New solutions for light detection system: preliminary tests

Motivations:

- T600 detector refurbishment
  - ✓ T_0 reconstruction
  - ▪ Improve granularity for event localization
- New requests
  - ▪ Possible use of magnetic field (no PMTs)
  - ▪ Cherenkov light, LAr dopants, ..
- R&D for future developments to larger masses (LBNE)
  - Detection system cost
  - Detection system compactness (to maximize LAr sensitive mass)

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Possible options: PMTs, APDs and SiPMs

	PMT	APD	SiPM
	Photomultiplier Tube	**Avalanche Photodiode**	**Silicon Photomultiplier**
Quantum Efficiency	25% … 40%	… 80%	… 80%
Single Photon Resolution	✓	–	✓
Operation Voltage	1 - 3 kV	100 - 500 V	20 - 80 V
Gain	10^4 - 10^9	30 - 300	10^5 - 10^7
Insensitivity to Magnetic Field	–	✓	✓
Miniaturization	–	✓	✓
Production Costs	Medium	Low	Potentially Low

SiPM better option

In principle SiPMs and APDs could be the solution BUT:

1. Small detectors -> increase detector coverage using SiPM arrays or bars
2. Typical room temperature operation, specific device developments may be needed
   -> mechanical and electrical checks (as we did in the past for PMTs)

-> We started and R&D to study these relevant aspects

First test campaign @ LNGS: SiPMs vs APDs

- Preliminary tests to validate alternative options to PMTs in the framework of SILENT project (*Low background and low noise techniques for double beta decay physics* funded by *ASPERA*):

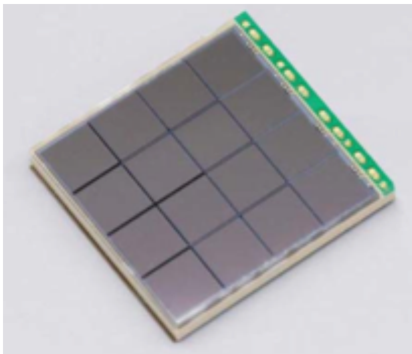
  - SiPM/APD mechanical stability at cryogenic temperature

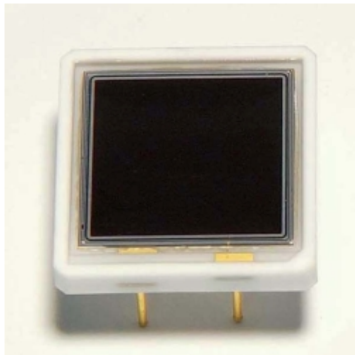
  - SiPM/APD operation at cryogenic temperature

- Three silicon sensors were involved:

  - ***SiPM*** - Hamamatsu S11828-334M – active area ***1.2 x 1.2 cm²***
  - ***Si-APD*** - Hamamatsu S8664-1010 – *windowless*, VUV sensitive – ***1x1 cm²*** active area
  - ***Si-APD*** - Hamamatsu S8664-1010 – *not VUV sensitive* – ***1x1 cm²*** active area

  and a ***high efficiency Hamamatsu 3" PMT*** (QE = 32%) suited for LAr applications (**R11065**)

SiPM 

 APD

Experimental set-up

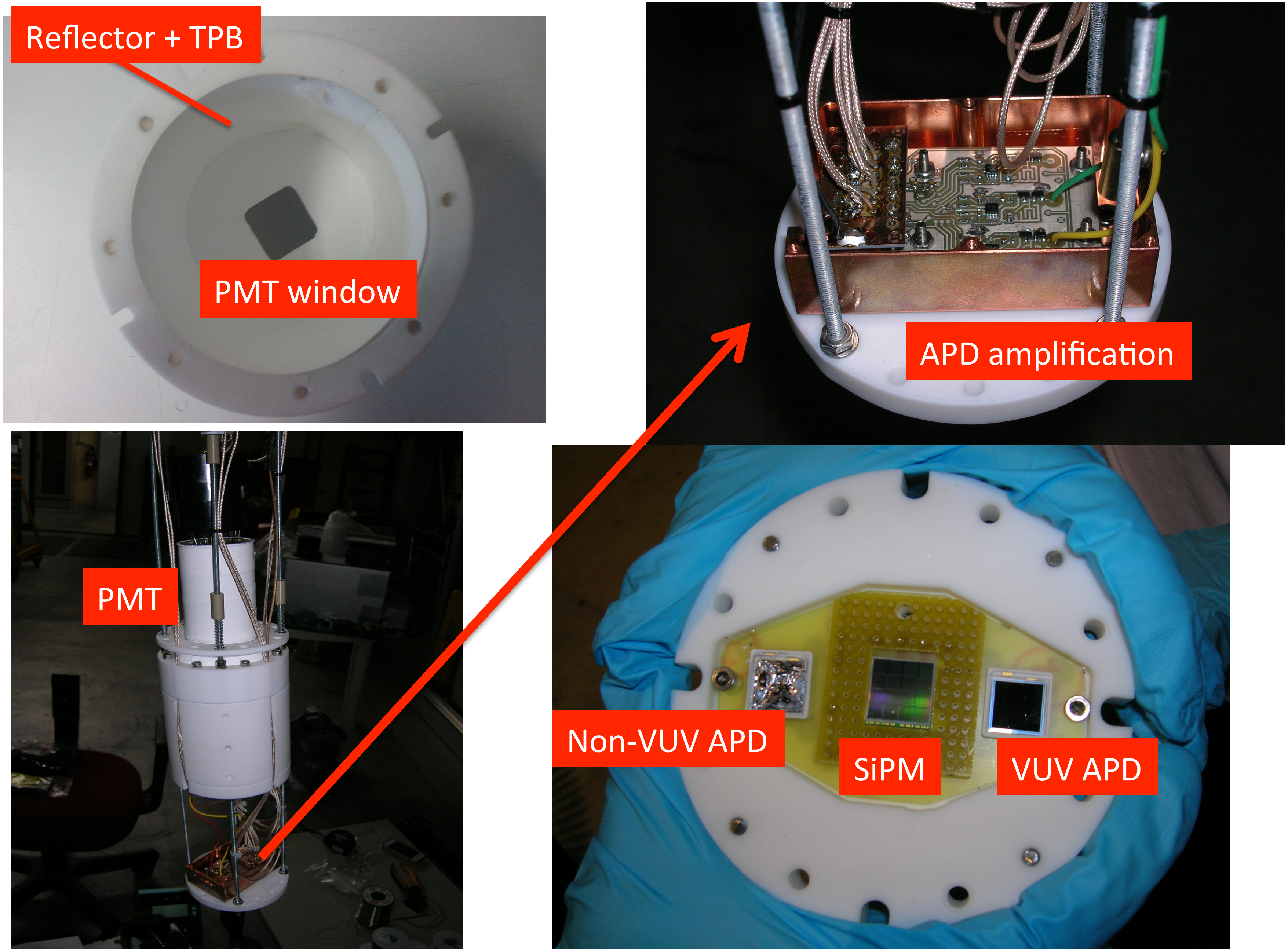
Scintillation chamber

- The scintillation chamber is a PTFE square cylinder (diameter ~ 8 cm, internal volume ~ 0.5 l)
    - The PMT is installed at the top end of the chamber; *the surface of the PMT is partially screened*, leaving a free surface of *a 2x2 cm^2 square*
    - The three silicon sensors are installed at the bottom end of the chamber
    - The chamber is lined up with an *highly reflective foil* (3M VIKUITI – reflectivity > 98% in the visible) *deposited with wavelength shifter* (TPB – TetraPhenyl Butadiene, peak emission @ 430 nm, efficiency ~ 100%) by vacuum evaporation
- The scintillation chamber is installed inside a stainless steel (vacuum tight) cylinder
- The cylinder is deployed in an open dewar

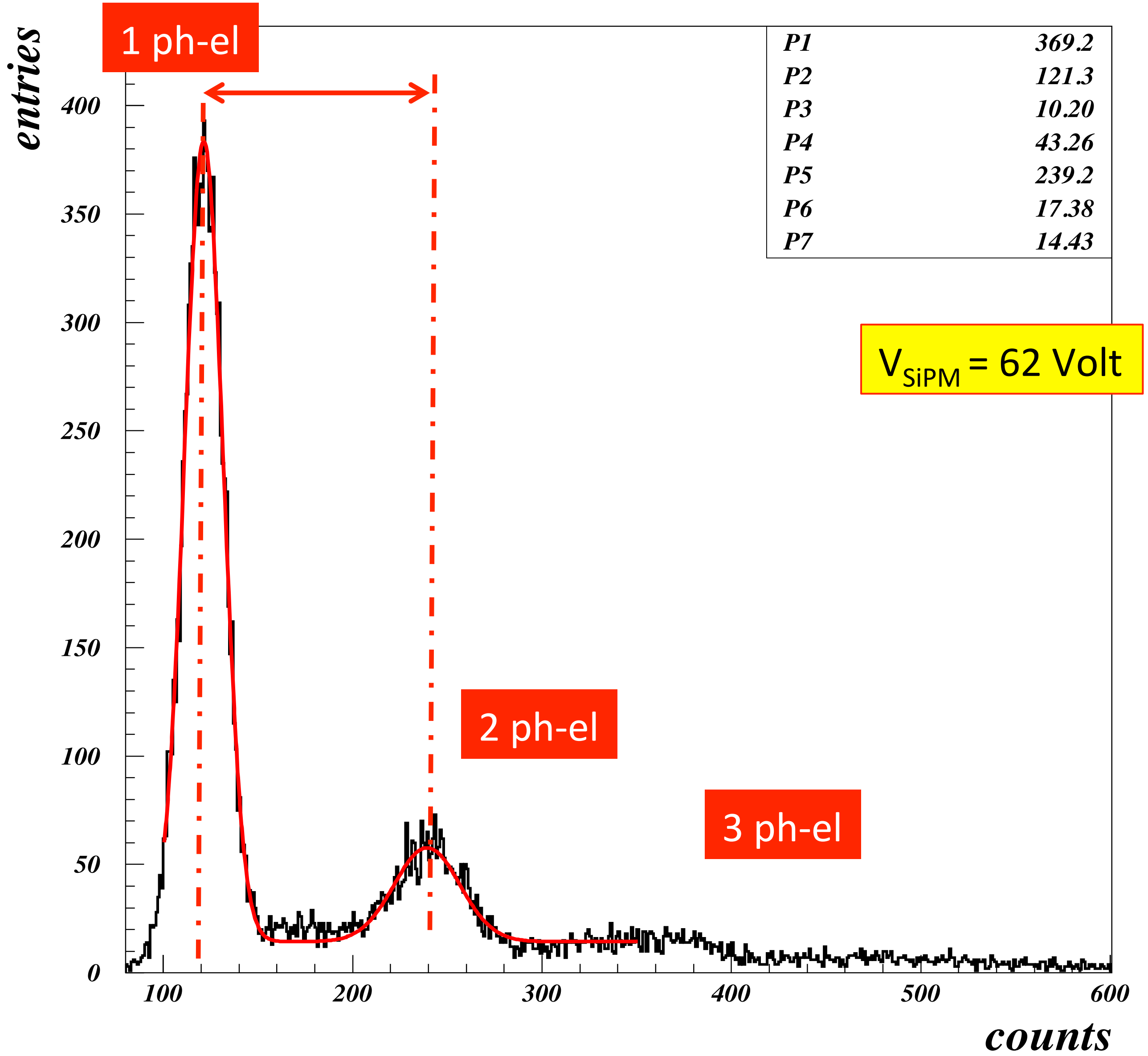
LAr run

- The cylinder is evacuated at a pressure of the order of 10^{-6} mbar
- The open bath is then filled with LAr while the internal volume is still being pumped down (in this phase we reach a pressure ~ 10^{-7} mbar)
- The cylinder internal volume (few liters) is filled with ultra pure 6.0 Argon on-line purified through a Trigon (Engelhard Q5-Cu0226) filter

Scintillation chamber – phase 1

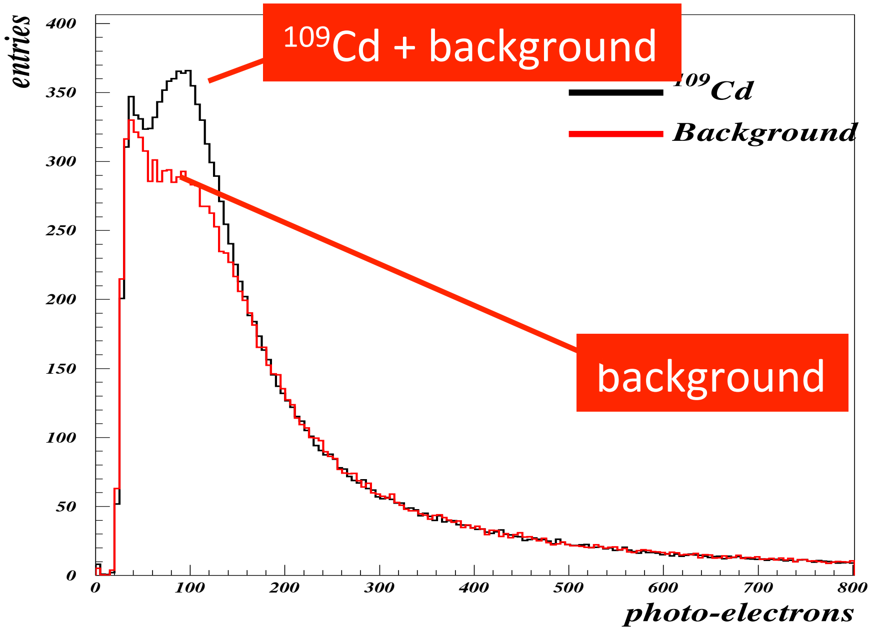


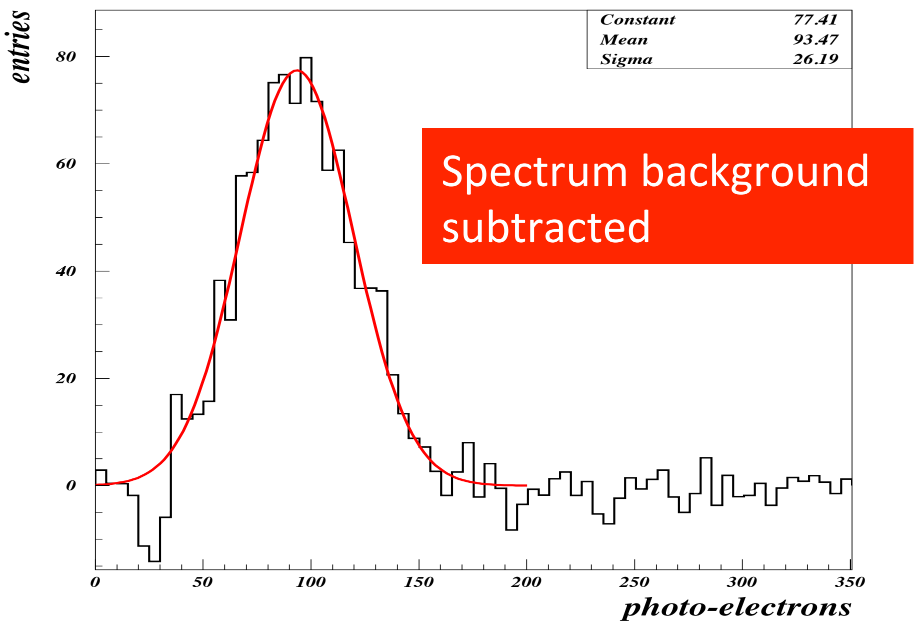
SiPM: SER



- SiPM signal readout with a *Camberra 2005 charge preamplifier + ORTEC 672 spectroscopy amplifier*;
- Signal acquired with a *multichannel*;
- ***The spectrum of first photo-electrons is vey well resolved***;
- The absolute *calibration factor between counts and photo-electrons* is obtained as the ***difference between first phel and second phel position***.

SiPM: Light Yield

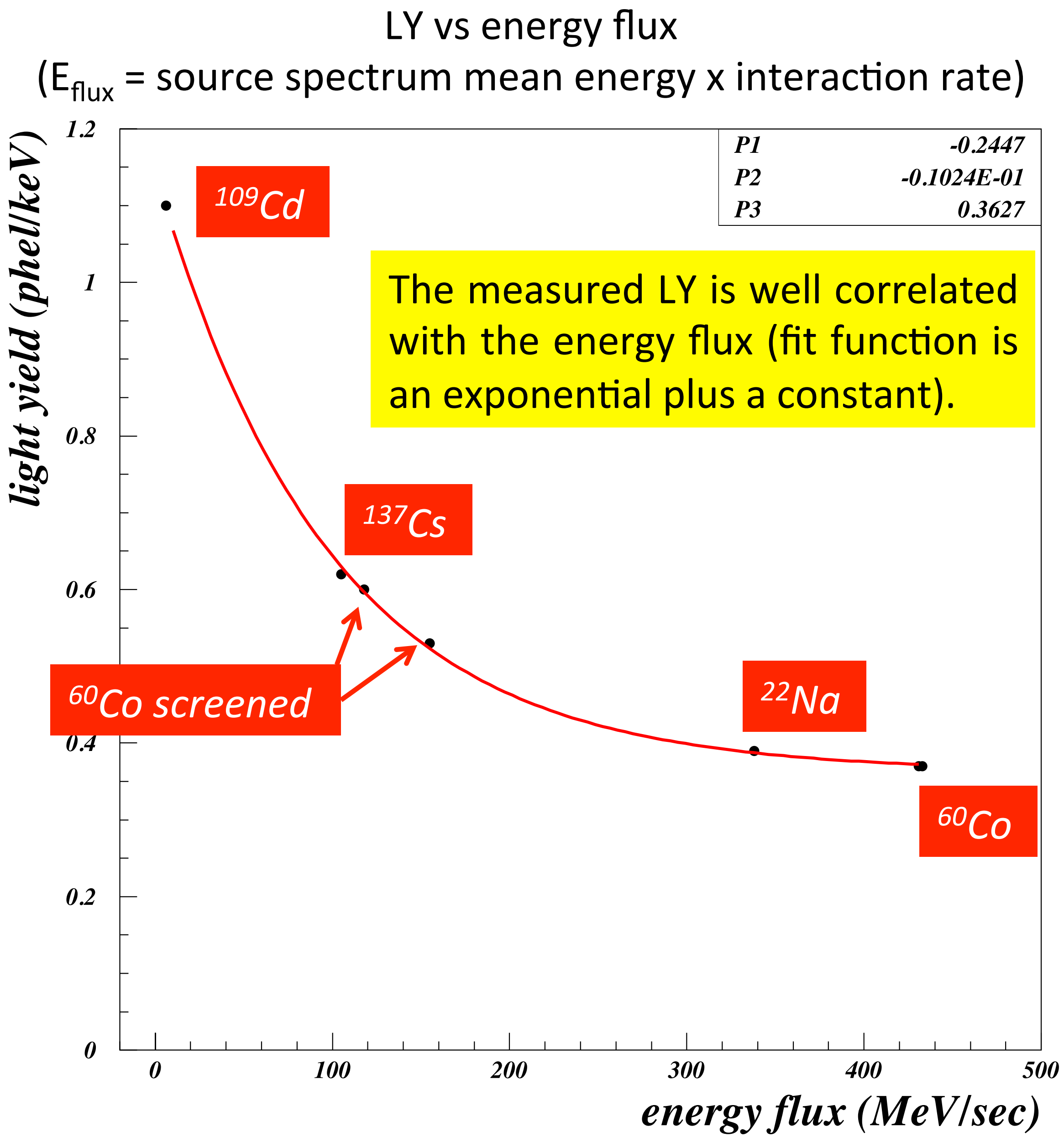




- Light Yield of the system is estimated with a ***^{109}Cd*** source positioned outside the stainless steel cylinder;
- ***^{109}Cd*** has a γ line at ***88 keV***;
- After background subtraction we find a Gaussian peak with a mean value of ***94 phel***:

$$LY = \frac{94\,phel}{88keV} \cong 1.1\frac{phel}{keV}$$

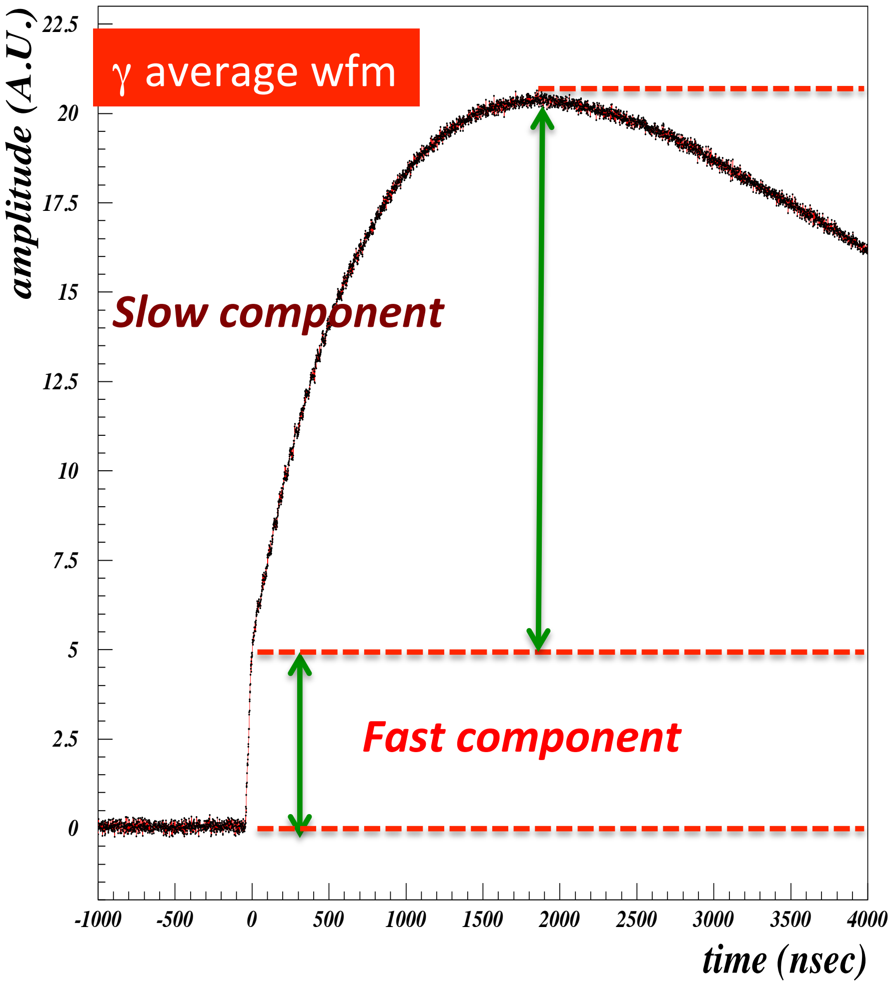
SiPM: LY vs energy flux

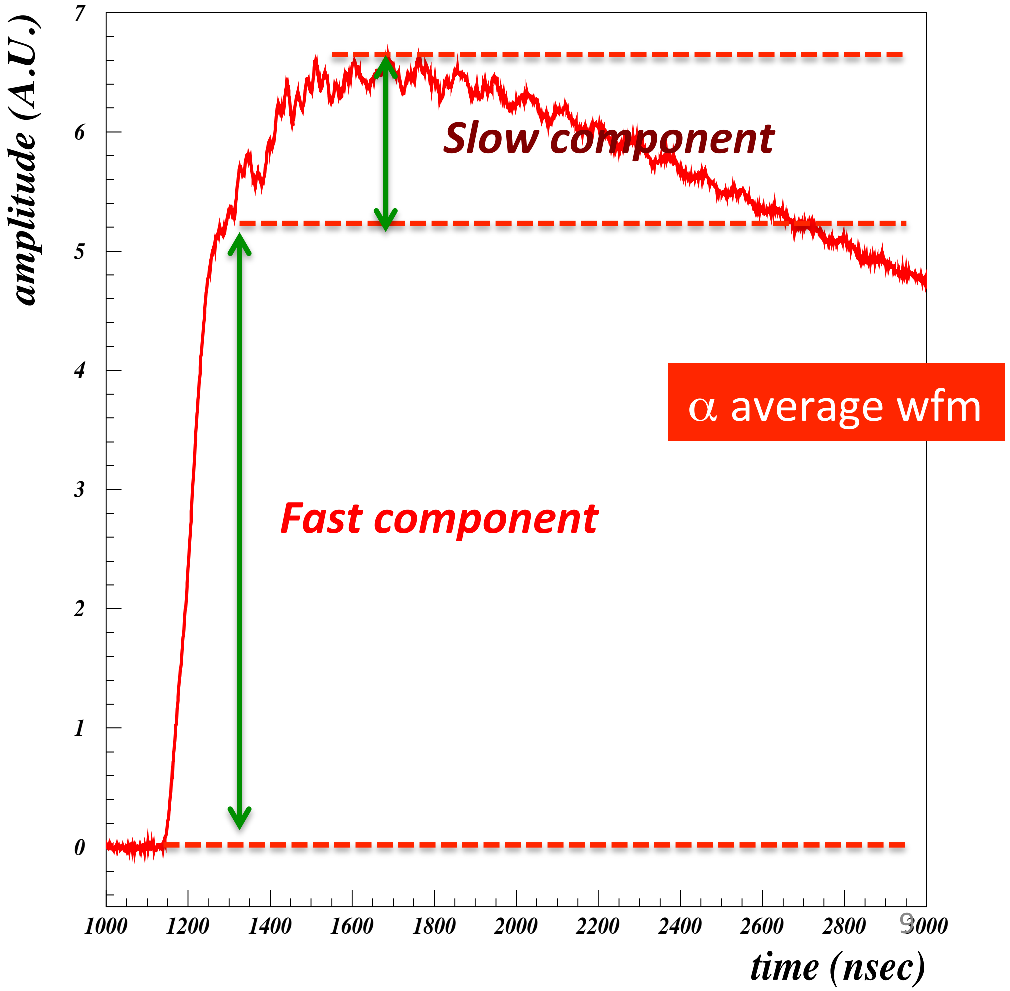


- The chamber has been irradiated with other, more intense, radioactive sources: **^{60}Co, ^{137}Cs, ^{22}Na**
- ***SiPM LY and gain decrease for more intense and more energetic sources***
- This effect might be due to the ***recovery time of the cells*** of the SiPM that *significantly increases at cryogenic temperatures*
- This is due to the ***increase of the resistivity of the quenching resistor of the cell*** -> optimized for room temperature.

SiPM: Pulse Shape Discrimination

- ***Direct signal from SiPM*** (no amplification) – Recorded with the scope
- ***Extremely clean PSD capability***





SiPMs vs APDs: results

- **In all the cryogenic tests we experienced mechanical problems with APDs**

  - VUV windowless Si-APD did not work, *probably for a problem with the bonding wire* (extremely delicate devices)

  - Non-VUV Si-APD with *glass window* is not suited to work in liquid Argon because *the differential shrinking of the glass window and of the ceramic packing systematically caused sensor breaking -> need of a different packing*

- **SiPMs worked in reliable way at cryogenic temperature in all the tests**

  - Robust
  - Easy to operate without HV
  - High gain -> no need of a preamplifier close to the sensor
  - Considerable reduction of materials inside detector
  - **LY ≈ 1 phel/KeV with 1.44 cm^2 active area** to be compared to the reference (state of the art) PMT≈ 2 phel/KeV with 4 cm^2 sensitive area
  - Suited for PSD application

➢ **Different APDs types can be tested**
➢ **SiPMs seem to be safer option**

Second test campaign on SiPMs @ LNGS

Given the successful results on SiPMs we decided to go on only on these devices:

- SiPM single die to test light bars
- SiPM arrays to improve the photo-sensitive area

All the available SiPM sample @ LNGS were successfully tested in LAr for mechanical stability

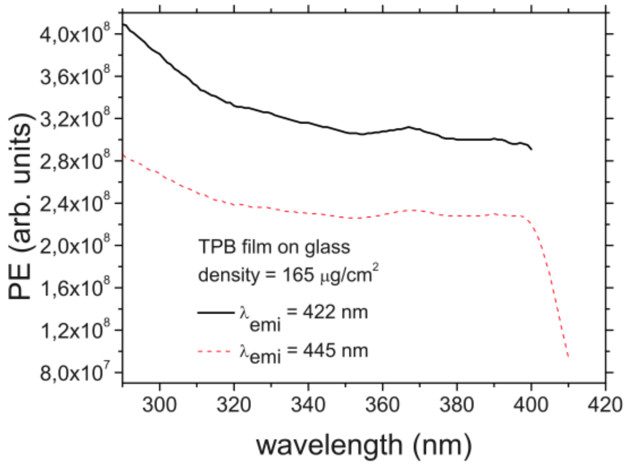
- n. 12 Hamamatsu Monolithic MPPC Array S11828-3344M 16 ch x (3x3 mm2/ch)
- n. 1 AdvanSiD ASD- SIPM1S-M 1 ch x (1x1 mm2/ch)
- n. 2 AdvanSiD (old technology -100 μm cell size) 1 ch x (3x3 mm2/ch)
- n. 2 AdvanSiD (old technology -100 μm cell size) 1 ch x (4x4 mm2/ch)
- n. 1 AdvanSiD Monolithic Array ASD- RGB1.5S-P-8x8A 64 ch x (1.45x1.45 mm2/ch)

Other samples will be available soon:

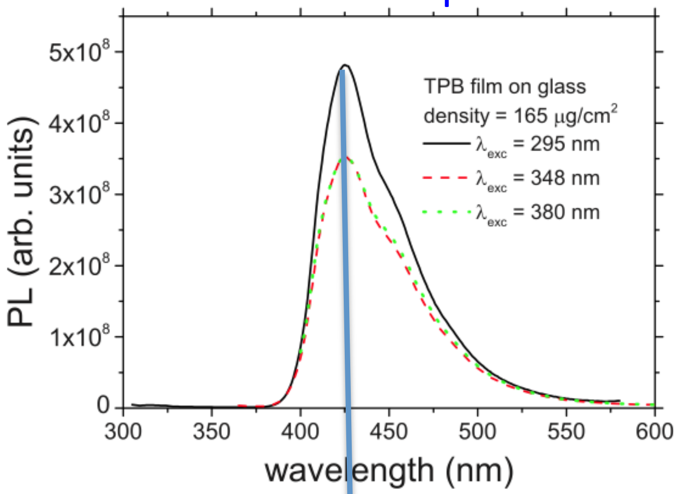
- AdvanSiD Hybrid Array RGB/NUV type 16 ch x (3x3 mm2/ch)
- AdvanSiD Monolithic Array RGB/NUV type 16 ch x (3x3 mm2/ch)
- AdvanSiD (single die) RGB/NUV type 1 ch x (3x3 mm2/ch)

SiPM spectral response vs WLS spectrum

TPB absorption spectrum



TPB emission spectrum



AdvanSiD new technologies:

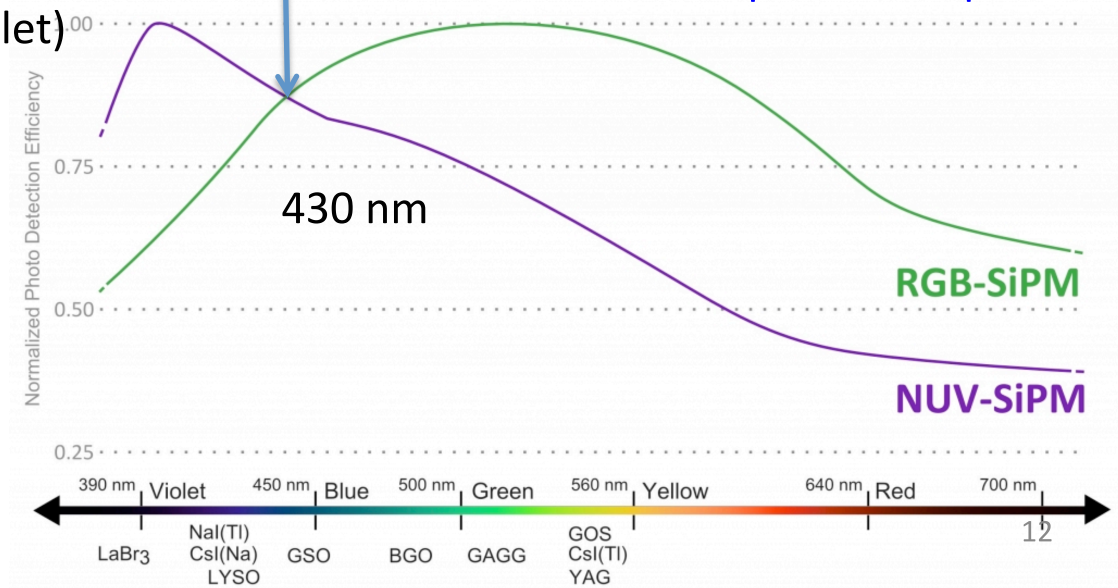
RGB n-on-p junction (Red-Green-Blue)

NUV p-on-n junction (Near-Ultra-Violet)

Main Features:

- Low Noise: Dark count rate of 100kHz/mm^2 at max overvoltage, 25 °C
- High detection efficiency: PDE 35% at max overvoltage and peak efficiency wavelength
- 40um cells, high fill-factor

SiPM Spectral Response



Light detection with multiple SiPM set-up

- Same experimental set-up previously used, properly adapted to place more SiPMs

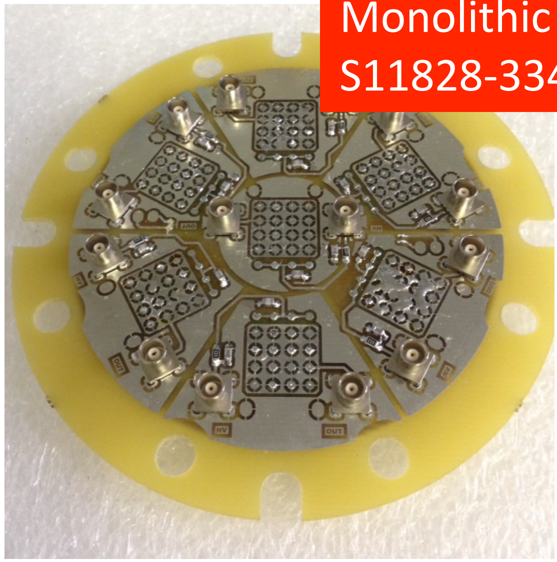
- Aims:
  - Light detection with an enlarged photo-cathode coverage
  - Test reproducibility on a higher number of SiPM samples
  - Study of related detector components
    - PCB for mechanical support and electrical connections
    - Voltage supply and signal feed-through
    - Signal to noise study, signal treatment (single/sum)

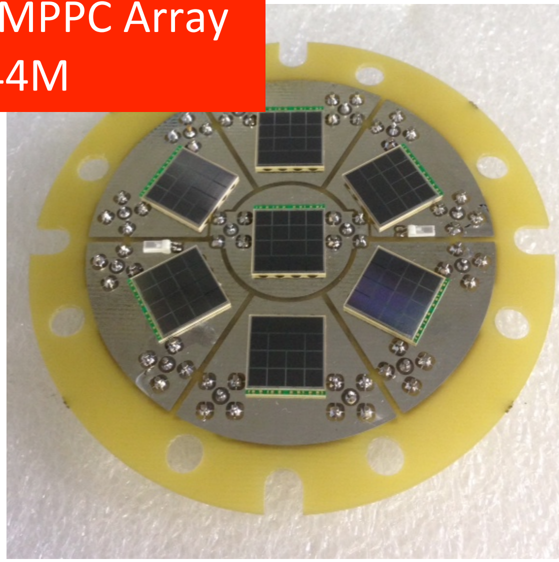
- Involved sensors:
  - 7 x (1.3x1.3cm^2) Hamamatsu Monolithic MPPC Array S11828-3344M
    16 ch x (3x3 mm^2/ch) on the same PCB
  - 2 x (1.3x1.3cm^2) Hamamatsu Monolithic MPPC Array S11828-3344M
    + 1 x (1x1mm^2) AdvanSiD ASD- SIPM1S-M on the same FR4 base

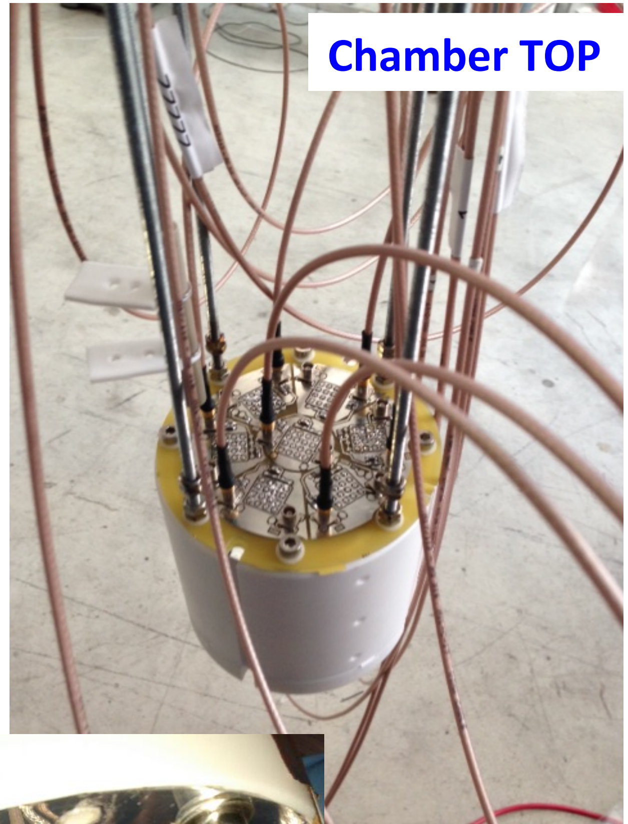
- Tests ongoing.

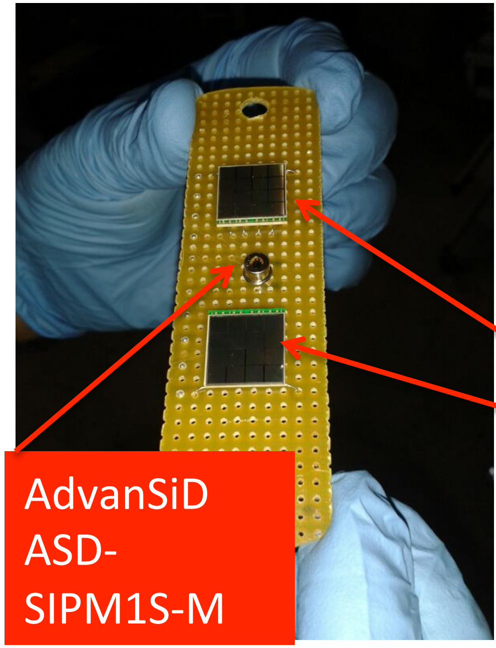
Scintillation chamber – phase 2

7 x Hamamatsu
Monolithic MPPC Array
S11828-3344M



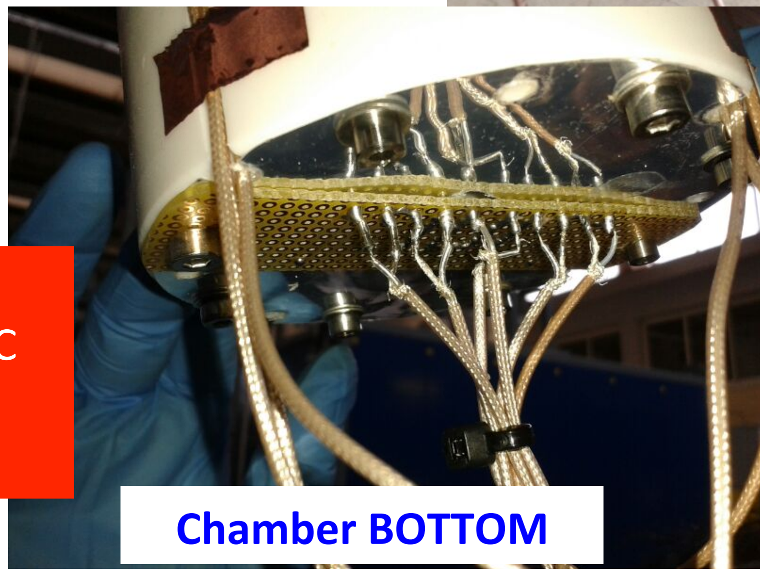




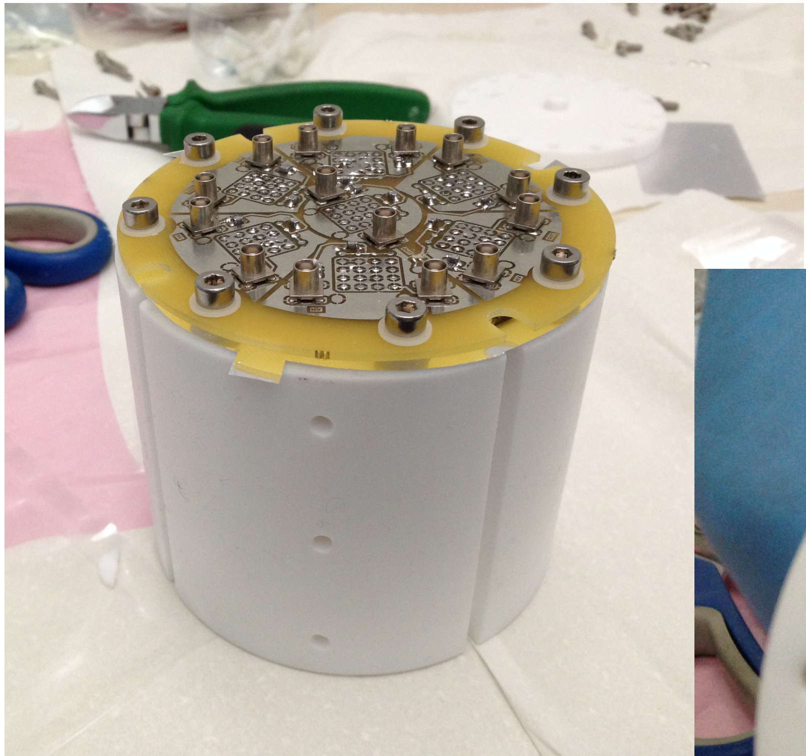


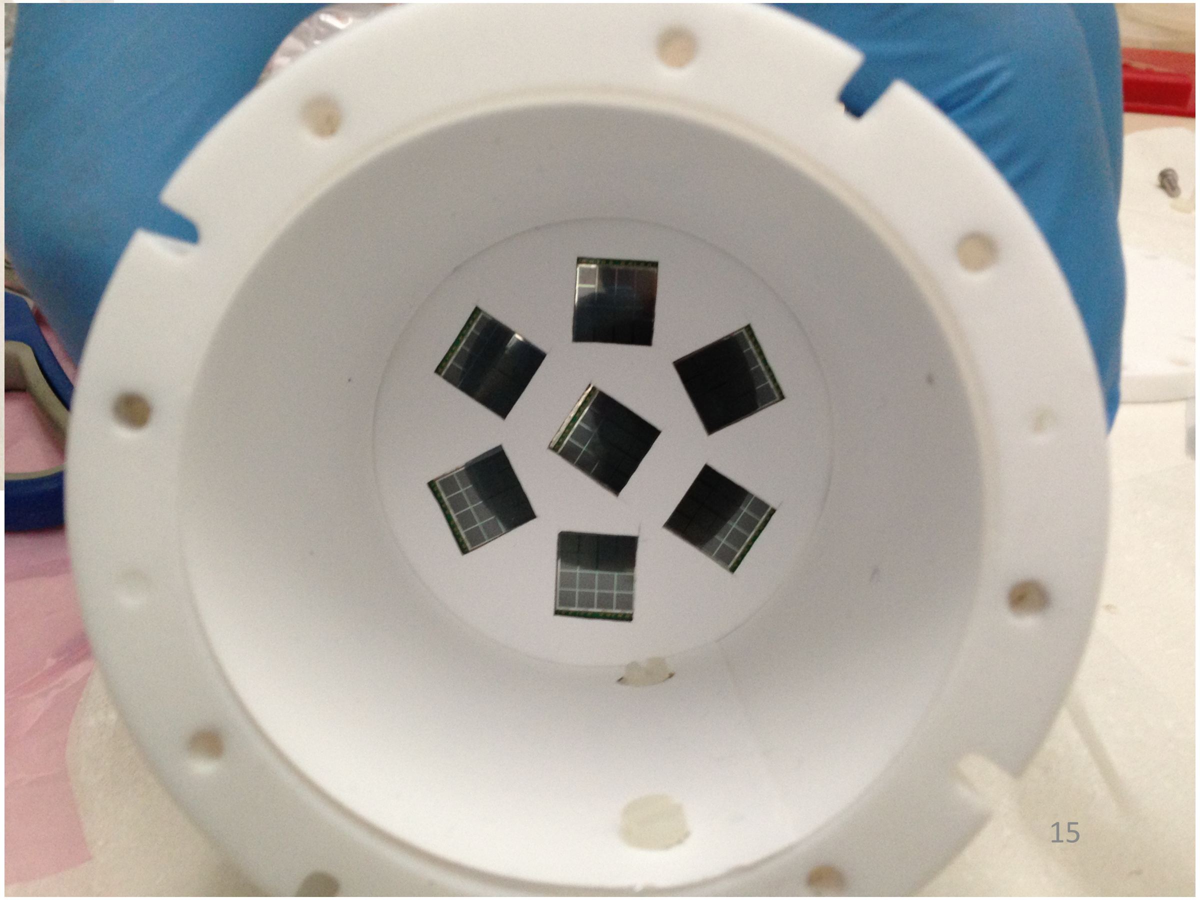
AdvanSiD
ASD-
SIPM1S-M

2 x Hamamatsu
Monolithic MPPC
Array
S11828-3344M



Scintillation chamber – phase 2

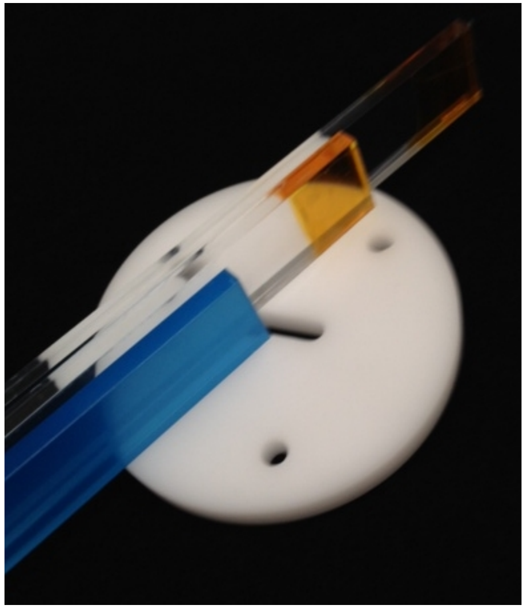




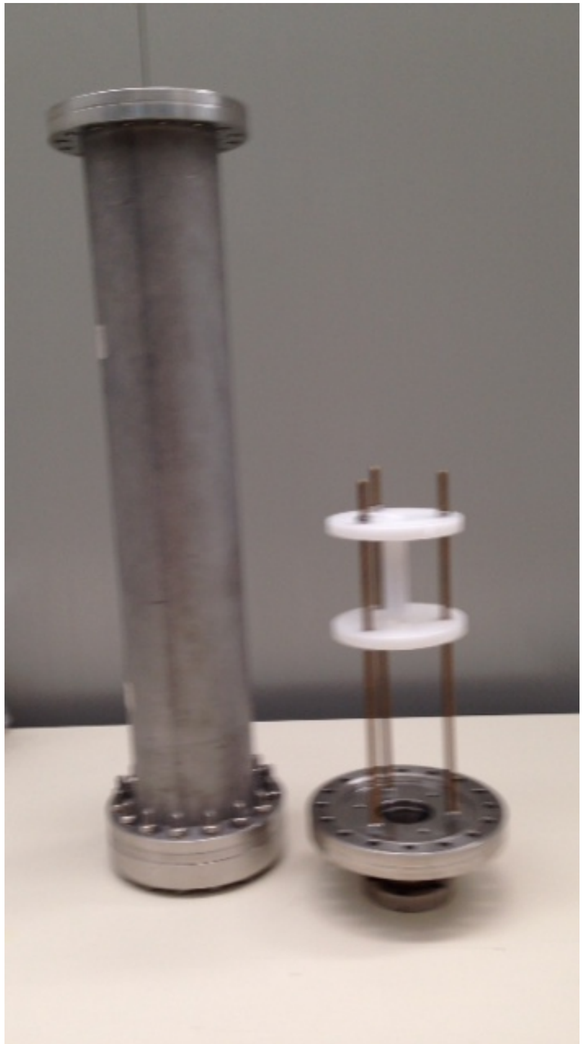
PTFE scintillation chamber (0.5 l) lined up with 3M VIKUITI reflector foil (> 98% in the visible range) TPB-deposited by vacuum evaporation

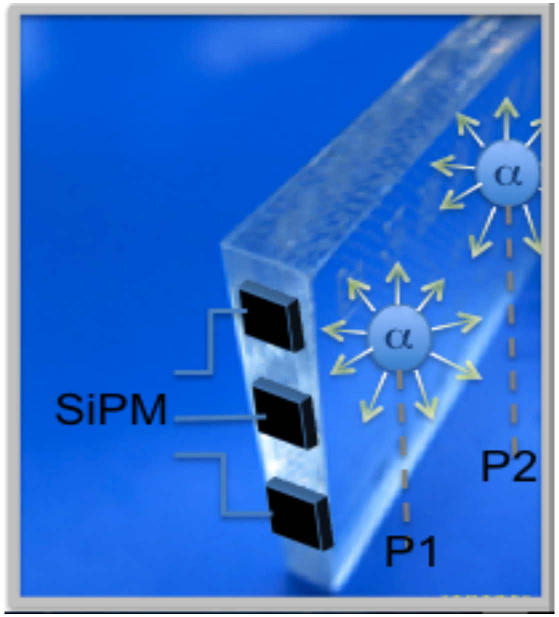
SiPM + Light guides @ LNGS

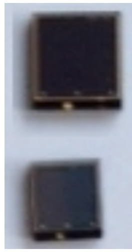
- 3 types of extruded bars available at LNGS (47 cm x 2.5 cm x 0.6 cm):
  - one standard acrylic bar - TPB coated on one side
  - one UV transmitting acrylic bar - TPB coated on one side
  - One standard acrylic bar – no coating
- TPB-coating by brushing: TPB +Polystyrene (25 % TPB, saturated) in toluene, for UVT bar more TPB is used: 425 nm shifted light
- A dedicated chamber test has been realized
- Single-die SiPMs optically coupled to the bars
- Foreseen measurements:
  - Cryogenic tests (mechanical tests)
  - Attenuation length (light yield vs alpha source position)
  - Bar-to-bar comparison



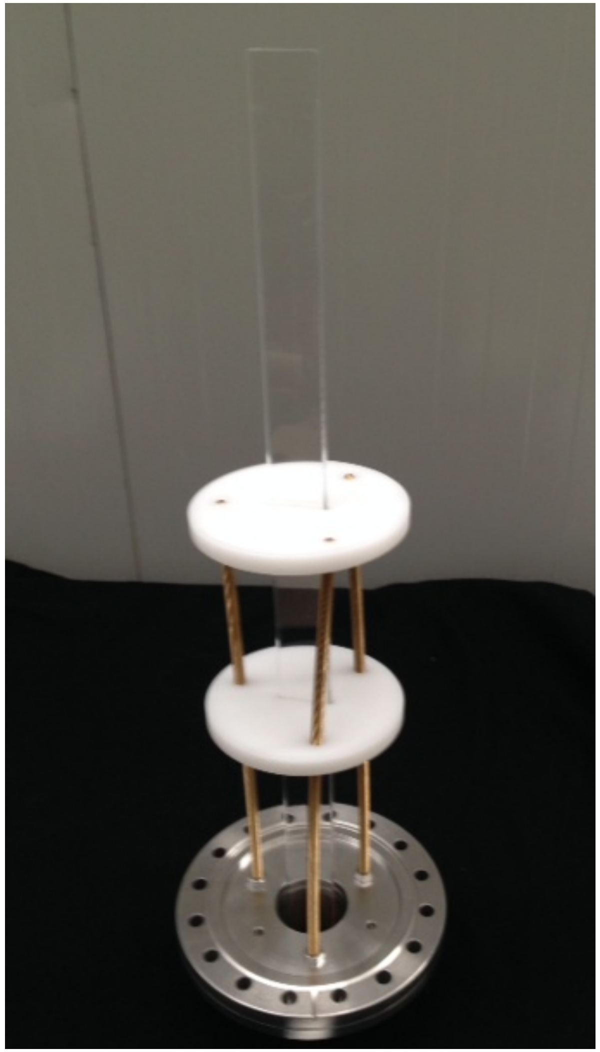
Experimental set-up for bar test @ LNGS







SiPMs:
AdvanSiD 1 ch x (3x3 mm2)
AdvanSiD 1 ch x (4x4 mm2)



Conclusions and next steps

- A set of different SiPM samples (different types and manufacturer) have been successfully tested in LAr @ LNGS for mechanical behavior.

- One Hamamatsu *SiPM sample* successfully detected TPB-shifthed LAr scintillation light working directly immersed in LAr. We measured a Light Yield higher than that of the most performing cryogenic PMT on the market (3” Hamamatsu R11065).

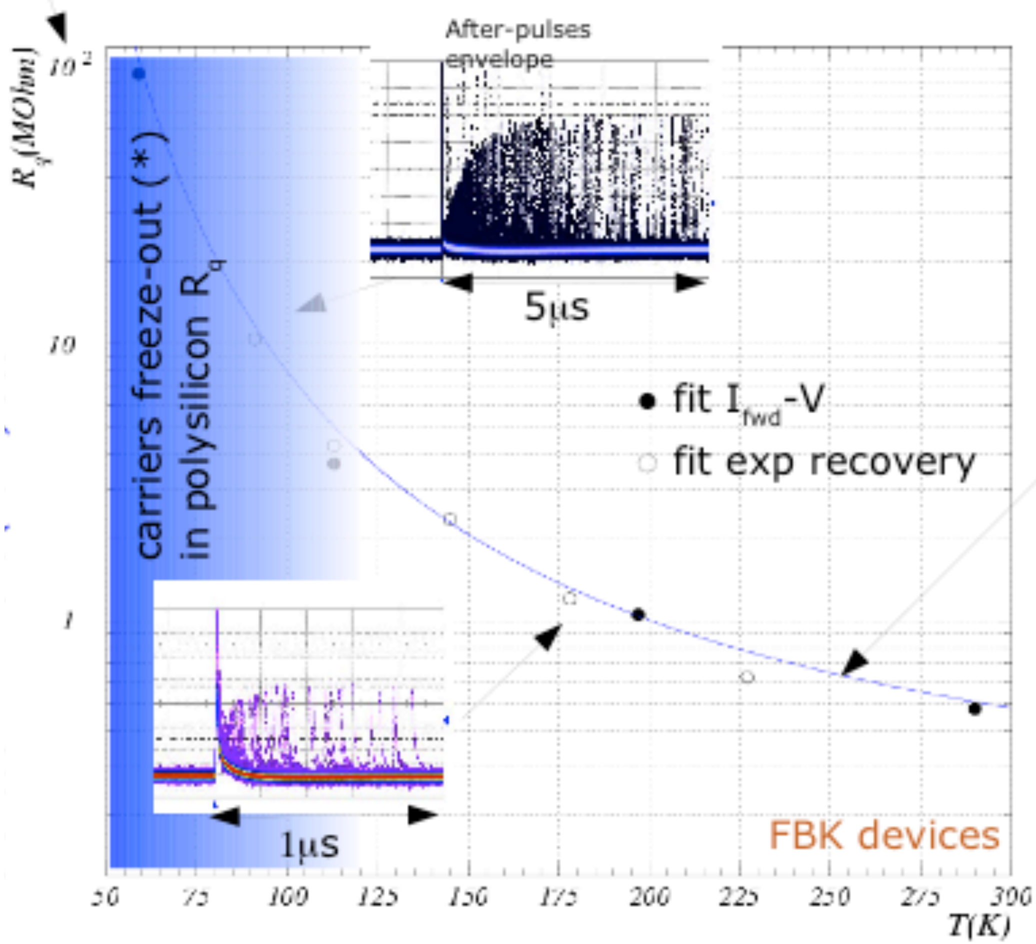
- Results have to be confirmed in extensive tests on more samples even for reproducibility. Tests *of various types of SiPMs and of different manufacturers (*Hamamatsu, AdvanSiD, SensL ?,…) have to be carried out too.

- We performed preliminary tests on APD samples and experienced problems with them in LAr. It could be interesting to test different samples (package).

- In the near future:
  - Extensive tests of *multiple SiPM- array LAr chamber* (ongoing).
  - Tests on bars coupled to SiPMs and optimization (soon).
  - *SiPM characterization with a laser/LED source at room and cryogenic temperature*. It could be necessary to optimize SiPM performance (quenching resistor, after-pulses and cross-talk reduction,…).

backup

RQ VS T



After-pulses envelope
5μs
1μs
carriers freeze-out (*) in polysilicon R_q
fit I_{fwd}-V
fit exp recovery
FBK devices
R_q (MOhm)
10^2
10
1
50
75
100
125
150
175
200
225
250
275
300
T(K)

Dark counts vs T