Wavelength Shifting Reflector Foils for Ar Scintillation Light in GERDA

Manuel Walter

Universität Zürich[UZH]

Doktorandenseminar
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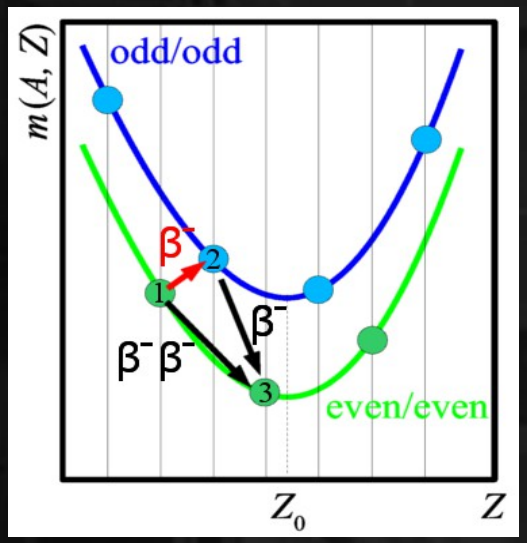
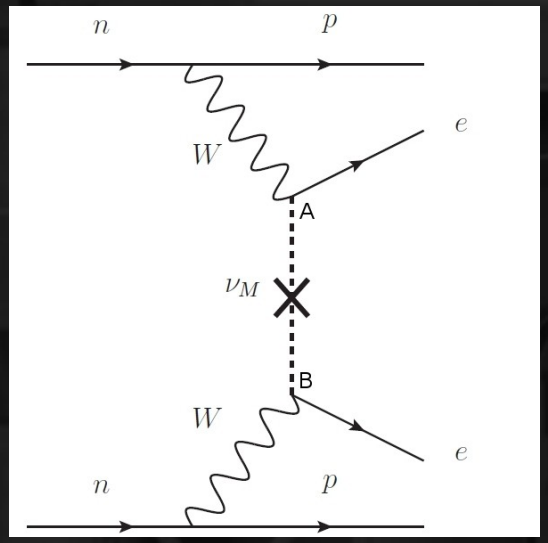
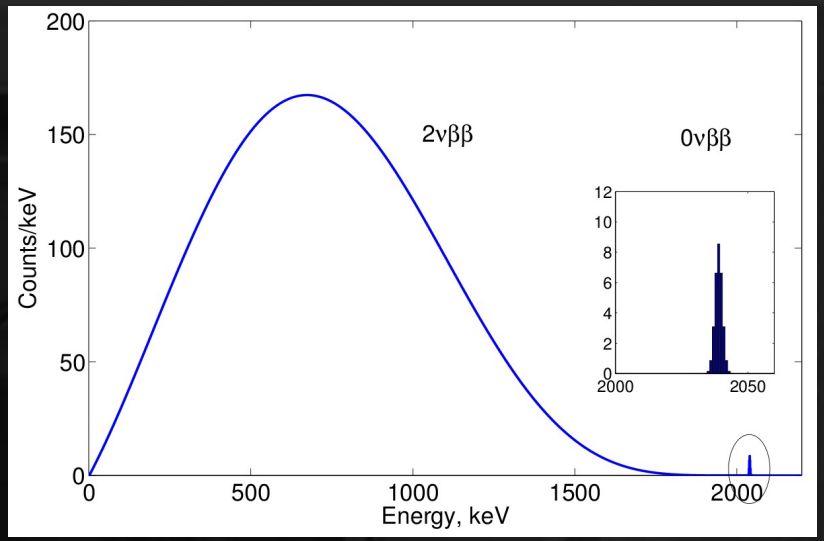
Double Beta Decay







2 ν ββ decay known for:
^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{150}Nd, ^{238}U, ^{130}Ba, ^{136}Xe
$T_{1/2}$ between $7 \cdot 10^{18}$ y and $2.5 \cdot 10^{24}$ y

0 ν ββ decay, controversial claim for ^{76}Ge with $T_{1/2} = 2.23^{+0.44}_{-0.31} \cdot 10^{25}\ y$

- Existence would imply total lepton number violation.
- Can be explained by Majorana neutrinos.

0νββ Ultra Low BG Experiment GERDA

Situated at LNGS.

18 kg enriched Ge-detectors :

- Detector = active material,
- very high energy resolution,
- directly immersed in 65 m^3 of liquid Ar.

Ar cryostat is surrounded by a water tank for shielding and to veto muons by their Cherenkov light.

Phase I (now) BG in region of interest:
10^{-2} counts/(kg keV y) · 5 keV · 18 kg = 0.9 counts/y.

Phase II:
One order of magnitude less.

Background Suppression
Liquid Ar as an active veto

Main BG in region of interest: β from ^{42}K, α from ^{222}Rn, γ ^{208}Tl.

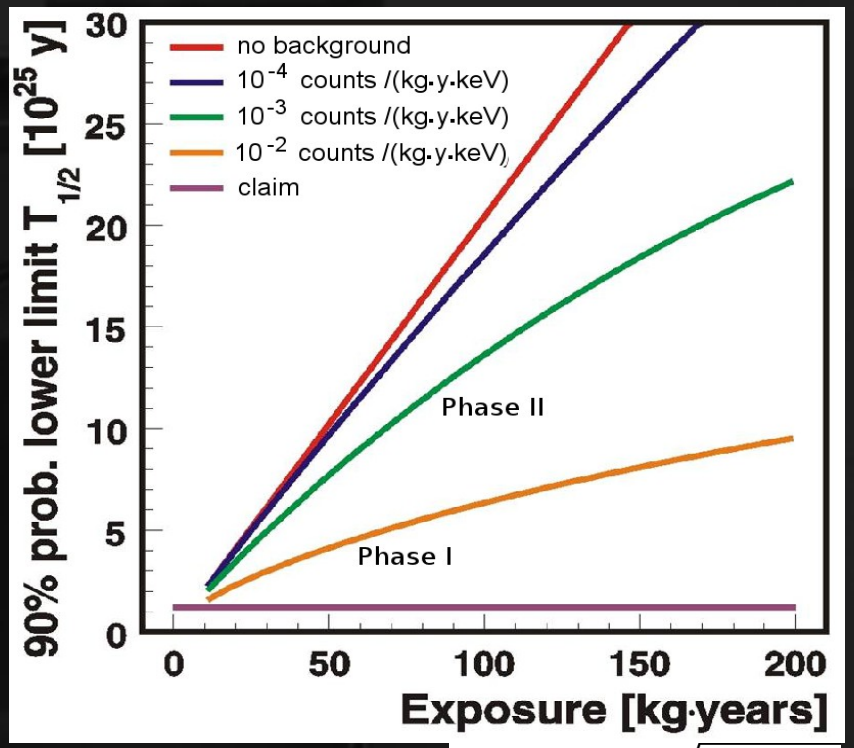
Ar is a scintillator => can be used as a veto.

128 nm => needs to be converted to longer wavelength before detection.

- Performed by reflector foils coated with TPB.
- Conversion yield determines rejection efficiency.
- Long term stability is needed.

Typical suppression factors in the ROI measured in a test set-up (source in active volume):

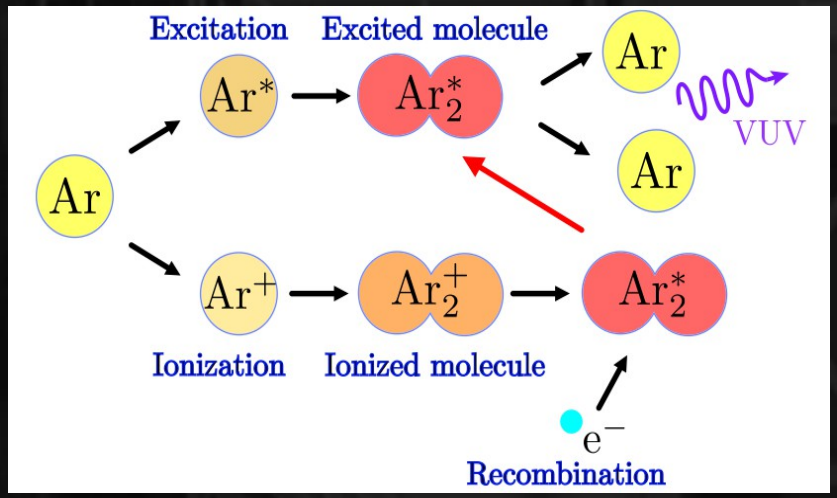
- ^{60}Co: 27, ^{208}Tl: 1180, ^{214}Bi: 4.6 [1].

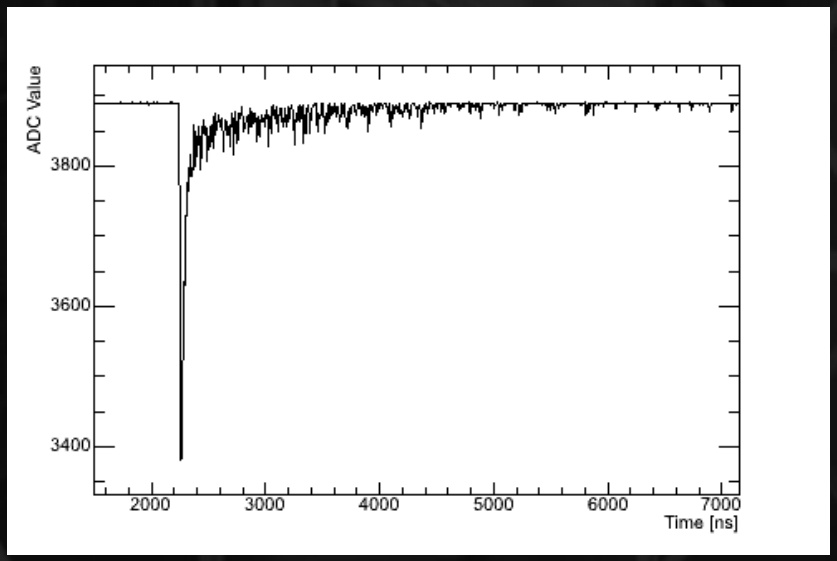


Half-life Limit: $T_{1/2}^{0\nu} = \sqrt{\frac{m \cdot t}{\Delta E \cdot B}}$

[1] "A liquid argon scintillation veto for Gerda", M. Heisel, 2011

Scintillation in liquid Ar





Ionizing particles excite or ionize Ar atoms, which form excited molecules.

No atomic energy level at emission wavelength.

Excimer are produced in a singlet and a triplet state with distinct life times:

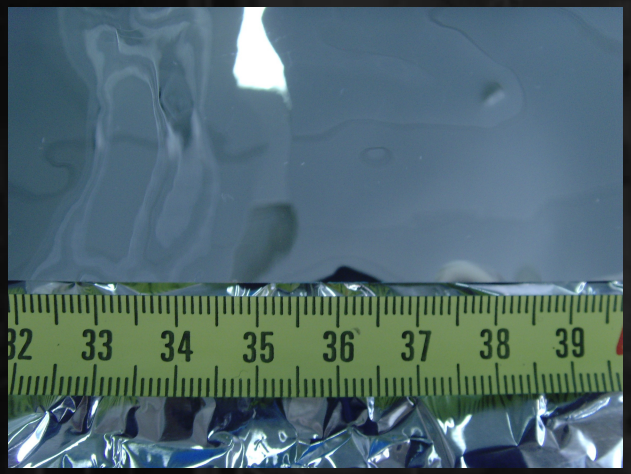
- Singlet ≈ 7 ns,
- Triplet ≈ 1600 ns.

Impurities cause non radiative de-excitation of excimers and a reduction of the triplet lifetime:

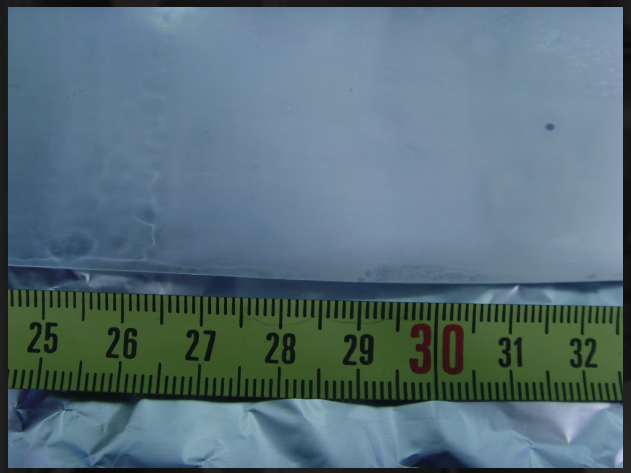
- Good quantity to monitor the purity.

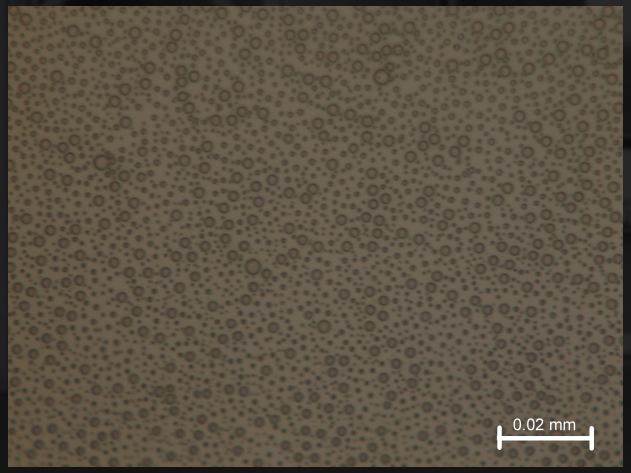
Coatings

10/1 PS/TPB on VM2000 (used in LARGE):
Uniform (UV and VIS), clear.

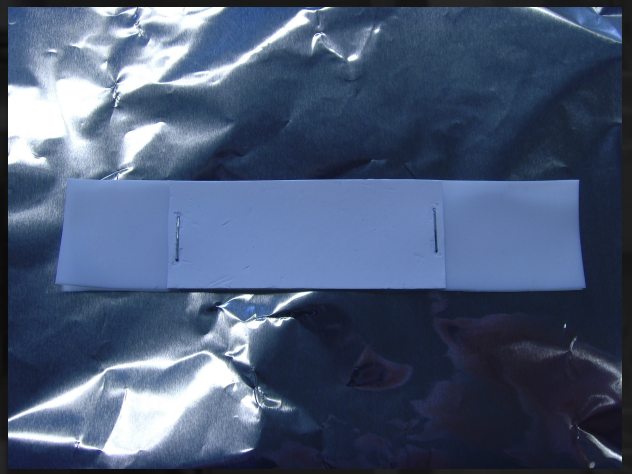


TPB + Makrolon on VM2000:
Milky, more uniform for higher Makrolon concentrations.





Dipped Tetratex (a PTFE fabric):
Very uniform for all coatings, can be coated with pure TPB.



Mechanical Stability

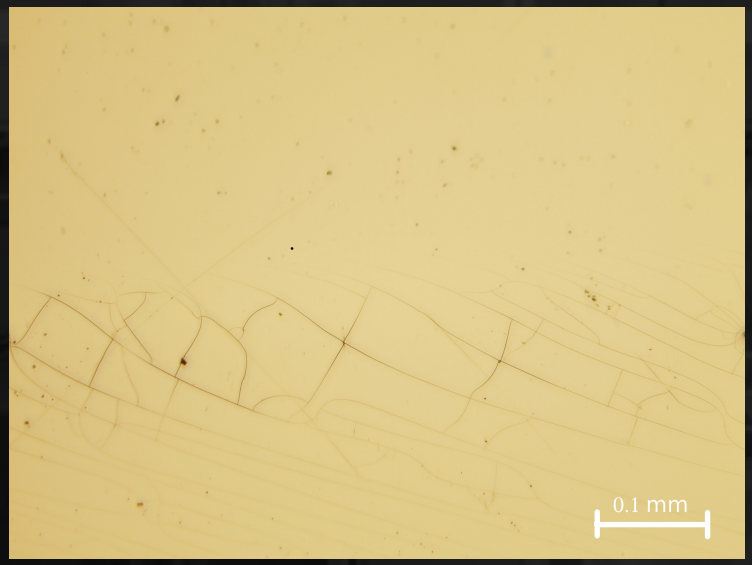
Evaporated Tetratex coating: unstable (can be blown of).

Dipped coatings of Tetratex: fragile (can partly be wiped of).

Dipped coatings of VM2000: stable (resist touching, not scratching).

Samples were stored for 2 month and 11 days in liquid N_2:

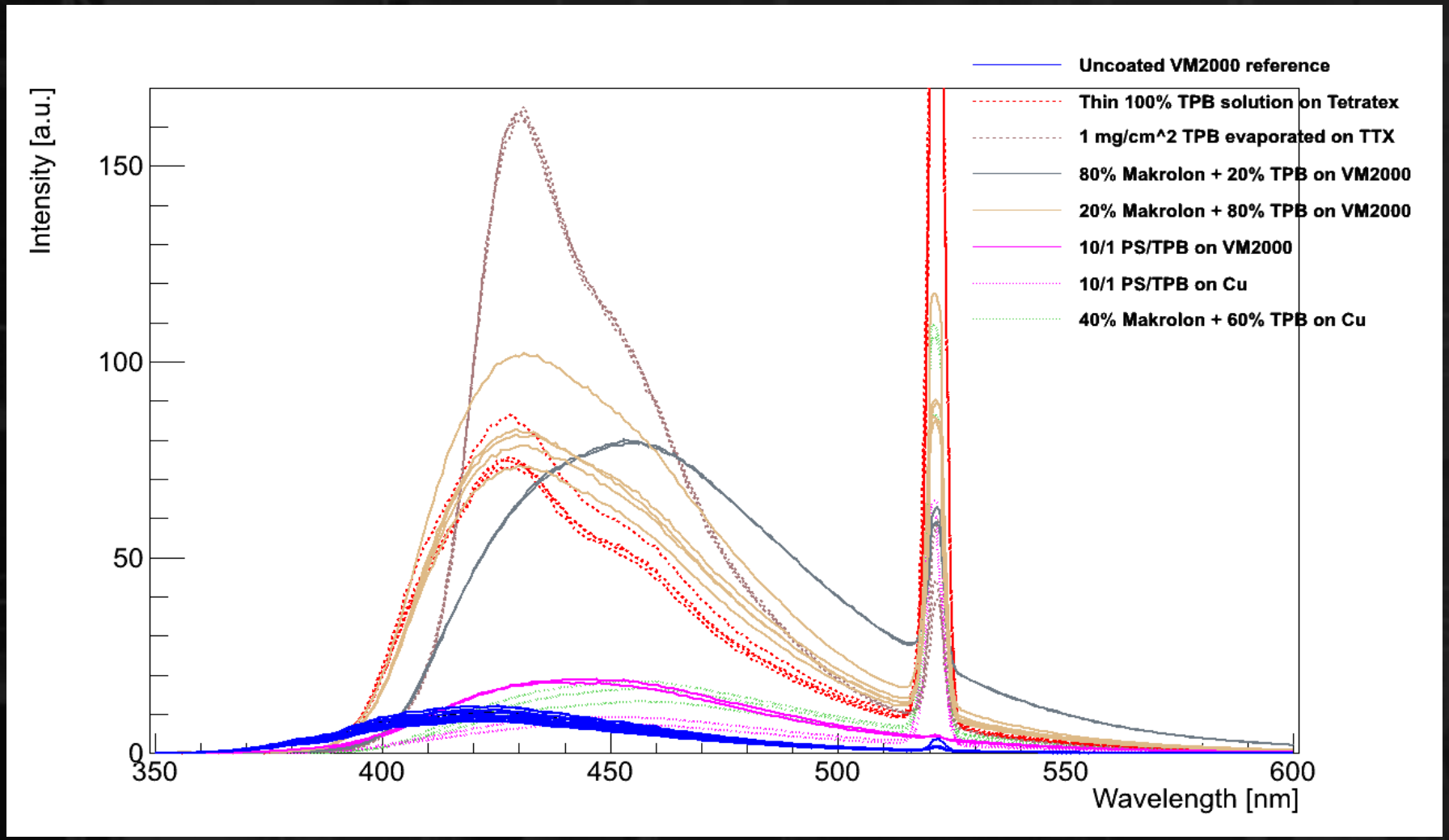
- No change observed by eye with day light and UV light.
- Microscope:
  - Cracks in PS+TPB coatings in thicker regions.
  - No change observable for other coatings.



Cracks in PS + TPB coatings on VM 2000 after storage in liquid N_2.

Consistent with coating falling off in LARGE.

Fluorescence Efficiency Pre Selection



Fluorescence spectra, excitation wavelength 260 nm, measured with a fluorescence spectrometer at MPI Heidelberg.

QE of PMT candidate is highest between 300 and 400 nm.

Intermediate Conclusion and Next Steps

Favourite candidate:

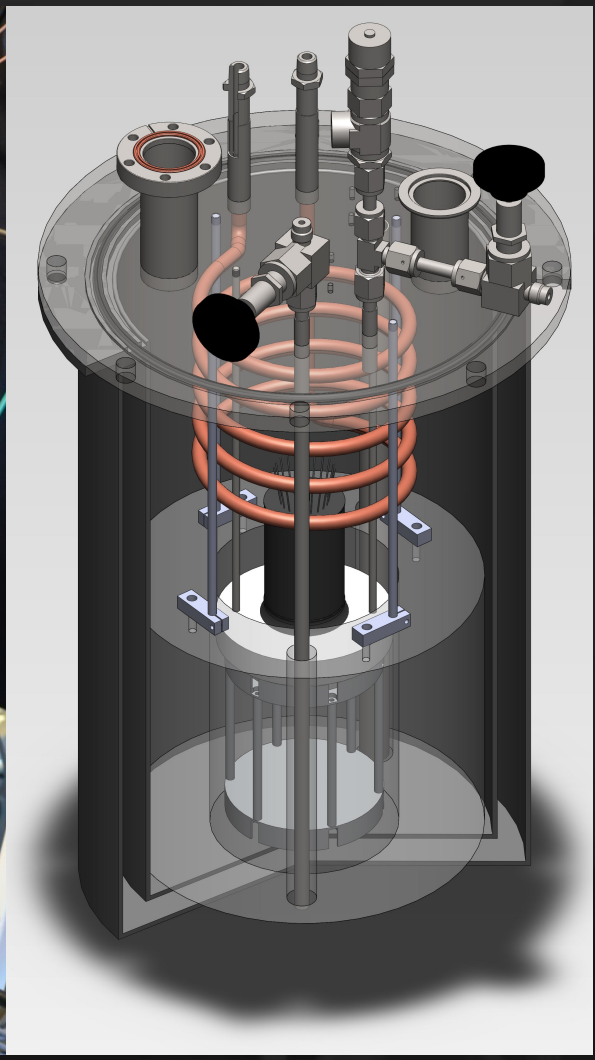
- Tetratex foil dipped with high concentration of TPB.
  - High efficiency.
  - Fits little better to the PMT sensitivity.
  - Coating soaked up => No big pieces can fall off, unlikely to loose significant efficiency over time.
  - Mechanical stability seems acceptable.

Next steps:

- Make further investigations on the stability.
- Measure the efficiency in liquid Ar.
  - Relative to a sample of uncoated VM2000.

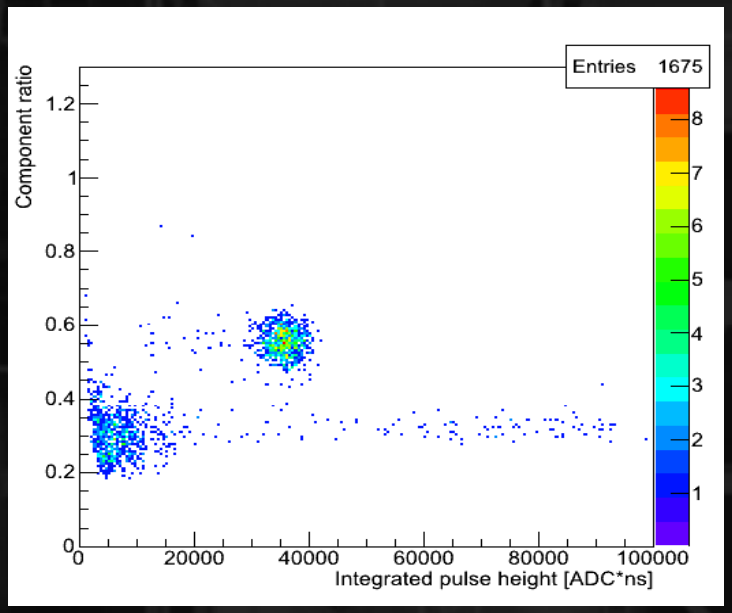
Liquid Ar Set-up

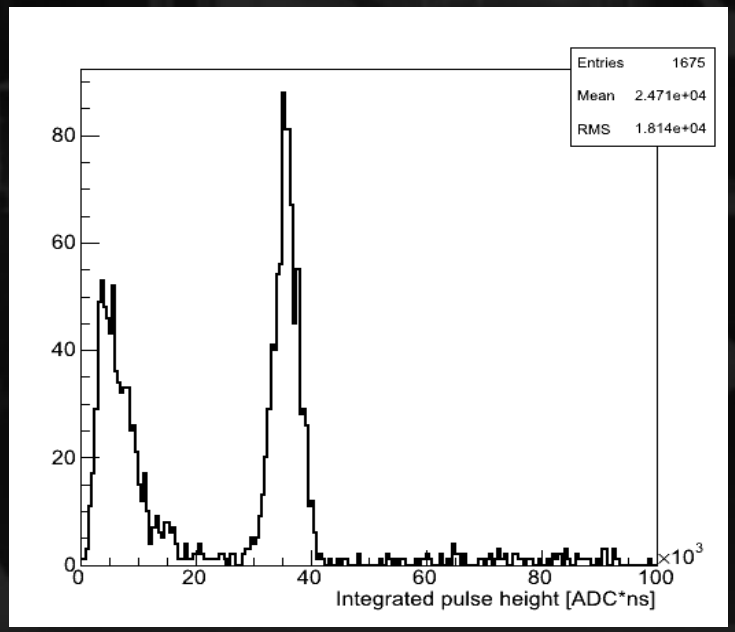
- Evacuation with a turbo pump.
- Cooling by LN_2 flowing through Cu coil in the dewar. Regulation by a gas flow meter.
- High purity Ar gas (6.0) is condensing on this coil.
- Scintillation light produced by an ^{241}Am α-source and shifted by a surrounding cylinder of WLS reflector foil.
- Level is measured by a cylindrical capacitor.



Picture and scheme of the LAr Set-up

Reference measurement





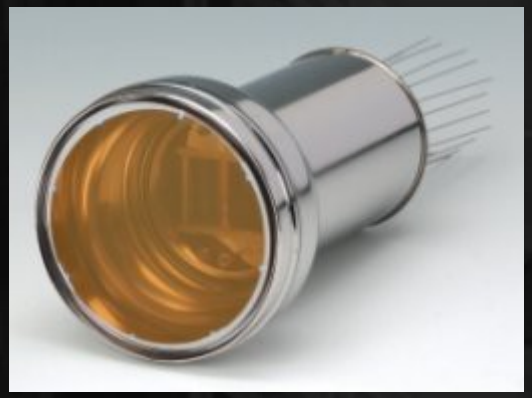
Efficiency of uncoated VM2000.

Component Ratio (CR = fast/total) depends on ionisation density
=> α-particles (high CR) can be distinguished from γ-rays (low CR).

α peak narrow and well visible:

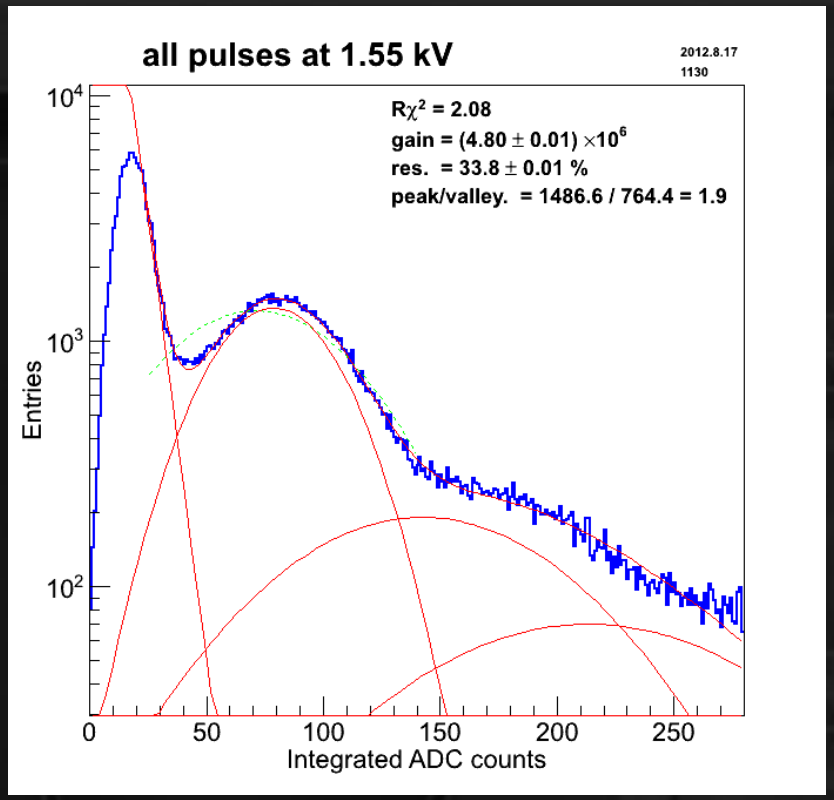
- well suited to compare the efficiency (peak position) and uniformity (peak width) of different coatings.

PMT Characterisation



3” Hamamatsu
PMT R11065-10

(Picture from
Hamamatsu Catalog)



Candidate to be used in GERDA.

Very low radioactivity.

High quantum efficiency and gain.

- Gain measured by the single PE spectrum.

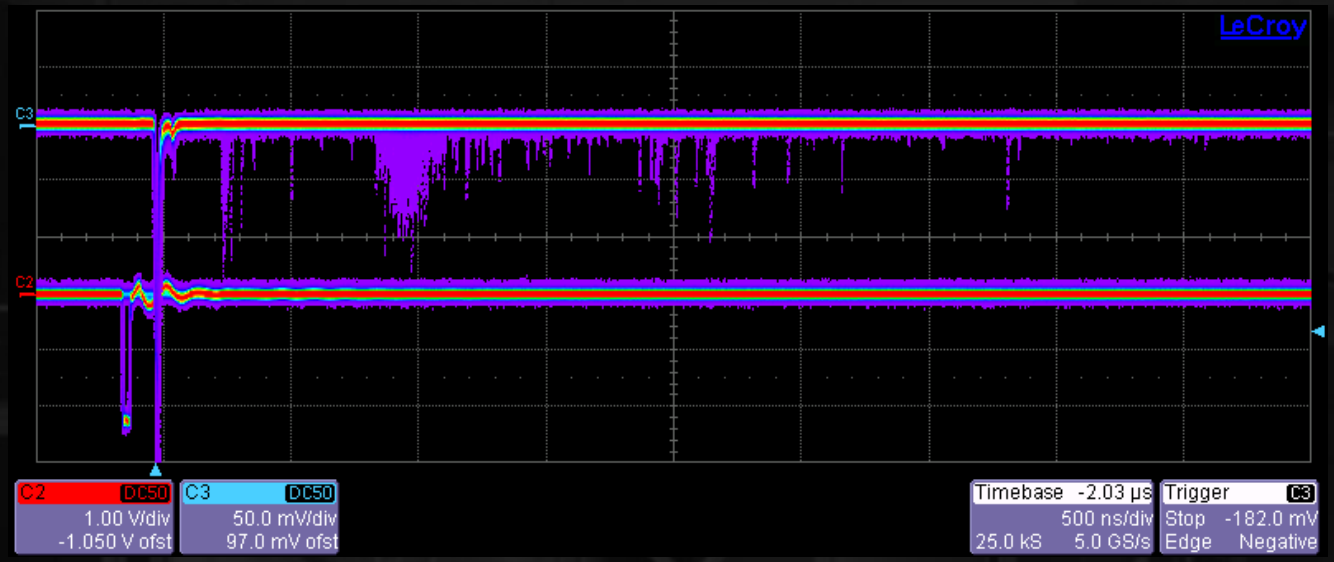
For cryogenic temperatures.

Spectrum of all pulses above $3\sigma_{baseline}$.

Fit-function:

$$\mathrm{Exp}+\mathrm{G}(\mu,\sigma)+\mathrm{G}(2\mu,\sqrt{2}\cdot\sigma)+\mathrm{G}(3\mu,\sqrt{3}\cdot\sigma)$$

R11065 Characterisation
After-pulses



Superposition of many LED driver pulses and the corresponding PMT responses.

About 20 % of this traces contain at least one after pulse.

- Reduced energy resolution,
- effects determination of triplet lifetime,
- results in wrong values of the CR.

Workaround:

- Use first 900 ns only.

Conclusion and Outlook

More stable coatings than presently used are found.

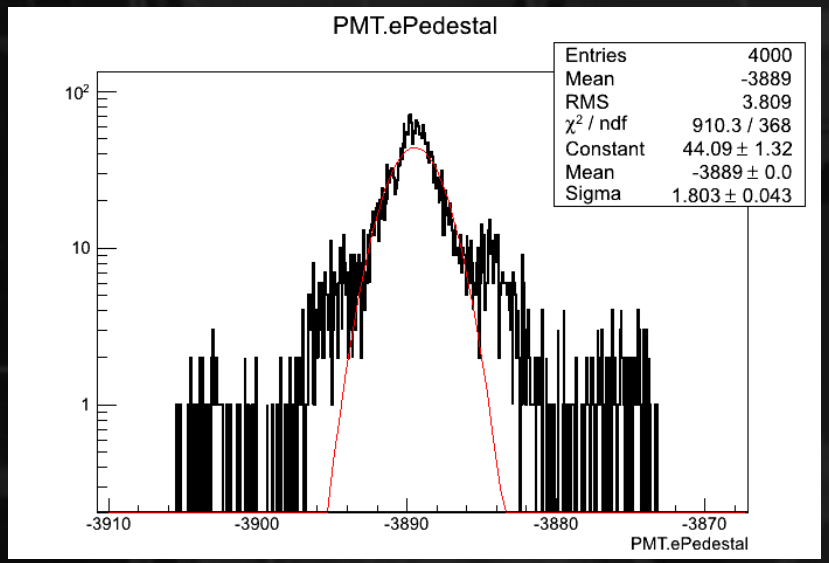
A measurement with a fluorescence spectrometer has been performed as an efficiency pre selection.

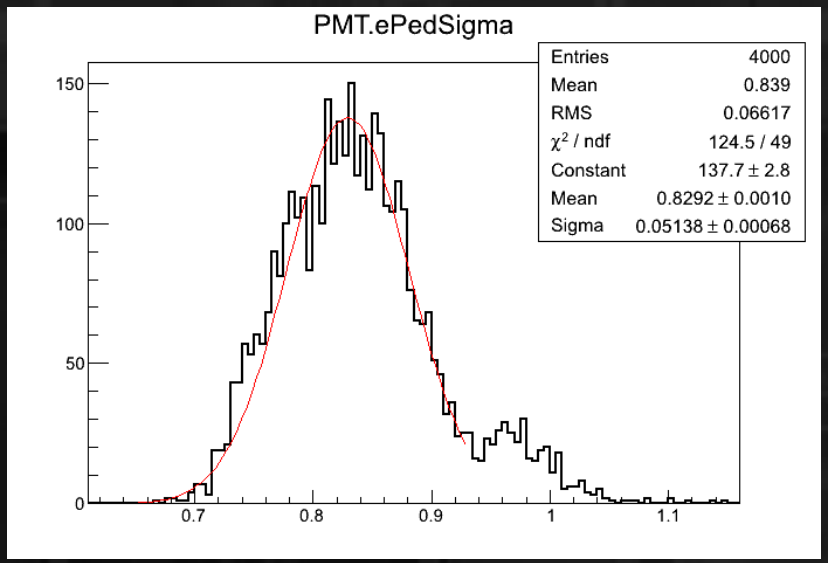
A set-up to measure scintillation light in LAr has been build.

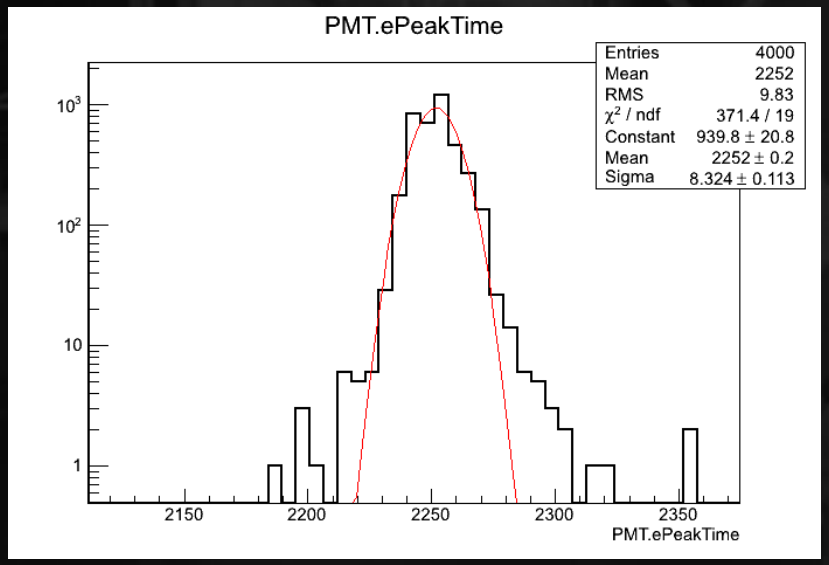
- A reference measurement has been performed.
- Several coated reflector foils are under preparation for an efficiency measurement.
- PMT R11065 has a high after-pulse rate.
- Working on a proper determination of the triplet life time.

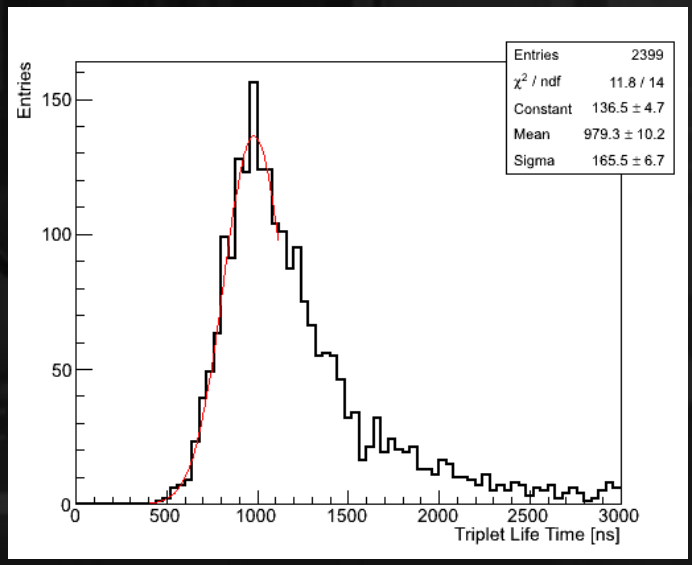

Backup slides

Cuts

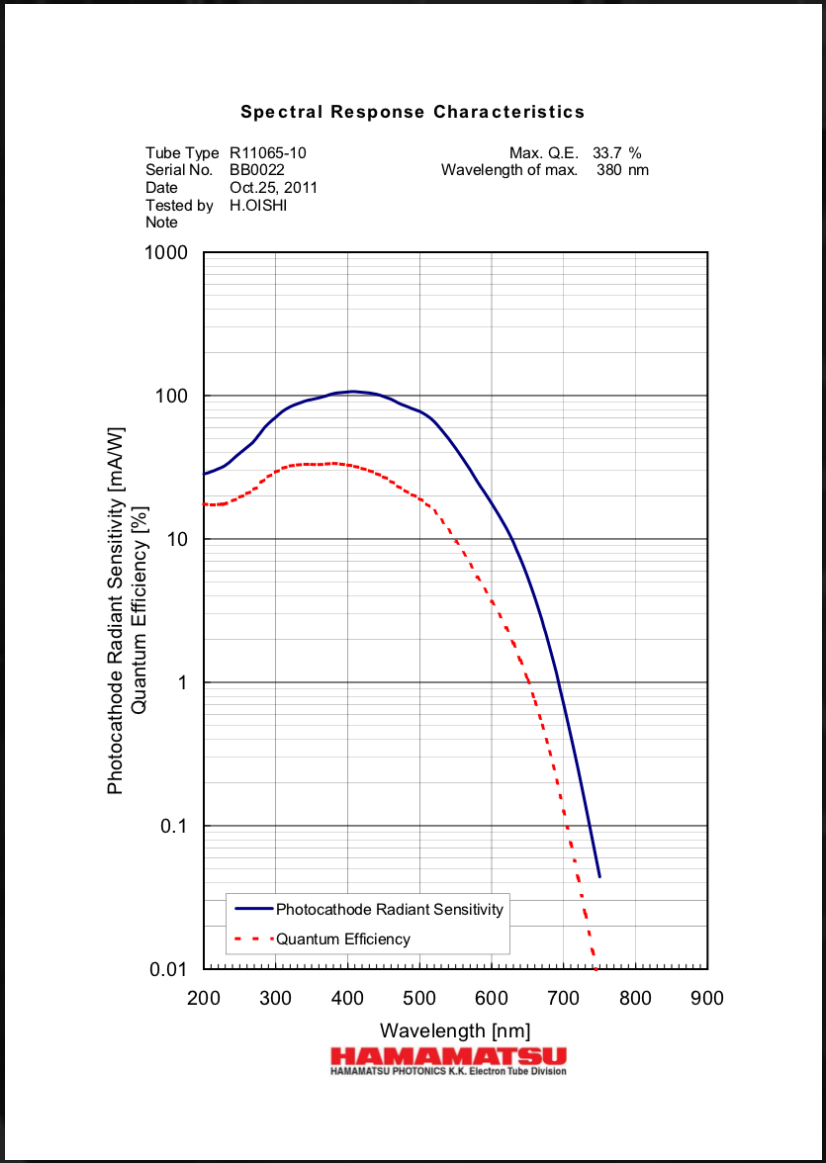

PMT.ePedestal
Entries 4000
Mean -3889
RMS 3.809
χ² / ndf 910.3 / 368
Constant 44.09 ± 1.32
Mean -3889 ± 0.0
Sigma 1.803 ± 0.043
PMT.ePedestal

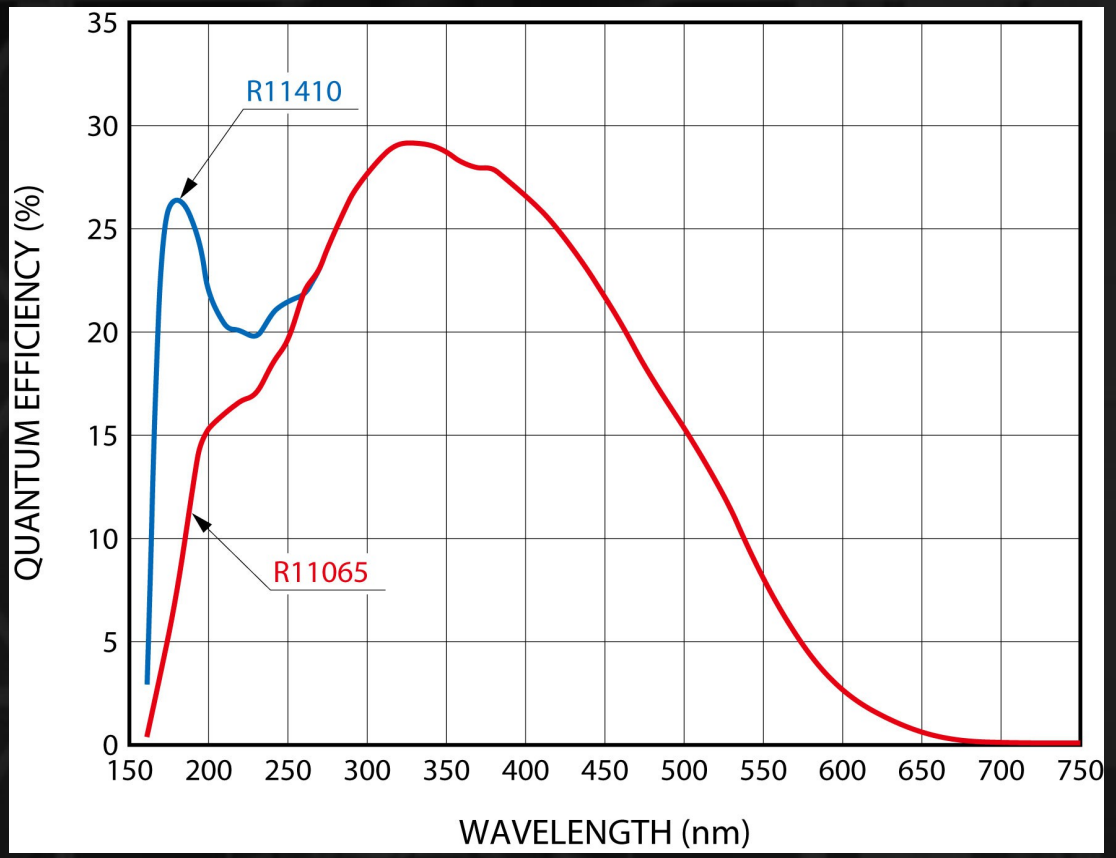

PMT.ePedSigma
Entries 4000
Mean 0.839
RMS 0.06617
χ² / ndf 124.5 / 49
Constant 137.7 ± 2.8
Mean 0.8292 ± 0.0010
Sigma 0.05138 ± 0.00068


PMT.ePeakTime
Entries 4000
Mean 2252
RMS 9.83
χ² / ndf 371.4 / 19
Constant 939.8 ± 20.8
Mean 2252 ± 0.2
Sigma 8.324 ± 0.113
PMT.ePeakTime

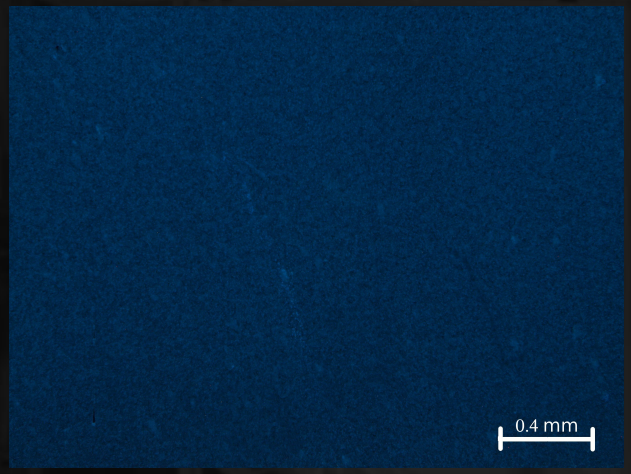

Entries
Entries 2399
χ² / ndf 11.8 / 14
Constant 136.5 ± 4.7
Mean 979.3 ± 10.2
Sigma 165.5 ± 6.7
Triplet Life Time [ns]

R 11065 QE


Spectral Response Characteristics
Tube Type R11065-10
Serial No. BB0022
Date Oct.25, 2011
Tested by H.OISHI
Note
Max. Q.E. 33.7 %
Wavelength of max. 380 nm
Photocathode Radiant Sensitivity [mA/W]
Quantum Efficiency [%]
1000
100
10
1
0.1
0.01
200 300 400 500 600 700 800 900
Wavelength [nm]
Photocathode Radiant Sensitivity
Quantum Efficiency
HAMAMATSU
HAMAMATSU PHOTONICS K.K. Electron Tube Division

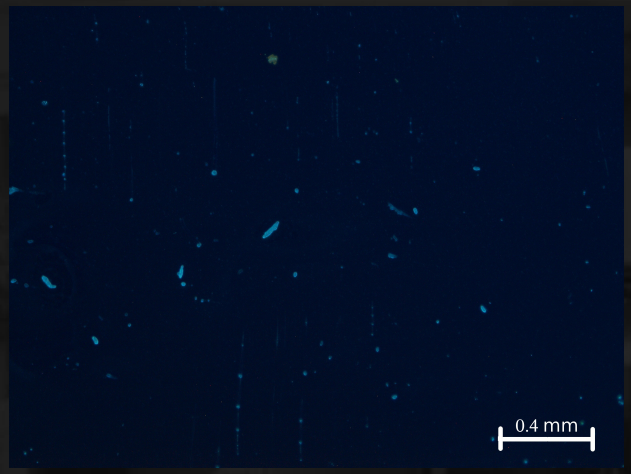

QUANTUM EFFICIENCY (%)
35
30
25
20
15
10
5
0
150 200 250 300 350 400 450 500 550 600 650 700 750
WAVELENGTH (nm)
R11410
R11065

Coatings

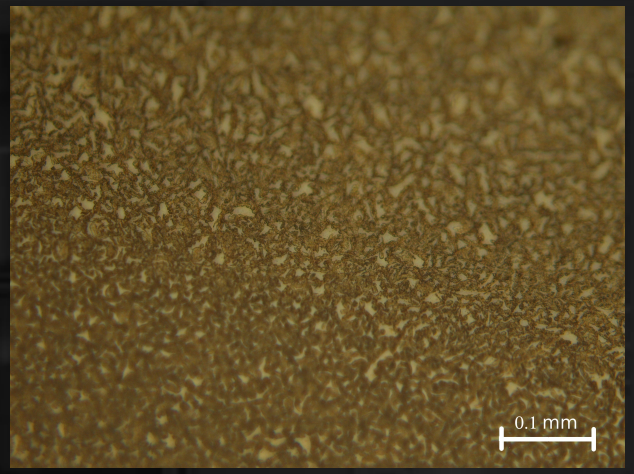


60%TPB

40% Makrolon



PST + TPB



80% TPB

20% Makrolon