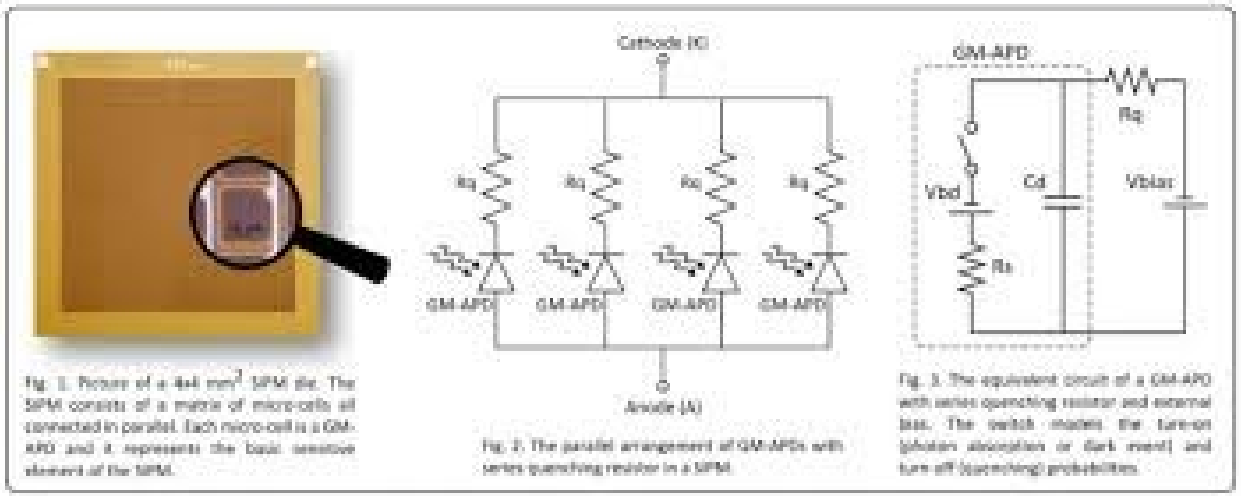
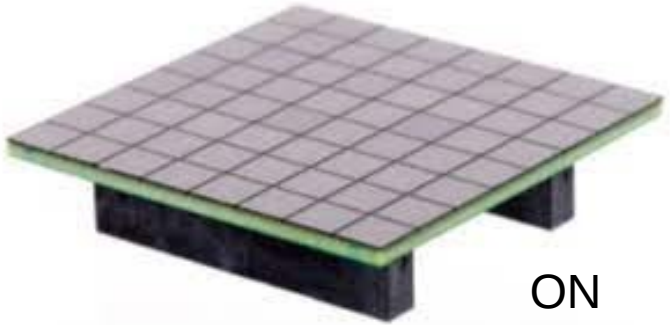
# Innovative photo-detectors

APOGEIA – WP 5.1
Alessandro Razeto - LNGS

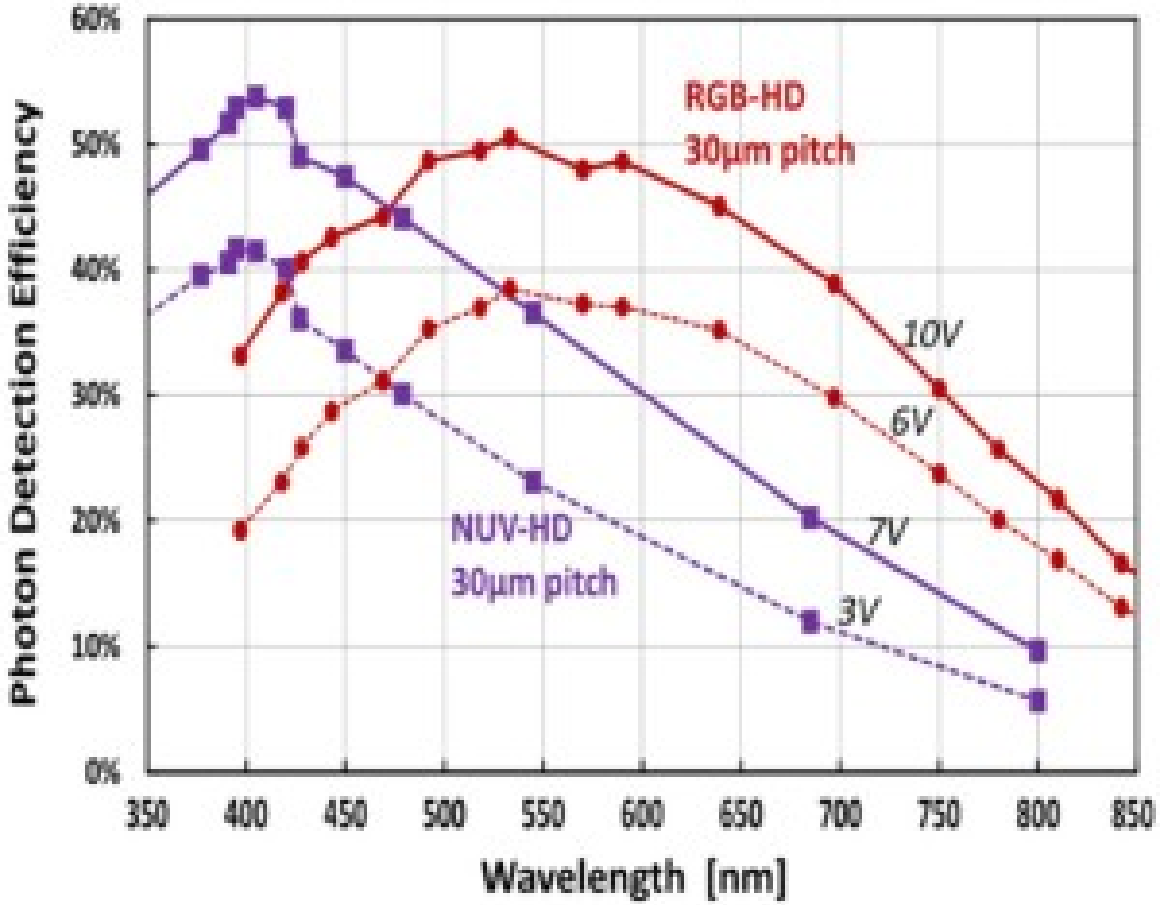
# A few words on Silicon Photo-Multipliers

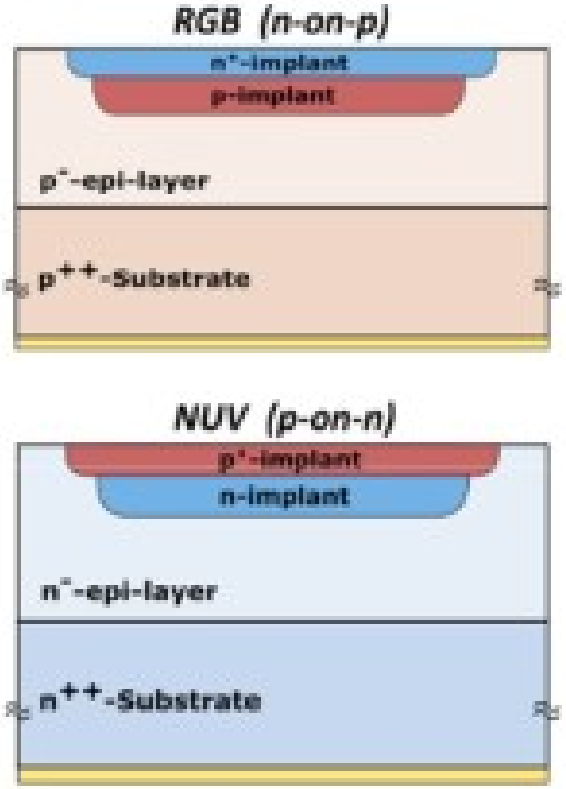


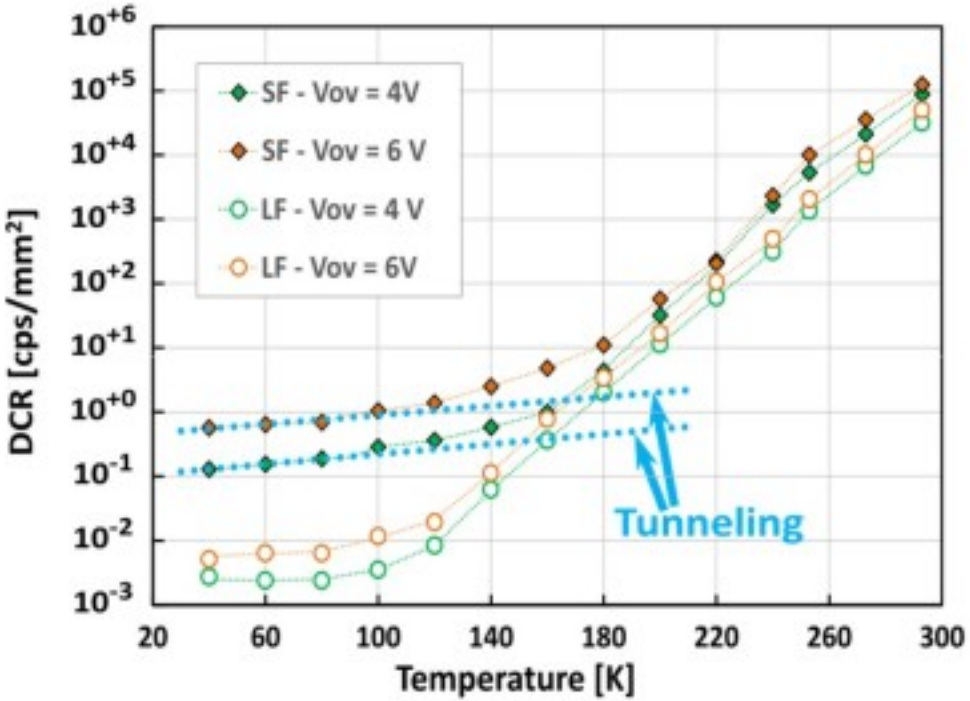
ON
(SenSL)

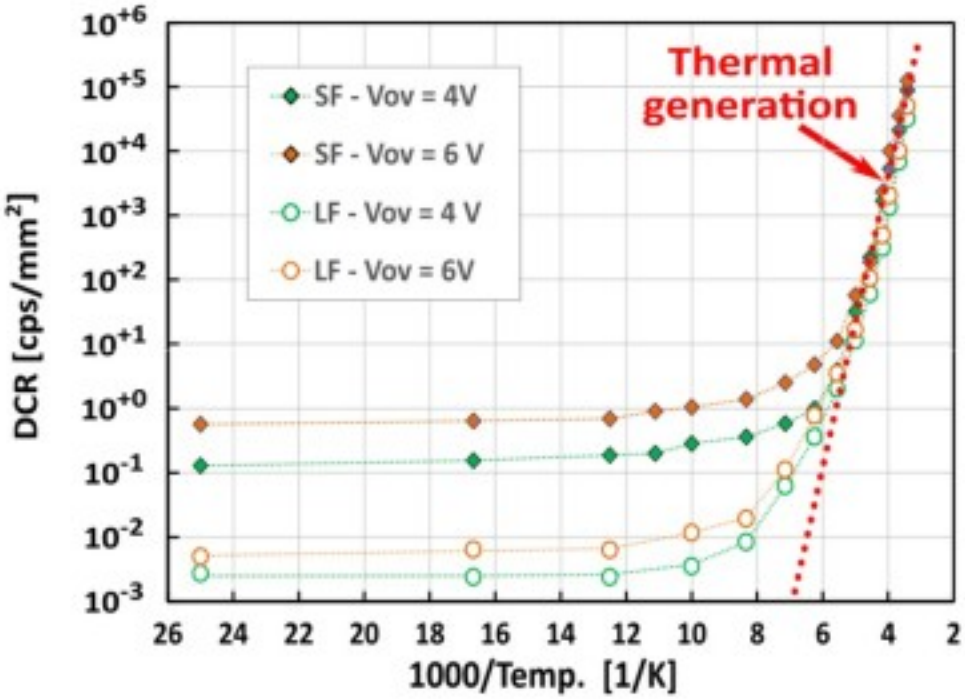
# SiPM (FBK)


Photon Detection Efficiency
60%
50%
40%
30%
20%
10%
0%
350
400
450
500
550
600
650
700
750
800
850
Wavelength [nm]
RGB-HD
30µm pitch
NUV-HD
30µm pitch
10V
6V
7V
3V


RGB (n-on-p)
n+-implant
p-implant
p--epi-layer
p++-Substrate
NUV (p-on-n)
p+-implant
n-implant
n--epi-layer
n++-Substrate

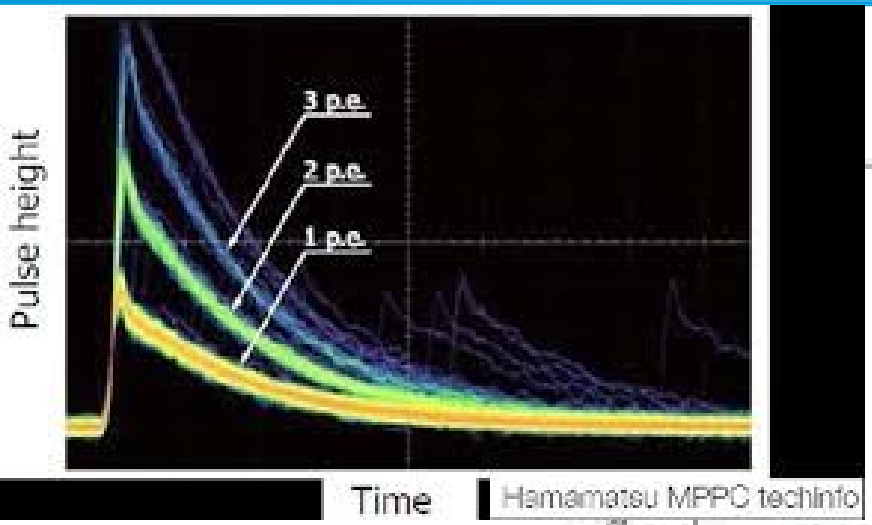
# Performances - DCR

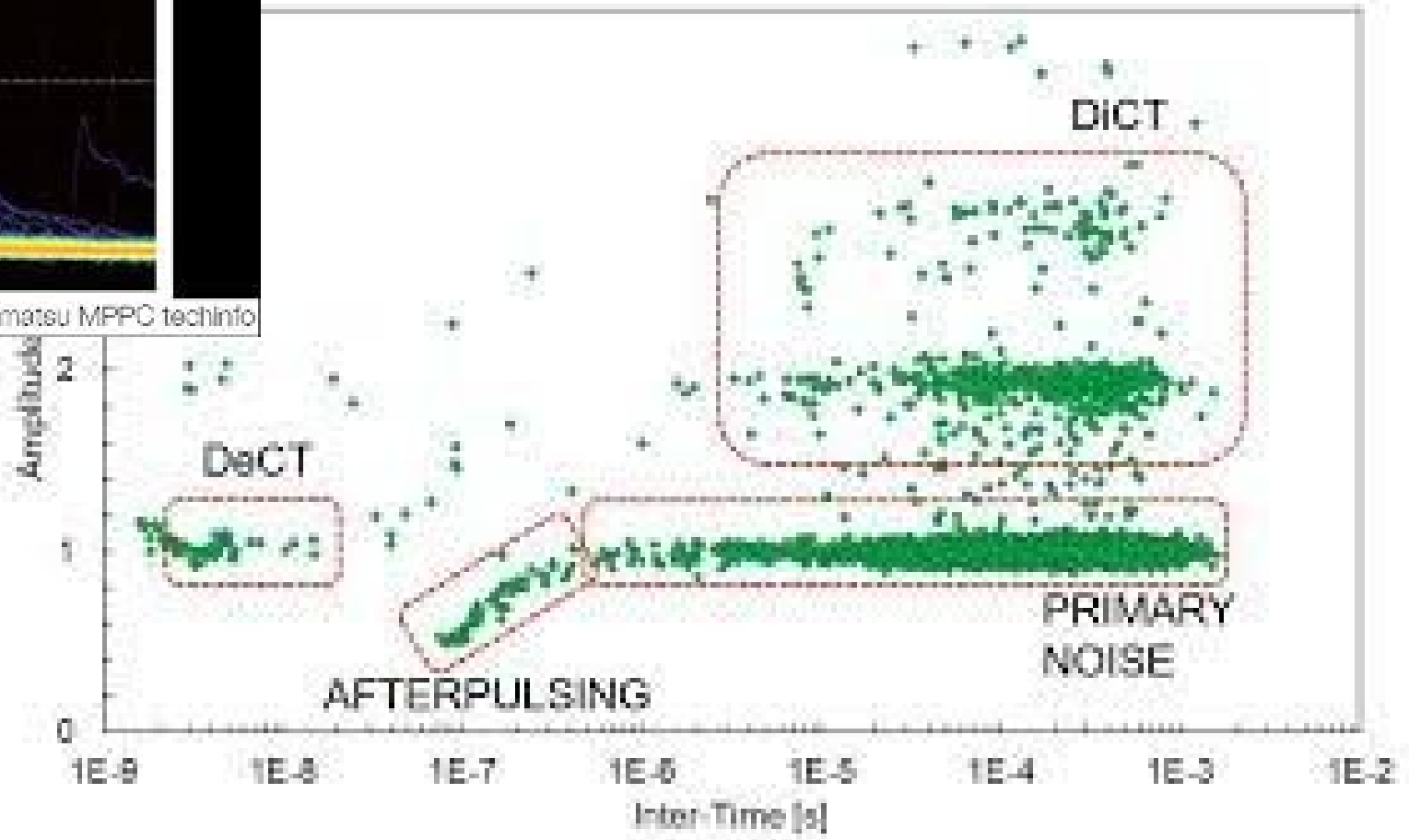



10-50 cps/mm² for PMTs

# Performances – Correlated Noise



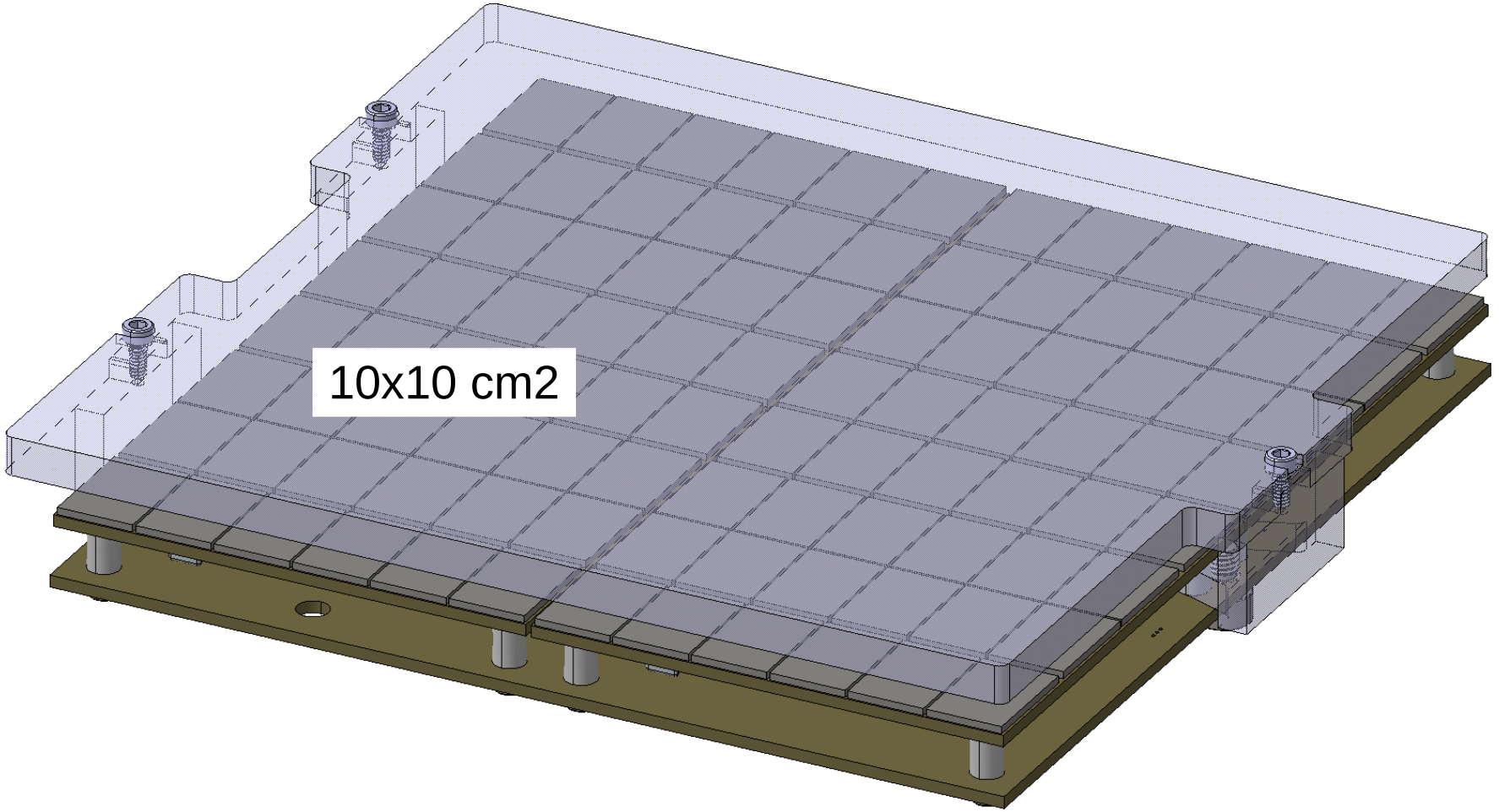



# what is available

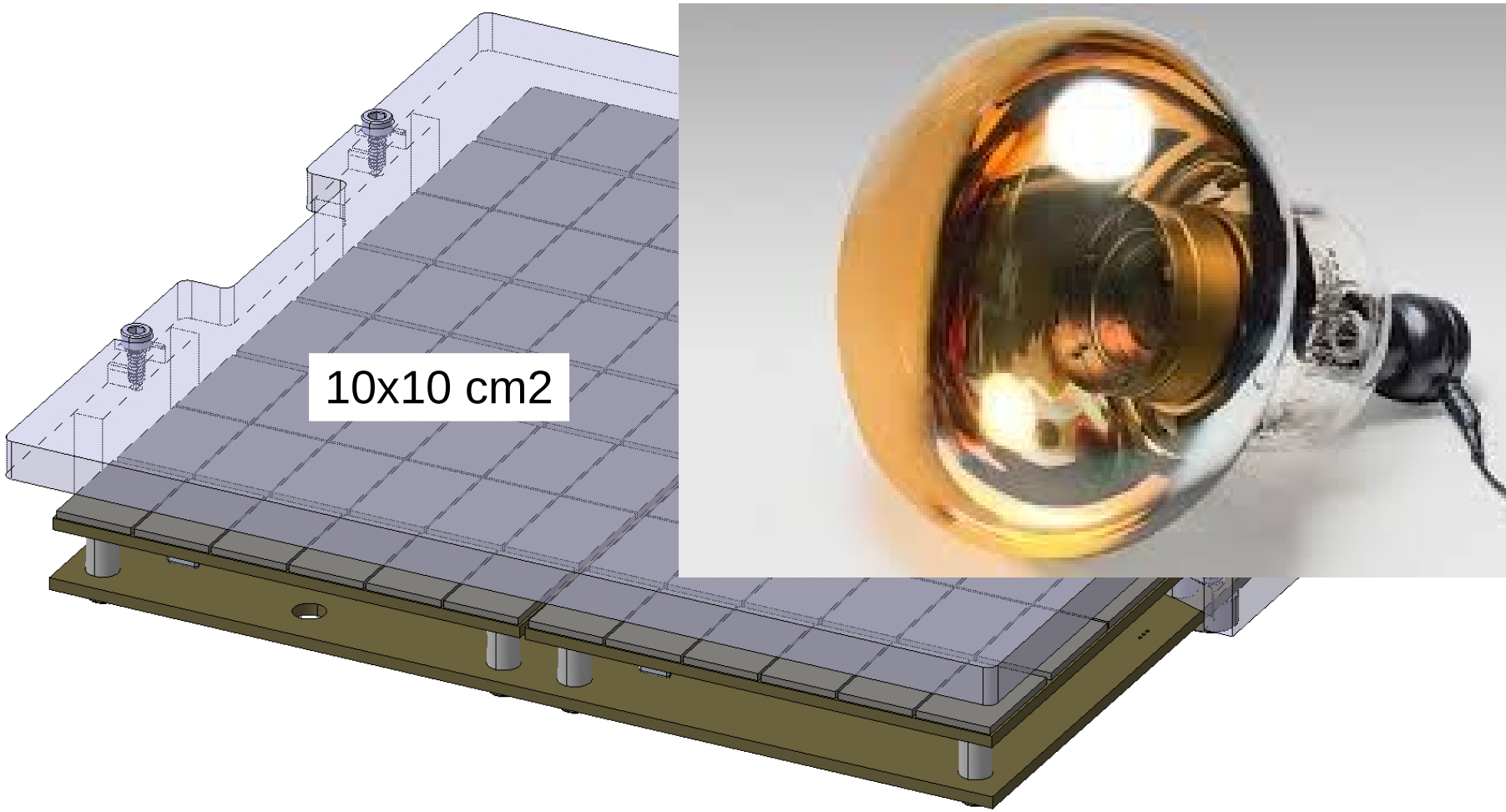
@ LNGS
Intense program to design large SiPM-based photo-detectors
- Prototype later internalized by DS

To the date is the largest photo-detector
- using radiopure components
- working in LN2/LAr

# What is available

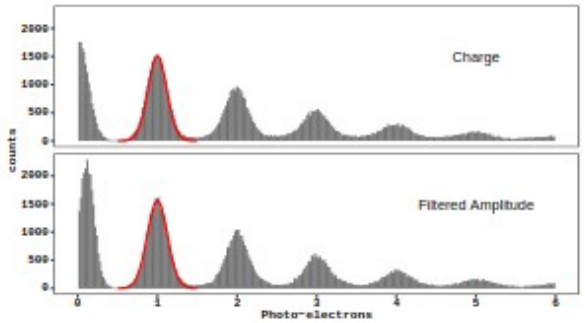


# What is available

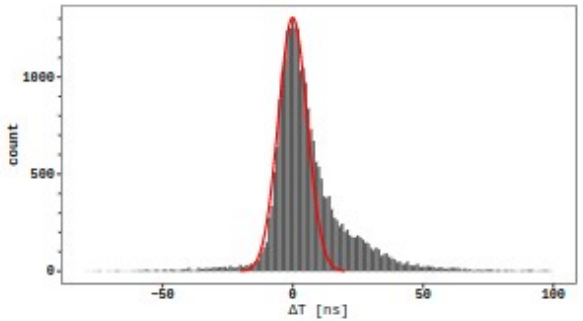


# Performances at 77 K

- PDE > 35%
- DCR ~ 100 cps
- iCT 20 – 50 %
- AP < 10%
- Power: 65 mA x 5.5 V
- Dynamic range: ~ 500 pe



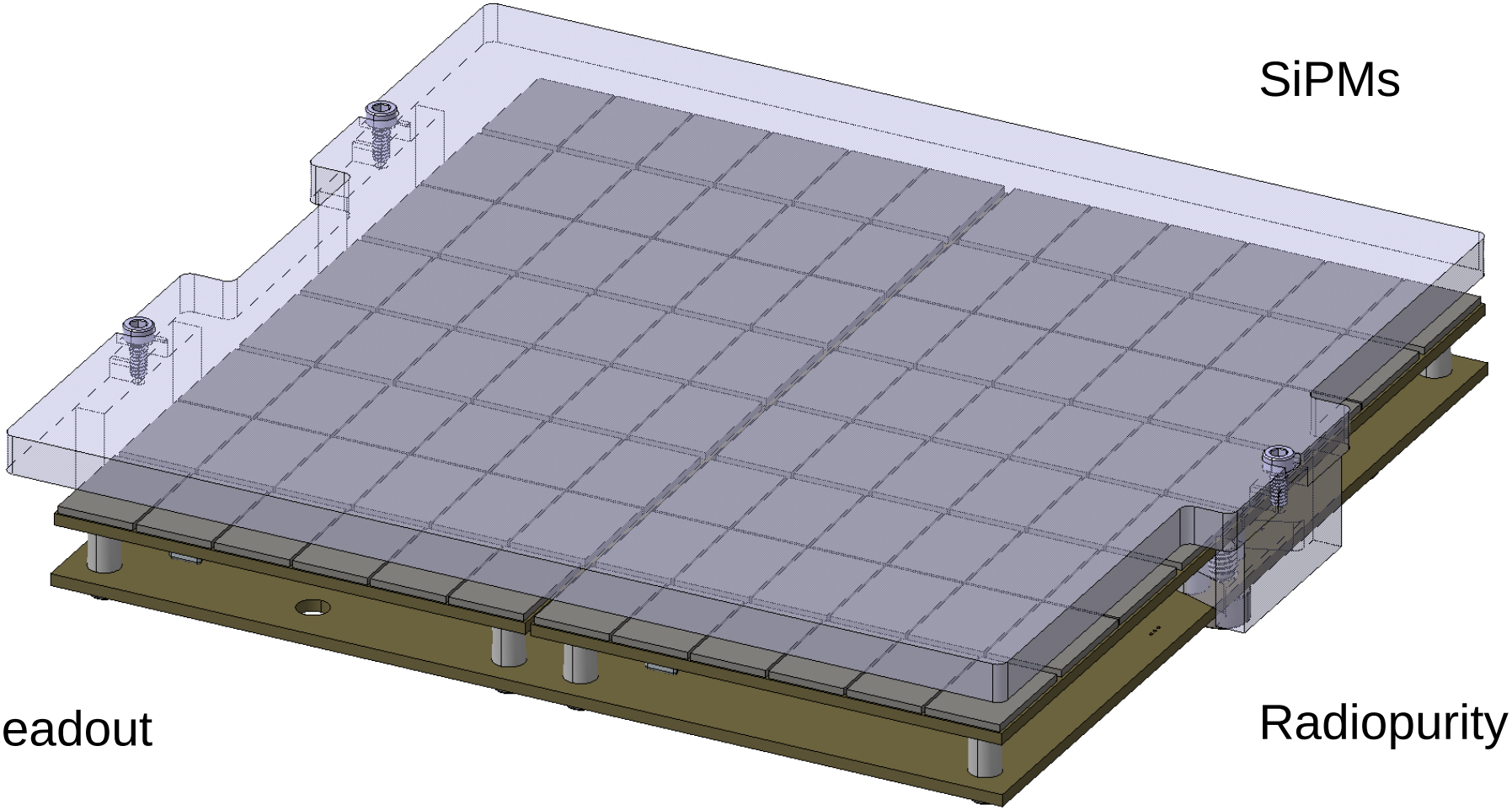

(a) Pulse Spectrum




(b) Timing

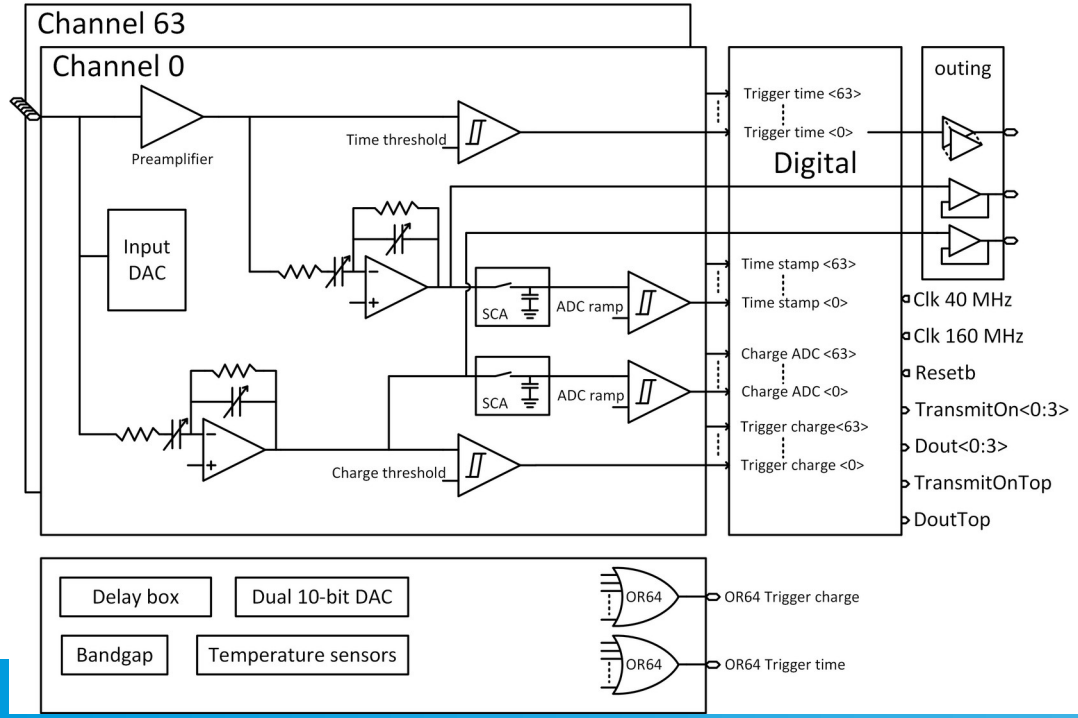
**Figure 8**: Performances of the MB¼ at 7 OV in liquid nitrogen. The finger plots for both charge and filtered amplitude (see text for details of filtering) exhibit similar SNR, 16 ± 1 versus 13.0 ± 0.5. The resolution of the first photo-electron is (12.5 ± 0.5) % for both algorithms. On the other hand, with the filtered signal it is possible to measure the time of the photo-electrons (relative to the laser pulse) achieving a jitter of 5.5 ns. The asymmetric shape of the time jitter is due to the presence of after-pulses in the signal.

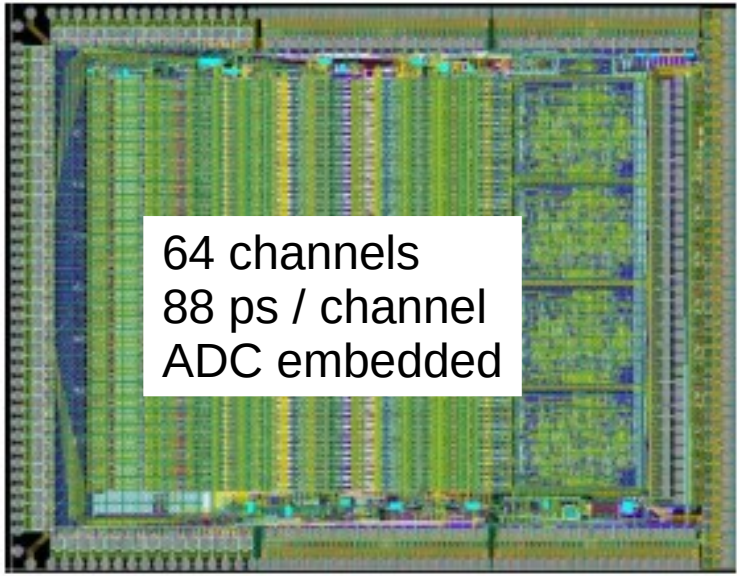
# Possible improvements



# Read-out

- Current design based on a discrete very low noise TIA
- It is possible to use integrated solutions that provide many pixels
- The read-out depend on the application requirements



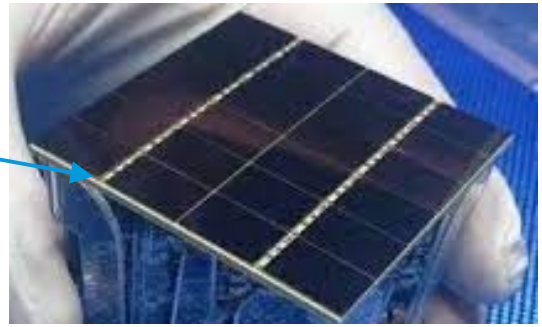



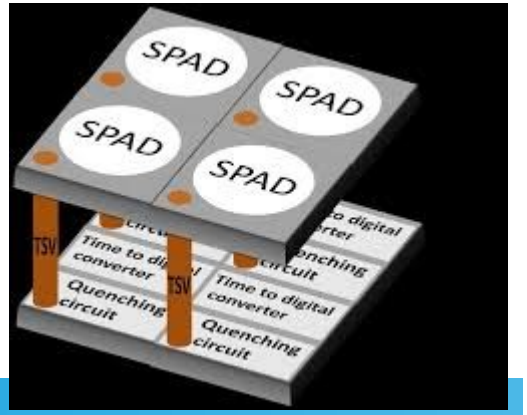
# Radiopurity

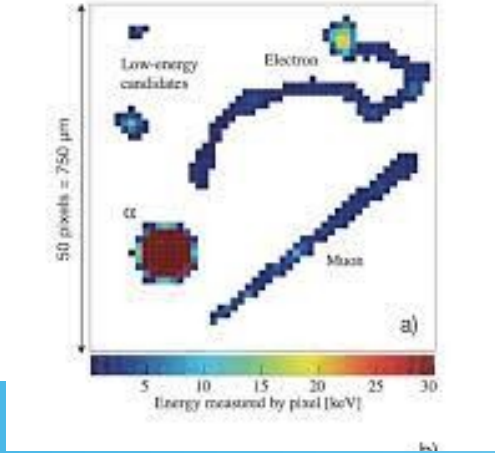
- The current bill of materials include:
  - About 200 SMD resistors
  - 7 chips
  - 60 plastic capacitors
  - 5 PCBs in Arlon – 40 g overall
  - Custom connectors
- It is possible to improve the radiopurity?
  - Develop better PCBs
    - With embedded resistors
      - Silicon-based PCBs?
  - Components with no solder

# SiPMs

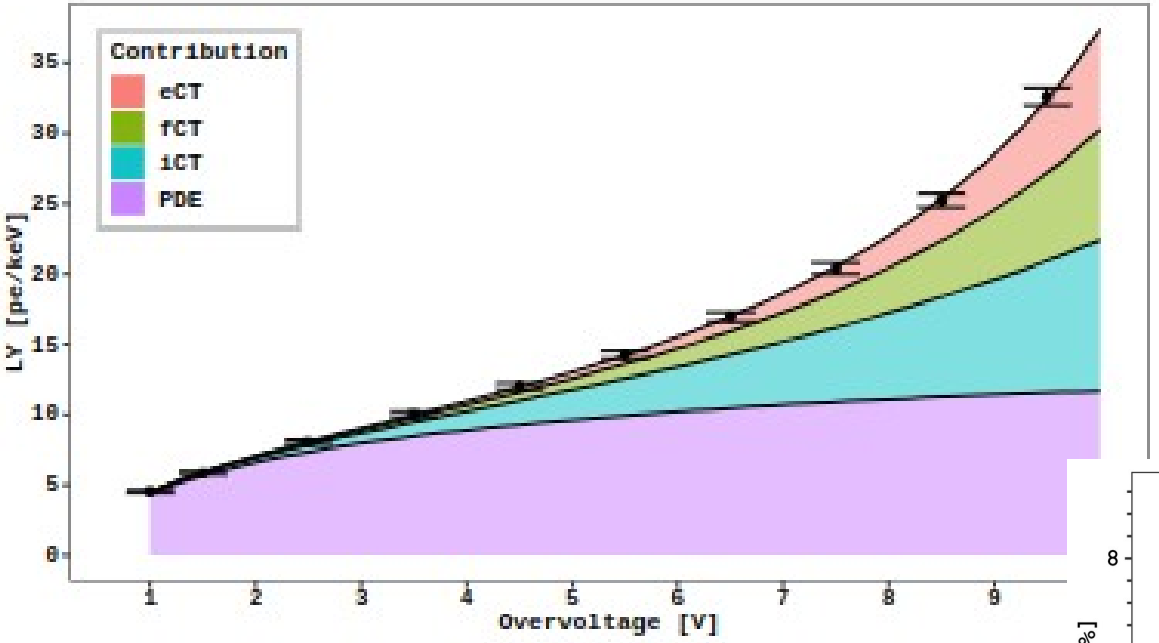
- Several improvement options
  - Increase PDE at 170 nm with back-side illumination
  - Increase fill factor with TSV (recover 5-10%)
  - Reduce cross-talk
- On a longer scale
  - 3D digital SiPMs: **SiPM-camera**
    - Timing included

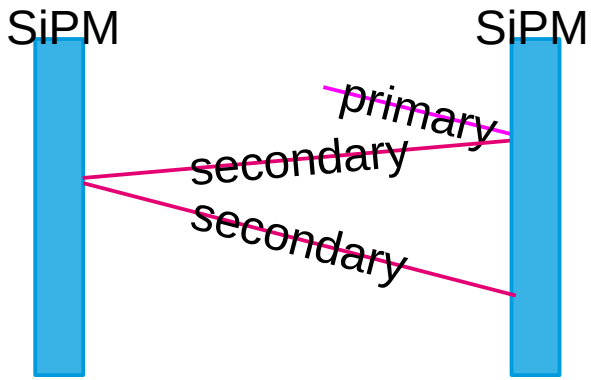


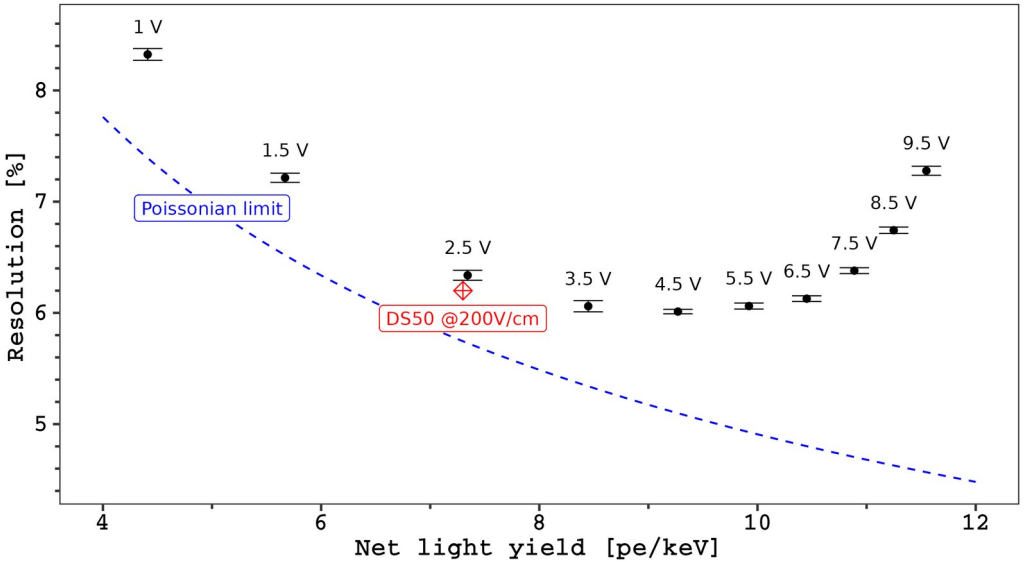


# Optical Cross-talk



# APOGEIA
# WP 5.1

# Goals

- Produce photo-detectors for low background experiments
  - Create a web of knowledge starting from the experience accumulated in LNGS
  - Deploy shared laboratories and infrastructures
  - Start industrial partnerships
- Design and test innovative SiPM-based photo-detectors
- Develop radio-pure components (PCB, connectors, …)
- Improve the performances of SiPM in collaboration with FBK

# WP 5.1 People

**Table 3.1f: Summary of staff effort**

| | WP5 | WPn+1 | WPn+2 | Total Person-Months per Participant |
|---|---|---|---|---|
| **Participant Number/Short Name** | LNGS | | | 36(new)+12(staff) MU |
| **Participant Number/ Short Name** | LSC | | | 24(staff) MU |
| **Total Person Months** | 72 | | | |

# WP 5.1 Milestones

**Table 3.1c: List of Deliverables**

| Deliverable (number) | Deliverable name | Work package number | Short name of lead participant | Type | Dissemination level | Delivery date (months) |
|---|---|---|---|---|---|---|
| 2 | Recirculation system | 5.1 | LNGS | R/DEM | PU | 18 |
| 3 | High pressure system | 5.1 | LSC | R/DEM | PU | 24 |

**Table 3.1d: List of milestones**

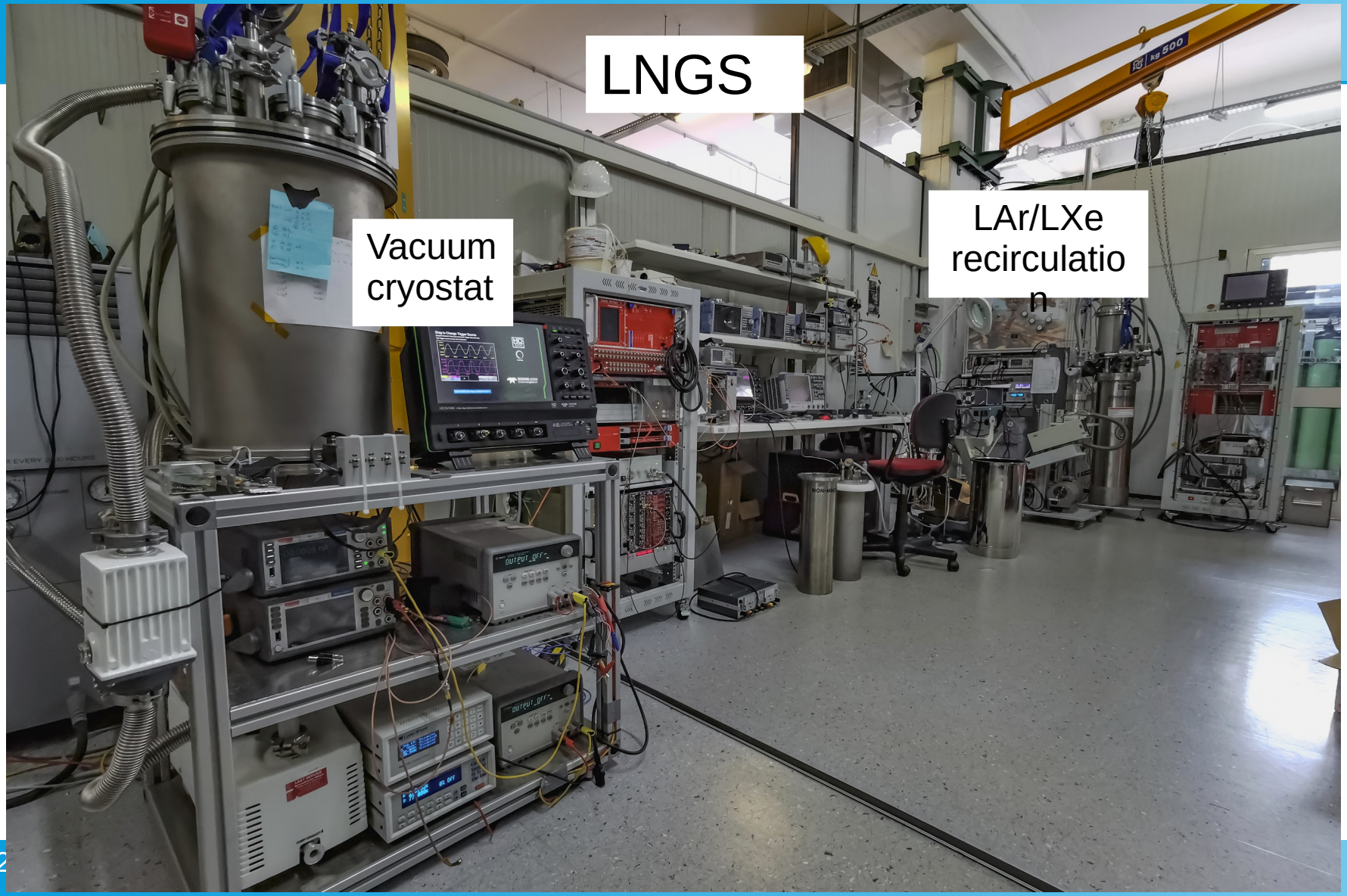
| Milestone number | Milestone name | Related work package(s) | Due date (in month) | Means of verification |
|---|---|---|---|---|
| 1 | Integration with NOA @LNGS | 5.1 | 12 | small prototypes |
| 2 | Finalisation of the laboratories | 5.1 | 24 | up and running |
| 3 | Prototype photo-detector | 5.1 | 36 | publication |

# WP 5.1 Budget

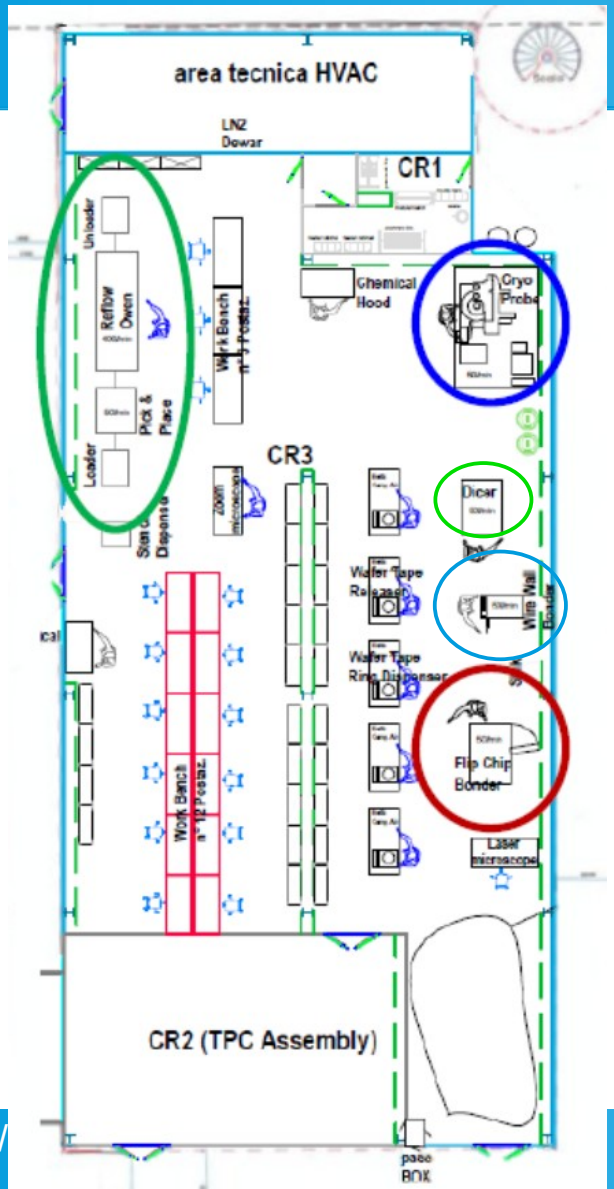
**Table 3.1h: 'Purchase costs' items (travel and subsistence, equipment and other goods, works and services)**

| Participant Number/Short Name | | |
|---|---|---|
| | **Cost (€)** | **Justification** |
| **Personel** | 150k | 1FTE/year x 3 years |
| **Equipment** | 80k | Instrumentation and equipment to upgrade setups in LSC & LNGS |
| **Travel** | 10k | |
| **Remaining purchase costs** | 30k | Consumables (PCB, components) |
| **Total** | 270k | |


LNGS


LNGS
Vacuum cryostat
LAr/LXe recirculation

# NOA




- Large clean room equipped with
  - Cryo silicon-prober
  - Silicon dicer
  - Flip-Chip
  - Wire bonder
  - ~~PCB assembly line~~
- Temporary in use by DarkSide
- Interested collaborations should contact LNGS
  - Define schedule
  - Pileup

# Experimental groups

- ANAIS
  - Contacts are active: we are testing NaI crystals coupled with SiPMs
    - First prototypes available in few months
- NEXT
  - Contacts are started: operate SiPMs in LXe gas
    - Climatic chamber in APOGEIA
- DARWIN
  - Will need light detectors: several options possible