Wavelength Shifting Reflector Foils for Liquid Ar Scintillation Light

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DPG Frühjahrstagung Dresden,
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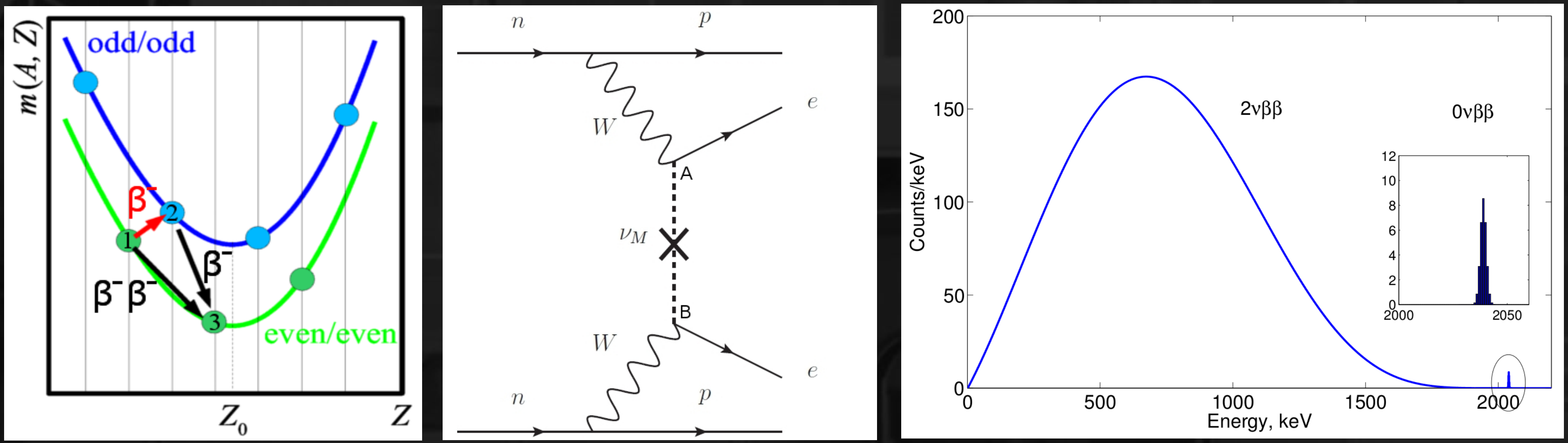
Double Beta Decay



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
with $T_{1/2}$ between $7 \cdot 10^{18}$ y and $2.5 \cdot 10^{24}$ y.

0 ν ββ decay, controversial claim for ^{76}Ge with $T_{1/2} = 1.19 \cdot 10^{25}$ y [1]

- Existence would imply total lepton number violation.
- Implies that neutrinos are massive Majorana particles.

GEDA[2] Phase I goal: Detection or exclusion $T_{1/2} = 2.2 \cdot 10^{25}$ y at 90% C.L..

[1] H.V. Klapdor-Kleingrothaus et al., Phys. Lett. B586, 198 (2004).
[2] The GERDA experiment for the search of 0νββ decay in ^{76}Ge, GERDA collaboration, arXiv:1212.4067 [physics.ins-det] (2013).

0νββ Ultra Low BG Experiment GERDA

Schematic view of the GERDA detector.

Situated at LNGS (Italy).

18 kg enriched Ge-detectors :

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

Water tank for shielding and to veto muons by their Cherenkov light.

Current background in region of interest (ROI): $2 \cdot 10^{-2}$ counts/(kg keV y) $\cdot$ 5 keV $\cdot$ 18 kg = 1.8 counts/y.

Phase II limit goal $T_{1/2} = 15 \cdot 10^{25}$ y:
+ 20 kg of Ge and one order of magnitude less background:

- Ar as active veto,
- pulse shape analysis of BEGes.

Liquid Ar as an active veto

Main BG in ROI:

β and γ from ^{214}Bi, β from ^{42}K and γ ^{208}Tl:

- Often in coincidence with an energy deposition in LAr.

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

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

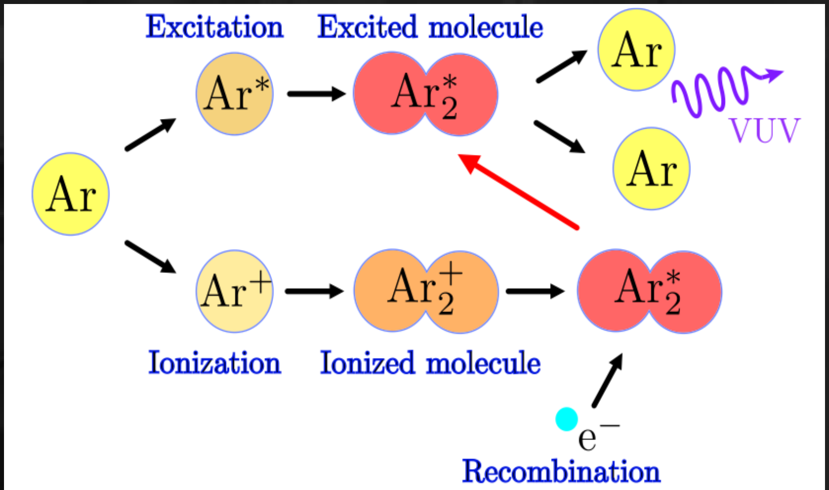
- Performed by reflector foils coated with Tetraphenyl butadiene (TPB).
- Conversion yield determines rejection efficiency.

Light is produced by triplet and singlet state excimers with very distinct life times.

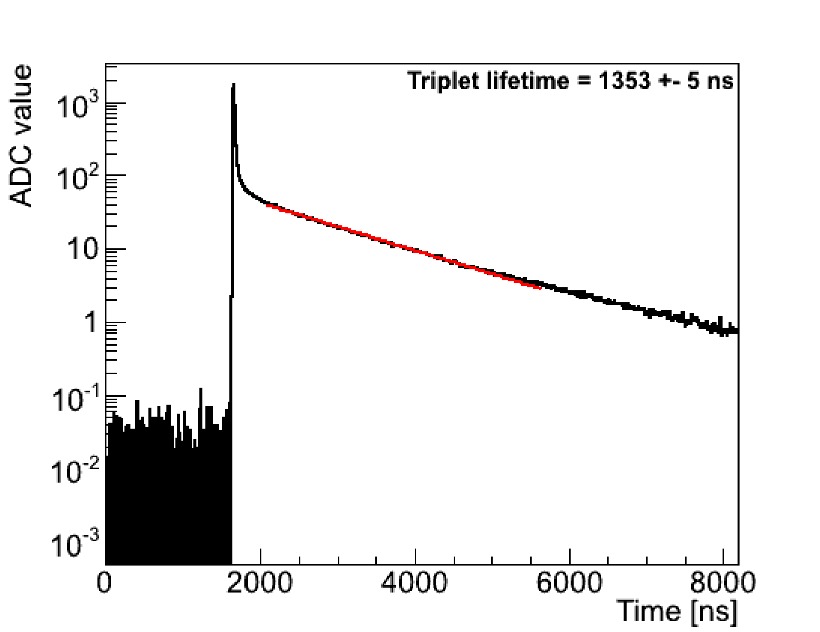
Typical suppression factors (measured [1]) in the ROI (source in active volume):

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

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



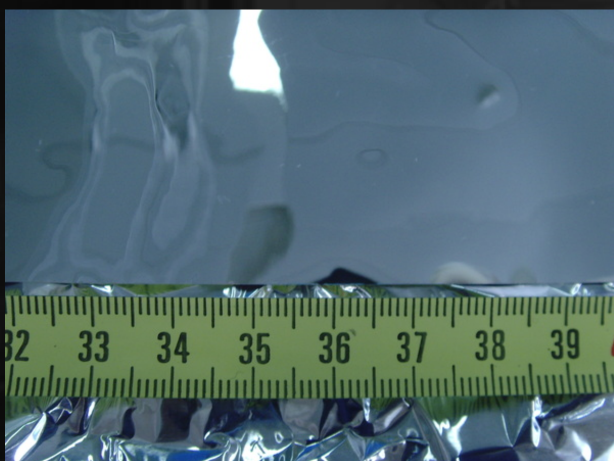
Scintillation process in Ar.

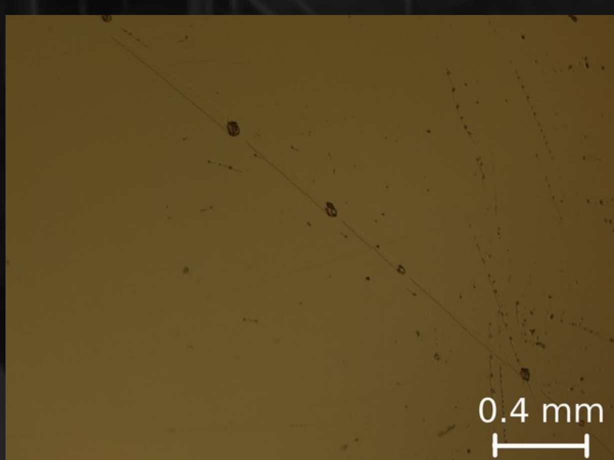


Mean PMT trace of Ar scintillation light.

Candidate Coatings
(measured in LAr)

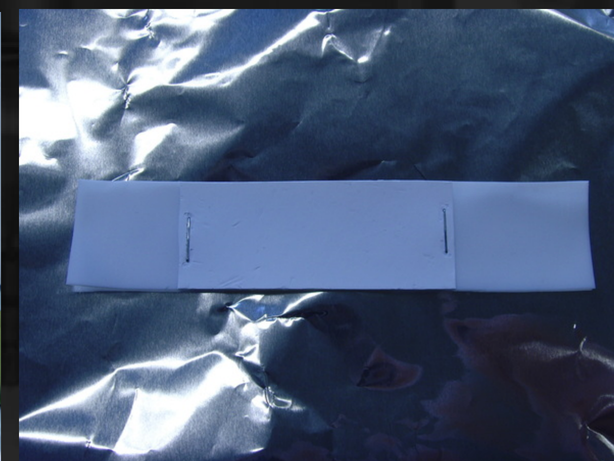
10/1 PS/TPB on VM2000 (a multi layer polymer foil): Uniform, clear, stable if thin, 0.073 mg/cm² ± 15%.

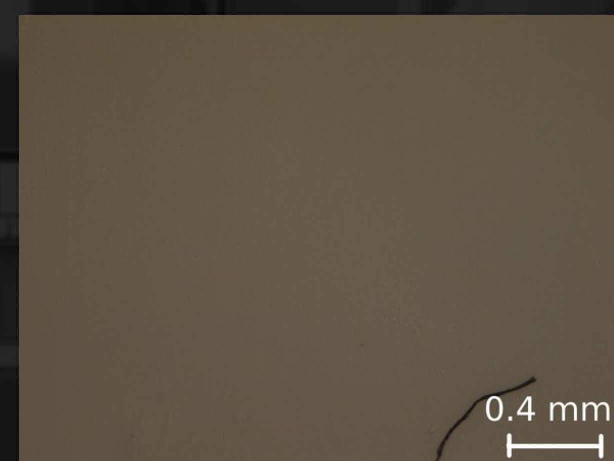




20% TPB + 80% Makrolon on VM2000: Uniform, milky, stable, 0.082 mg/cm² ± 10%.

Tetratex (a PTFE fabric) dipped in pure TPB solution: Uniform, diffuse, stable, 0.88 mg/cm².

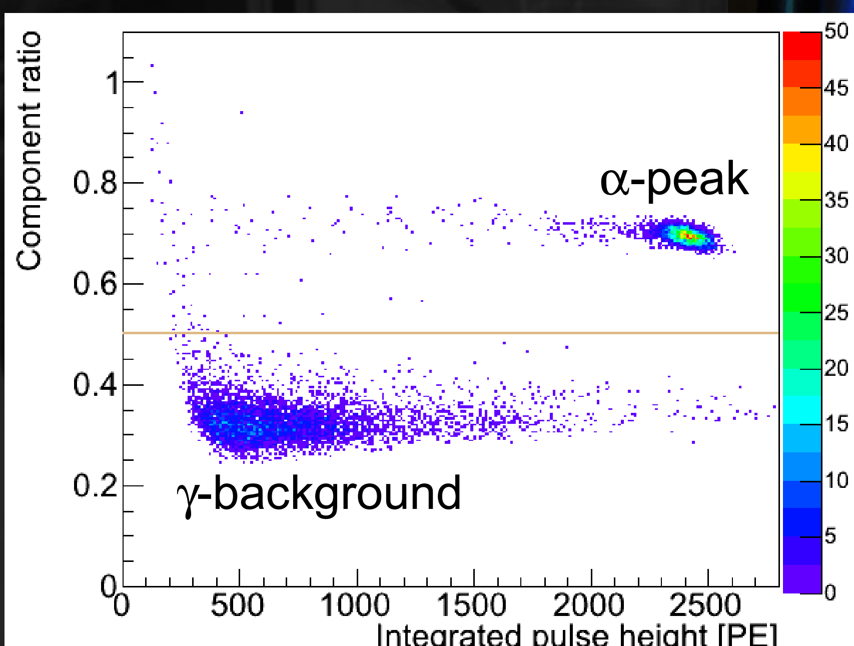


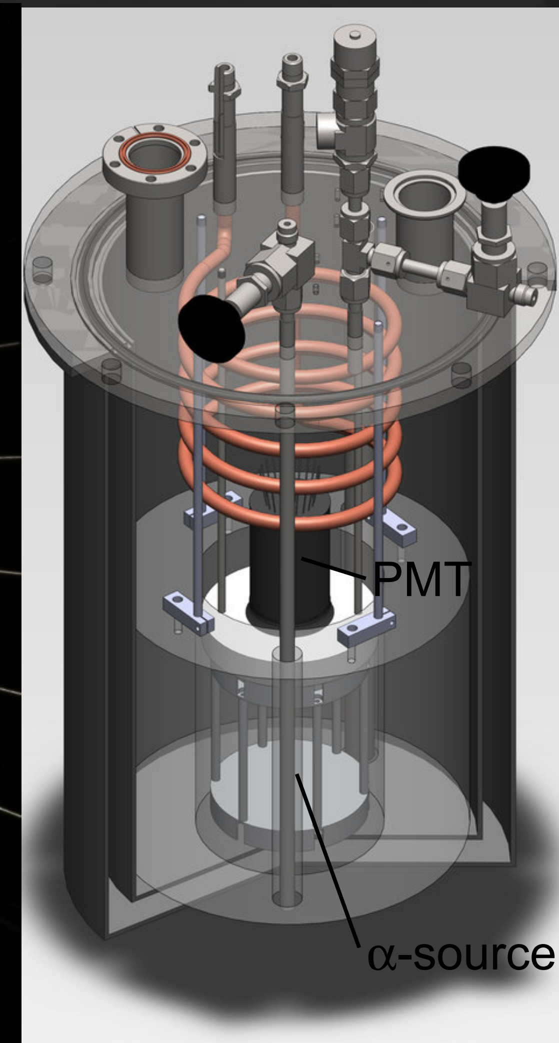


Liquid Ar Set-up at Uni Zürich

Cooling by LN_2 flowing through Cu coil in the dewar condensing high purity Ar gas (6.0).

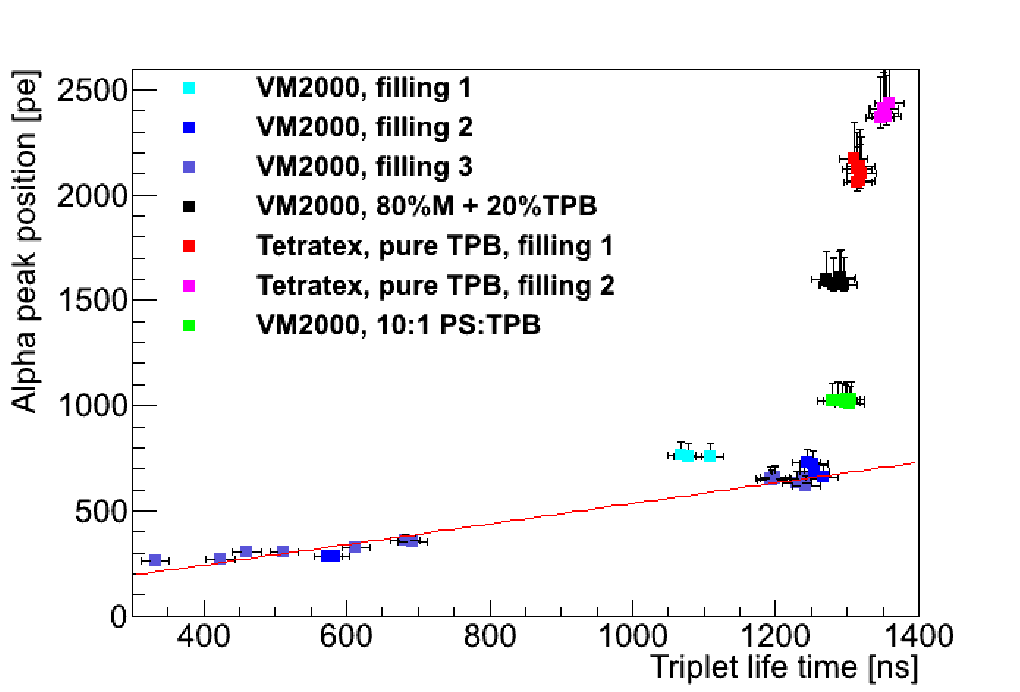
Ar is excited by α-particles from ^{241}Am. The scintillation light is shifted by a surrounding cylinder of WLS reflector foil and detected by a R11065-10 PMT.





Schematic view of the LAr Set-up.

Results



	rel. efficiency
VM2000	1.0
VM2000, PS + TPB (10/1), 0.073 mg/cm²	1.5
VM2000, 80% M + 20% TPB , 0.082 mg/cm²	2.3
Tetratex, pure TPB, 0.88 mg/cm²	3.3

Efficiencies are measured relative to an uncoated VM2000.

To compare efficiencies of different coatings at the same triplet lifetime a linear function is fit to the peak position versus triplet lifetime of VM2000.

Highest efficiency for TPB on Tetratex.

For all coatings:

- WLS appears to resist cooling cycles (visual inspection of the setup and the coating with a UV lamp).

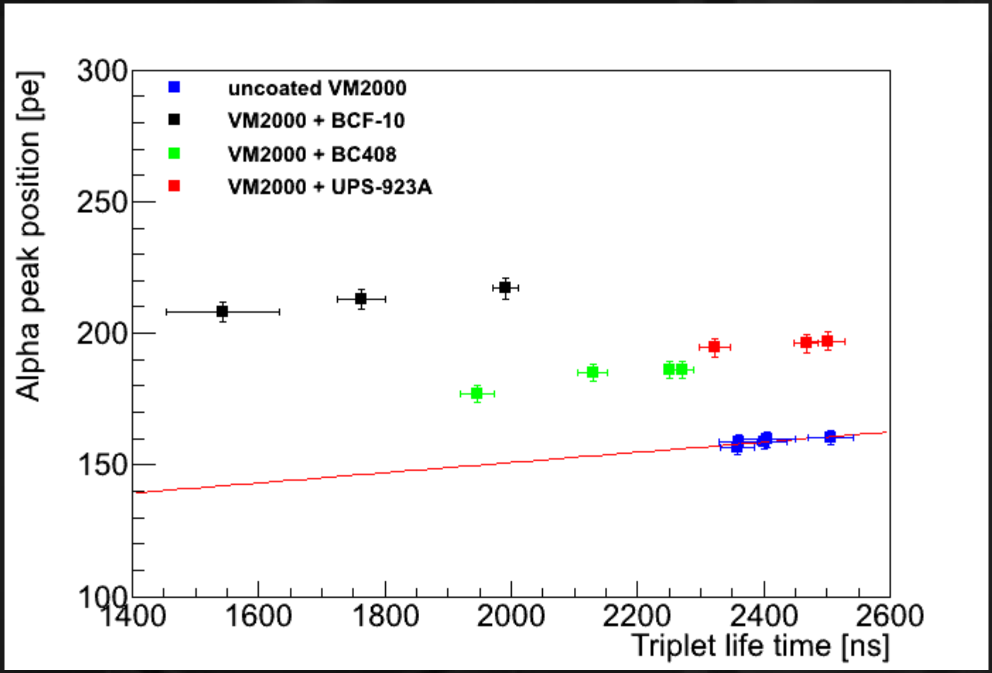
Commercial Scintillators as WLS

BC408, UPS-923A and BCF-10 fibre dissolved in Toluene (3.3 g/100 ml) and wet coated onto VM2000.
⇒ thickness of:

- UPS-923A: 0.16 mg/cm^2,
  BCF-10: 0.26 mg/cm^2
  and BC 408: 0.25 mg/cm^2.

Efficiency measured using GAr scintillation light, relative to VM2000:

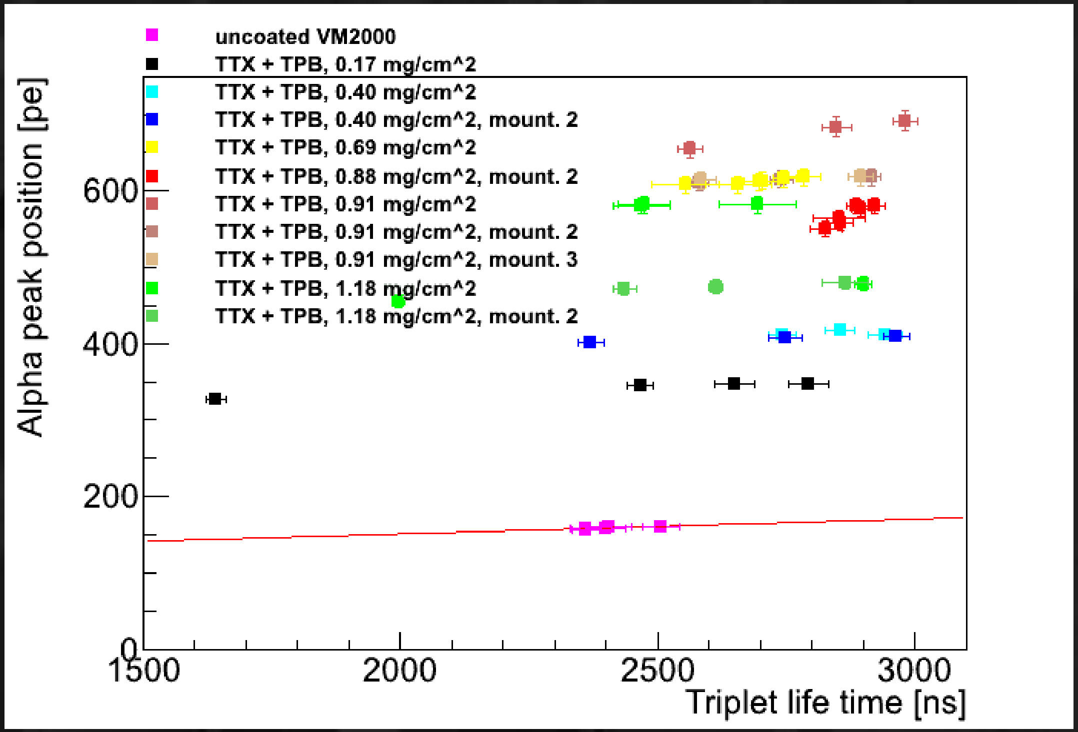
- 1.2 for BC408 and UPS-923A,
- 1.5 for BCF-10 fibre
  (like PS + TPB from LAr).

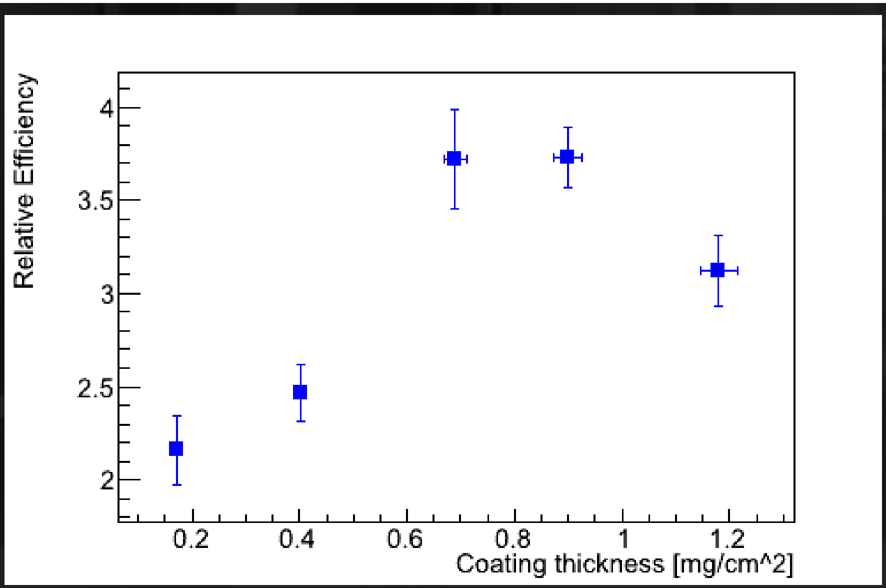


Result: These commercial scintillators with a high light yield coated to VM2000 are less efficient than TPB on Tetratex.

TPB Concentration Optimisation

- Concetration/thickness dependent efficiency measured using GAr scintillation light (error bars statistical only).
- Most coatings measured several times (unmounted between measurements):
  ⇒ fluctuation ≈ 8.6 %.
- Optimal thickness at about 0.8 mg/cm^2 (error bars from fluctuation).
- Coating test successfully performed on a 45 cm x 93 cm sheet of Tetratex.





Conclusion

TPB on Tetratex is an efficient, stable and low radioactivity wavelength shifting reflector foil which is easily scalable to several square meter.

It is planned to be installed in GERDA in summer 2013.

Backup slides

Radiopurity

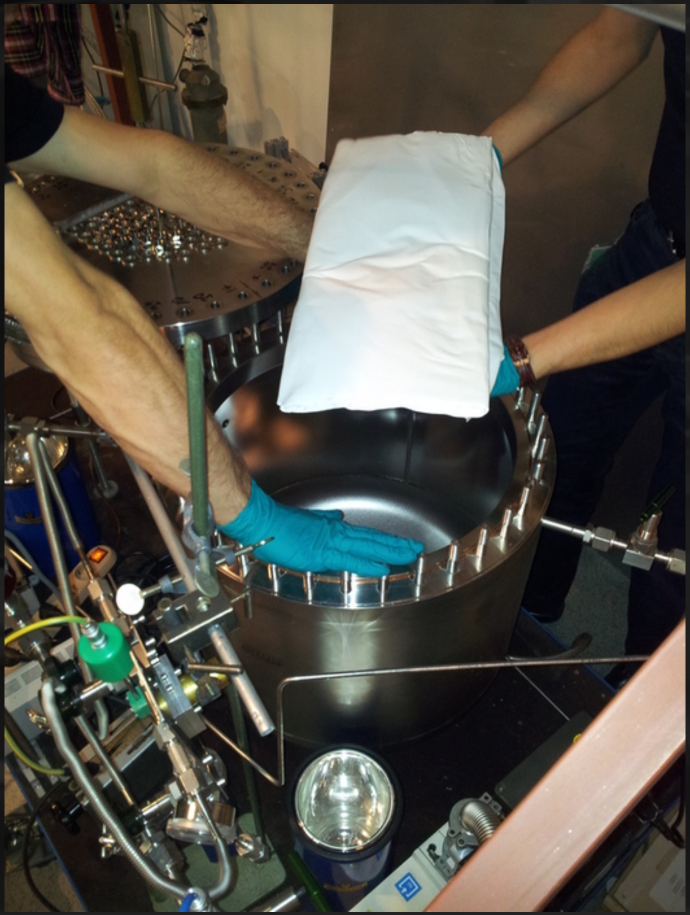
For GERDA ≈ 2 m^2 (≈ 200g) of reflector foil are needed.

Radioactivity from ICP-MS, measured by LNGS chemistry laboratory (± 30%) [mBq/kg] (weight of TTX ≈ 0.1 kg/m^2). Coated TTX simulated by A. Wegmann (MPIK Heidelberg):

- Raw BI: Th $2.7 \cdot 10^{-5}$ cts/(kg·keV·y), Bi $8.2 \cdot 10^{-6}$ cts/(kg·keV·y),
- after LAr and AC: Th $6.7 \cdot 10^{-7}$ cts/kg·keV·y, Bi $8.2 \cdot 10^{-7}$ cts/kg·keV·y.

Radon emanation measurement performed by H. Simgen at the MPIK Heidelberg: < 105 μBq for about 4 m² at 90% C.L..

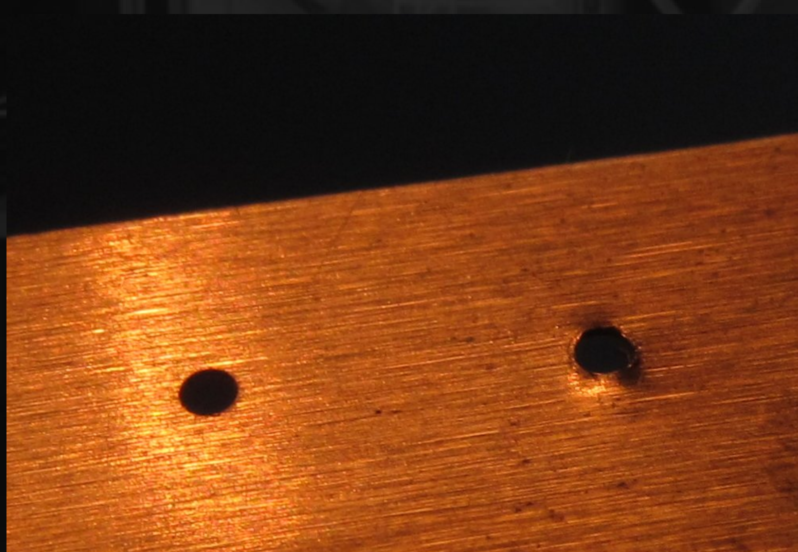
	Uncoated TTX	TPB	Coated TTX
K	9	4	23
Th	0.21	0.06	0.70
U	0.9	0.17	1.5



Installation Suggestion

Stich TTX to Cu shroud (0.1 mm) in 4 channels, using 0.1 mm thick Nylon wire:

- Ring of 1 mm holes ~ 4 cm apart at the top.
- larger distance at the bottom an 4 rows going from top to bottom.
- Tested with 10 LN_2 cooling cycles.



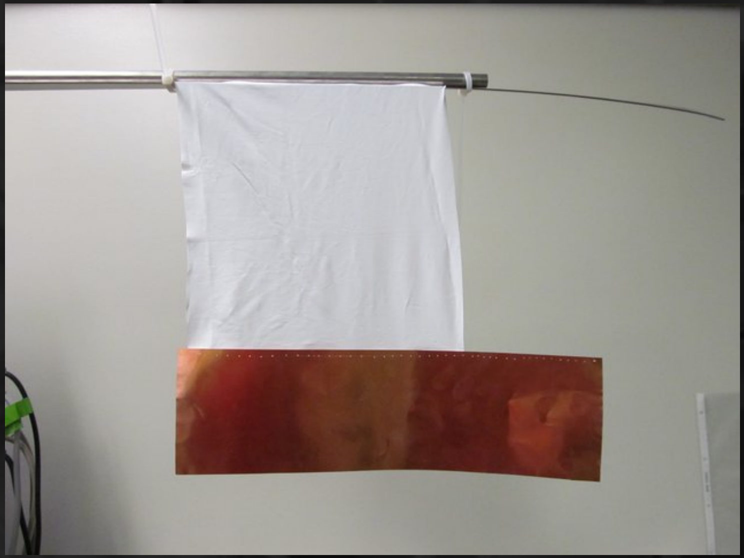
Installation Suggestion

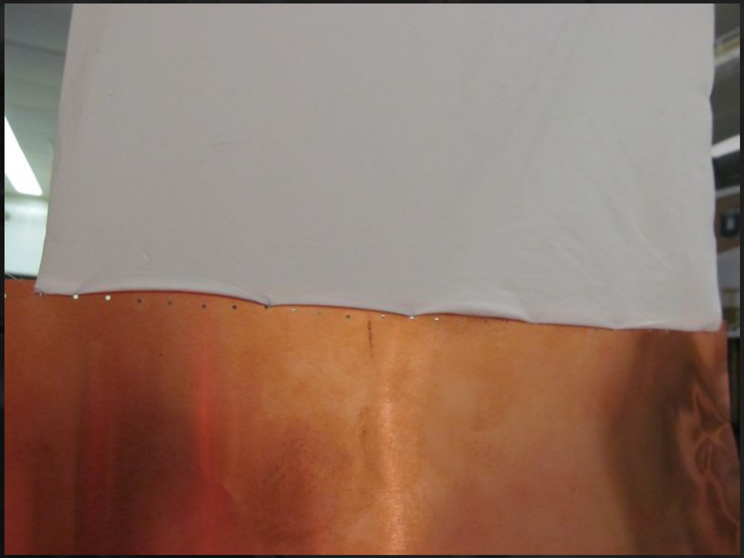
Stability test:
Hang 0.1mm thick Cu on TTX.

After 34 days:
TTX stretched by 2 mm (left), 33 mm (right).

Remaining stretch after hanging on the Cu for 1 day:
-2 mm (left),
21 mm (right).

No issues with the stitches.





Reminder

- Wavelength shifting (WLS) done by Tetraphenyl-butadiene (TPB) coated on VM2000 or Tetratex (a PTFE fabric) with or without a polymer.
- Performed stability tests:
  - Thermal cycles in liquid N_2,
  - long term storage in liquid N_2.
- Shifting efficiency pre-selection was performed with a fluorescence spectrometer at MPI Heidelberg.
- Must be possible to coat foils large enough for GERDA.
- Experience from evaporatively coated foils produced by other groups show:
  - High shifting efficiency [1] [2] [3] [4] [5],
  - up to about 0.3 mg/cm² stable on VM2000 (apparatus for samples of several cm) [5],
  - but unstable with apparatus for large samples (several 10 cm) [3].

[1] ArDM collaboration, “Development of wavelength shifter coated reflectors for the ArDM argon dark matter detector”, Jinst, June 2009.
[2] McKinsey et al., “Scintillation time dependence and pulse shape discrimination in liquid argon”, PHYSICAL REVIEW C 78, 035801 (2008).
[3] Own experience with samples from ArDM and the thin film workshop at CERN and private conversation with people from ArDM.
[4] Gehman, Seibert, et al., “Fluorescence Efficiency and Visible Re-emission Spectrum of Tetraphenyl Butadiene Films at Extreme Ultraviolet Wavelengths”, NIM A **654,** 116 (2011).
[5] Private conversation with E. Segreto from WARP and visit of their laboratory.

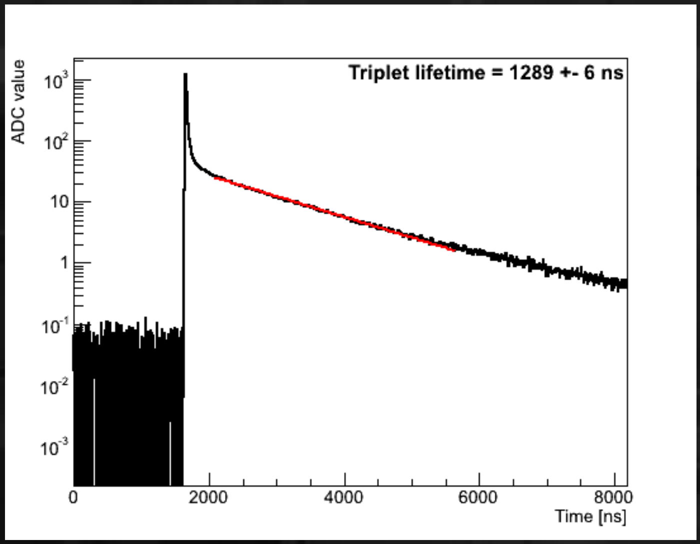
Analysis procedure

Triplet lifetime:

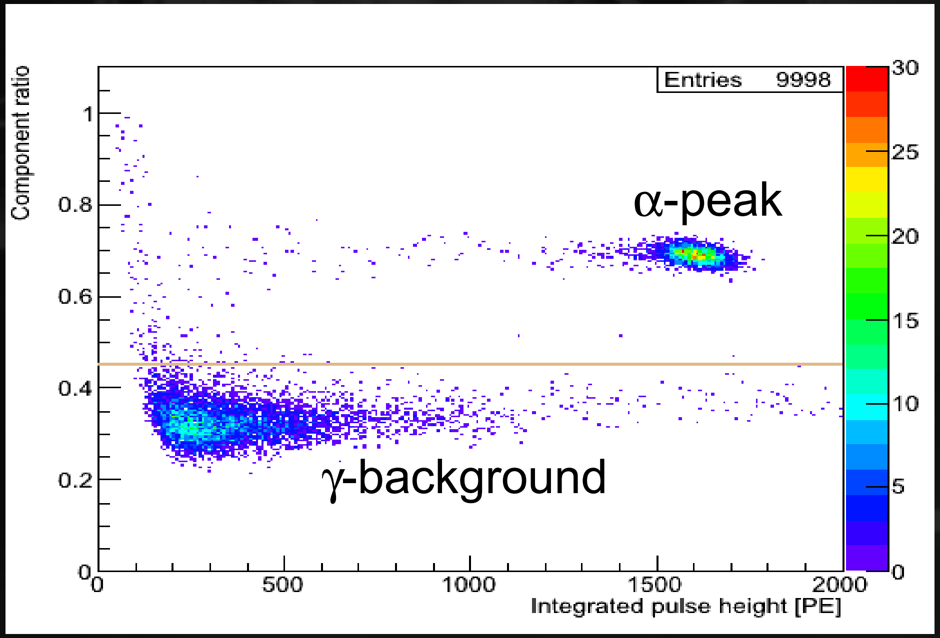
- Fit exponential to mean trace of events > 50 photo electrons.

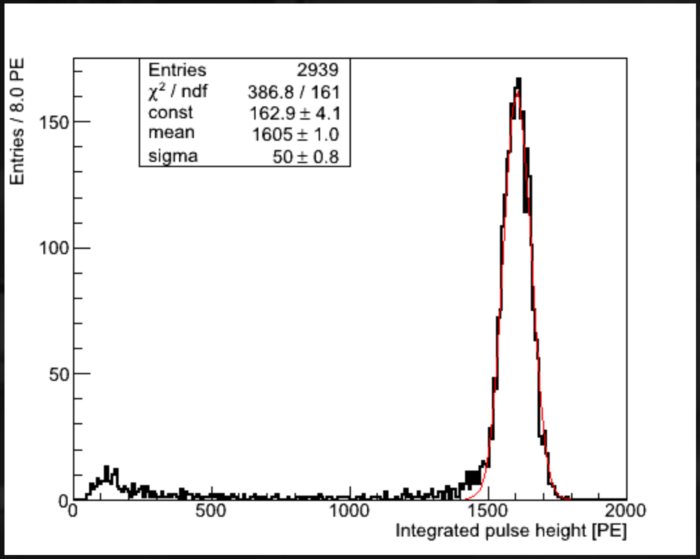
Select α events by component ratio (fast light / total light).

Fit histogram of integrated pulses with a Gaussian.



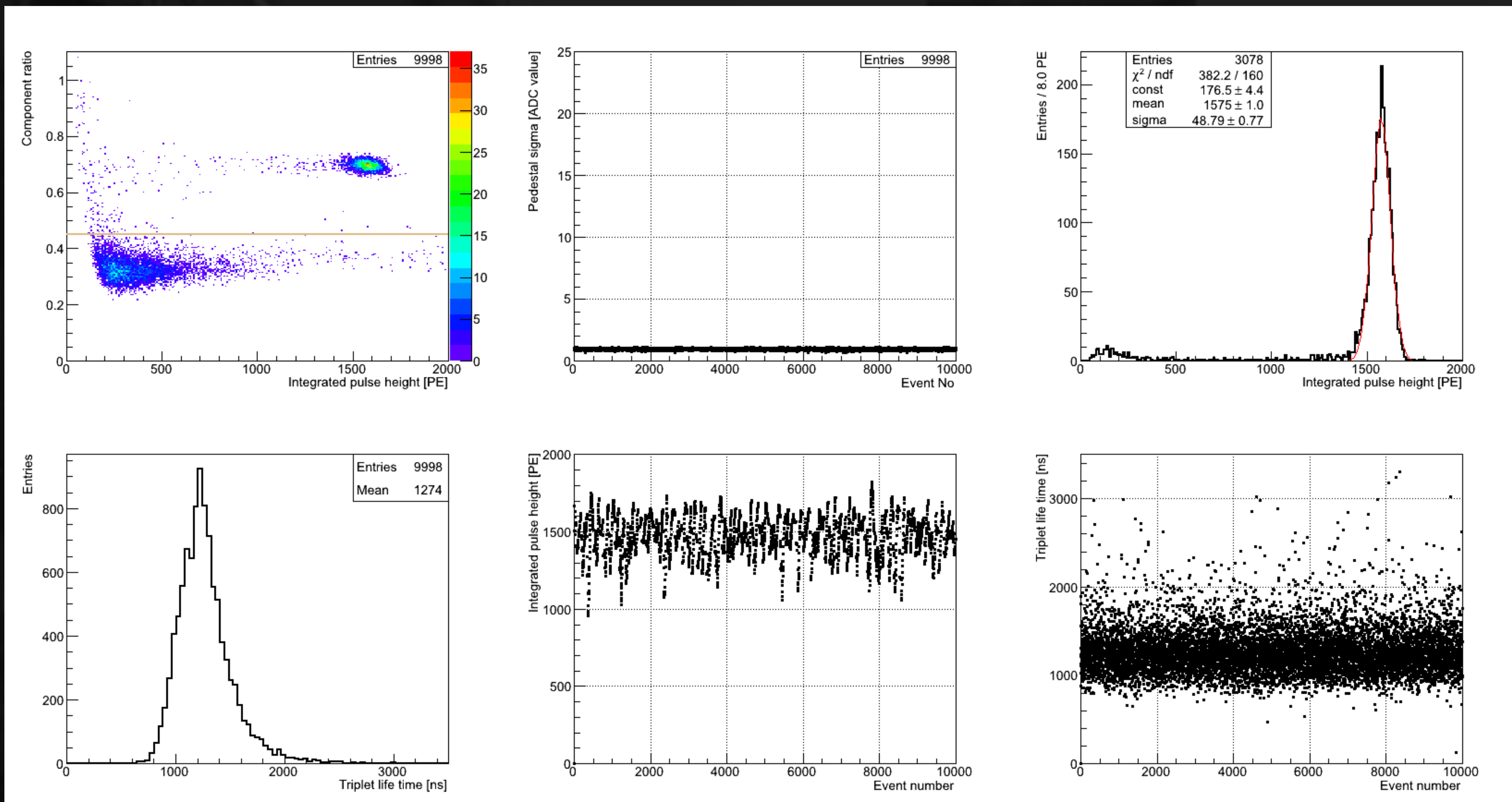
Mean Trace with exponential fit.



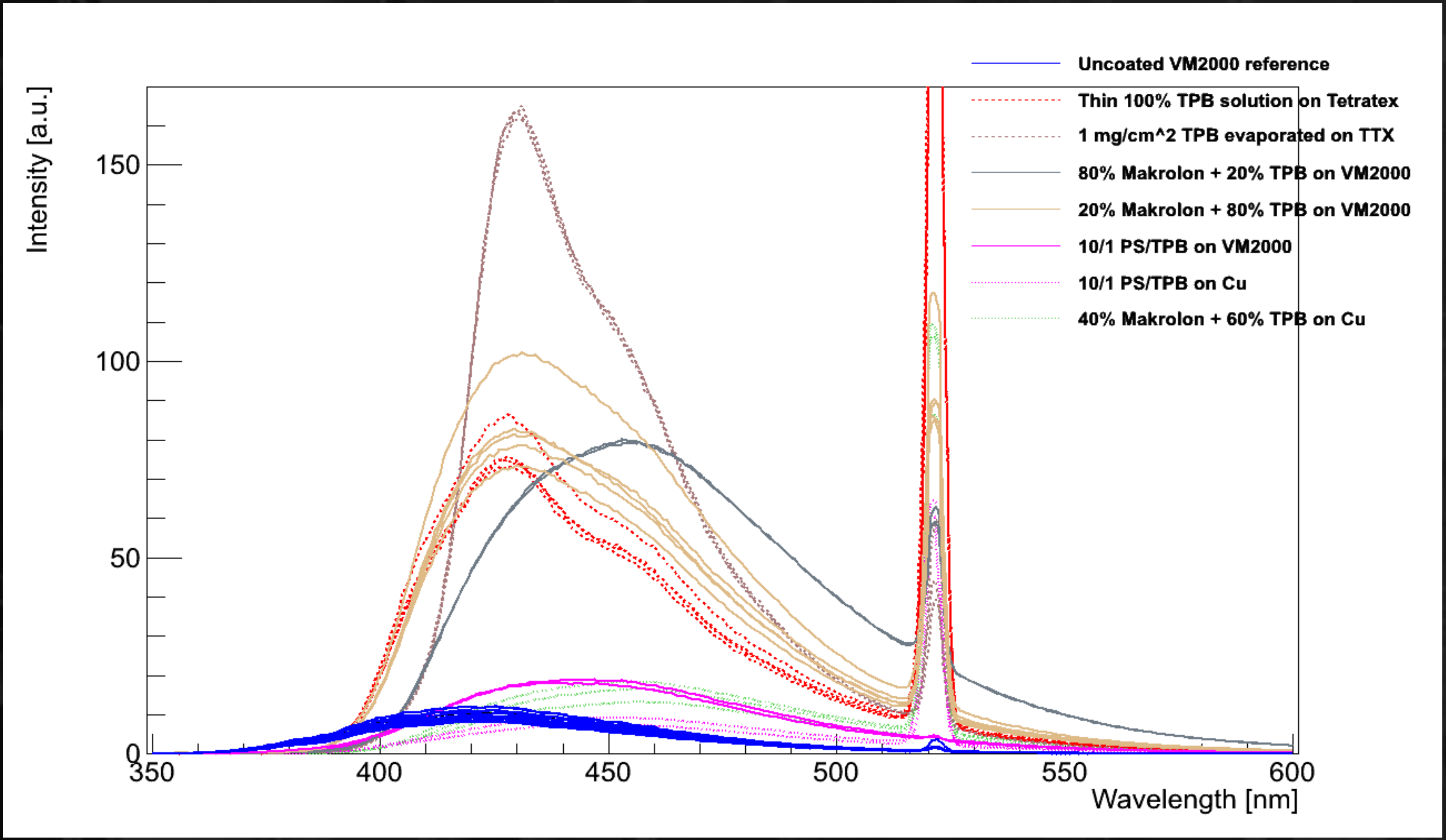


Energy spectrum of events with a component ratio > 0.45.

VM2000 with 80% Makrolon + 20% TPB



Fluorescence efficiency



Fluorescence spectra (excitation wavelength 260 nm), measured with the fluorimeter at MPI Heidelberg.

QE of PMT R11065 is highest between 300 and 400 nm.

Mechanical Stability

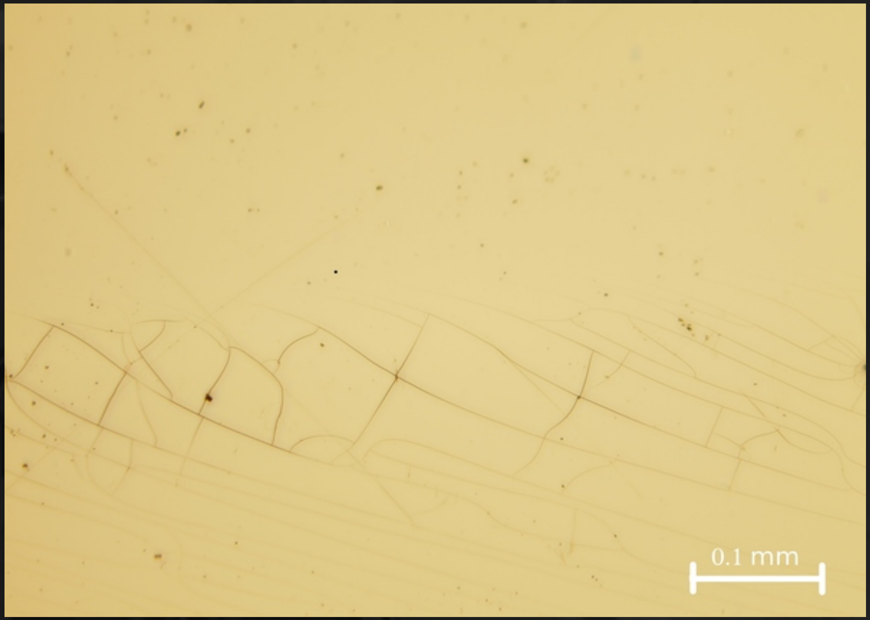
Evaporated Tetratex coating: unstable (can be blown of).

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:

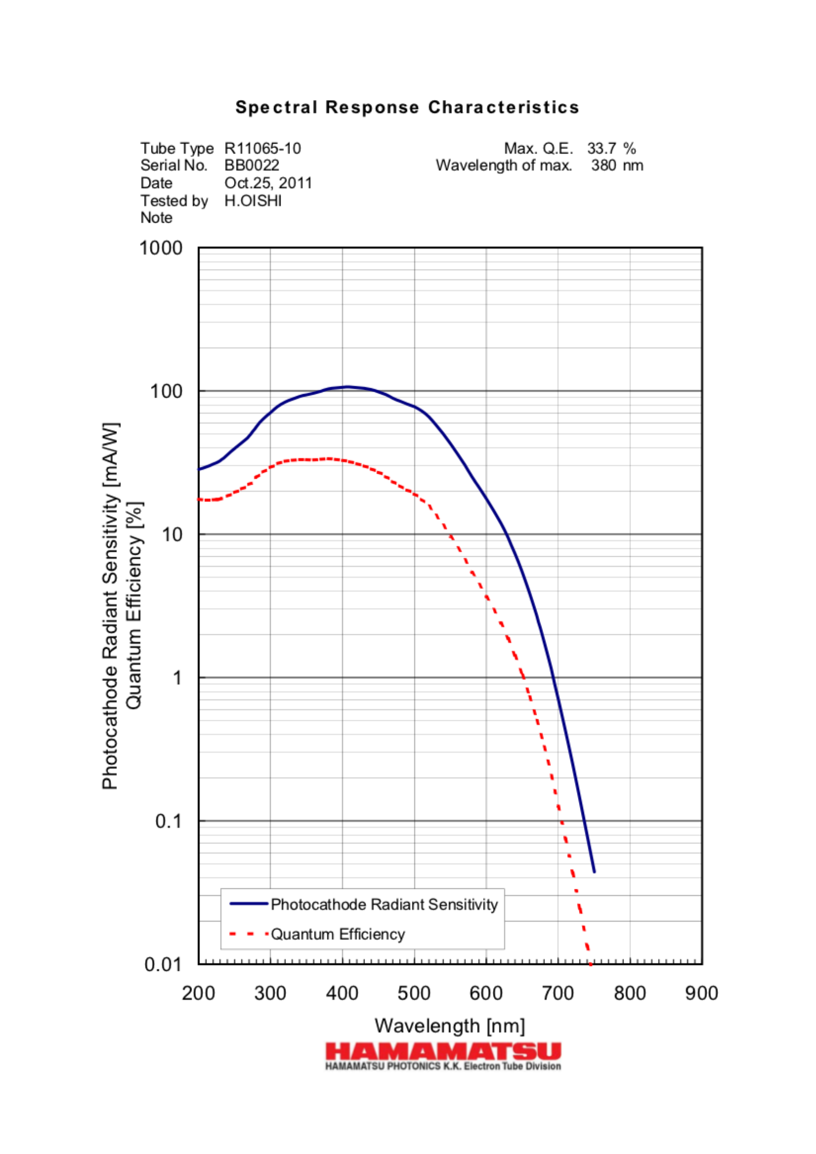
- No change observed by eye with day light and UV light.
- Microscope:
  - Cracks in PS+TPB coatings in thicker regions.
  - No change observable for other coatings.



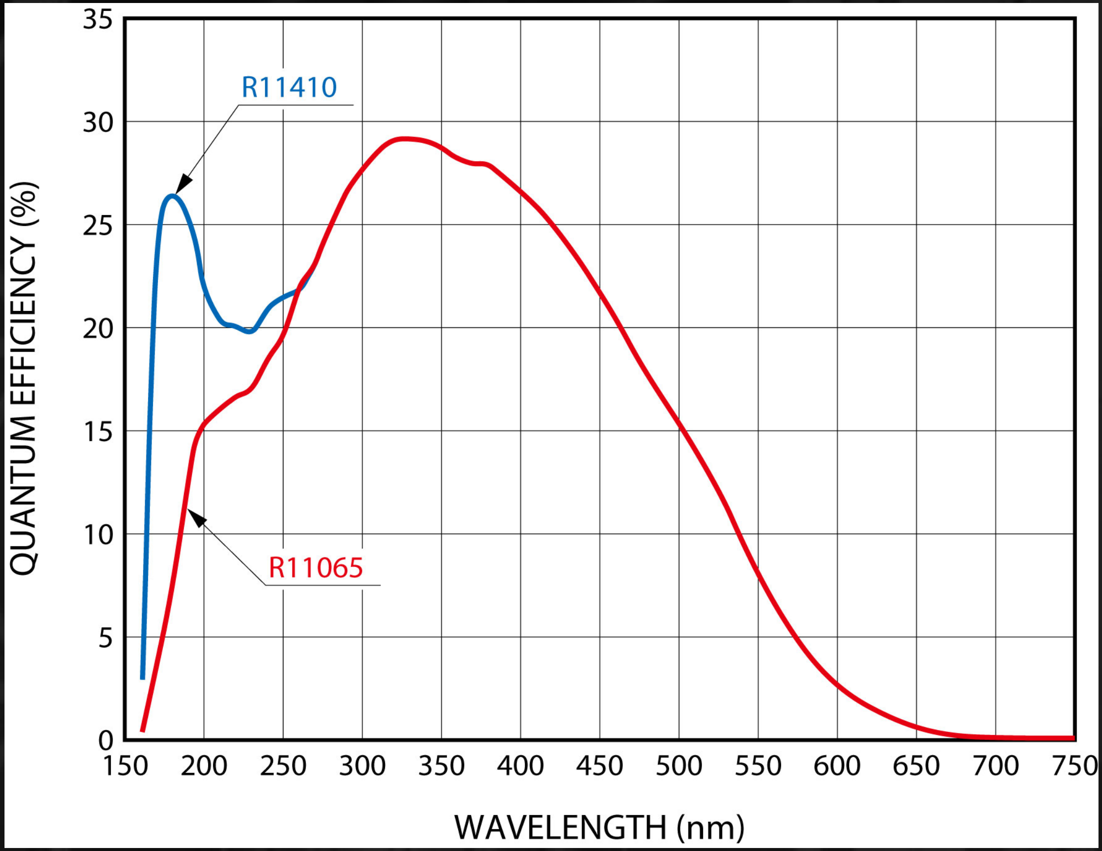
Cracks in PS + TPB coatings on VM 2000 after storage in liquid N_2.

Consistent with coating falling off in LARGE.

R 11065 QE

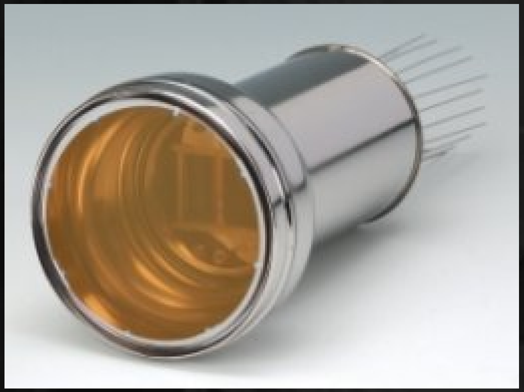


Spectral Response Characteristics
Tube Type R11065-10
Serial No. BB0022
Date Oct.25, 2011
Tested by H.OISHI
Note
Max. Q.E. 33.7 %
Wavelength of max. 380 nm
Photocathode Radiant Sensitivity [mA/W]
Quantum Efficiency [%]
1000
100
10
1
0.1
0.01
200
300
400
500
600
700
800
900
Wavelength [nm]
Photocathode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



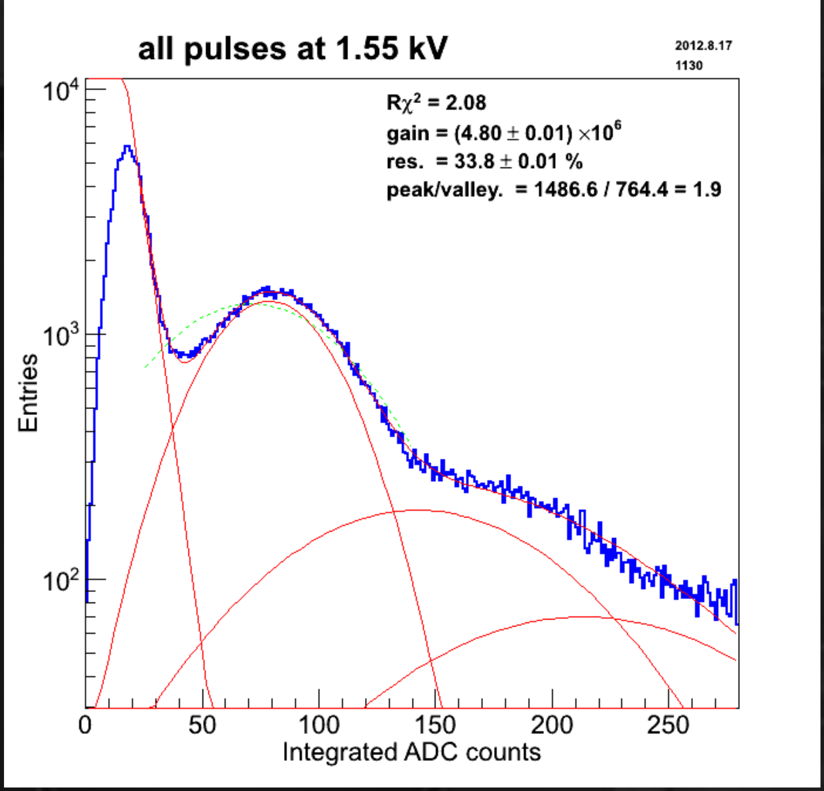
QUANTUM EFFICIENCY (%)
35
30
25
20
15
10
5
0
150
200
250
300
350
400
450
500
550
600
650
700
750
WAVELENGTH (nm)
R11410
R11065

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.

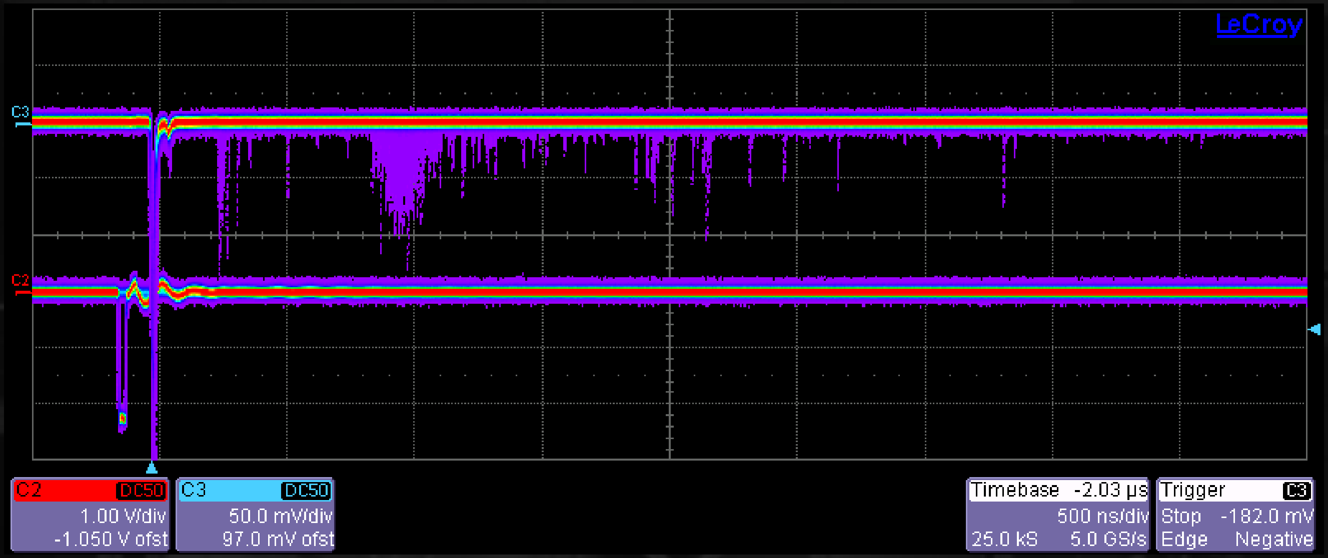
For cryogenic temperatures.

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

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



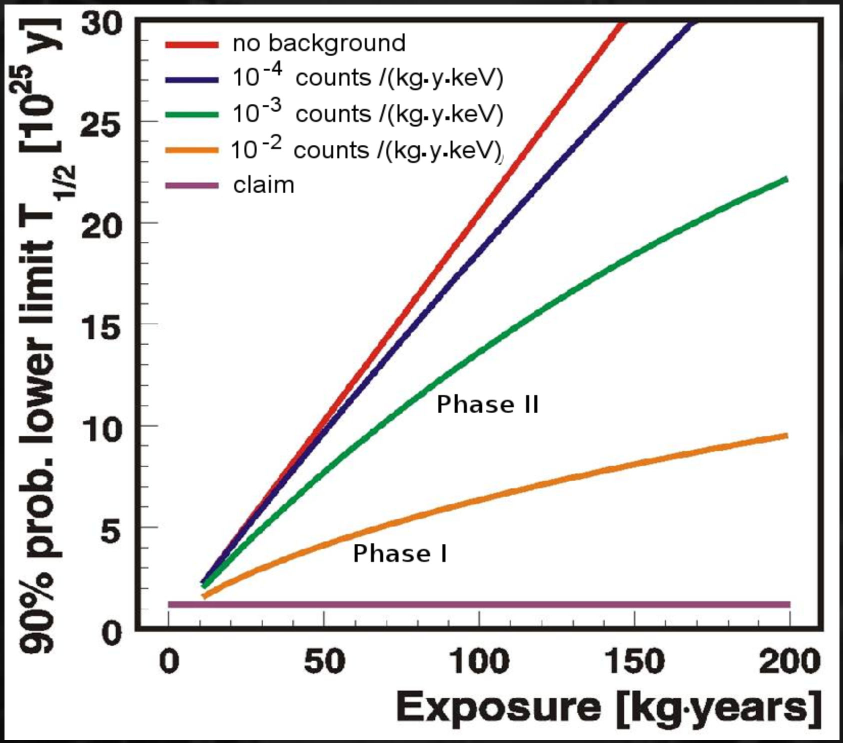
Superposition of many LED driver pulses and the corresponding PMT responses.

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.



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

- Good quantity to monitor the purity.

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