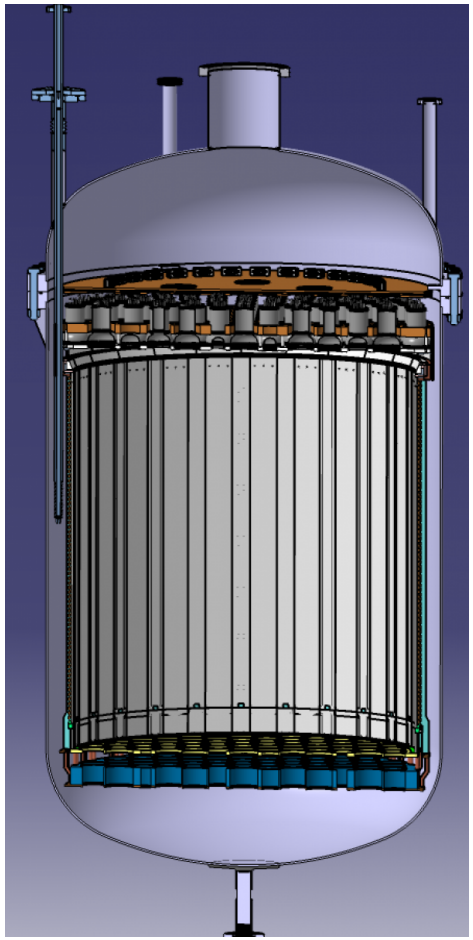
Time Projection Chamber (TPC)

- 248 PMTs (127 bottom, 121 top)
- 3" R11410-21 by Hamamatsu
- installation planned for mid-2014
- PMTs are being tested first:

1. screening at LNGS
2. operating all PMTs at room temperature and $-100^{\circ}C$ at MPIK
3. detailed tests of some PMTs in LXe at UZH

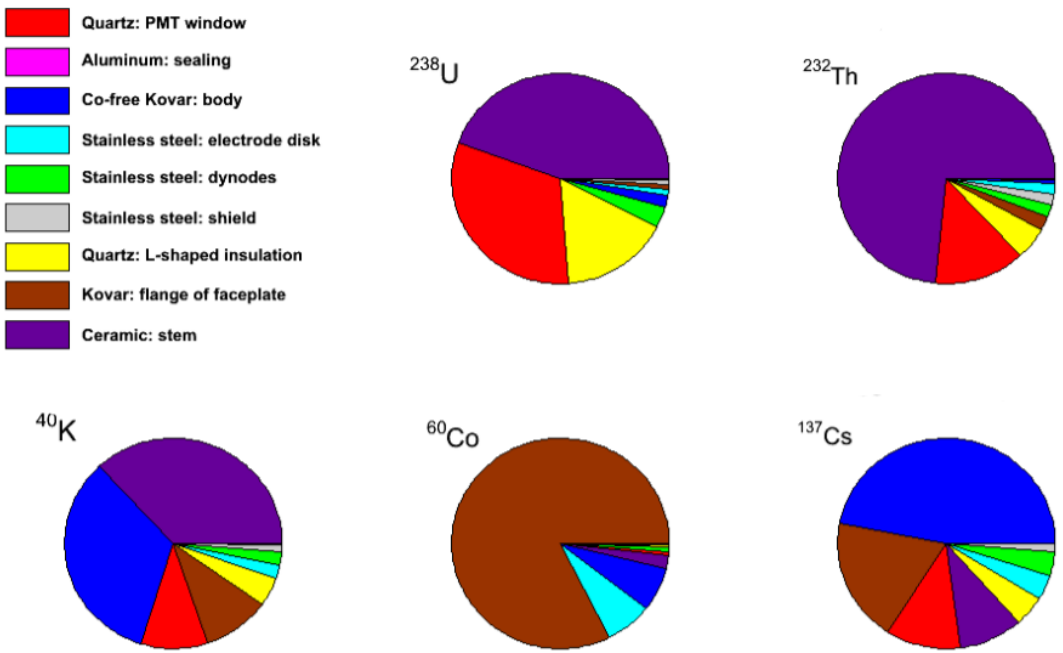


PMT requirements

1. high **quantum efficiency** (QE) at $175nm \rightarrow$ low energy threshold
2. low **radioactivity** $\rightarrow$ low contribution to background
3. low **dark count rate** and low amount of afterpulses (due to ionization of residual gas atoms) $\rightarrow$ low accidental coincidence rate
4. good **SPE resolution** and high **peak to valley ratio** (P/V) $\rightarrow$ distinction between signal and noise
5. low electron **transit time spread** (TTS) $\rightarrow$ good time resolution of the detector

Screening: bulk materials

- by means of High Purity Germanium detectors
- identify radioactive isotopes by γ-lines
- α decays in natural decay chains can cause (α, n) reactions



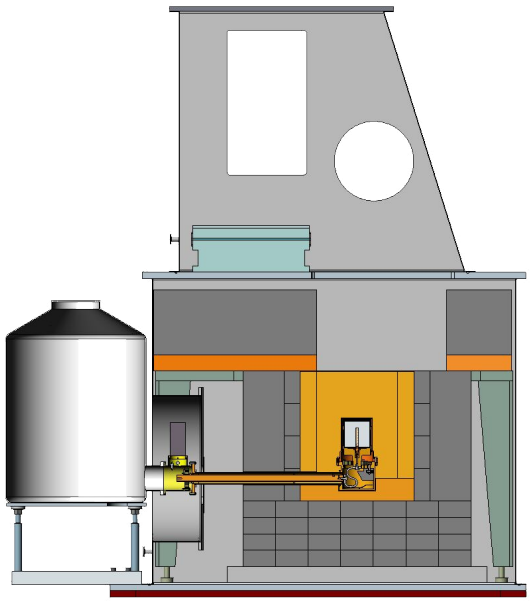


Figure: GeMPI facility

Screening: whole PMTs

Component	mBq/PMT
^{232}**Th**	0.41 ± 0.07
^{235}**U**	0.37 ± 0.05
^{238}**U**	< 13
^{60}**Co**	0.74 ± 0.04
^{40}**K**	13 ± 1
^{137}**Cs**	< 0.19
^{110m}**Ag**	≈ 0.7

Table: radioactivity average over 60 R11410-21 PMTs

Figure: GATOR facility at LNGS

Quantum efficiency

- average QE of -21 PMTs is 36%

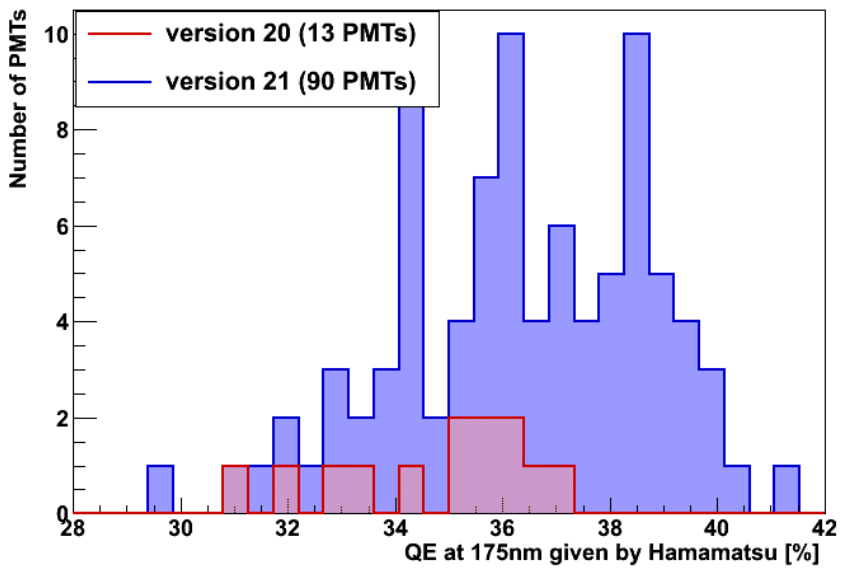


Figure: Quantum efficiency

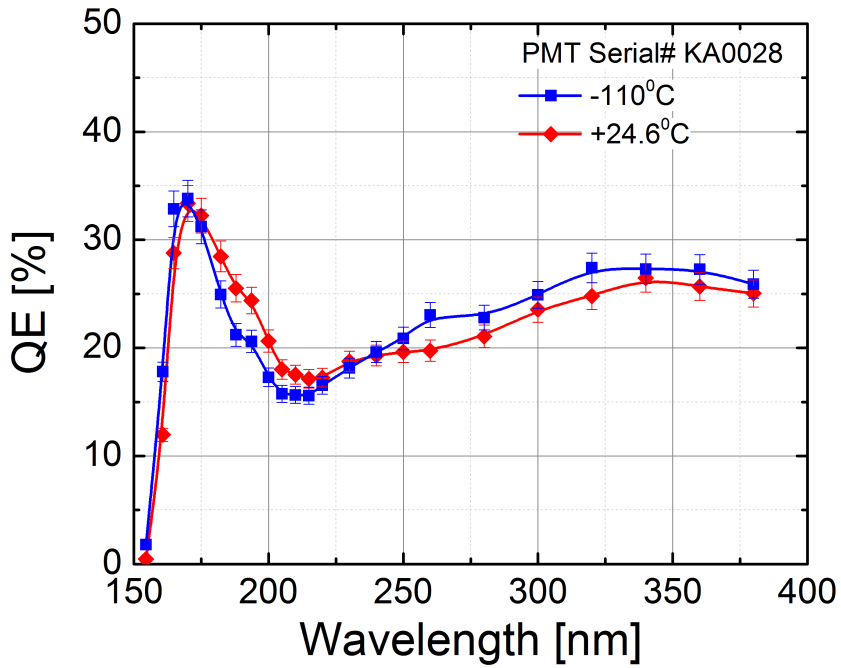


Figure: Quantum efficiency vs λ
measurement by Alexey Lyashenko (UCLA)

Setup at MPIK: faraday cage

- room temperature measurements
- light-tight faraday cage
- 12 PMTs can be tested simultaneously
- every PMT position is equipped with 1 LED
- measure DC rate, SPE for different HV, afterpulses, TTS

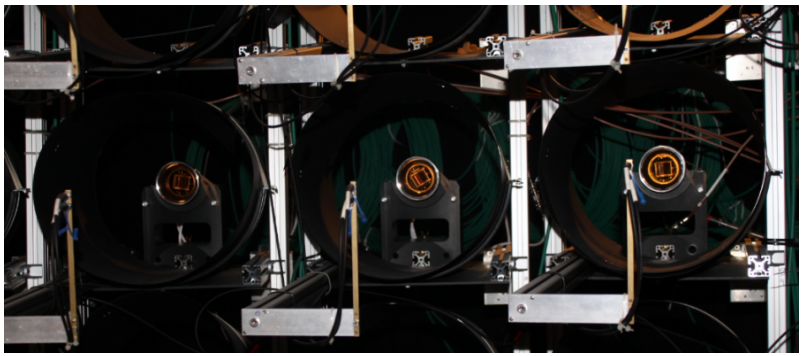


Figure: PMT structure front

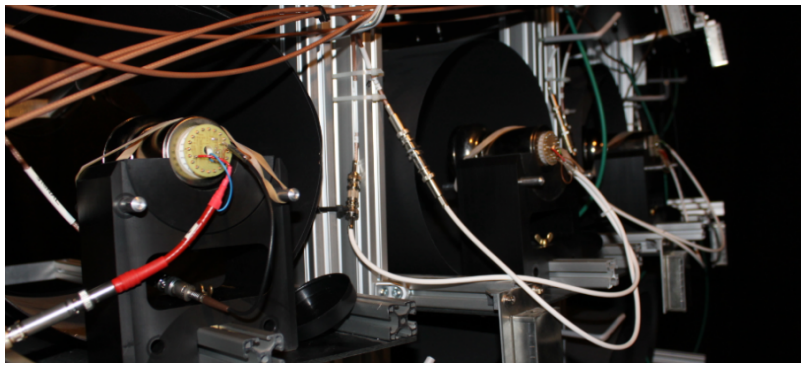
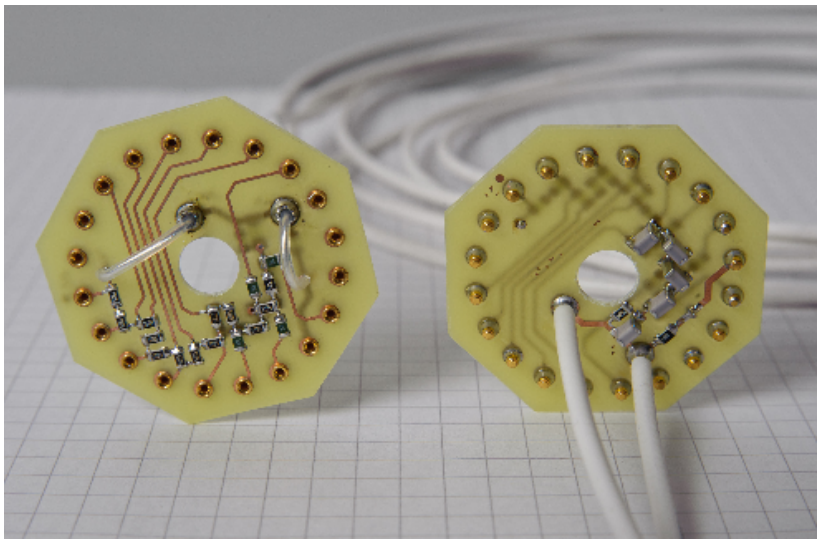


Figure: Back side

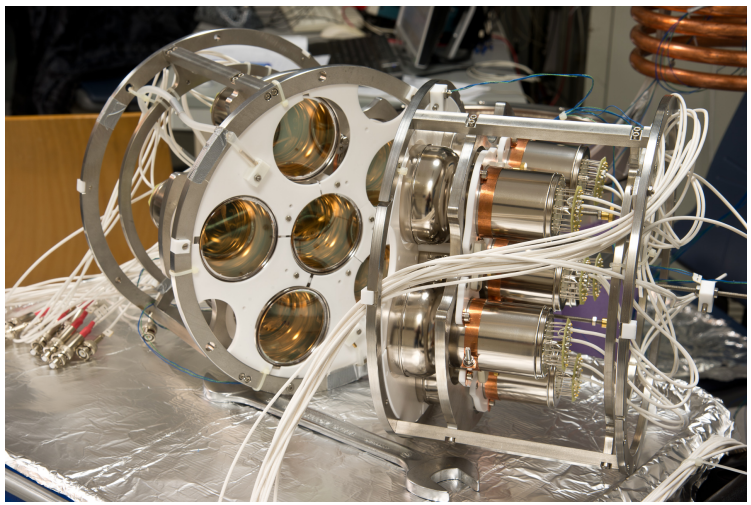
Bases

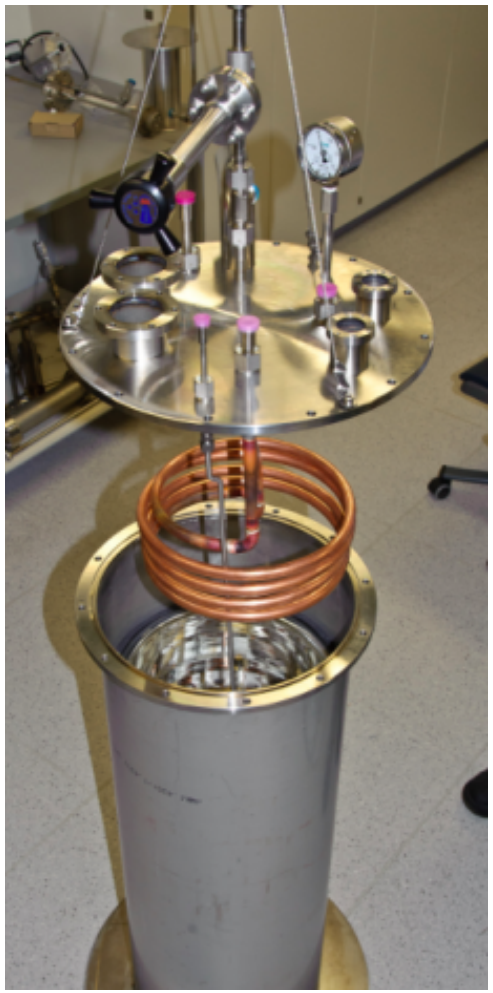
- use bases with the same design as for XENON1T
- low heat dissipation
- good linearity



Setup at MPIK: cooling tank

- cooling tank for measurements at $-100^{\circ}C$ with 12 PMTs
- filled with N_2 vapour, cooling by LN_2 flow through coil
- measure DC rate and SPE for different HV (3 LEDs)





Cooldown procedure

- cool down every PMT 3 times (thermal stress test)
- cooling speed limit of $2^{\circ}C/\text{min}$ specified by Hamamatsu
- from $20^{\circ}C$ to $-100^{\circ}C$ within 3h
- stable temperature for 5h

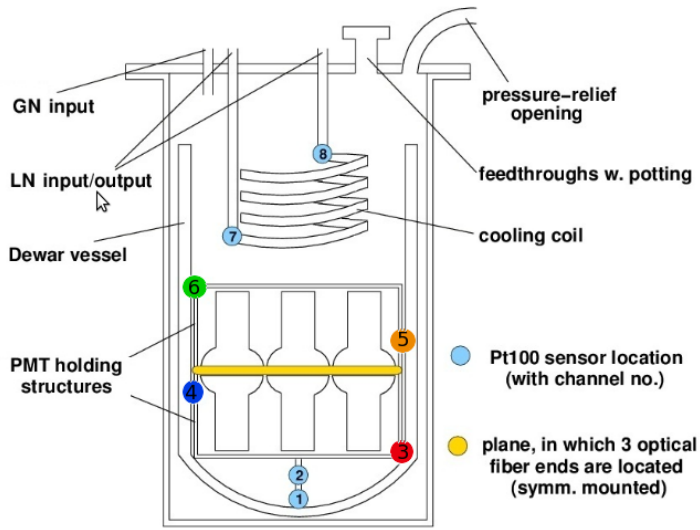


Figure: PT-100 positions

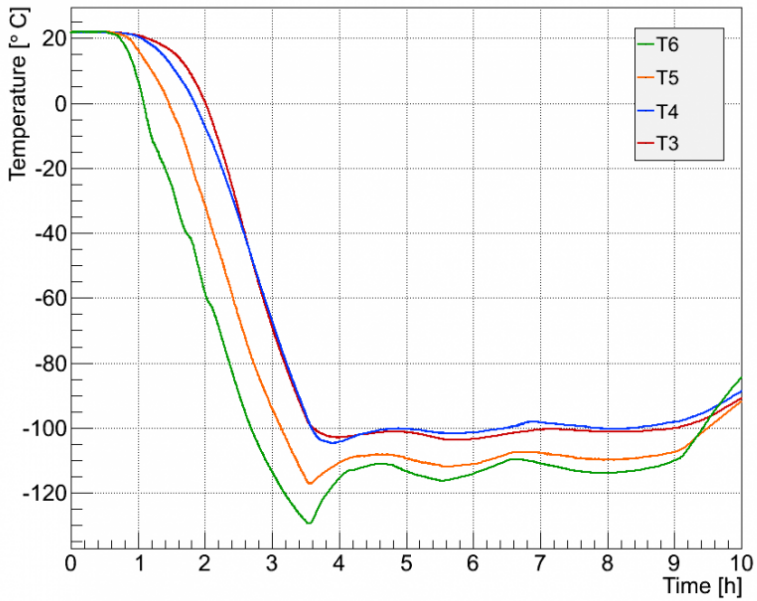
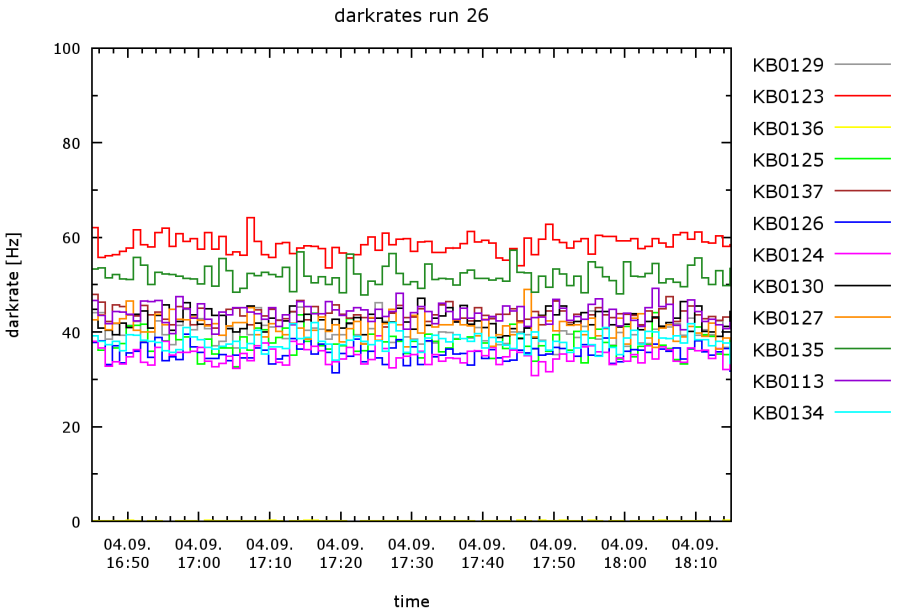
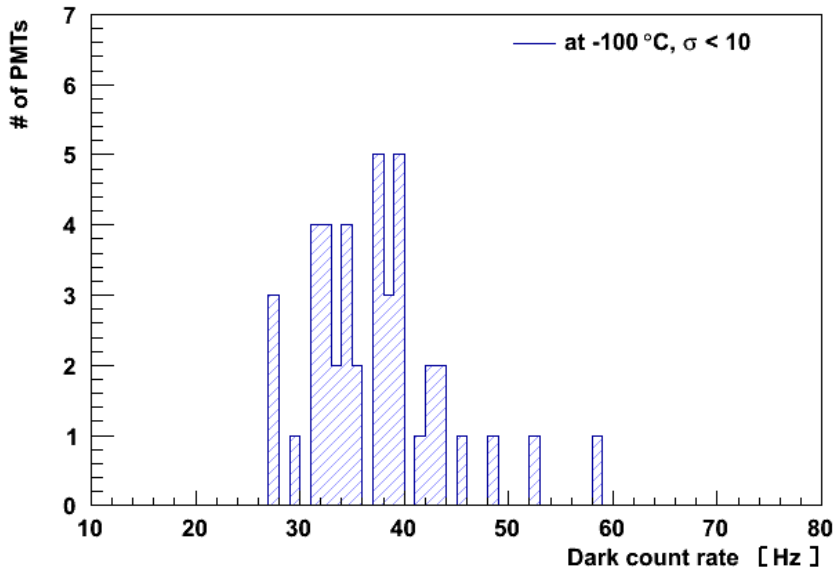


Figure: Temperature curves

Dark count rate at -100°

- scaler counts pulses larger than $\approx 1/4$ PE
- typically around $40 Hz$





Gain vs. HV

- SPE spectrum is acquired for several values of the HV between $1300V$ and $1700V$

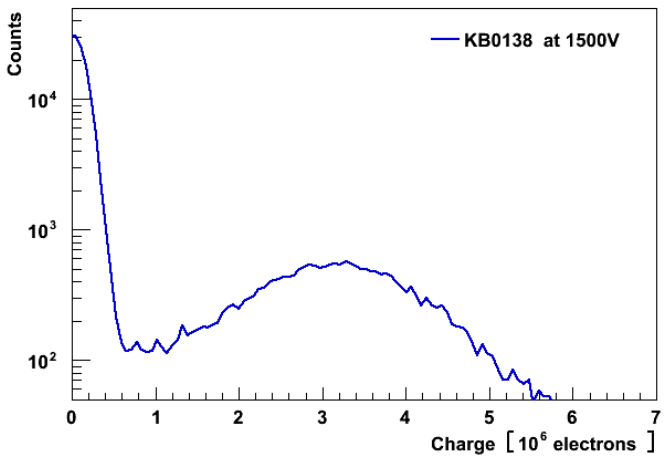


Figure: SPE spectrum

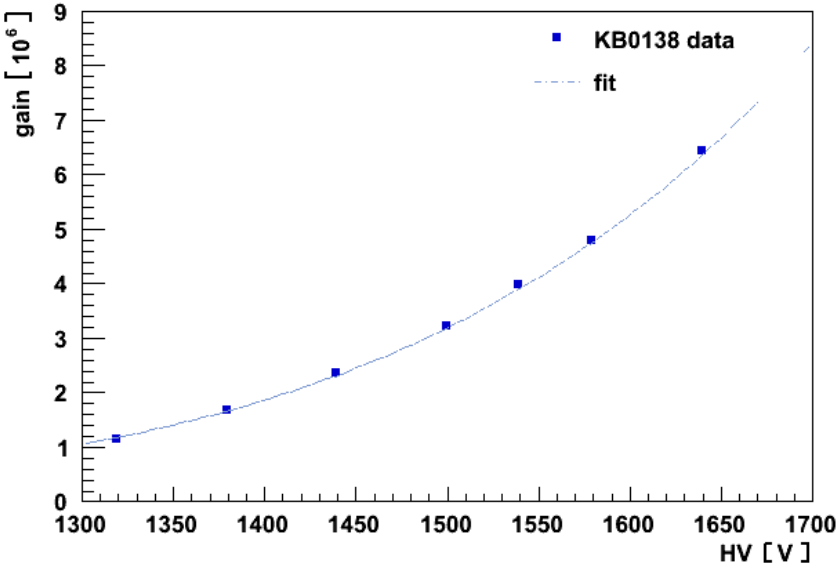
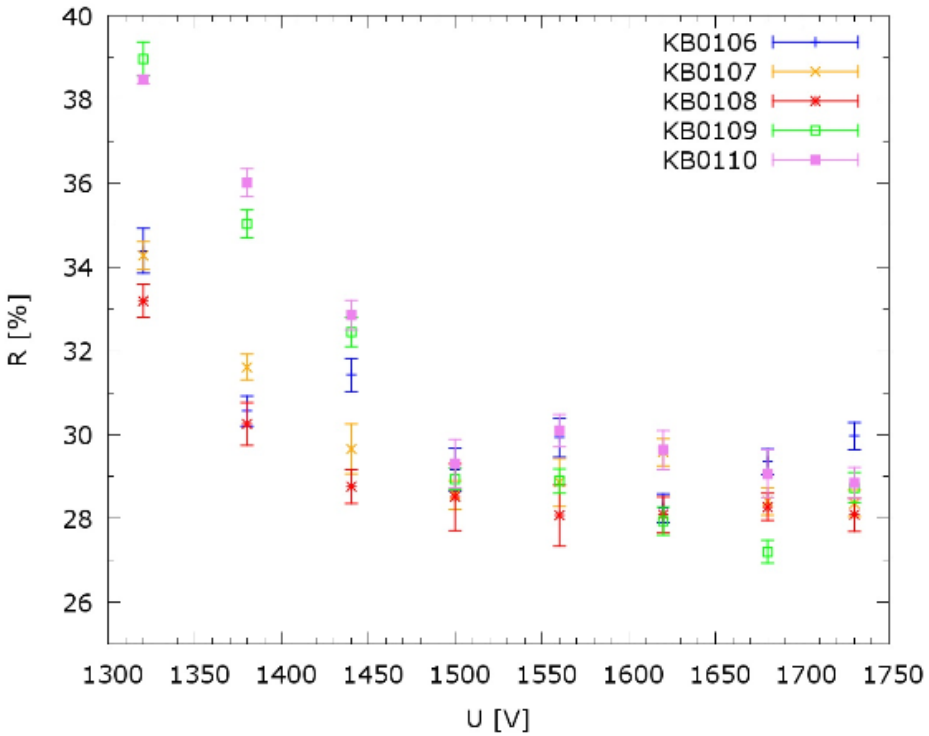
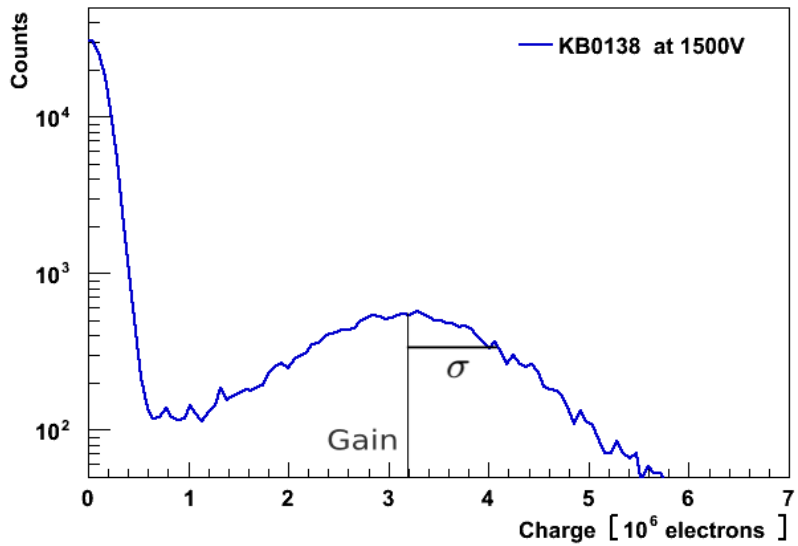


Figure: HV scan

SPE resolution

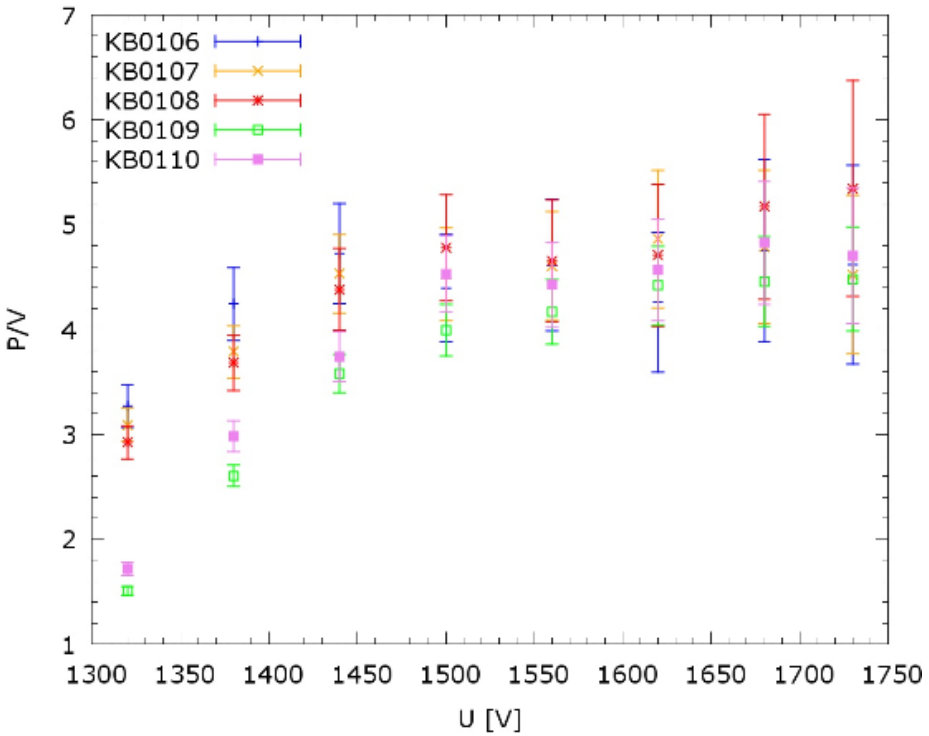
- at voltages $\geq 1500V$ $R = \frac{\sigma}{gain} \approx 30\%$

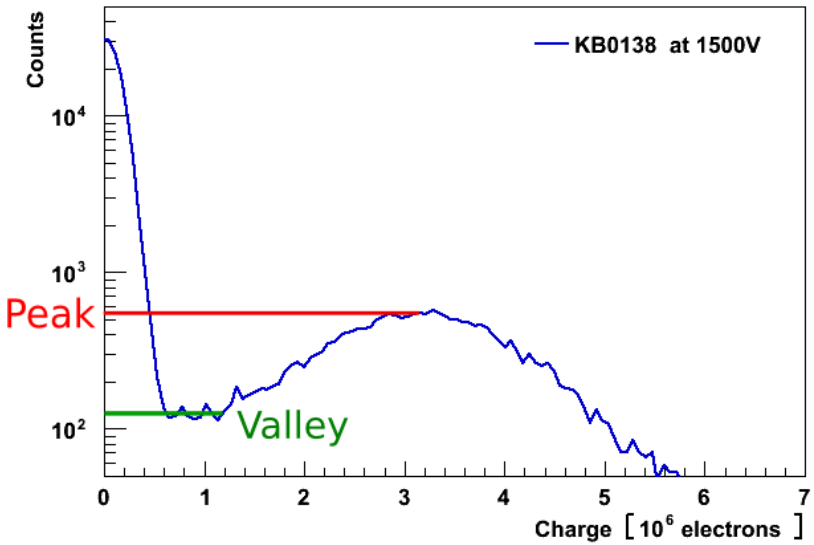




Peak to valley ratio

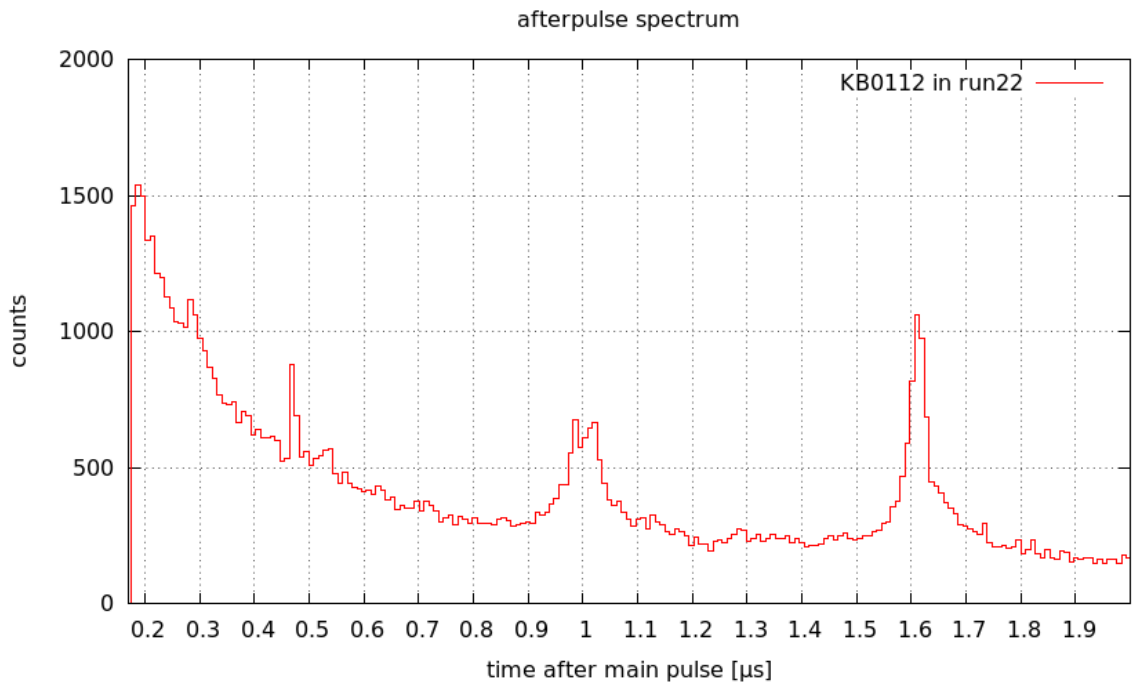
- at voltages $\geq 1500V$ $P/V \approx 4$





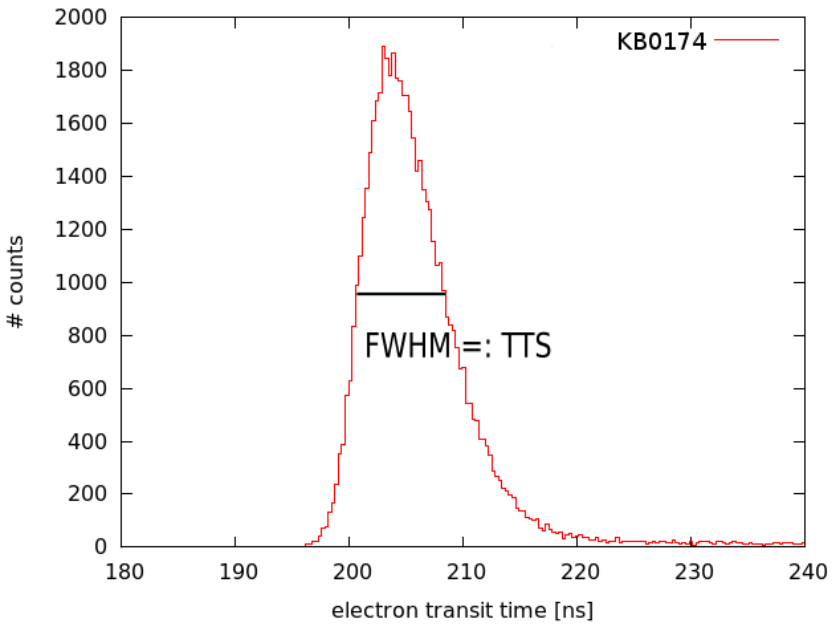
Afterpulses

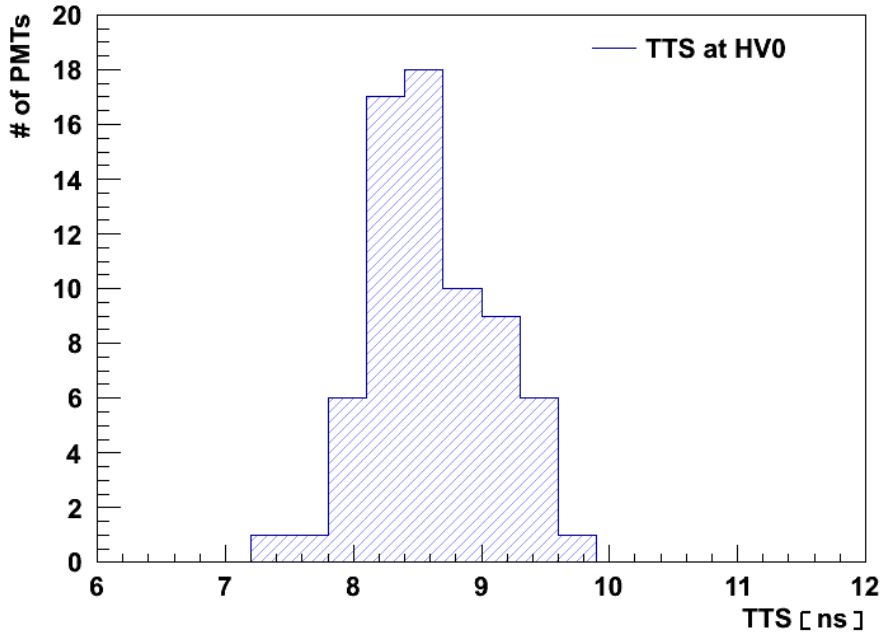
- measure time differences between main pulse and subsequent pulses
- afterpulse probability is $< 10\%$ for all PMTs up to now



Transit time spread

- measure time differences between LED pulse and the resulting PMT pulse
- on average $TTS = (8.5 \pm 0.5)ns$





Setup at UZH: MarmotXL

- LXe chamber for measurements with 3 (now 5) PMTs
- stable operation over a few months

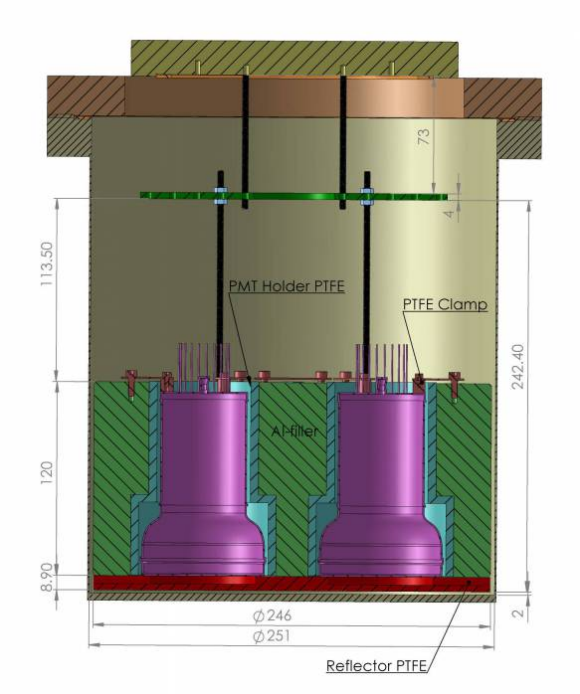


Figure: PMT chamber inside

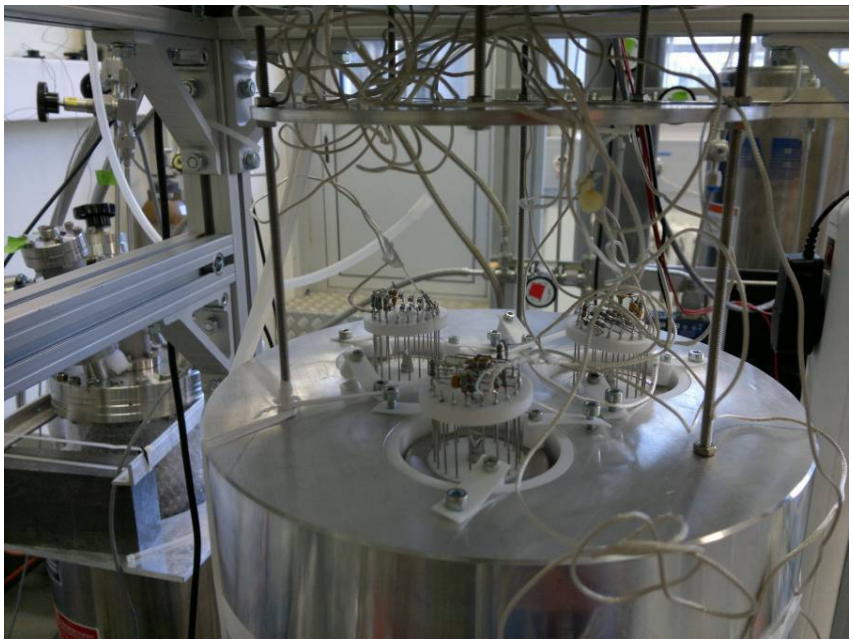


Figure: PMT chamber outside

Dark count rate

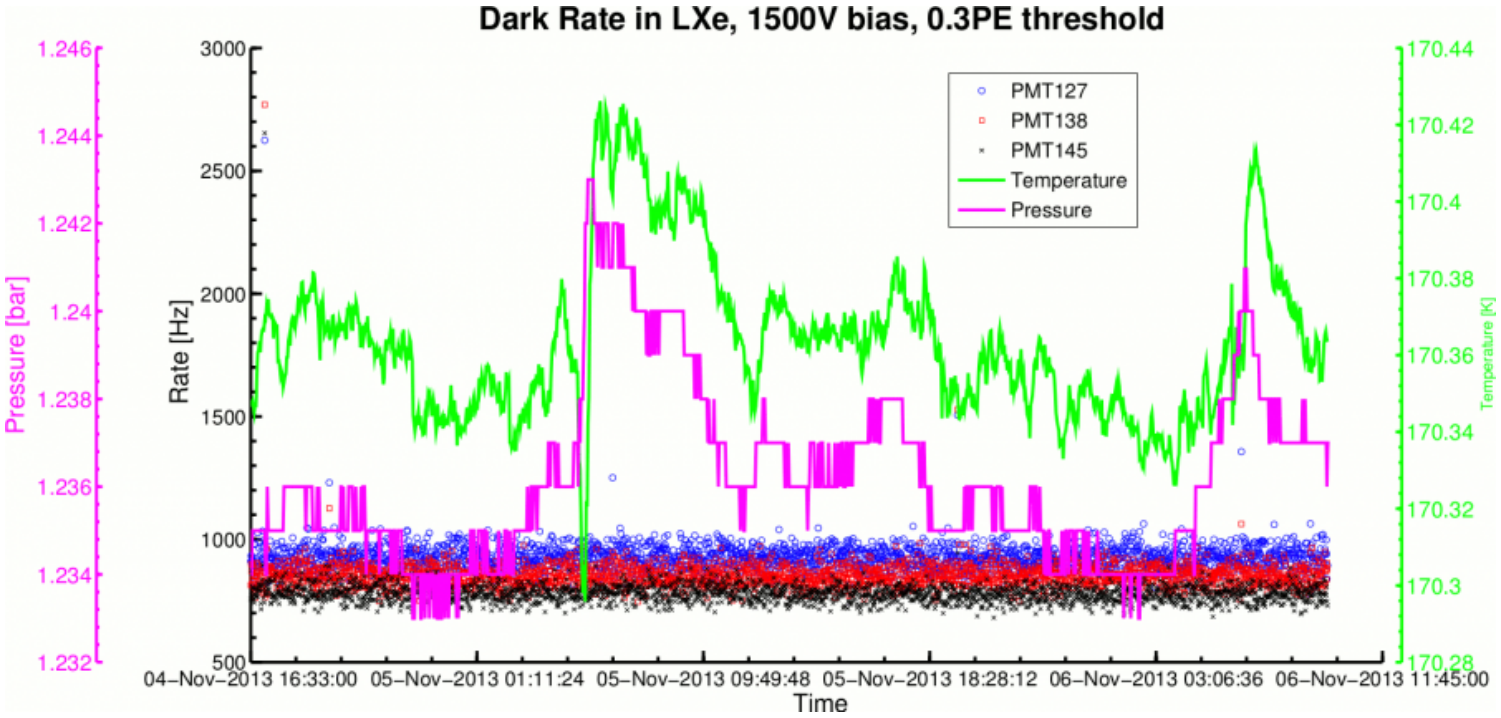


Figure: Stable dark count rate over 2 days in LXe

Afterpulses

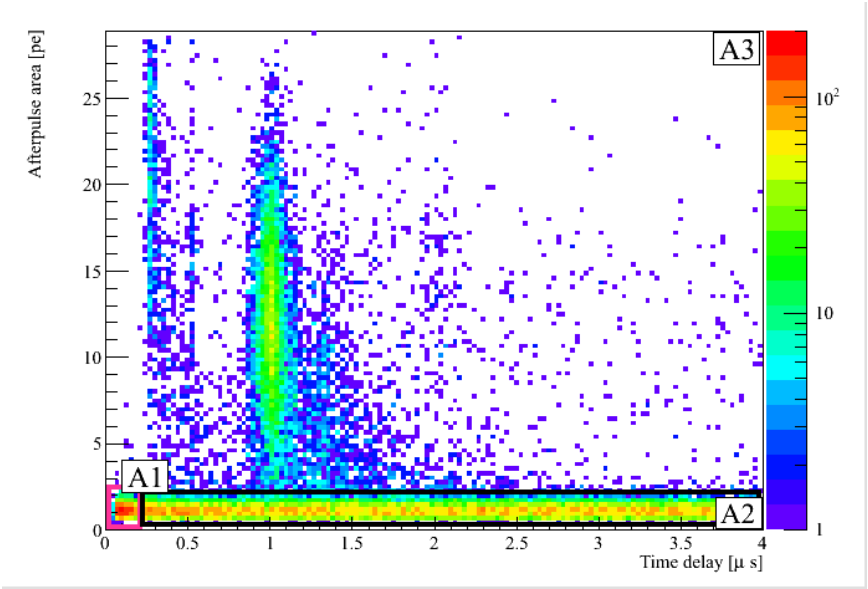


Figure: Charge vs. time (KB0104)

- A1 and A2: up to 2PE: late pulses and DC rate
- A3: afterpulses

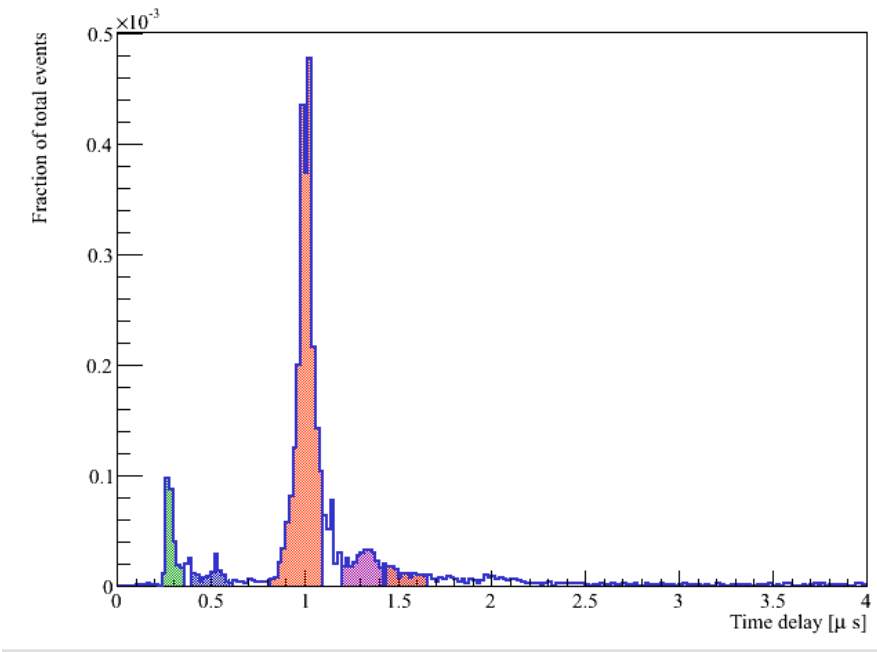


Figure: Afterpulse spectrum

- KB0104 afterpulse probability of 1.6%

Summary

- 60 of 248 PMTs have been tested
- PMTs will be installed into the TPC next year
- radioactivity of the order mBq/PMT
- Quantum efficiency: 36%
- SPE resolution: 30% and P/V ≈ 4 around $1500V$
- DC rate: $40Hz$ at $-100°C$
- TTS: $8.5ns$
- these properties meet the requirements of XENON1T