LAr instrumentation studies for low background experiments

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Date

DPG Dresden 2013, TK 109.2

GERDA

See talks: T 103.1, HK 43.2

$$T^{0\nu}_{1/2} \sim \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \; [y]$$

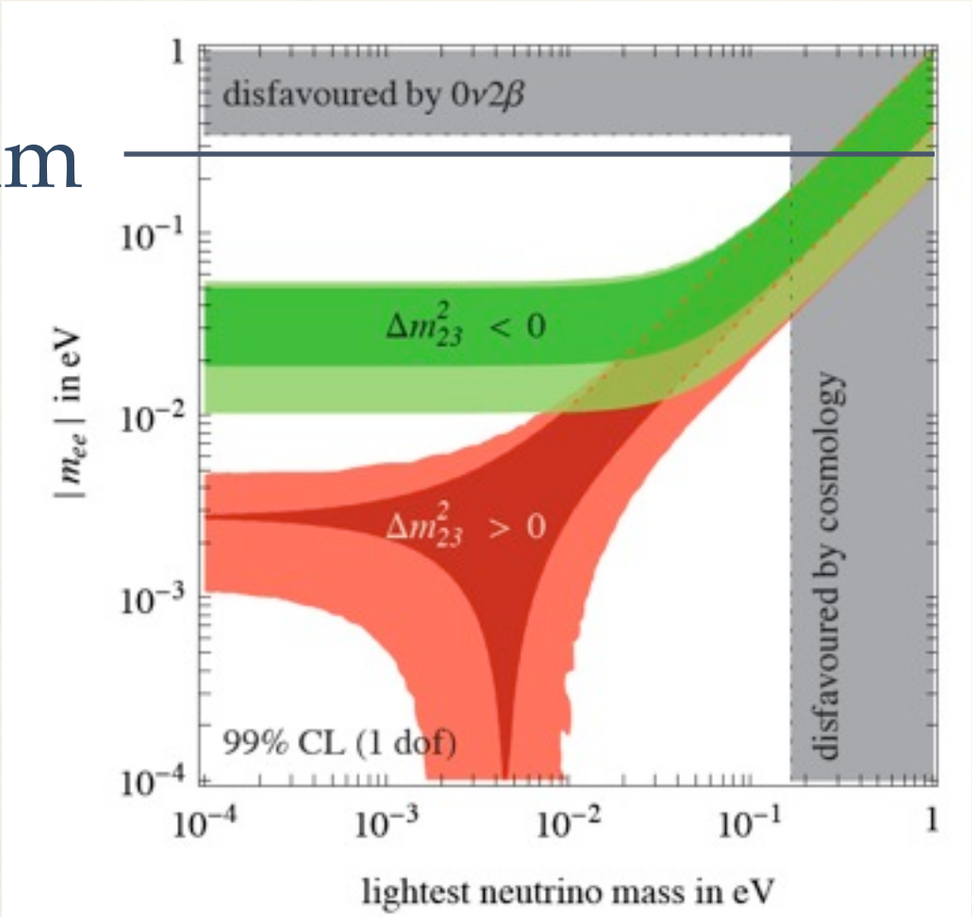
For a better limit we need:

- more mass
- lower background
- better energy resolution
- measure longer ??

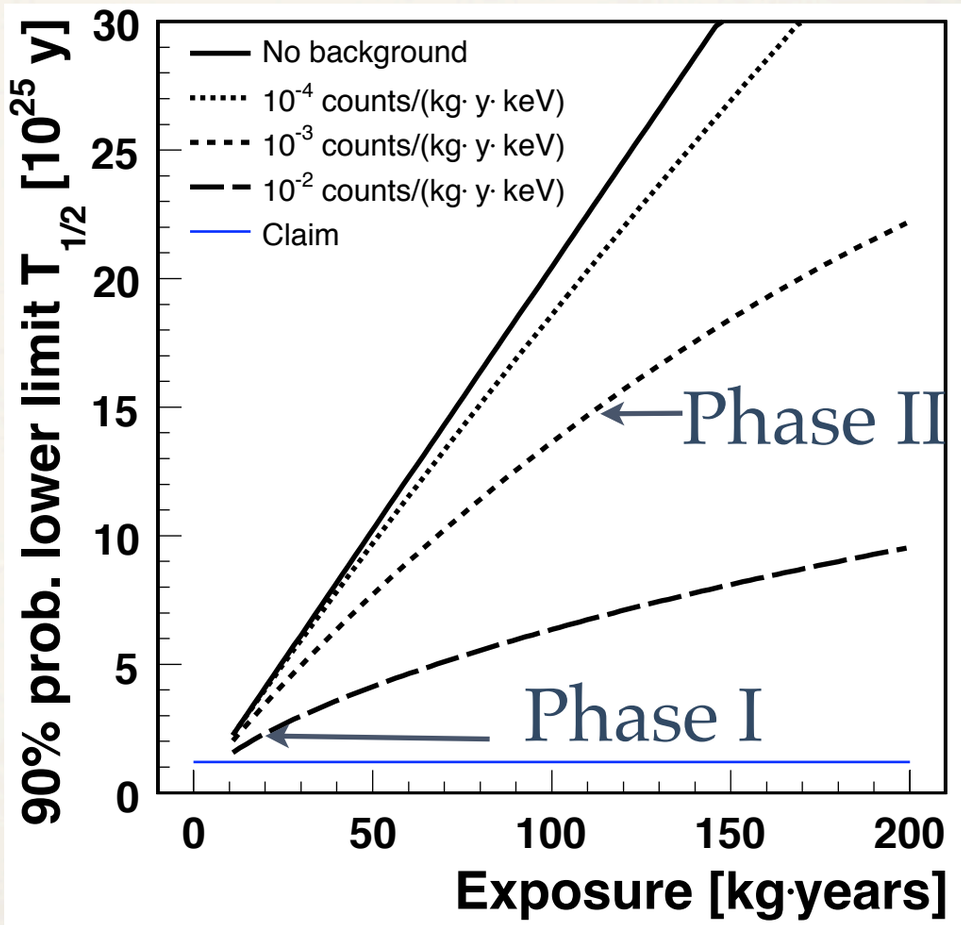
M - mass of the isotope
t - time

B - background
ΔE - resolution

Claim



F.Feruglio et al. Nucl.Phys.B 637 (2002)



A. Caldwell et al. Phys.Rev. D 74 (2006) 092003

GERDA

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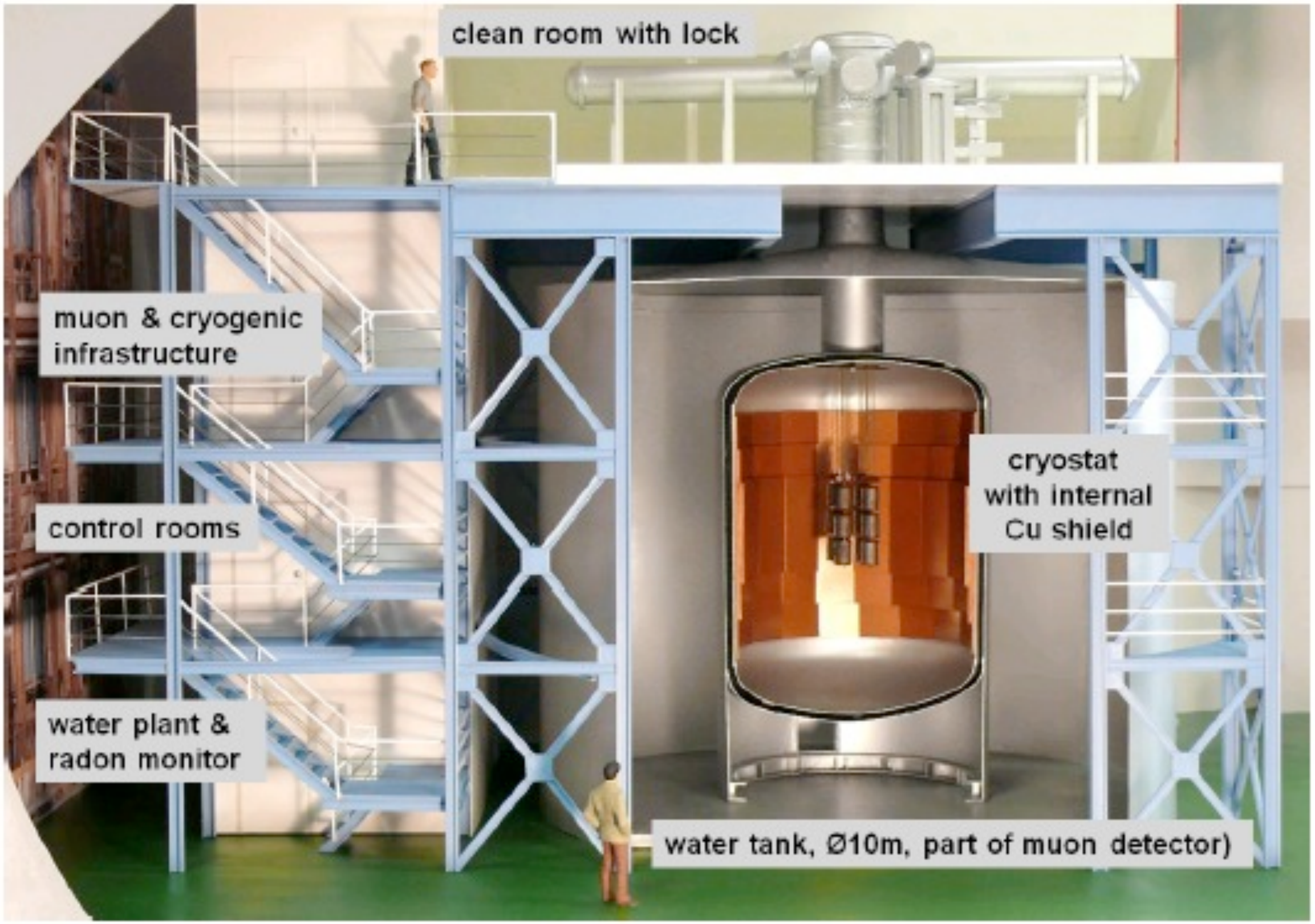
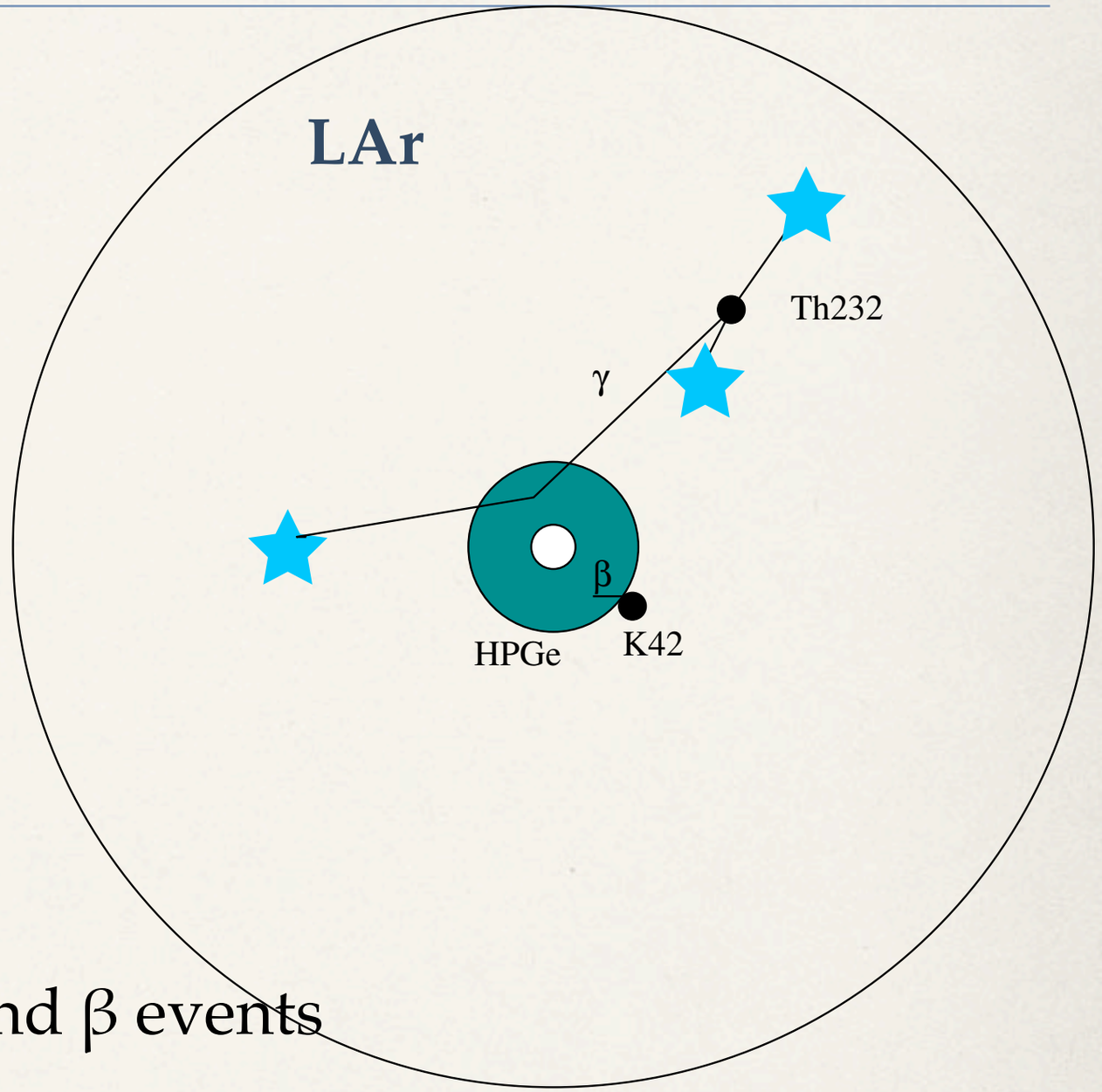


LAr veto - The concept

In the Region of Interest
around 2040 keV



- Nearby ^{208}Tl events can be easily vetoed with very high efficiency
- ^{214}Bi is less effective
- Does not work well for surface α and β events
  - Veto efficiency in GERDA will strongly depend on the origin of the background

Requirements for LAr veto

- Instrumented volume: a radius of 1-2 radiation length from the HPGe
  - bigger volume would increase only the dead time (Ar39)
- Light detector must be close enough to the HPGe detectors (attenuation length, solid angle)
- Low background: in GERDA the induced background should be $<<10^{-3}$ cts/(keV kg Y) - at 30 cm this means a total radioactive budget of < 100 μBq Th.
- Cryogenic compatibility

Wavelength shifter - The Idea

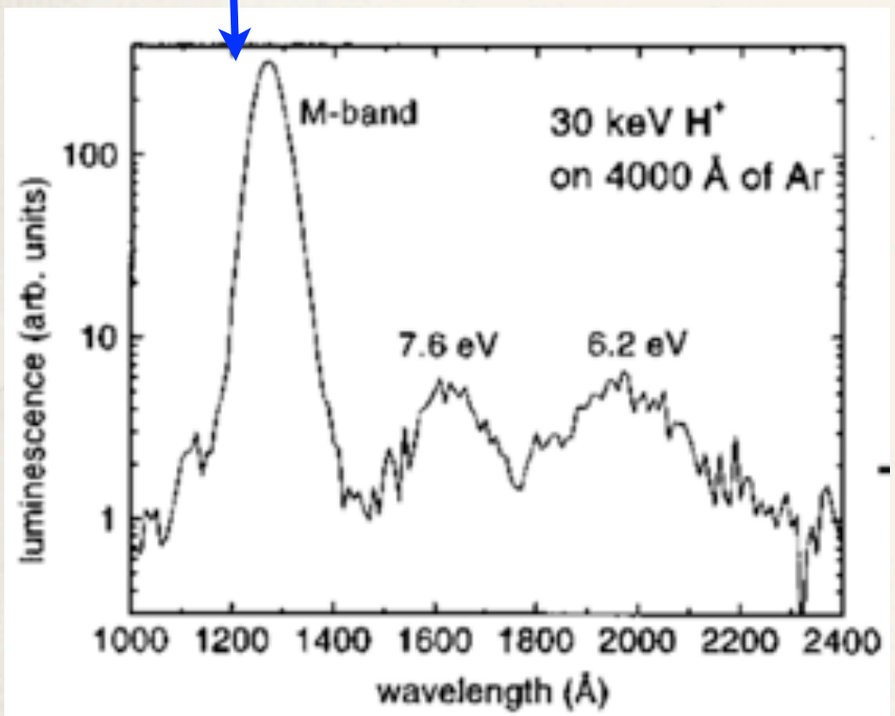
TPB

128 nm (VUV) → 430 nm → Detected with PMT

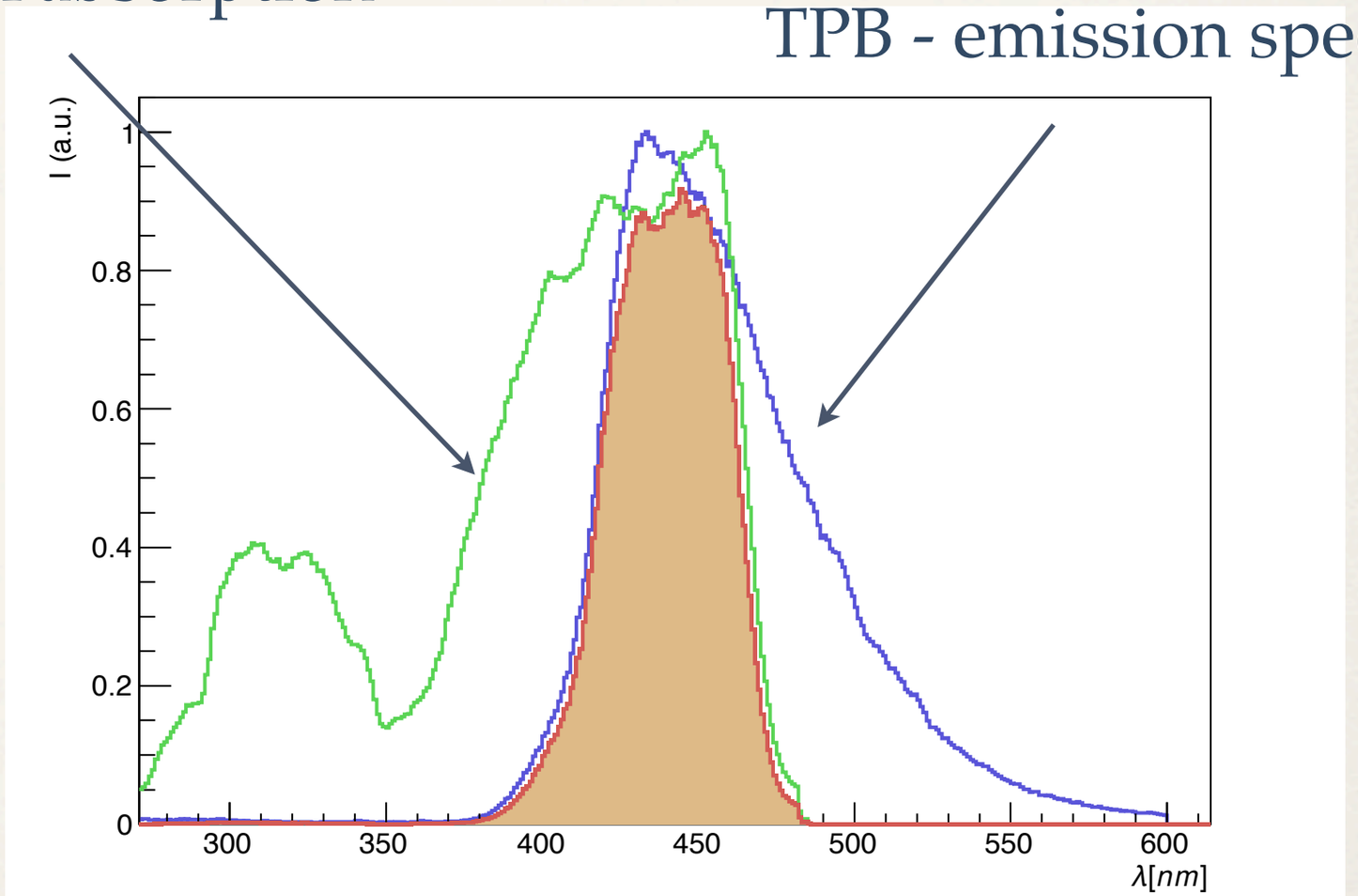
430 nm → Collected with WLS fiber

BCF-91A absorption

Emitted by Ar



TPB - emission spectrum



Inefficient (~60%), but it works

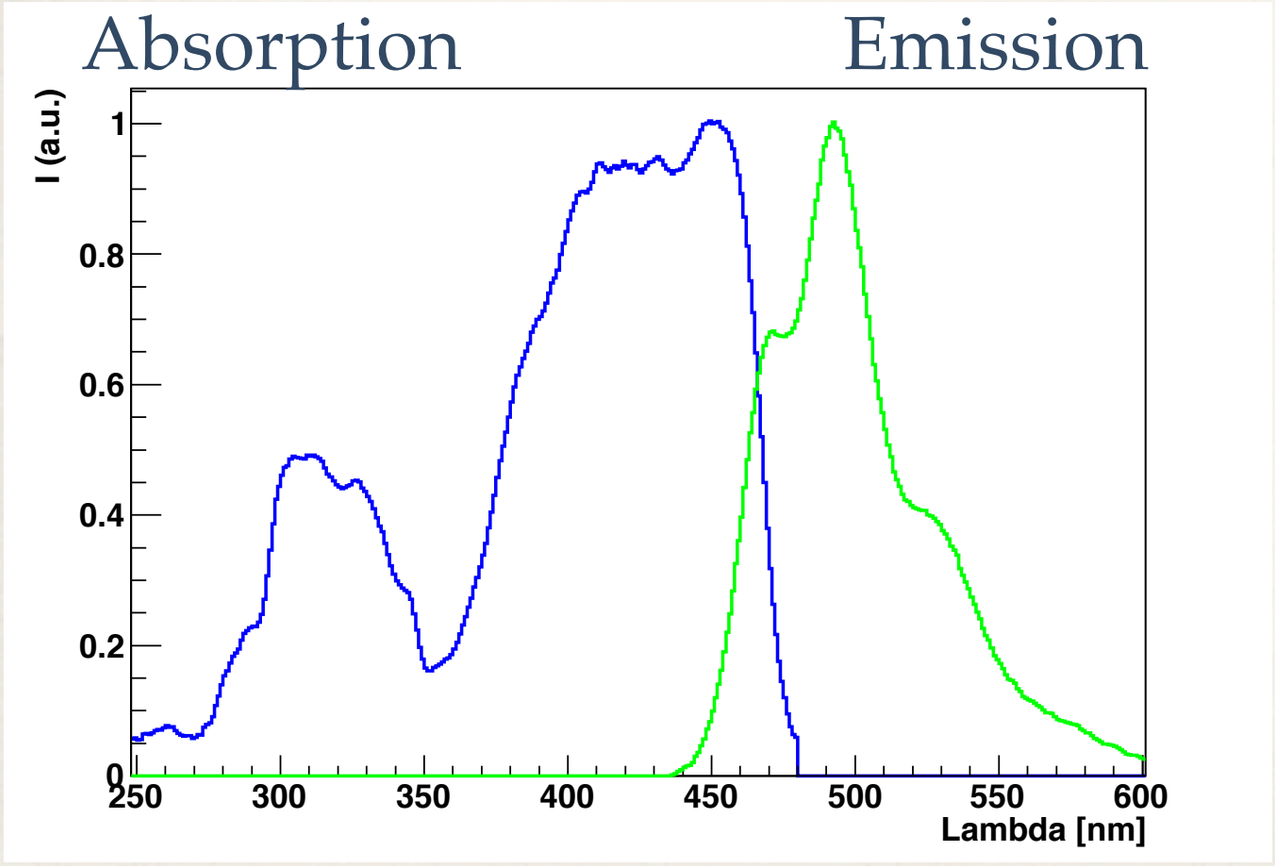
WLS fibers

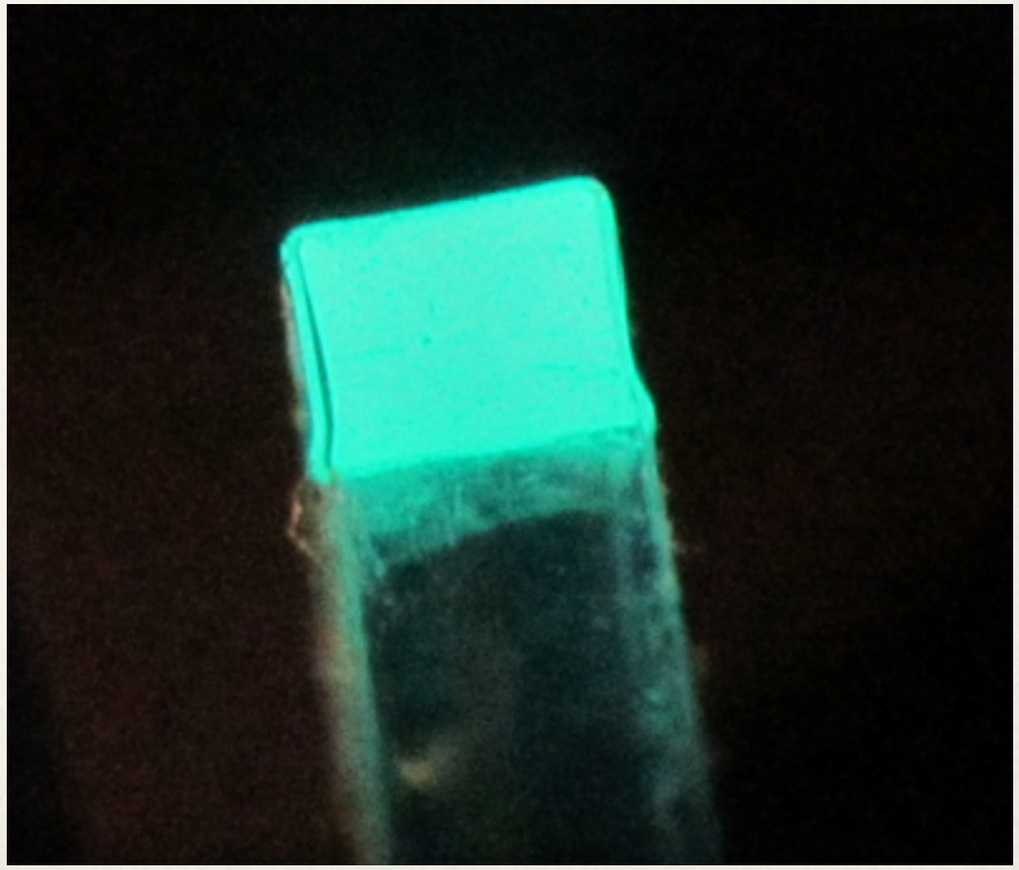
Multi-clad Fibers Properties –

Second cladding material: ..... Fluor-acrylic
Refractive index: 1.42
Thickness, round fibers: ..... 1% of fiber diameter
Thickness, square fibers: ..... 2% of fiber size

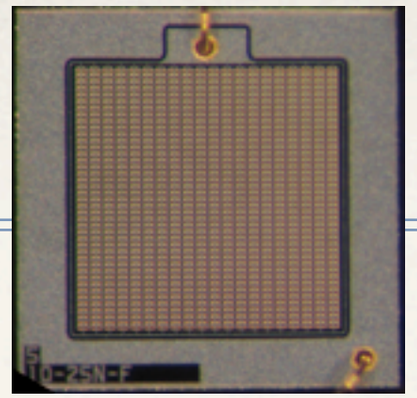
Numerical aperture: 0.74
Trapping efficiency, round fibers: ..... 5.6% minimum
Trapping efficiency, square fibers: 7.3%

Square multiclad fiber under the microscope



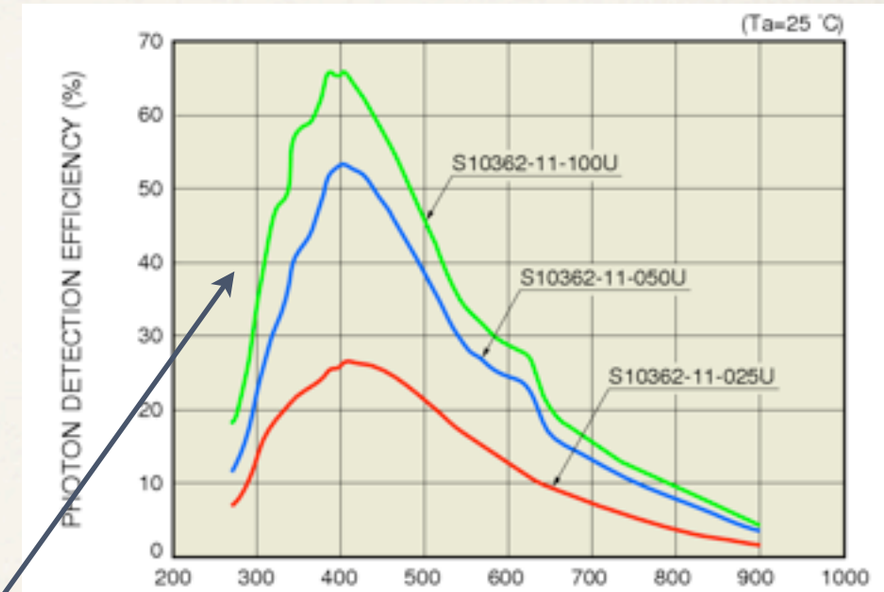


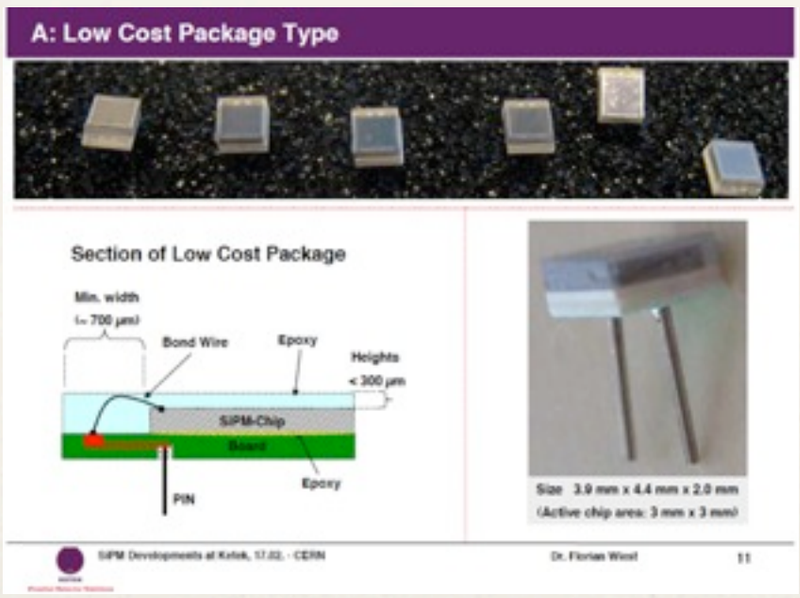
SiPMs

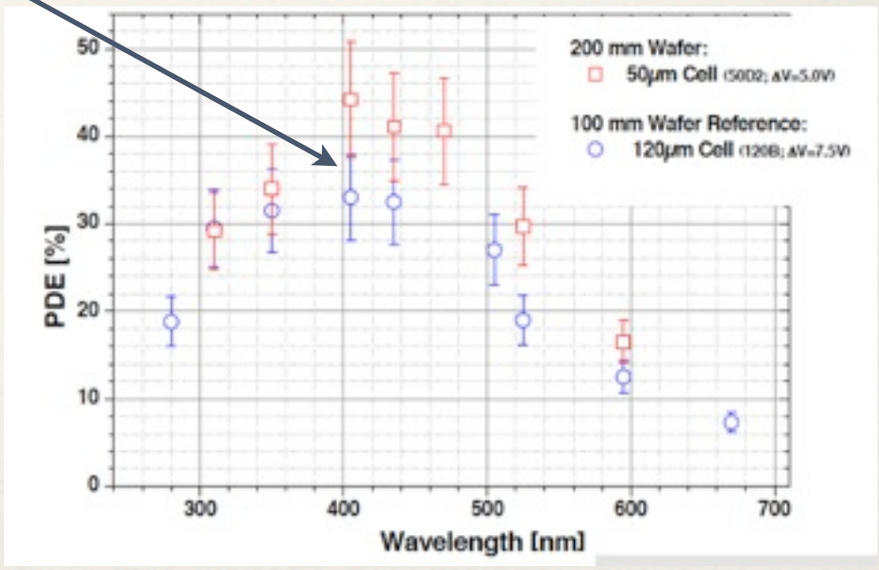


- candidates: Hamamatsu & Ketek SiPMs
- Ketek GmbH Munich based company. Willing to sell SiPMs in ‘die’.
- SiPMs work at LN temperature
- Good QE, negligible Dark Rate

PDE







Efficiency

Fiber trapping eff. = 7.3%

Solid angle coverage

λ Attenuation length

SiPM QE

$$\varepsilon = \varepsilon_{tpb} \cdot \varepsilon_{\Omega} \cdot \varepsilon_{spektr} \cdot 2 \cdot \varepsilon_{trapp} \cdot \frac{1}{L} \int_0^L e^{-\frac{x}{\lambda}} dx \cdot \varepsilon_{coupl} \cdot \varepsilon_{PDE}$$

Scintillator (TPB) QE

WLS spectral efficiency

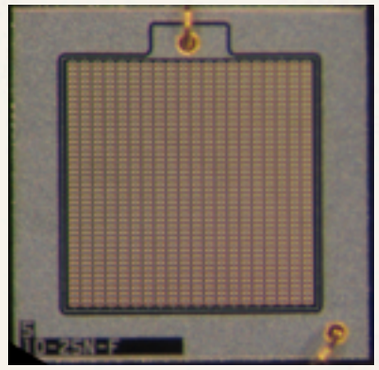
Length of the fiber

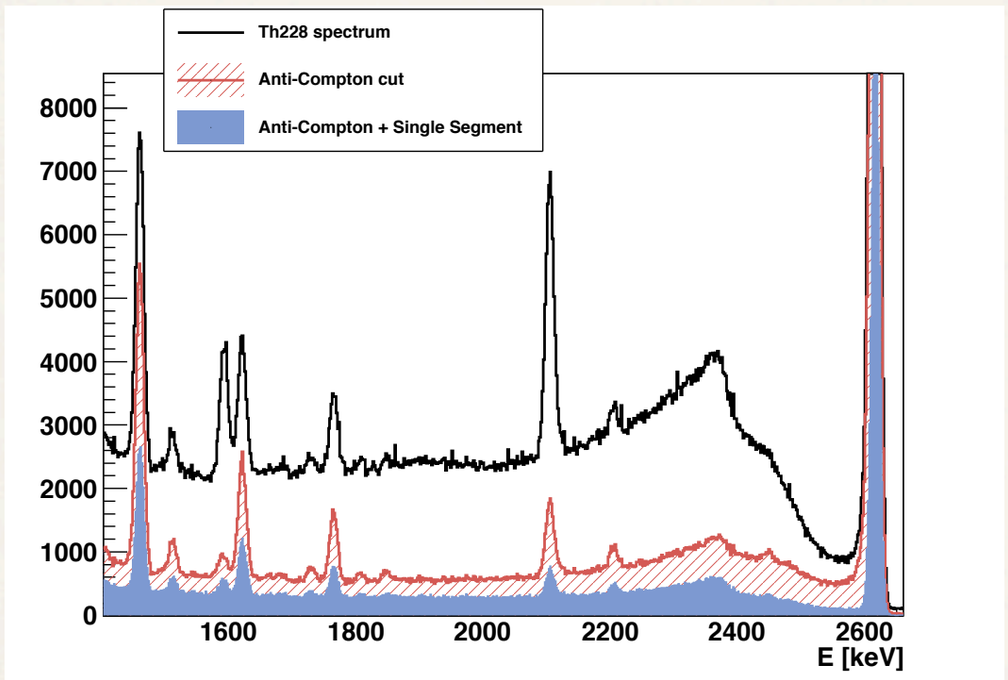
Optical coupling geometric ineff.

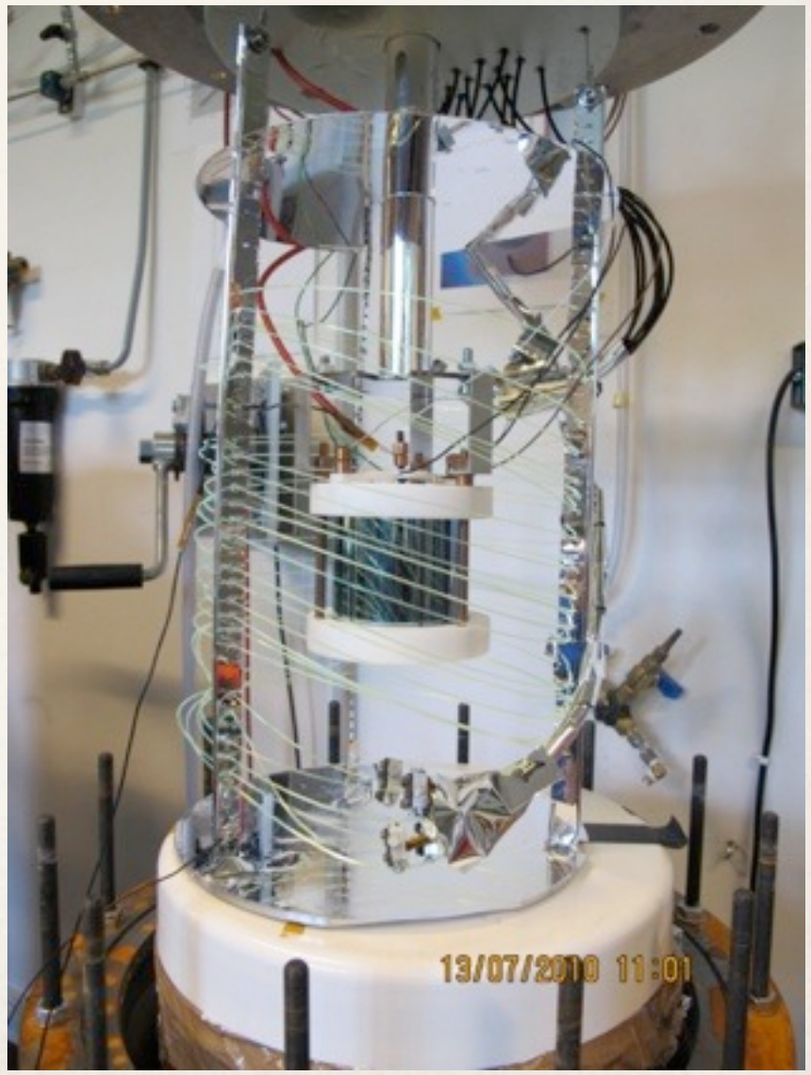
- **The resulting total Photon Detection Efficiency is about 1%**

SiPM + WLS fiber design

- Idea was tested at small scale (<20 l)
- SiPMs are working at cryogenic temperatures
- TPB coated WLS fiber concept works

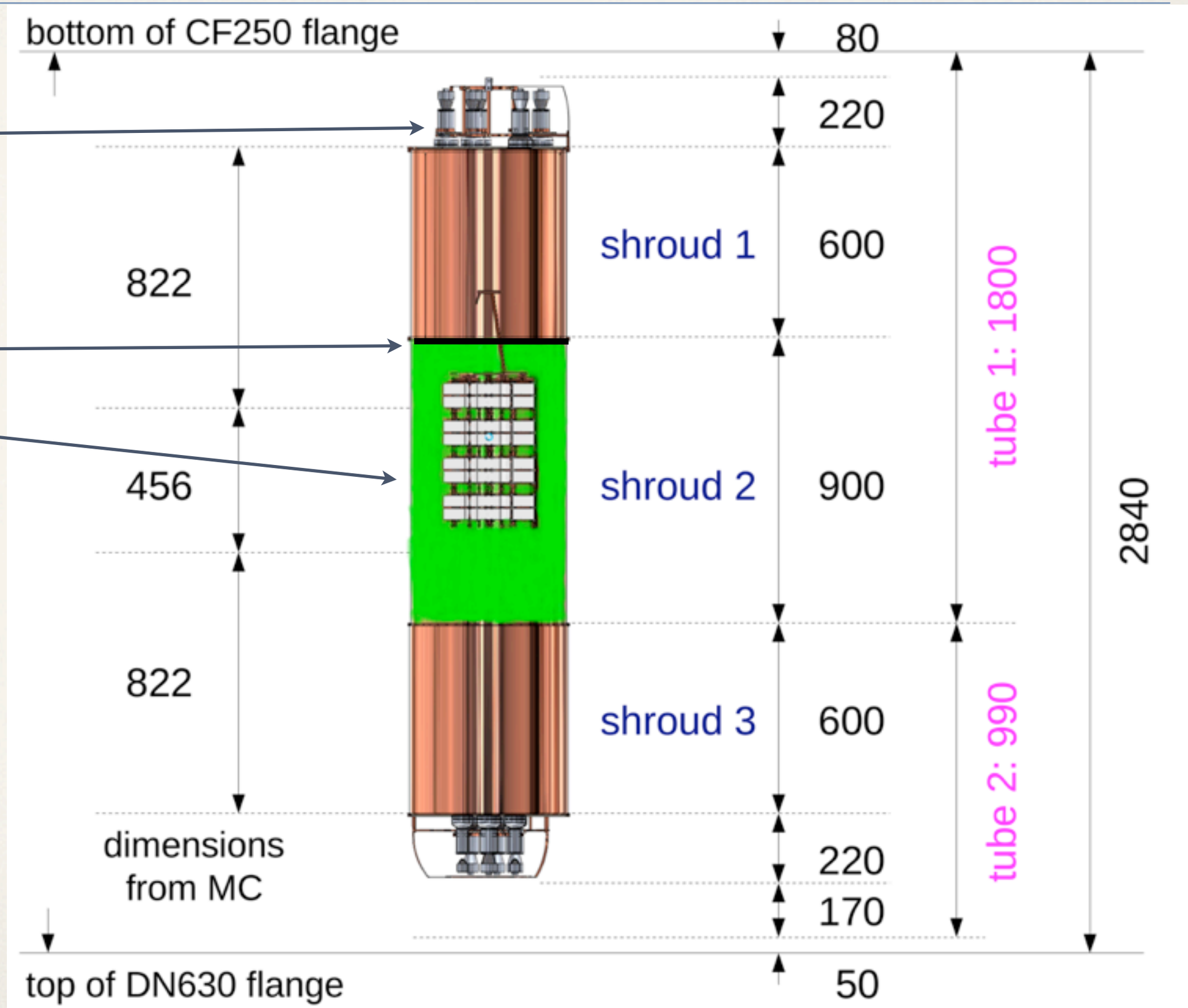




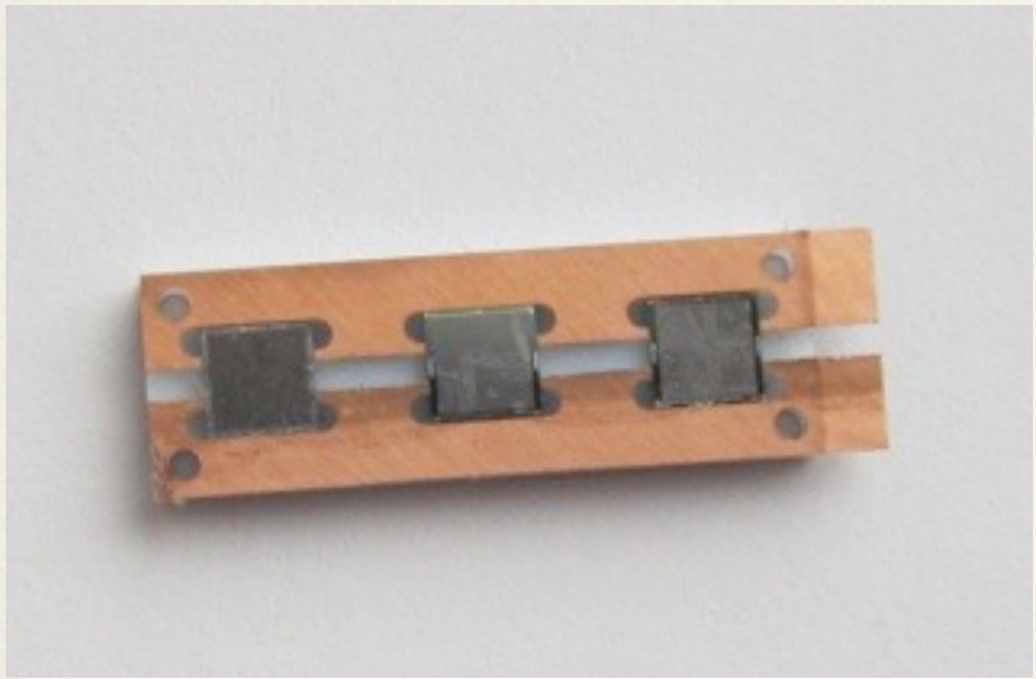


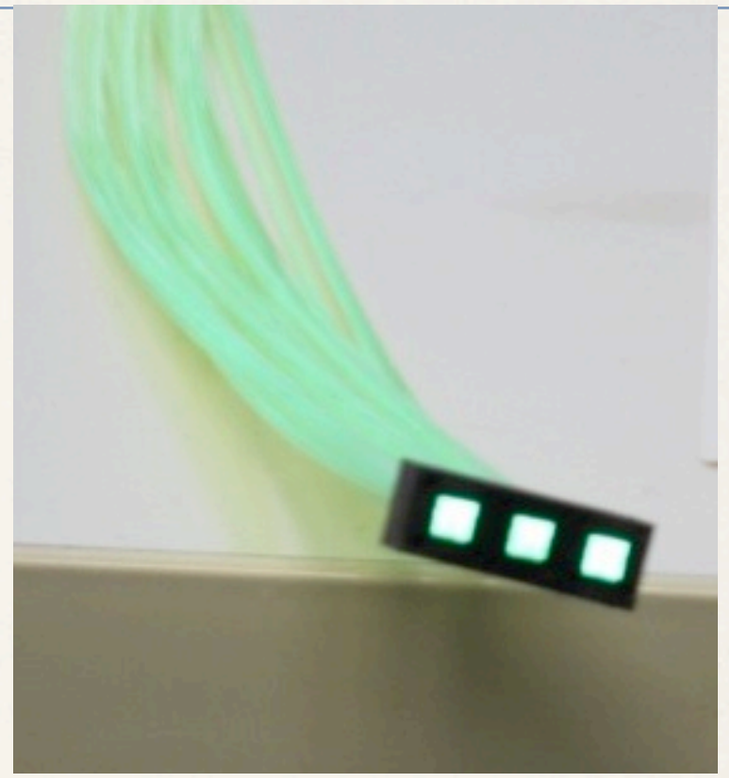
Ref: NIM A 654 (2011), pp. 225-232

An Option for GERDA

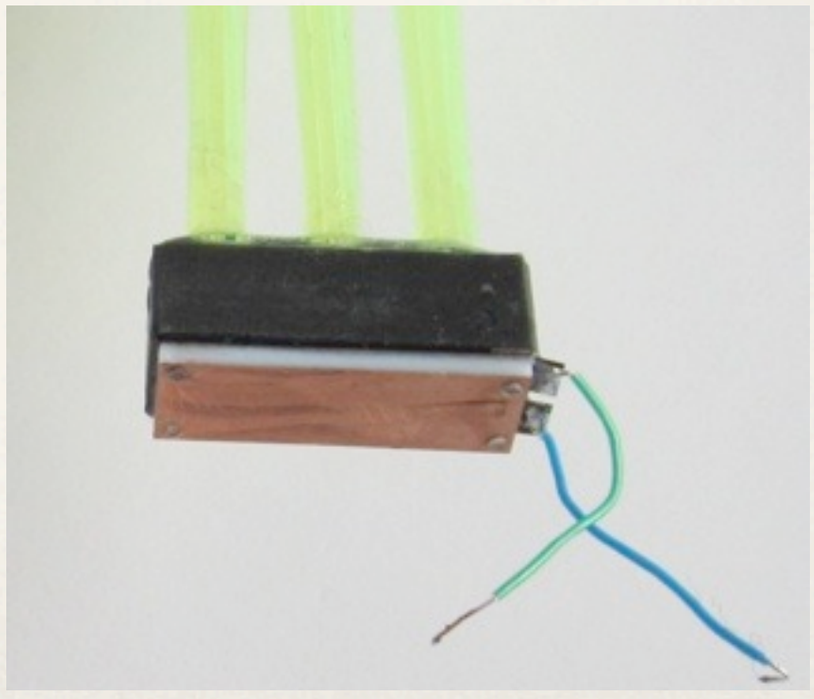


New SiPM holder, coupling





- SiPM delivered in ‘die’, low background packaging is developed
- 9 fiber coupled to 1 SiPM
- units of 27 fibers = 38 mm,
- full coverage = 40 strips, manageable quantity



Induced background

ICPMS results: WLS fiber measured at LNGS

Element	Conc.	Activity Bq/kg	Background cts/(keV kg Year)
K	15 ppb	4.6×10^{-4}	-
Th	14.3 ppt	5.8×10^{-5}	3.4×10^{-4}
U	3.4 ppt	4.2×10^{-5}	2.3×10^{-5}

- The whole setup consists of about 1 kg fiber (4 m^2 photon detector)
- Relevant activity: *O*(>100 μBq)
- Compatible with the background goal of GERDA Phase II (10^{-3} cts/keV kg Y)

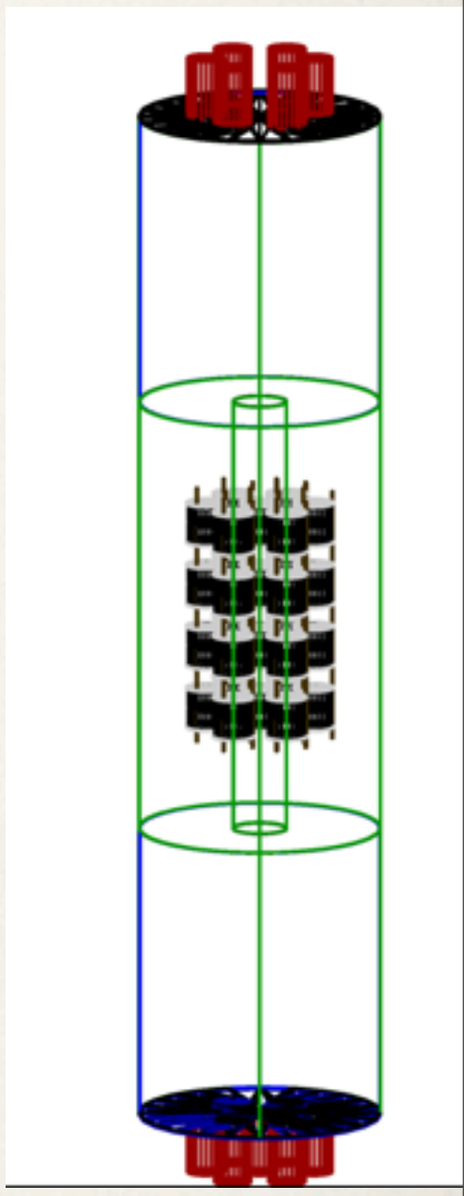
Pro's and Con's

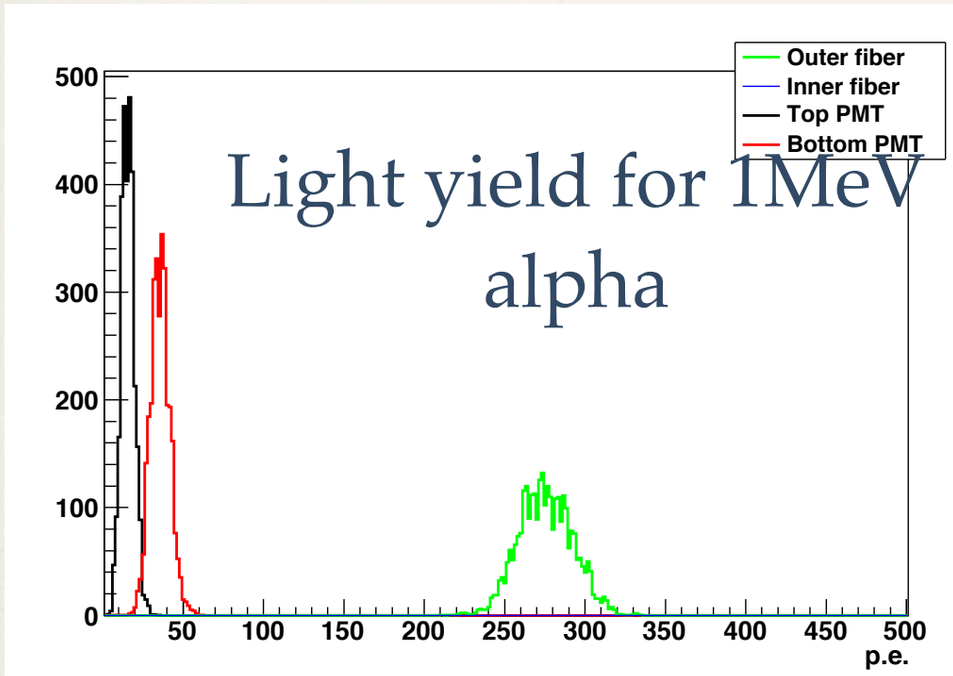
Advantages of using WLS fibers or other scintillators

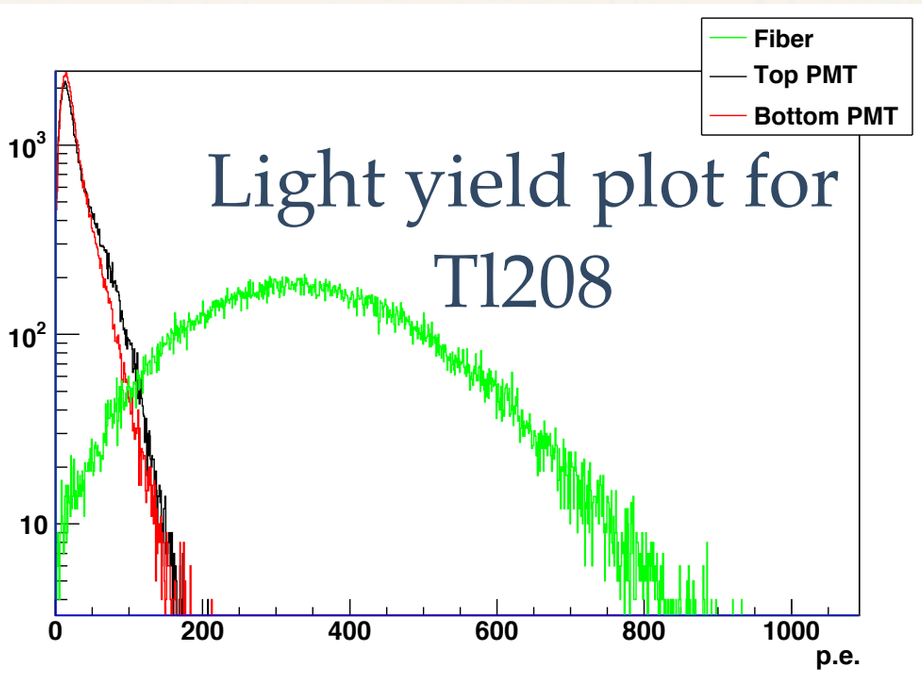
- Many small parts - work intensive
- Fiber + SiPM: 1 kg = 4 m^2 with about 1% <u>total</u> PDE = 58 μBq Th
  - Acceptance angle 360°
  - Compatible with cryogenic environment
- For the same p.e. yield with 8″ PMTs with 20% PDE, 330 cm^2
  - 6 pieces = 6 kg = 780 mBq Th (PMT glass Borexino hep-ex/0109031)
  - Coverage with 8″ PMTs would be only 0.8 %. Small solid angle or mirror foil.
- With low background 3″ PMTs 35 pieces ~ 40 mBq Th (metal housing)

MC simulation

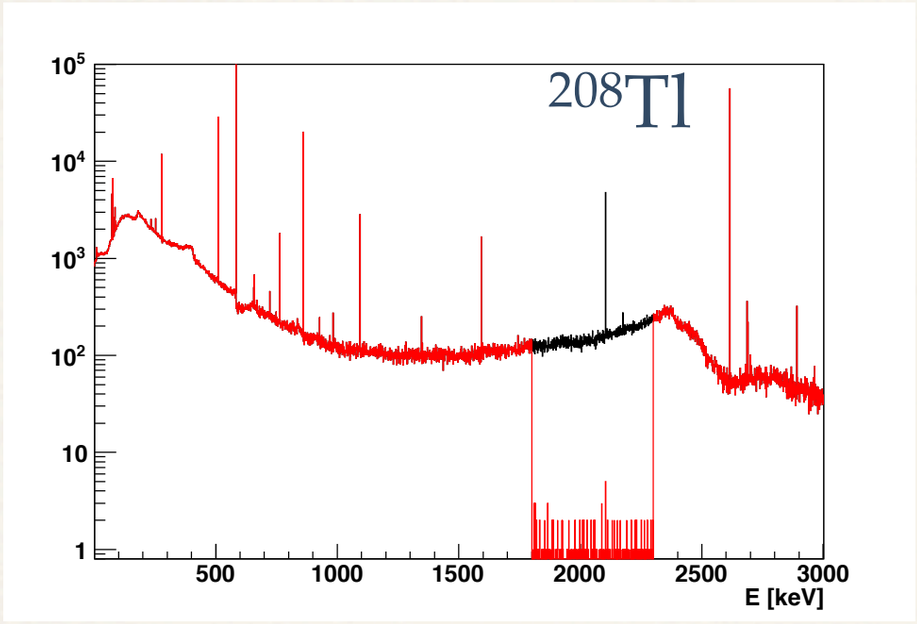
- Fibers are also sensitive on the outer side
- Shifted photons (green) can also hit the PMTs
- Light tracing simulation needed - Geant4
- Optical photons are traced in LAr, in the fiber until the SiPM or PMT

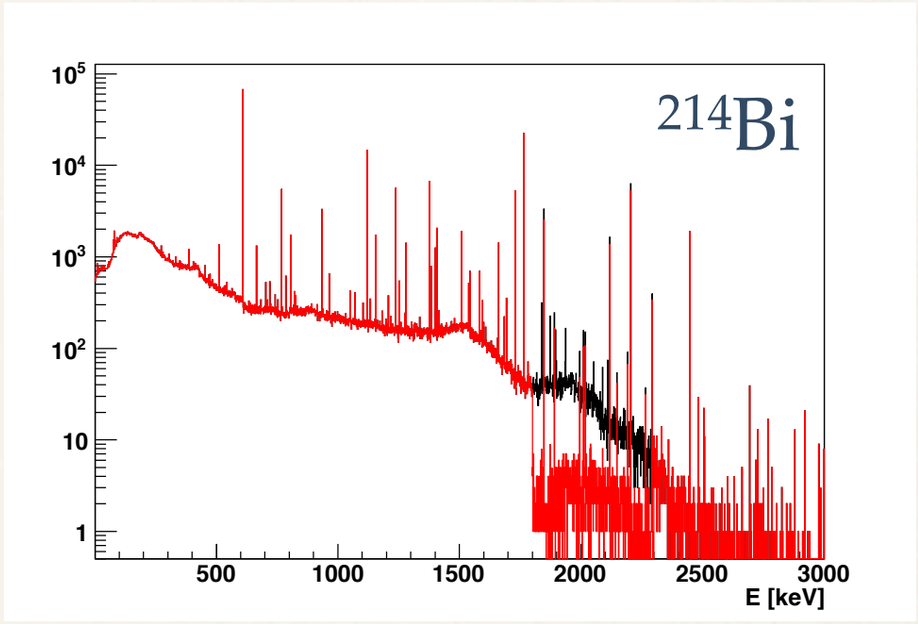






Expected Suppression Factors



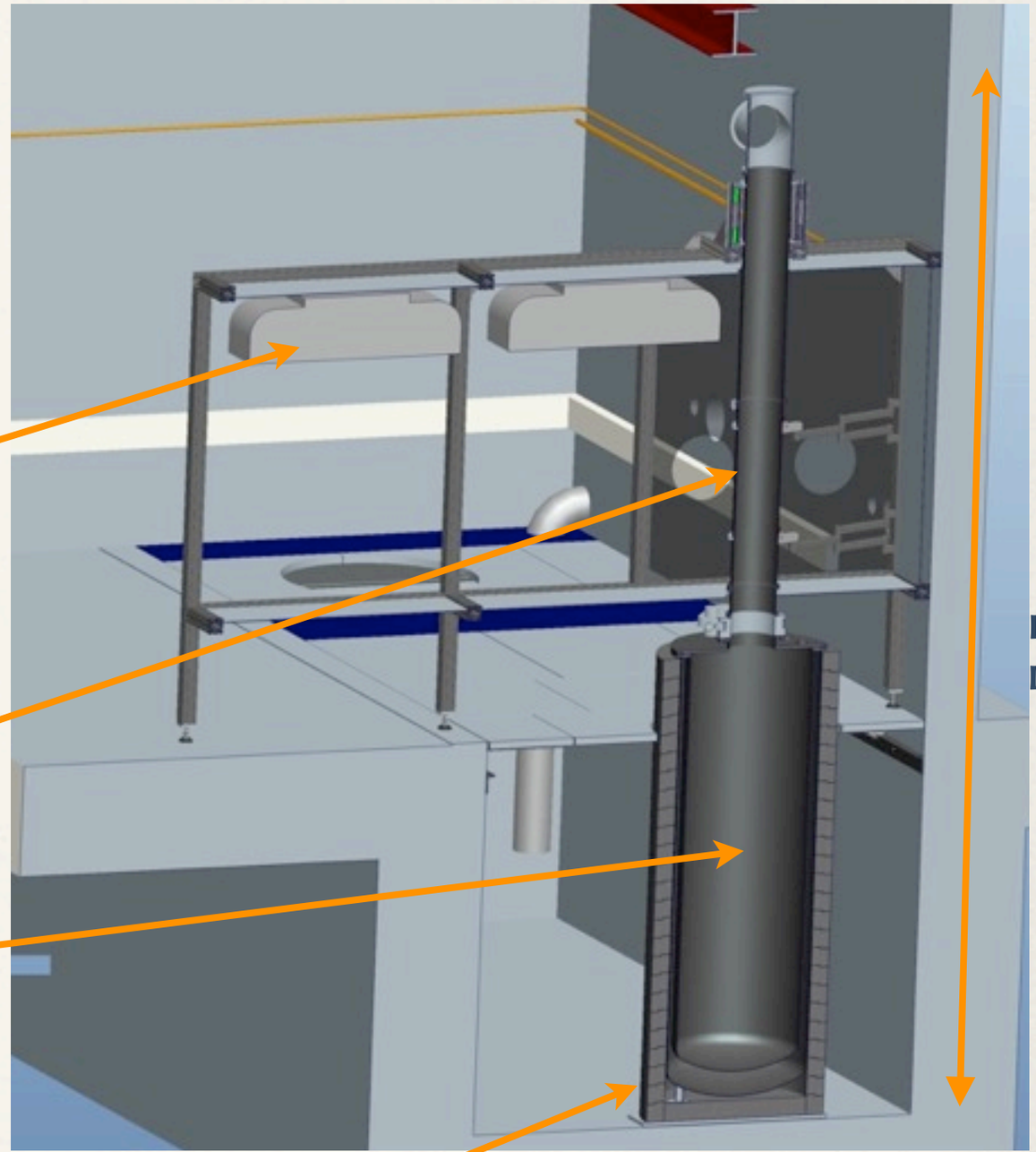


Most dangerous background sources

	In Phase II holders	in LAr	External	In WLS fibers
^{214}Bi	9.9	54.8	-	38
^{208}Tl	365.8	-	112.1	>1000

To be done in 2013

- Test and validation at TUM Underground Lab.
- Production of Gerda LAr veto



Test cryostat at TUM

Summary - Outlook

- WLS fiber + SiPM is a working concept
- Significant reduction of the background is possible
- LAr instrumentation with fibers to be implemented in GERDA
- Deployment - this year
- 1 ton test-stand ready to be used at TUM