THE UNIVERSITY *of* EDINBURGH

PMT Test Results

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Watchman Collaboration Meeting
PMT Working Group
10th January 2019
08:00 HST (18:00 GMT)

CONTENTS

OPERATIONS

Timeline

July – Aug	Set up test stand in Edinburgh and Sheffield
Aug - Sept	Installation and commissioning at Boulby
Sept – Oct	Initial testing and refinement of procedure
Oct 12th	First official tests begin – **run one**
Nov 15th	Both tents operational – eight PMTs per day max.
Nov 22nd	Thanksgiving - all 101 PMTs tested at least once
Nov – Dec	Underground testing of eight PMT sample

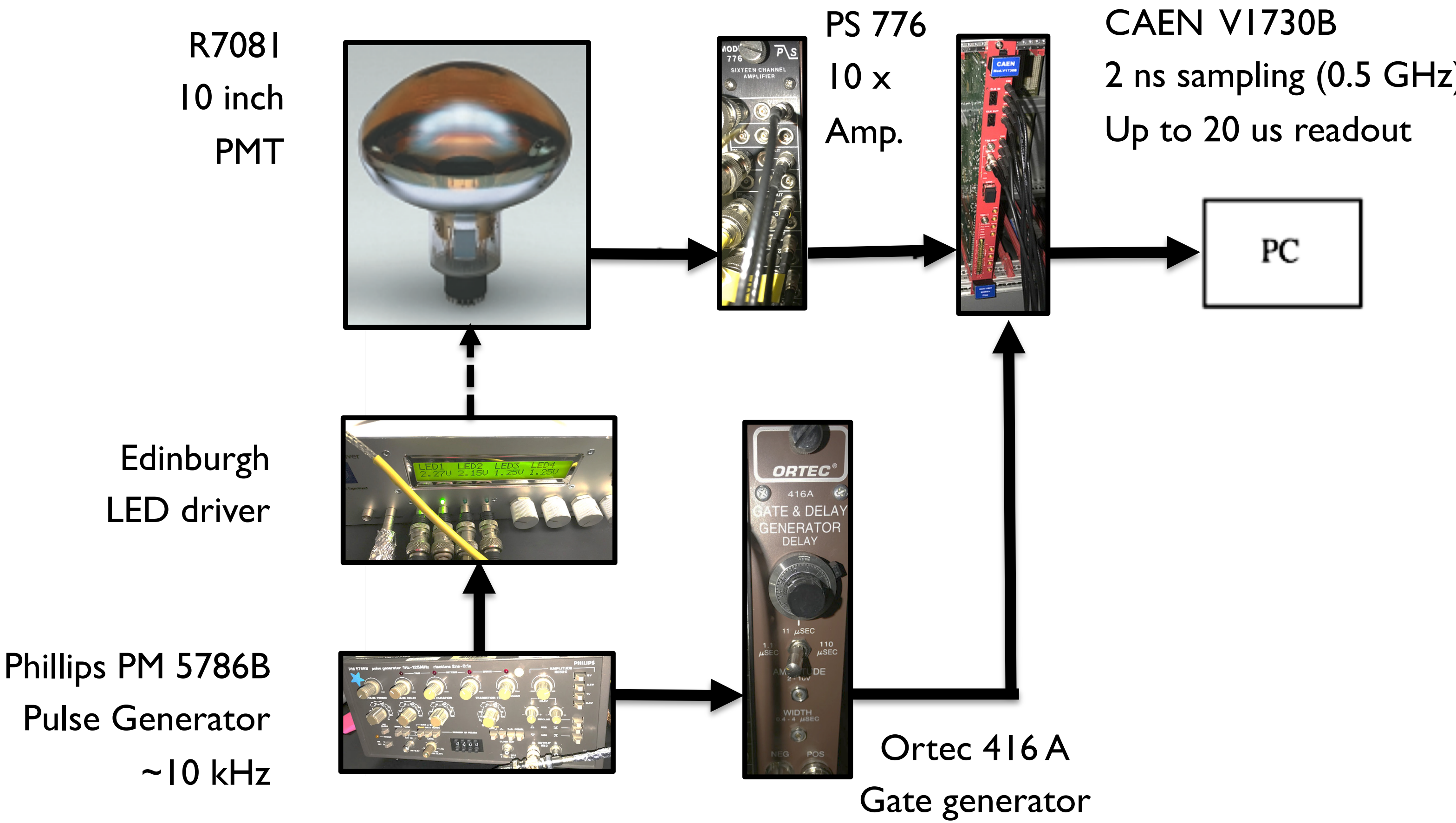
Tested PMTs Google Sheets

Boulby Shifts Breakdown

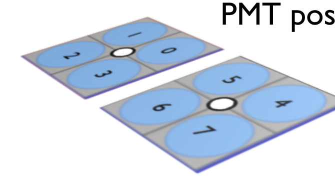
Institute	# Shifts
AWE	35
Davis	15
Edinburgh	39
Livermore	9
Liverpool	10
Sheffield	49

A BIG
thank you
to all shift
takers!

Boulby Test Rig



Boulby Test Rig

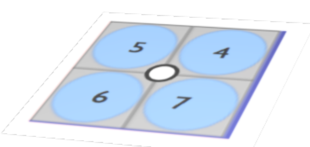


PMT positions

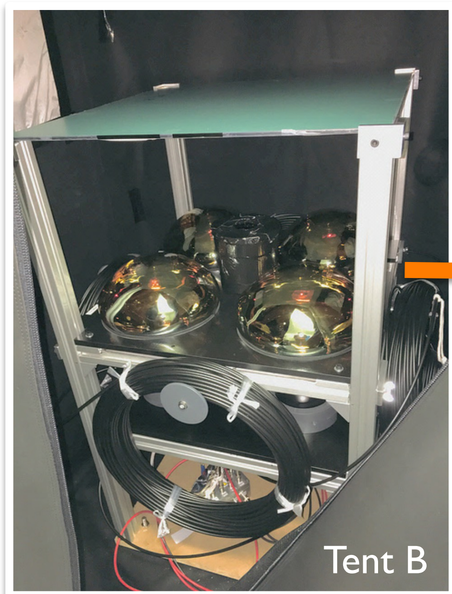
Square mirror / attenuator

Single optical fiber under central ND filter

Four PMTs



PMT positions



Custom mechanical support structure (1/2)

The mechanical structures were located inside mobile photographers dark tents within a dedicated lab room. Image above shows Tent A (B) at back left (front right).

Data Taking Procedure

Afternoon — Load next set of PMTs and ramp to nominal HV
Other tasks: PMT cable crimping, software development,…

Next morning — Testing begins - follow operating instructions guide
Main data taking steps shown in table below

	Test	Events (M)	Time (min)	Gate (ns)	Volume (G)
1	Nominal HV	3.0	5	220	0.7
2	Gain – 5 HV steps	3.0 x 5	25	220	3.5
3	Operating HV	3.0	5	220	0.7
4	Afterpulsing	0.5	15	10200	3.0
5	Dark Rate	9.0	15	220	2.1

- Periodic checks (data volume, charge spectra) and e-log entries
- Meta-data recorded in **Tested PMTs** Google sheets:
  - PMT serial numbers, HV current, ambient temp, …
- Operations meeting conference call held daily

Common Software Tools

Fixed window charge histograms

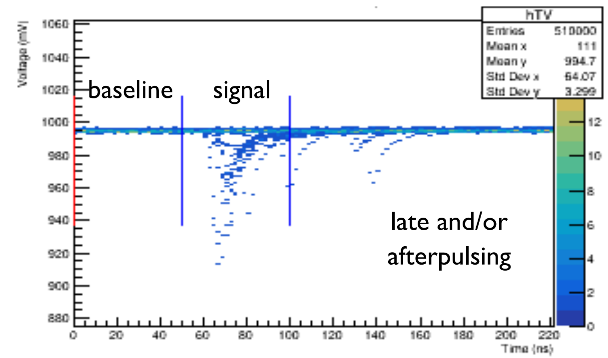
- Gain Calibration
- Peak to Valley
- Full Spectrum Fit

Peak to valley fitting routine

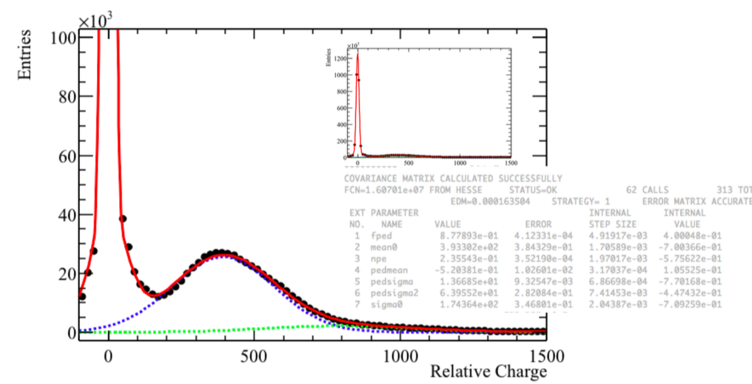
- Peak to valley results
- Gain calibration and consistency results

In progress

- Full fit working and ready to utilise
- Common analysis framework skeleton on Github



Calibrated waveforms sample showing example fixed windows



Full fit to charge spectrum example npe = 0.2

RESULTS

The University Of Sheffield.

Gain Calibration

Liz Kneale

Gain Calibration

Procedure

Record SPE spectrum at 5 HV settings

100 V intervals around operating voltage

Find SPE peak - three methods studied

1. Maxima in fixed ranges above pedestal
2. TSpectrum – use second peak
3. TSpectrum then Gaussian from peak to valley fit

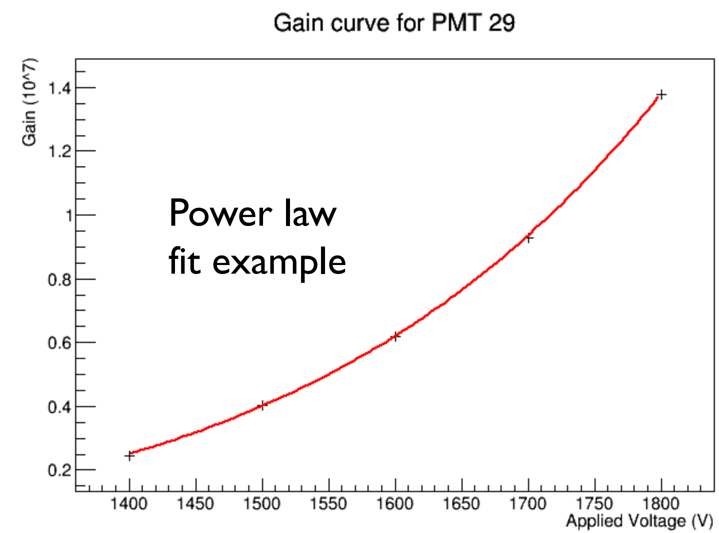
Determine HV for 10^7 Gain

Fit TGraph with power law

Gain calculated relative to the charge of the electron

R = 50 Ohms, electronics gain = 10 / 2 = 5

Gain = 10^7 for Q = 400 mV ns (or 8 pC)



Gain Calibration

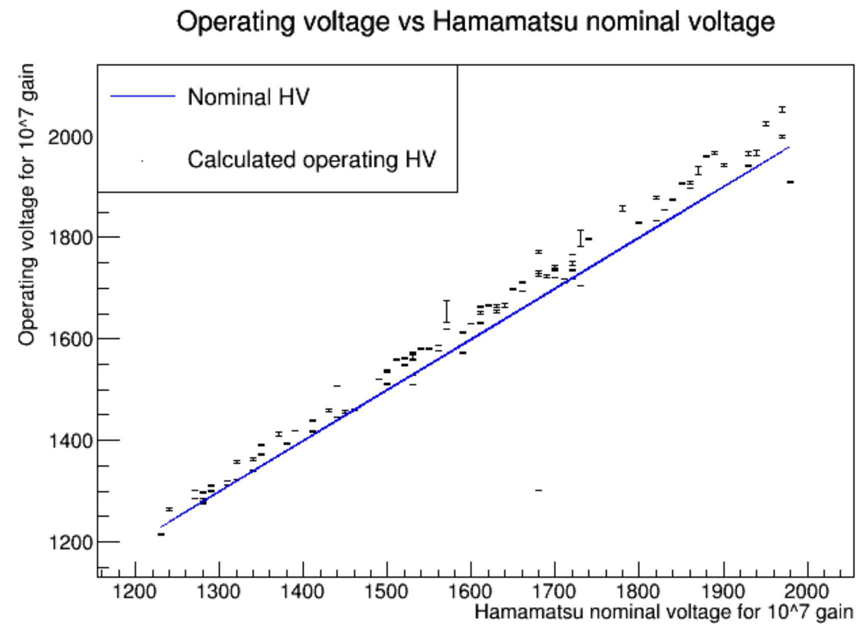
Results

Good agreement with Hamamatsu shipping data

Some workarounds required to include all data due to

- spectra with more than two peaks
- TSpectrum finding fake peaks
- No clear peak for some low HV steps

Areas which can developed further are understood



Gain Consistency

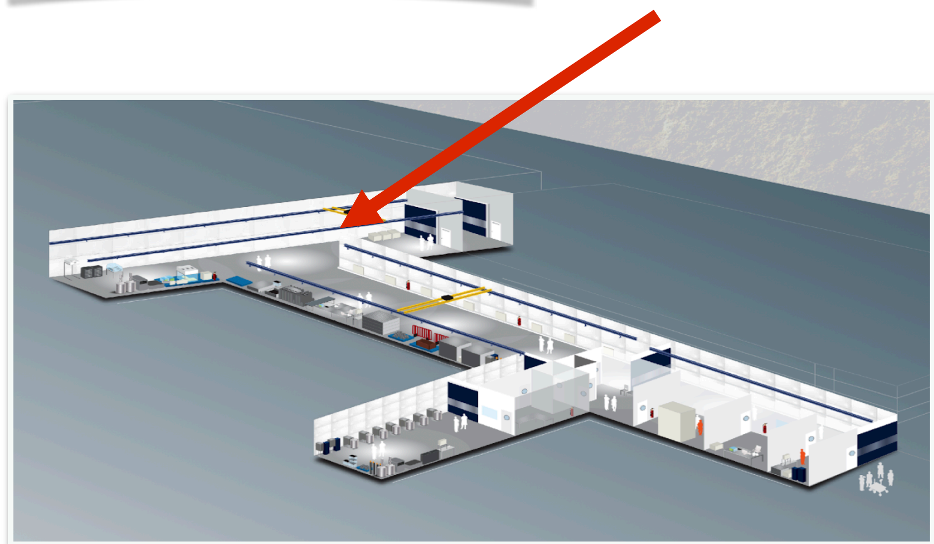
Leon Pickard
UC Davis

Shipping Underground

Eight PMTs were transported in two sealed skips (temporary PMT shipping solution)

Other equipment was transported in a third open skip

Testing location. Furthest away from possible light sources (e.g. communal room)



Timeline

November

22nd, (23rd) surface testing - batch one (two)

26th shipped underground in afternoon

27th arrived underground in morning

29th, (30th) underground testing – batch one (two)

December

4th shipped to surface

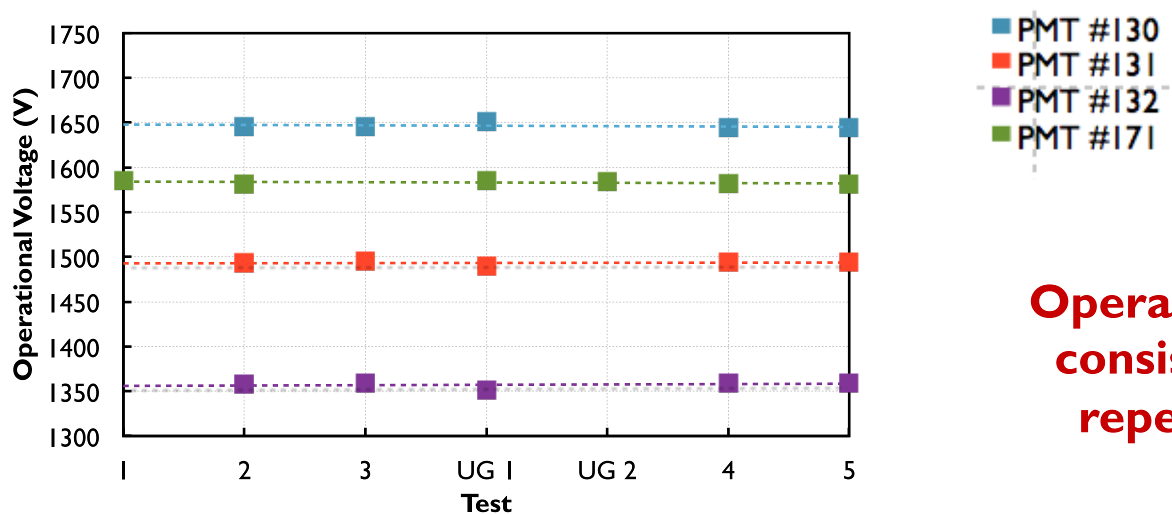
6th,(7th) surface testing = batch one (two)

Surface & Underground Conditions

	Surface	Underground
Temp. range (°C)	20 – 24	23 – 24
Light exposure	PMT testing room in darkness.	Lab in darkness overnight. Testing carried out remotely (dark rate test done locally)
Time of tests	9 am – 5 pm	5 am – 10 am
Average Magnetic field (μT)	45	49
Vertical / Horizontal field (μT)	42 / 16	45 / 19
Cosmics rate	$2 \times 10^{-2}\ cm^{-2}s^{-1}$	$4 \times 10^{-8}\ cm^{-2}s^{-1}$

Gain Calibration Repeatability

- Measured operating voltages consistent over runs (HV for Gain 10^7)
- The largest range only 9V (PMT #171)
- No discrepancy observed between the underground (UG) and the surface runs.
- The fit uncertainties were also consistent over all run periods – all below 1V



Operating voltages consistent under repeat testing!

Peak to Valley

Matthew Needham

Procedure

TSpectrum to identify pedestal and SPE peak

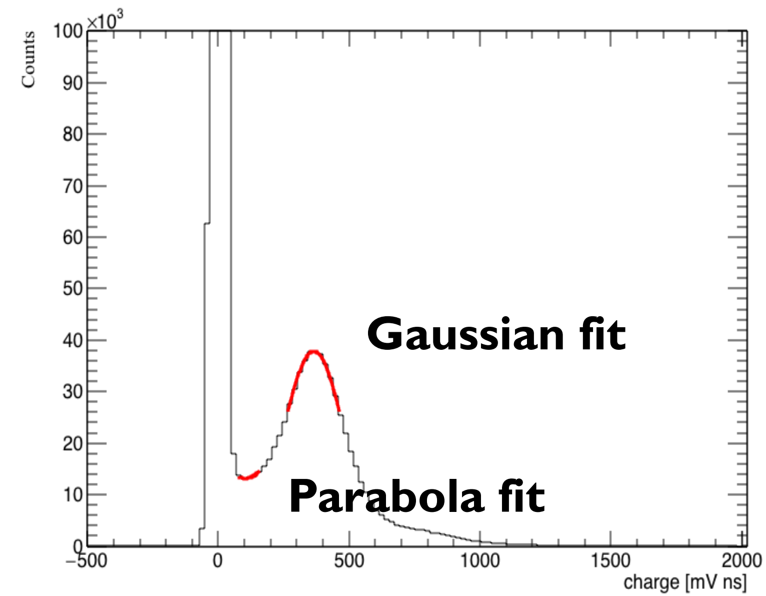
Gaussian fit around SPE using TSpectrum result
repeat fitting with range adjusted to maximum

Parabola fit to valley using TSpectrum result
repeat fitting with range adjusted to found minima

Peak to valley calculated from fit parameters

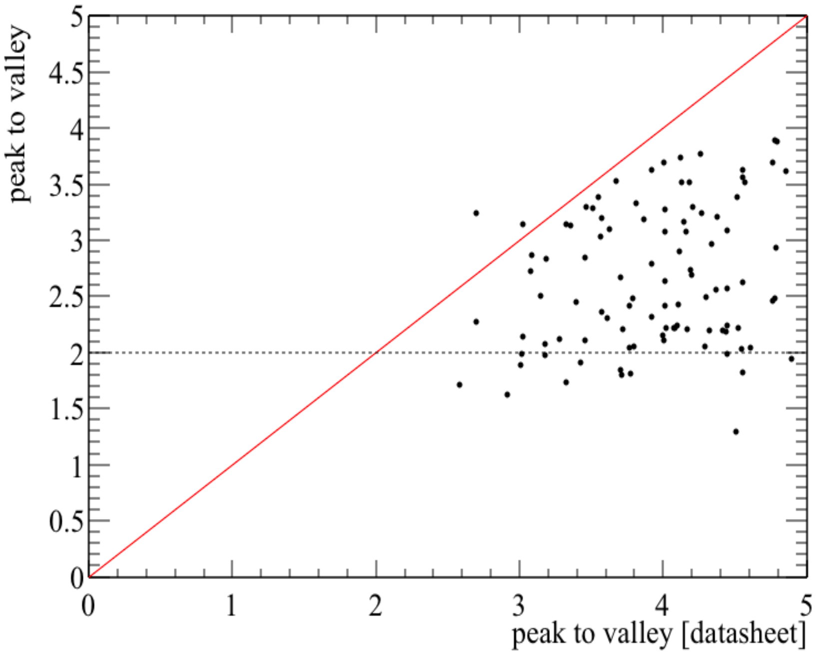
Charge histograms with window around peak gave slightly larger ratio (~ 0.2)

Peak to valley uncertainty from fit ~0.01



Results reproducible at 0.01-0.02 level

Results



Our results are clearly correlated with those from Hamamatsu ☺

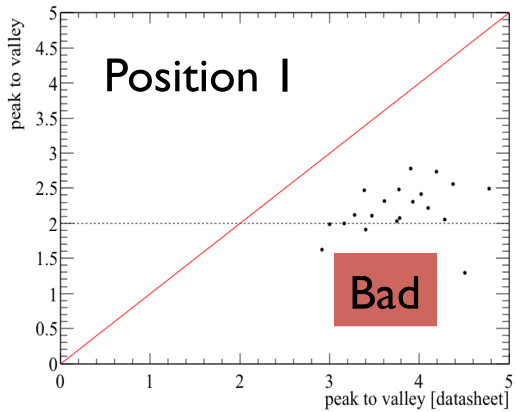
Most tubes measuring slightly smaller peak-to-valley ☹

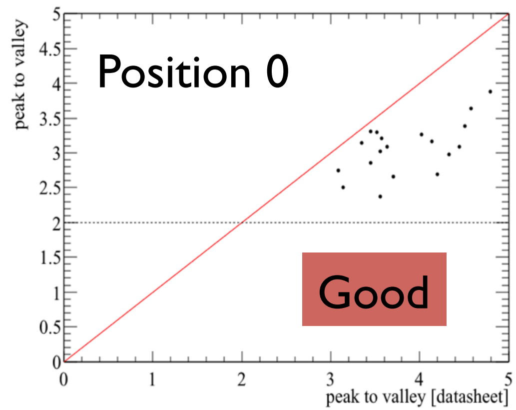
Peak-to-valley mostly above 2 though

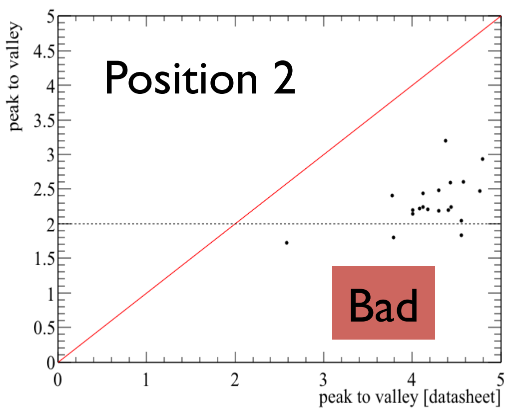
Double Chooz report higher ratios when using u-metal shield
[C. Bauer et al. 2011]

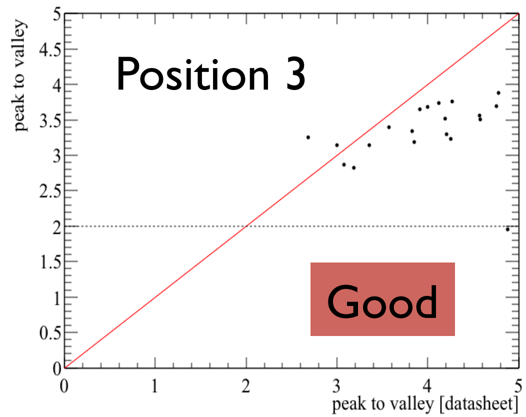
Results

Data divided according to position in Rig A







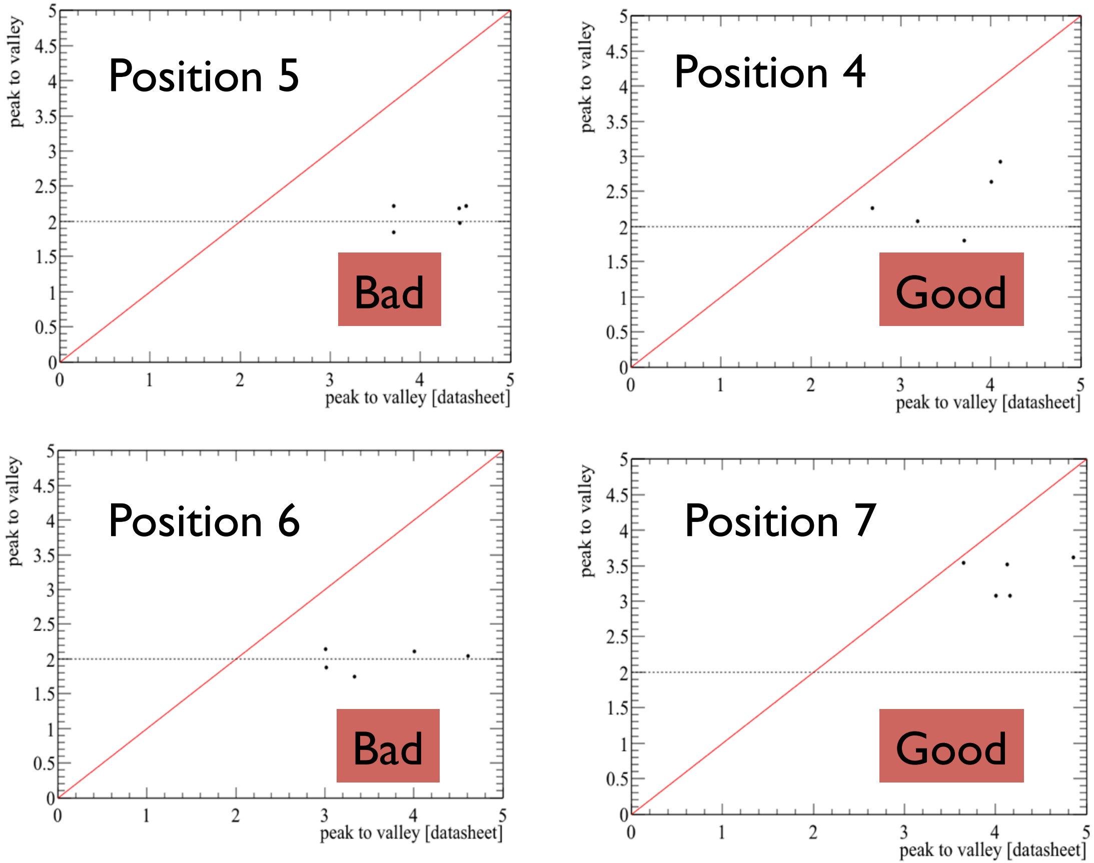


Could differences lower ratios be down to position in the rig ?

Related to noise?

Results

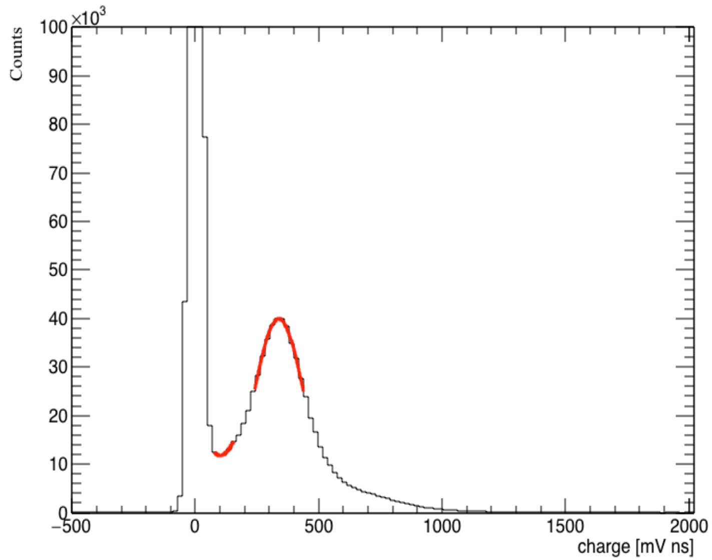
Data divided according to position in Rig B



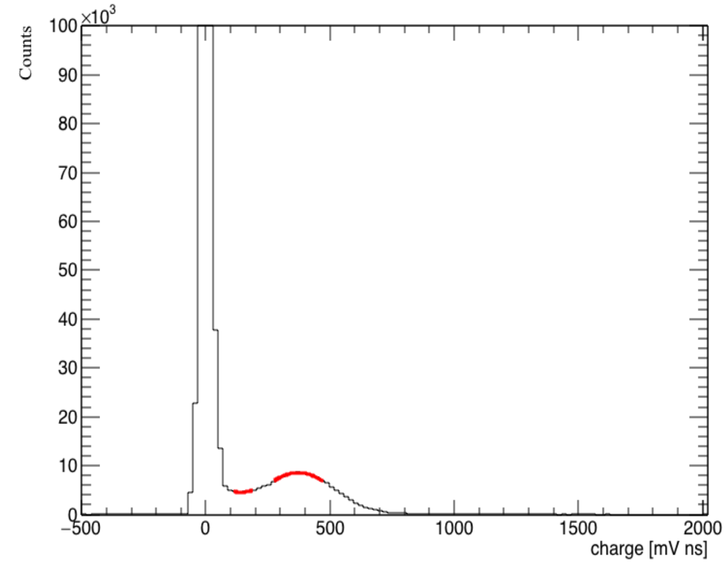
Twenty PMTs were tested in the second rig (tent B) during run one

80 were tested in rig A

Visible differences



PMT 42 in location 3



PMT 32 in location 6

Do results hint at noise or illumination playing a role ?

Surface and Underground

PMT ID	Surface test 1	Underground	Surface test 2
130	3.9	4.4	3.8
131	2.5	3.2	2.4
132	2.2	3.1	2.3
133	3.3	3.0	3.3
90	2.9	3.6	2.8
159	2.4	3.2	2.3
166	2.5	3.4	2.5
171	3.5	3.5	3.6

PMTs appear to perform better underground
Could this be due to a less noisy environment?

Peak To Valley
Summary

- Fits were successful for all PMT data
- Surface results are similar before and after transit
- Higher ratios for underground results not prescribed to underground specific conditions
- Good comparison to Hamamatsu shipping data found for certain rig positions
- Further investigations into consistency of grounding, illumination and background noise required

Dark Rate

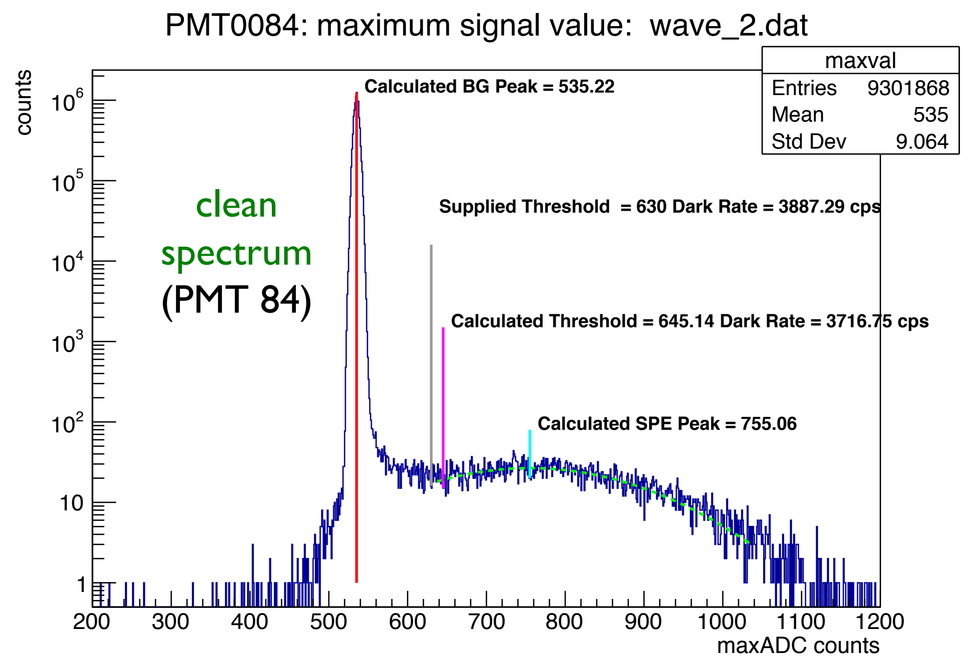
Steve Quillin
Tom Shaw

Dark Rate

Count events above SPE threshold

1. Fixed: ADC = 630
2. Calculated: Ped+(SPE-Ped)/2
3. Manually determined

- The fixed threshold method is comparable to Double Chooz (10 mV threshold)
- Baseline noise and offsets motivated studying a second method



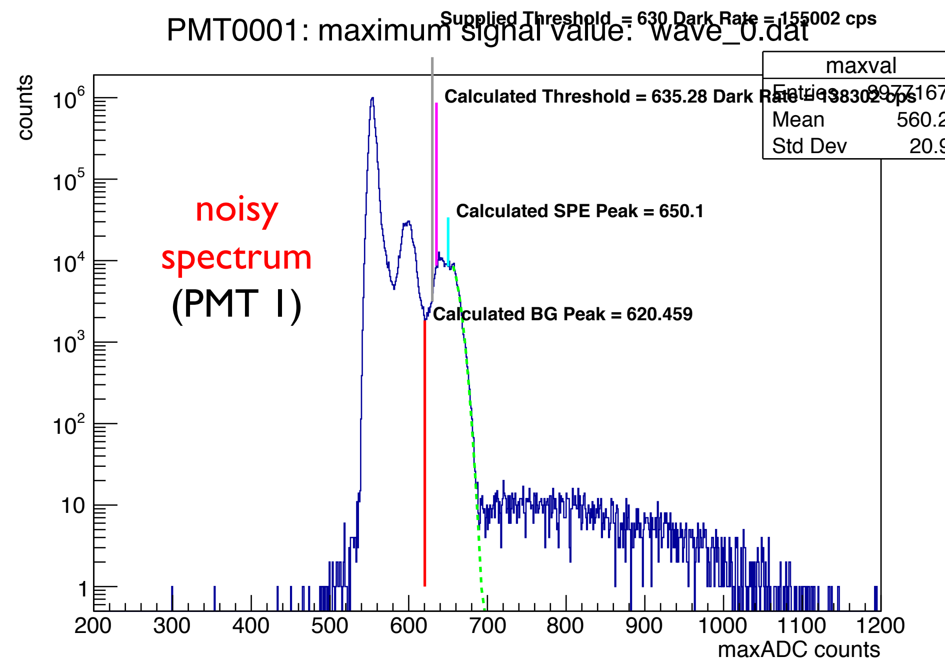
Example of pulse peak histogram
(peak of voltage pulse in arbitrary units)

Dark Rate

Count events above SPE threshold

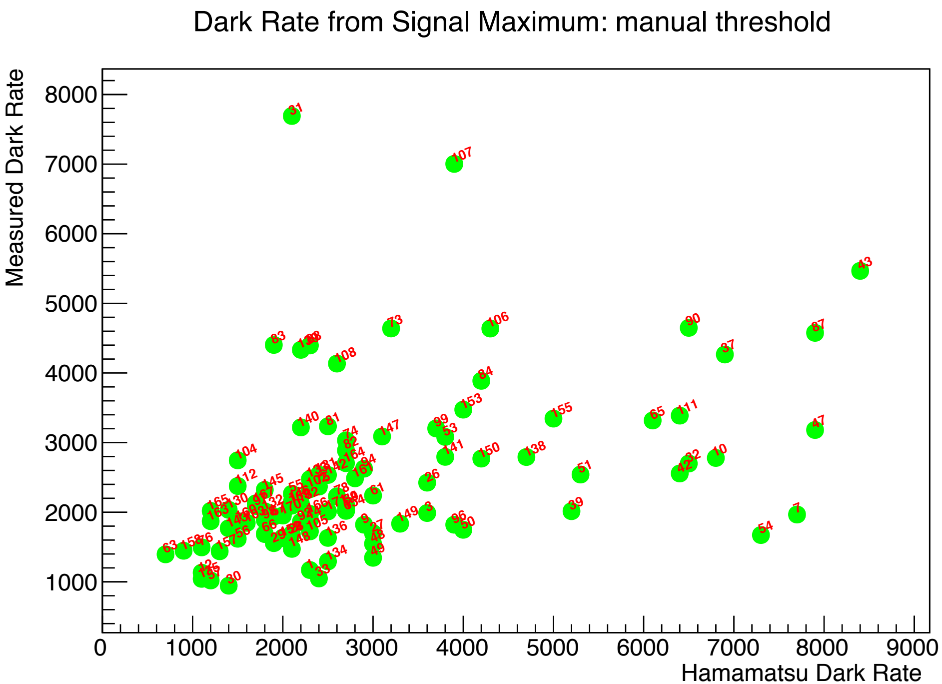
1. Fixed: ADC = 630
2. Calculated: Ped+(SPE-Ped)/2
3. Manually determined

- The fixed threshold method is comparable to Double Chooz (10 mV threshold)
- Baseline noise and offsets motivated studying a second method
- A third manual threshold method was used to allow outliers to be included



Example of pulse peak histogram
(peak of voltage pulse in arbitrary units)

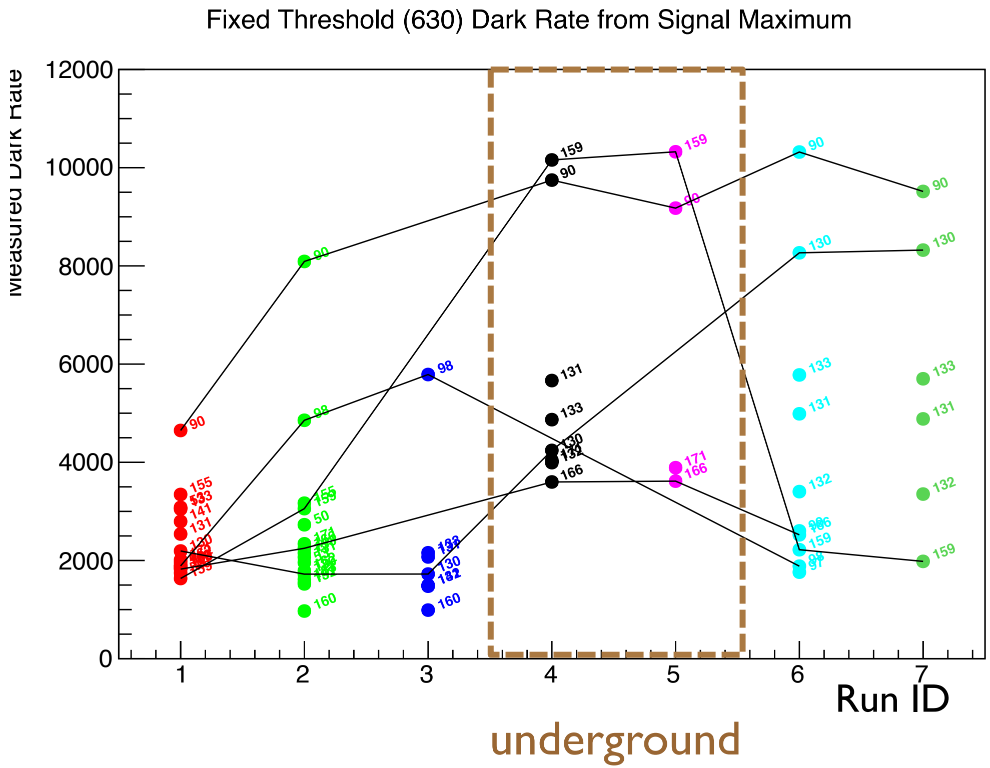
Dark Rate



Tested vs Hamamatsu dark rate using manual threshold method

	mean	std dev
Shipping Data	3044	1763
Manual Threshold	2489	1172
Double Chooz	2200	500

Dark Rate



Comparison of dark rates for surface and underground testing

The fixed threshold method used for these results

Need to investigate noise and baseline

The University Of Sheffield.

Afterpulsing

Anthony C. Ezeribe

Types of Afterpulsing

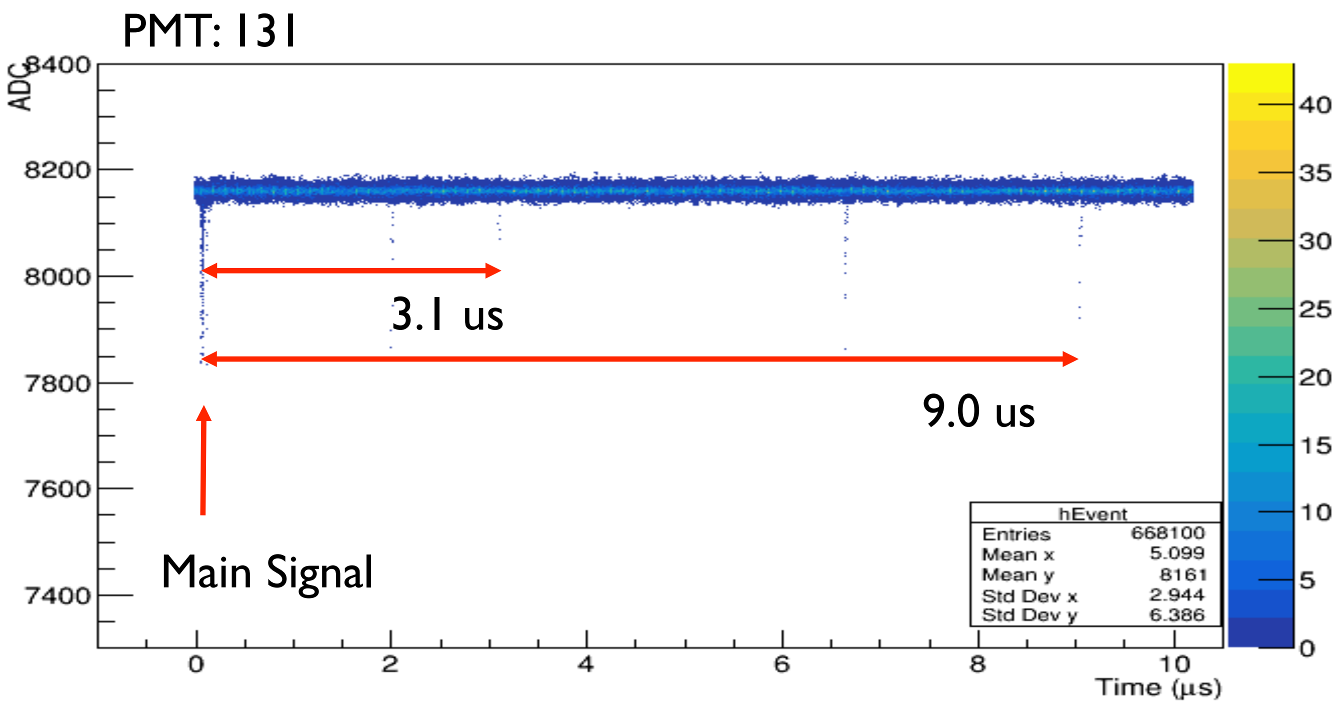
Two categories of **Afterpulsing**

1. photoelectron in-elastically scatters off PMT dynode
   - afterpulse arrives up to 80 ns after signal pulse
2. positive ion is created in PMT residual gas
   - afterpulse arrives between 100 ns and 10.2 us after signal (delay can also be larger)

Late pulsing is caused by elastic scattering of electron off first dynode: not preceded by a initial pulse.

Aim to measure rates and multiplicities

Afterpulsing Examples



CONCLUSIONS

Next Stages

- The first pass analysis was carried out over the Christmas period
- More time is required to digest and refine the results
- Some areas clearly need attention
  - detailed understanding of noise
  - relationship between figures of merit and light levels
  - contribution of fields to noise and performance

- After-pulsing analysis is underway
- Further data analysis and testing is necessary
- Documentation of analysis and results to come

Summary

- ✓ PMT testing was a real success
- ✓ Data was acquired for101 PMTs by thanksgiving
- ✓ A sample of 8 PMTs underwent testing underground
- ✓ Comparisons to Hamamatsu shipping data look good
- ✓ There are clear pathways forward to improve methods and automation towards large scale testing
- ✓ Great collaboration to work in!

Thanks!

Gary Smith

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