SiPM Workshop

from fundamental research
to industrial applications

Bari, Italy, 2-4 October 2019

Packaging strategies for large SiPM-based cryogenic photo-detectors

Izabela Kochanek, LNGS
iza.kochanek@lngs.infn.it

VINCENZO DE VIRGILIO
FOTOGRAFIA

LIGHT DETECTION IN DARK SIDE

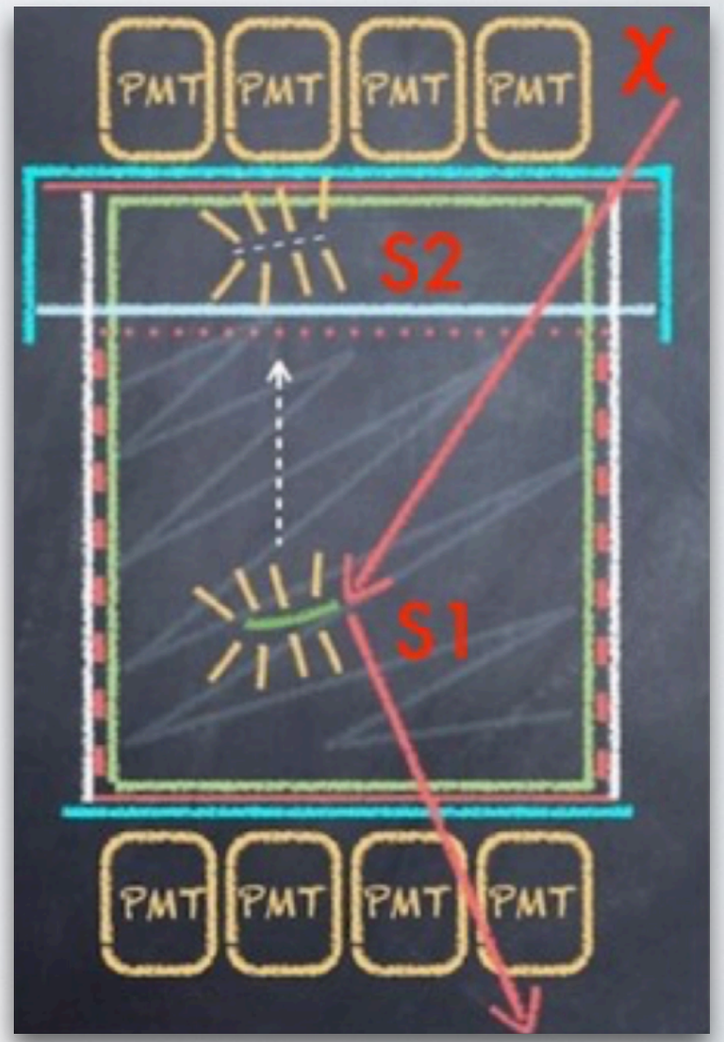
DarkSide is a stepped program for the realization of increasing size dark matter direct detection on a liquid argon target.
The current detector, DarkSide-50, is located at LNGS and using 50 kg of UAr inside a dual-phase Time Projection Chamber (TPC)

- Interaction in the active volume produces **scintillation light (S1)** and ionization electrons. S1 is detected by photosensors (like PMTs) on top and bottom of the TPC.

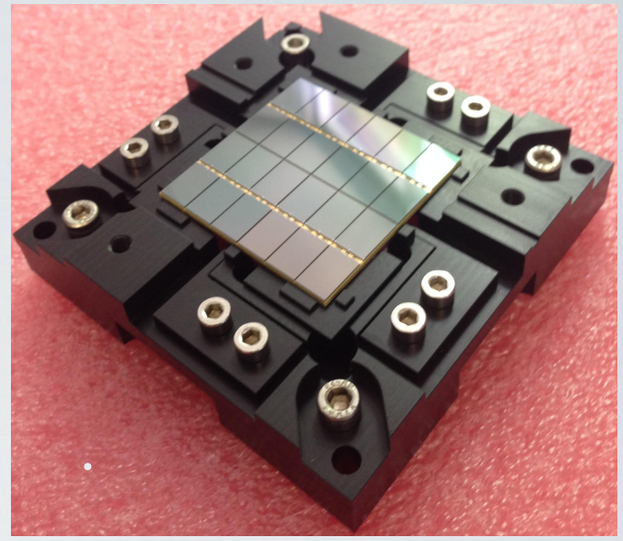
- Electrons are drifted by means of an electric field to the liquid-gas interface and extracted in the gas phase and accelerated toward the anode. The interaction between e- and the gas produces **electroluminescence light (S2)**, detected by the photosensors.

- The presence of S1 and S2 allows to reconstruct the position of the original interaction allowing fiducialization

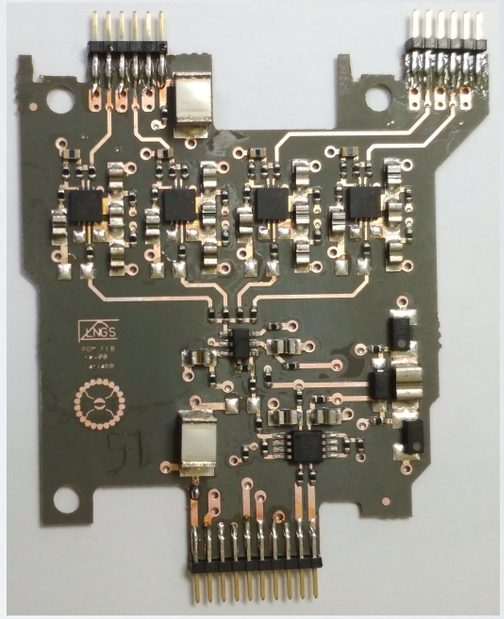
- The shape of S1 allows the discrimination of nuclear recoils from electromagnetic interaction (PSD) with a rejection better than 10^8
- Other discriminations are possible to further reduce the Background (S2/S1, multi-site interactions, …)



PDM photodetector module

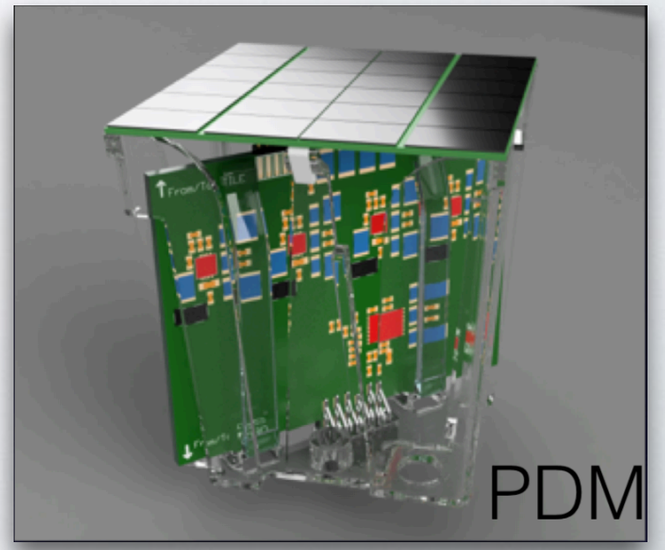


- SiPMs are small size devices (tens to hundreds of mm^2)
- A solution is to group SiPMs in arrays of size comparable to that of PMTs and read out this array (tile) as a single channel with appropriate electronics
- Tile + electronics form a PhotoDetector Module (PDM)
- About 10000 PDMs are foreseen
  - The production procedures (electronics & packaging) will require high reliability

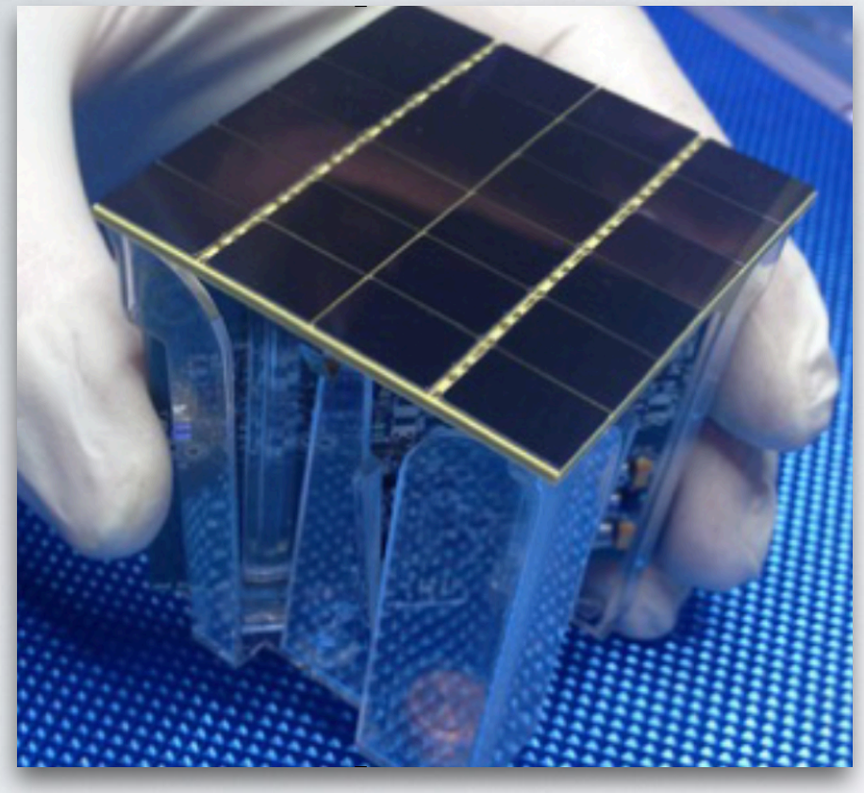


Requirements:

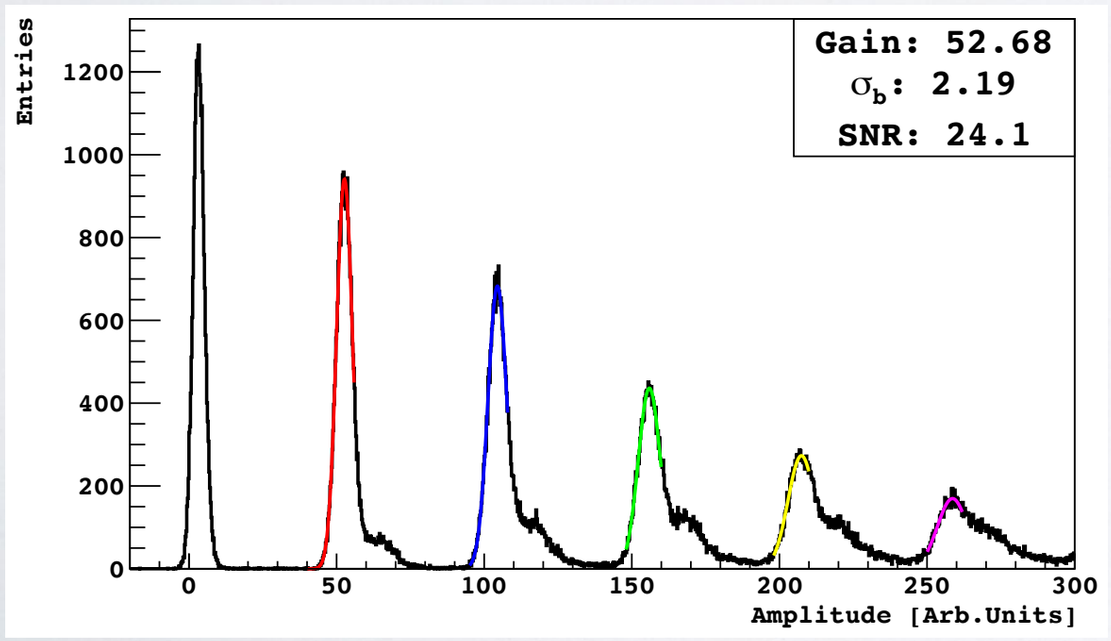
- 25 cm^2 surface (8280 channels in total)
- overall PDE > 40% at 420 nm
- dynamic range > 50 pe
- time resolution of O(10 ns)
- overall noise rate below 0.1 Hz/mm^2

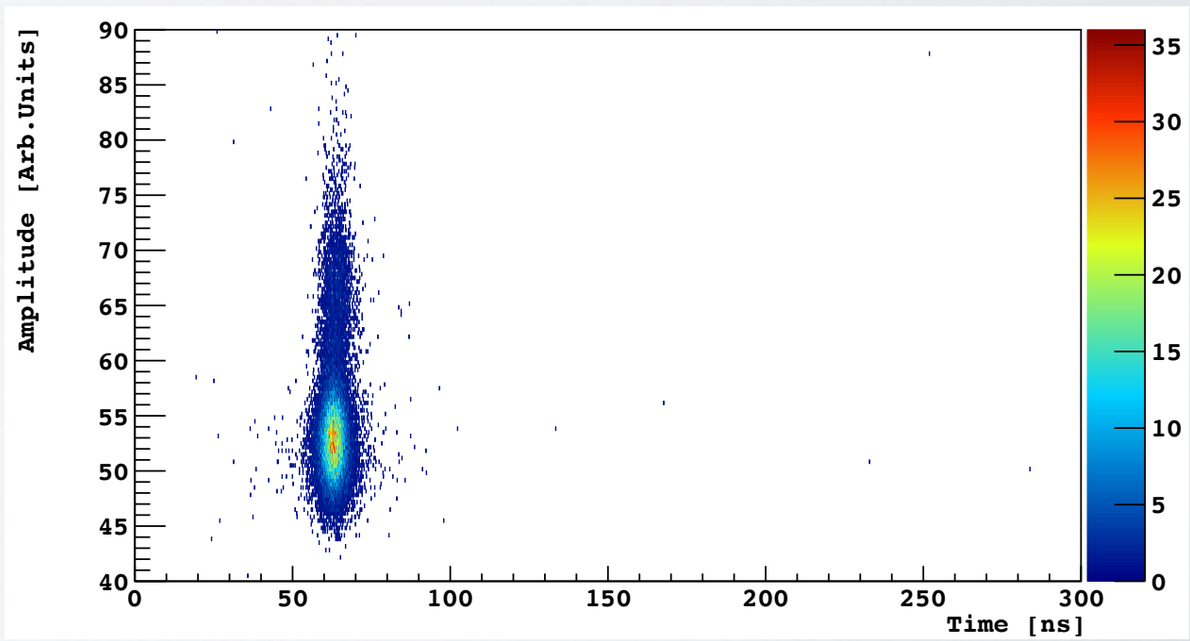


PDM PERFORMANCES

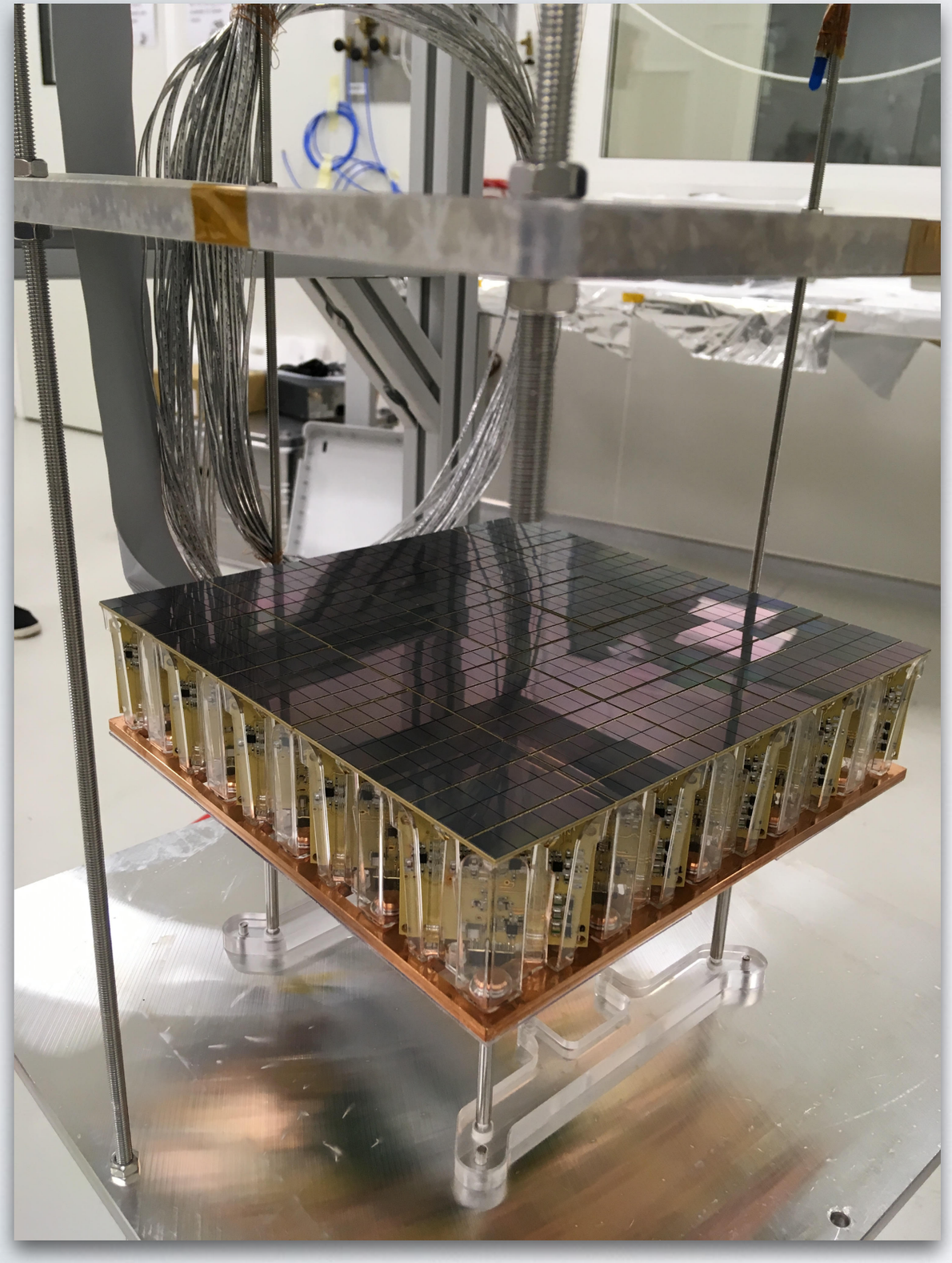


- The PDM integrates the SiPM tile and the readout electronics inside an acrylic cage
- 24 cm^2 total active surface
  - 24 x 8x12 mm^2 SiPMs
- SiPMs are from FBK developed for low after and low dark rate operation in liquid argon.





MOTHERBOARD

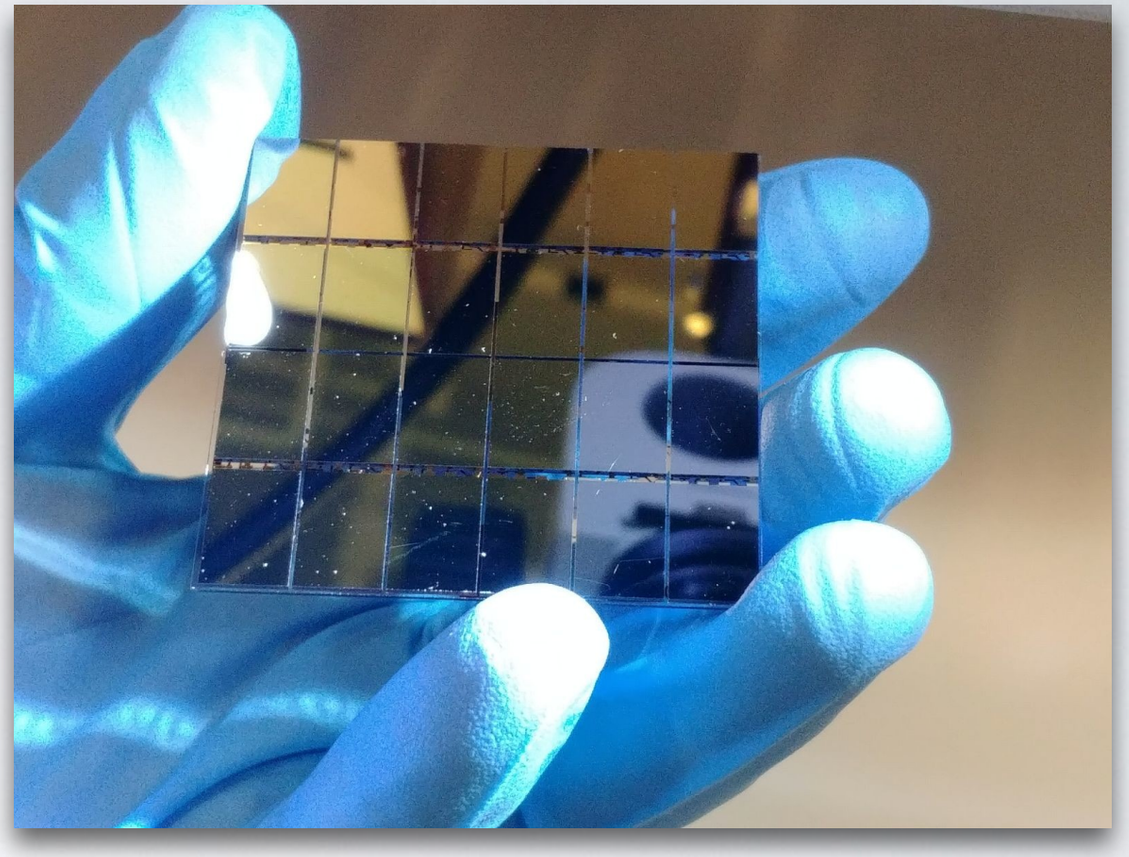


- Mechanical structure required to assemble all components and to efficiently dissipate heat in LAr target, minimizing the production of bubbles
- power dissipation density limited to 100 μW/mm^2, corresponding to a total dissipated power of 250 mW per PDM
- signal extraction via analog optical transmission
- each PDM can be turned on and off individually
- goal radio purity ~ 10 mBq/MB
  - 3'' PMT can be ~ few mBq

PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

Problems:

1. CTE of substrate
2. Radio-Purity
3. Bonding reliability
4. Anode contact



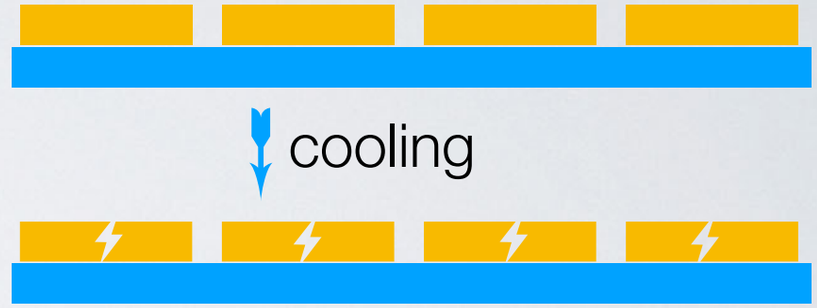
Requirements:

- Low CTE substrate
  - with good rigidity
- High Radio-Purity
  - ~ few mBq/m^2 for U/Th chains and for ^{40}K
- >> 99% die bonding reliability in LAr
  - 0.99^{24} = 79% yield for PDM
- TSV to avoid wire bonding

PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

CTE of substrate | Radio-Purity | Bonding strategies | Anode contact

Material	CTE [ppm/K]	U/Th [mBq/kg]	^{40}K [mBq/kg]
Silicon	**3-5**	very low	very low
FR4	12-14	very high	very high
PTFE/Teflon	120	0.1-10	<5
Polyimide/ Kapton	20	1-10	<10
Arlon NT	5-7	100	1000
Fused Silica	0.5	5-20	-
Selected FS	0.5	0.05	-



- Stress on SiPM due to difference of CTE
- R&D on substrate
  - Silicon PCBs are not trivial: Si is not an insulator
  - Multilayer Fused Silica PCBs require die bonding
  - Pyralux-Invar-Pyralux
- Arlon NT is readily available

PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

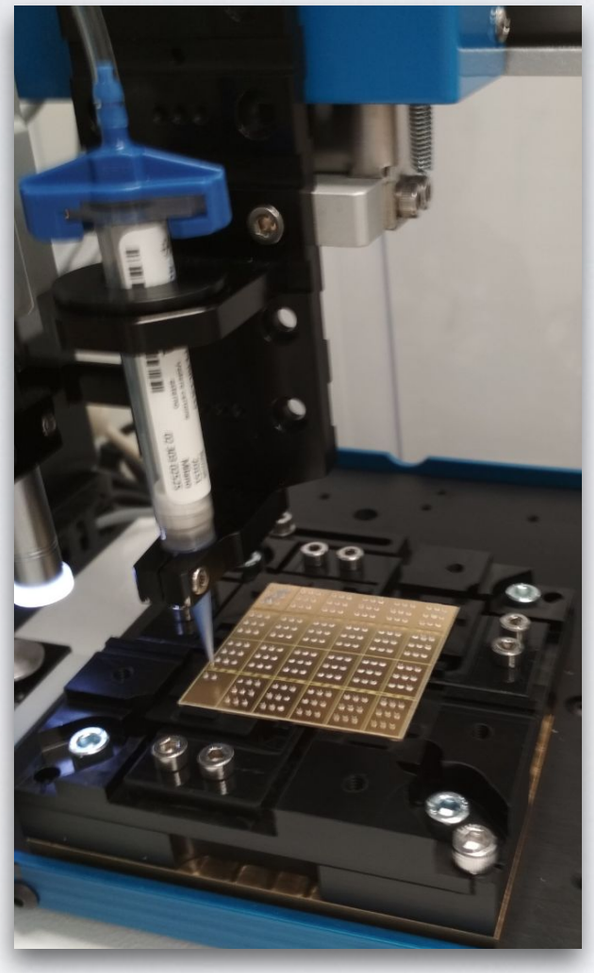
Material	CTE [ppm/K]	U/Th [mBq/kg]	^{40}K [mBq/kg]
Silicon	**3-5**	**very low**	**very low**
FR4	12-14	very high	very high
PTFE/Teflon	120	0.1-10	<5
Polyimide/ Kapton	20	1-10	<10
Arlon NT	5-7	100	1000
Fused Silica	0.5	5-20	-
Selected FS	0.5	0.05	-

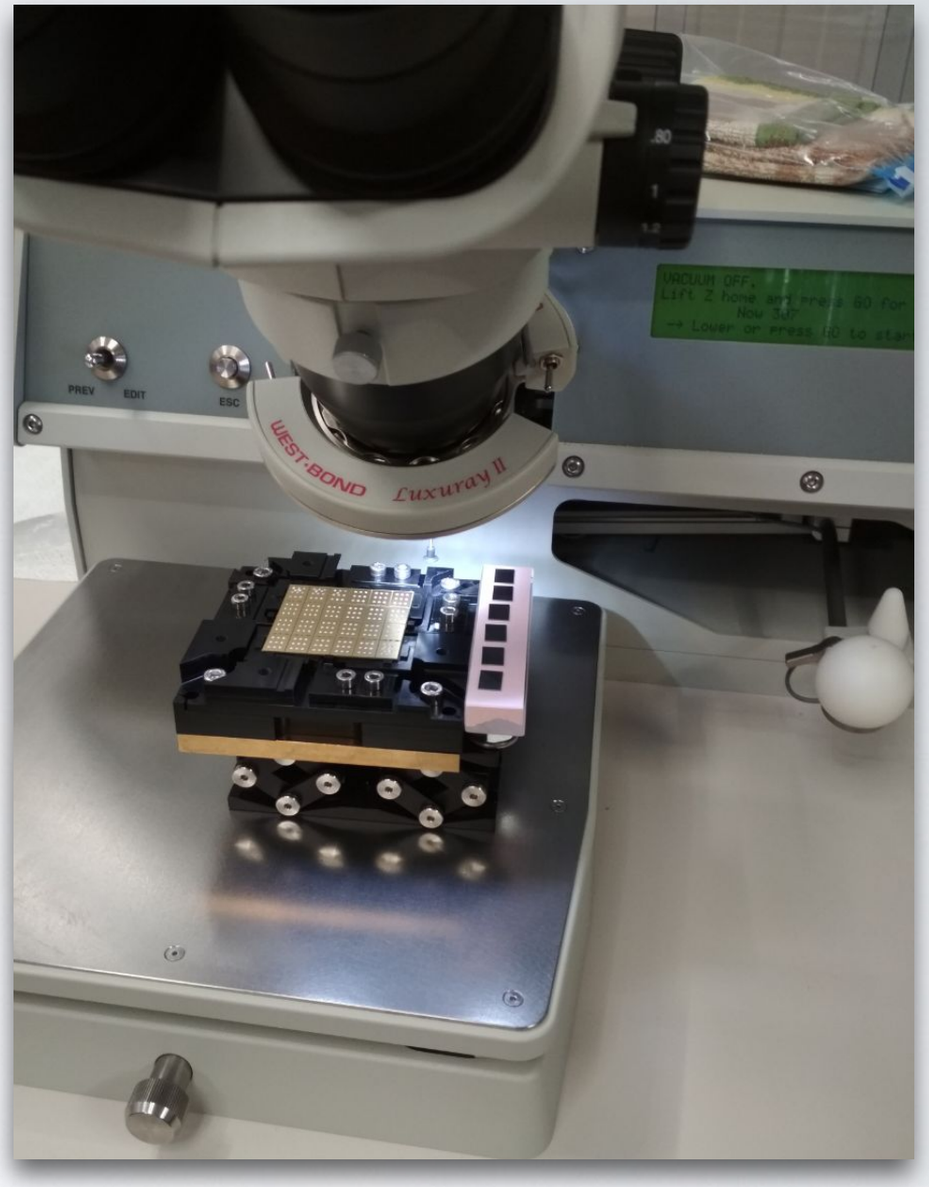
- Arlon is at the edge of DS-20k acceptance for radio-purity: R&D on other solutions is ongoing
- components ~60 μBq/kg
- main background from substrate (at this moment)

PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

- epoxy bonding

Current procedure uses robot dispenser plus a manual die bonder.





Temporary solution:

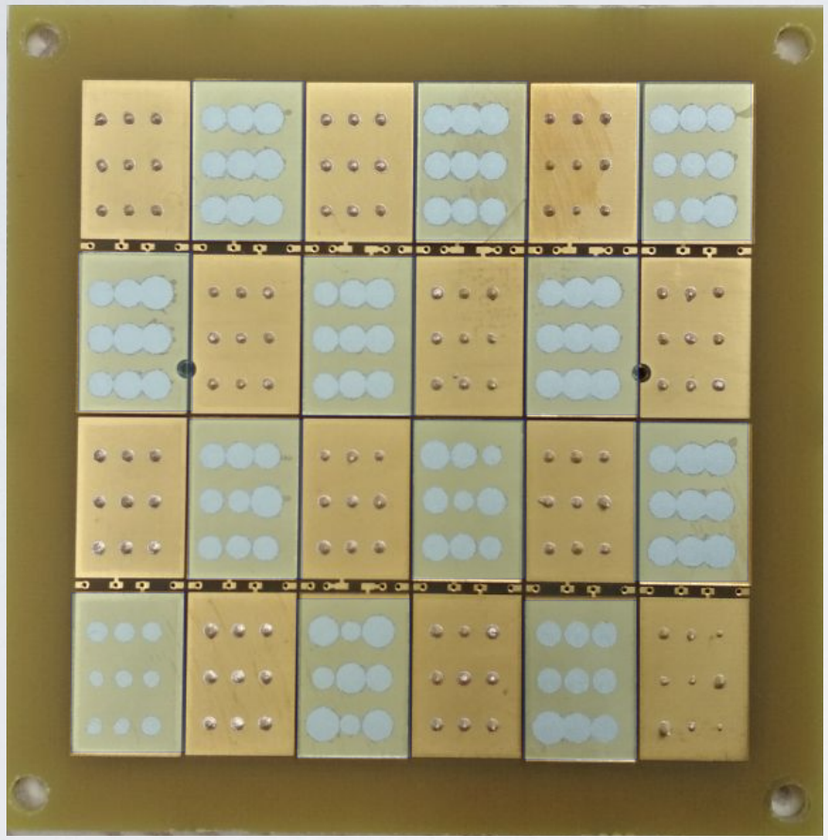
- cryo-graded conductive epoxy bonding
  - EPO-TEK EJ2189 cured at 100°C for 1h
  - the current TTiN SiPM backside does not allow other solutions.

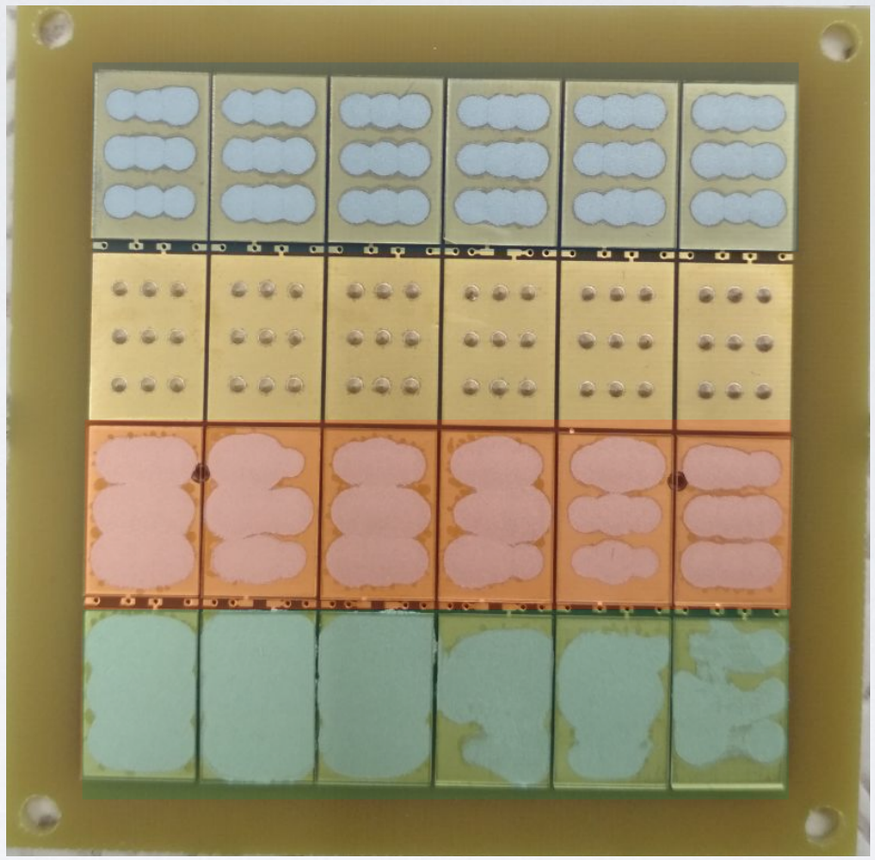
PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

CTE of substrate | Radio-Purity | **Bonding strategies** | Anode contact

- reliability

tests done with fused silica dies





- bonding force
- dot size
- number of dots

- too much epoxy can shortcut neighbor pads
- too less epoxy will not hold the SiPM

~1800 SiPMs successfully bonded

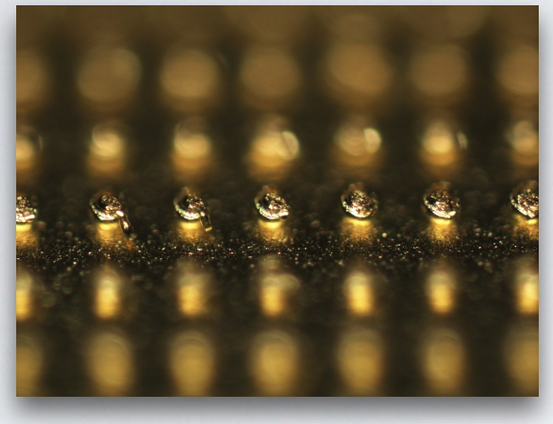
We performed many reliability tests in LN_2

- Current reliability > 99.9%

PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

CTE of substrate | Radio-Purity | **Bonding strategies** | Anode contact

thermo-compression

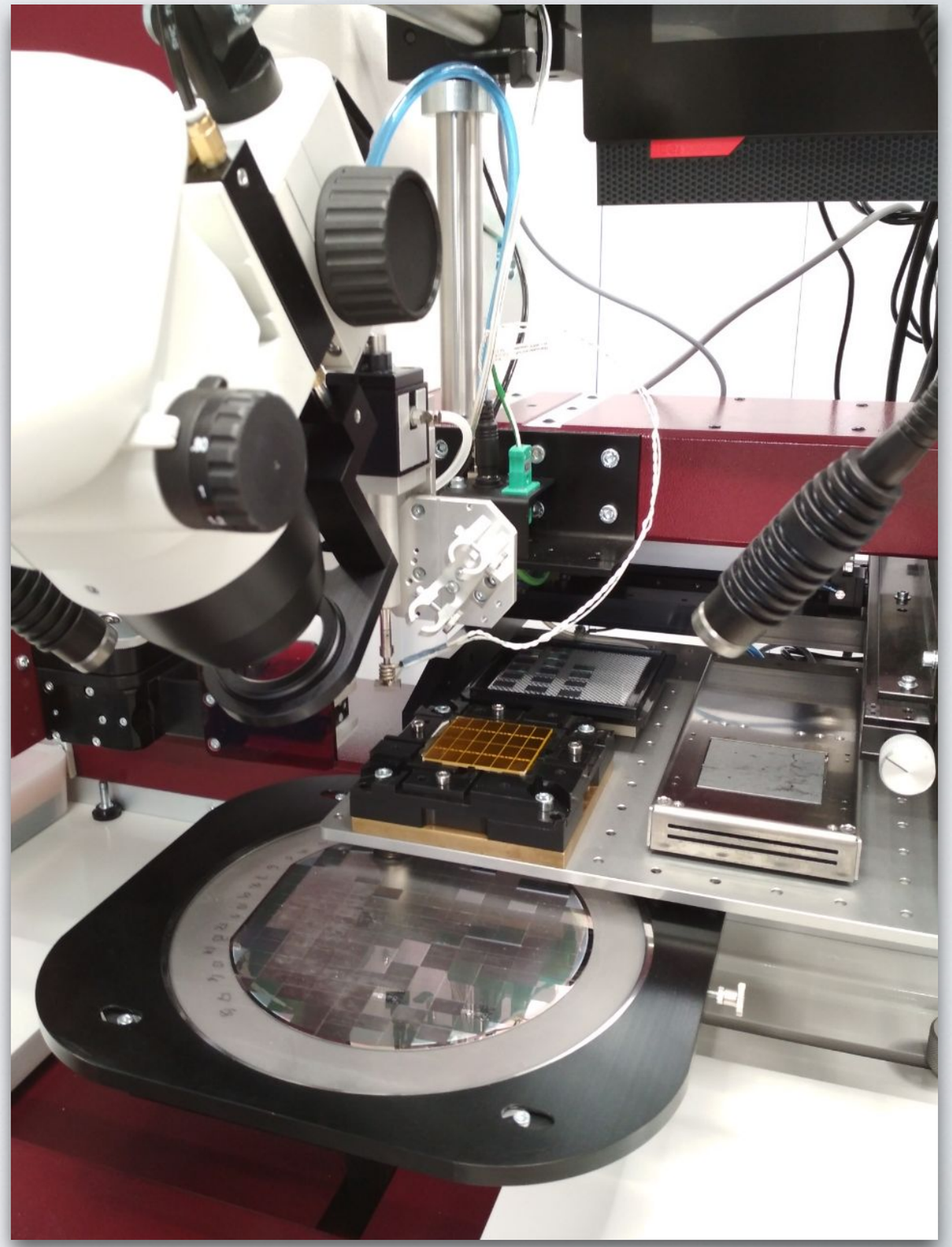


Silver loaded epoxy is not radio-pure
- and not reliable in the long term

We are moving to a new procedure:
- indium/solder bump bonding
- gold studs ball bonding

Both solutions were tested are provided very strong bonds

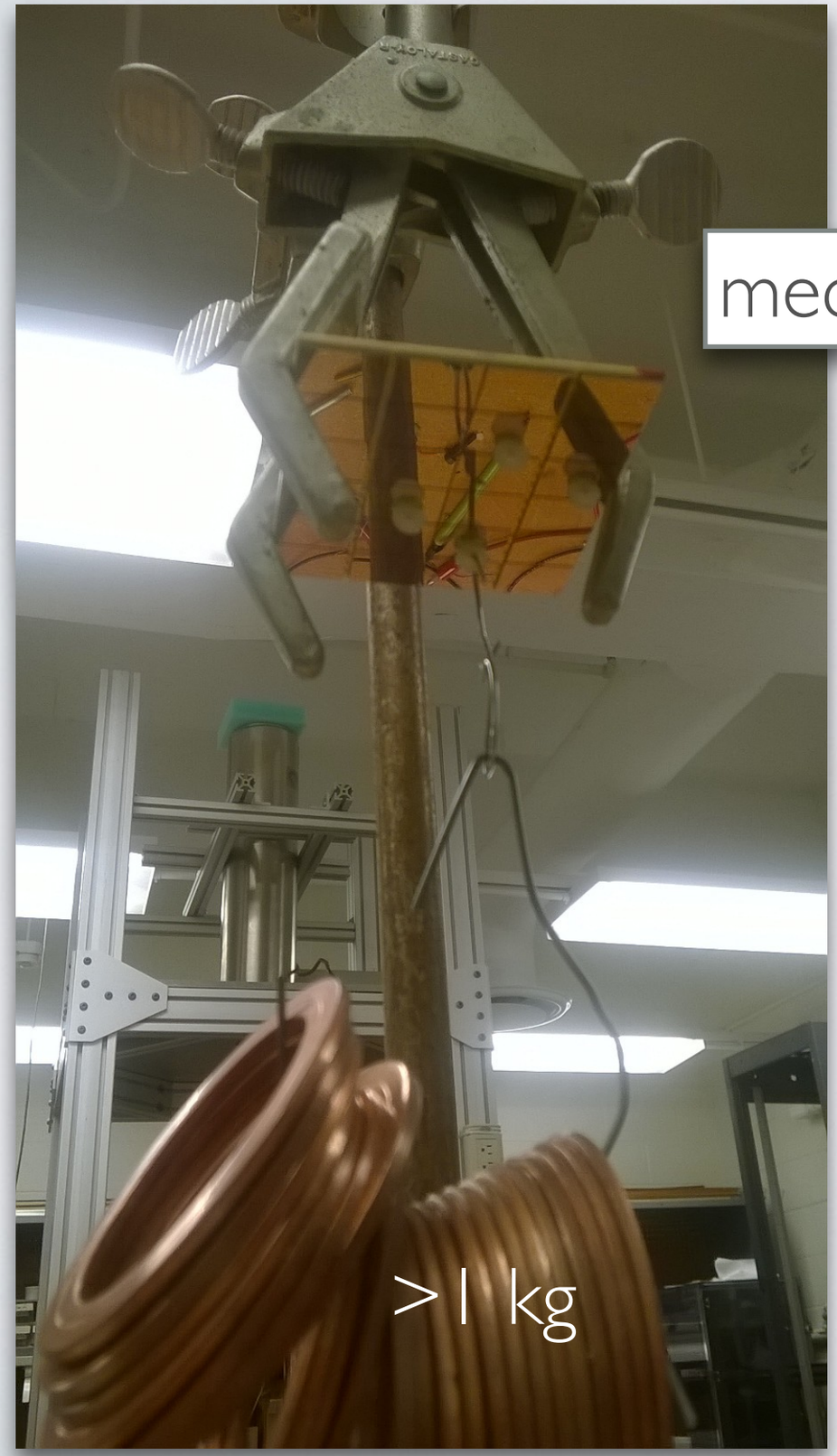
A procedure has already been defined. Final tests with first LFoundry wafers in November.



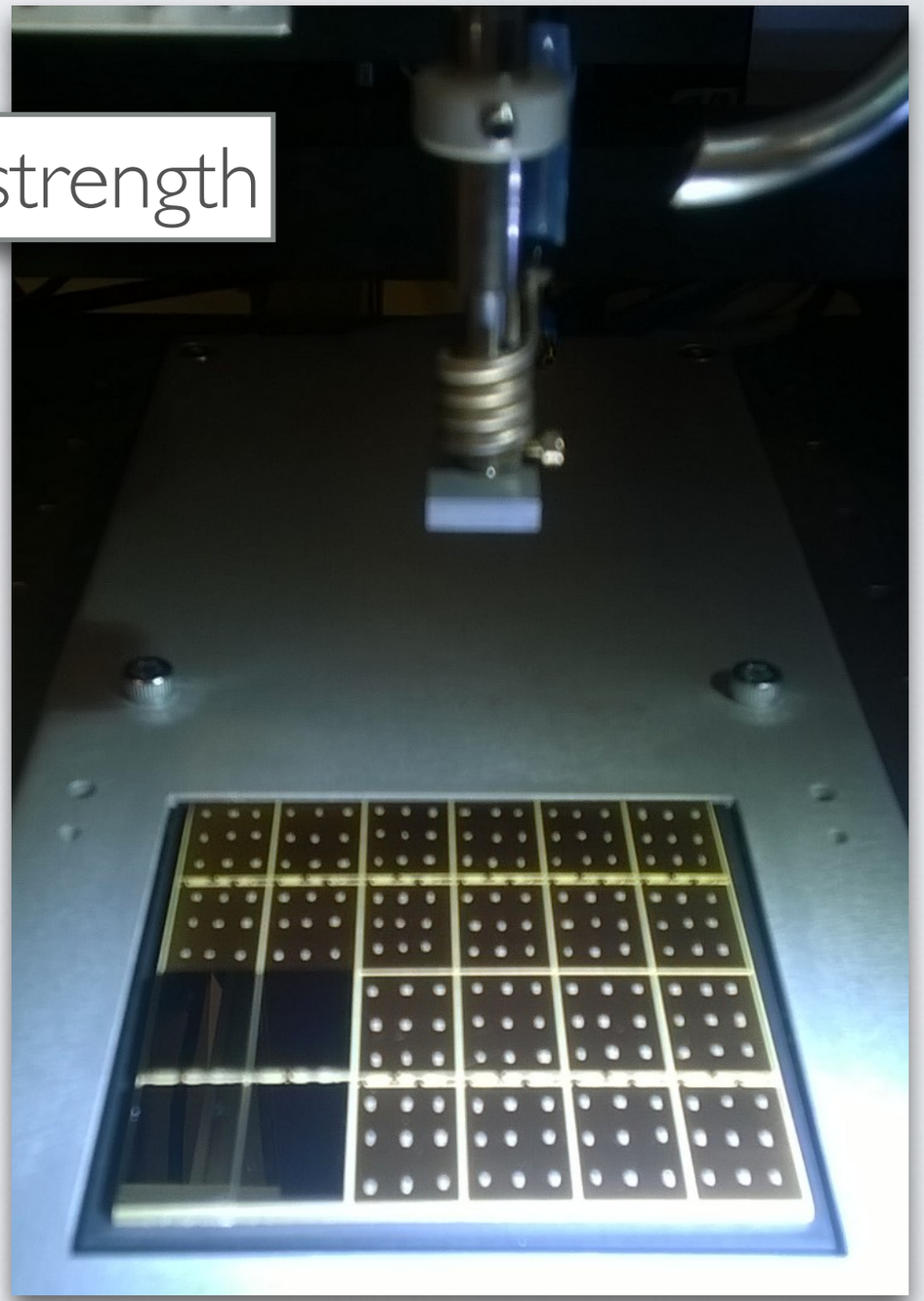
PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

CTE of substrate | Radio-Purity | **Bonding strategies** | Anode contact

- thermo-compression



mechanical strength



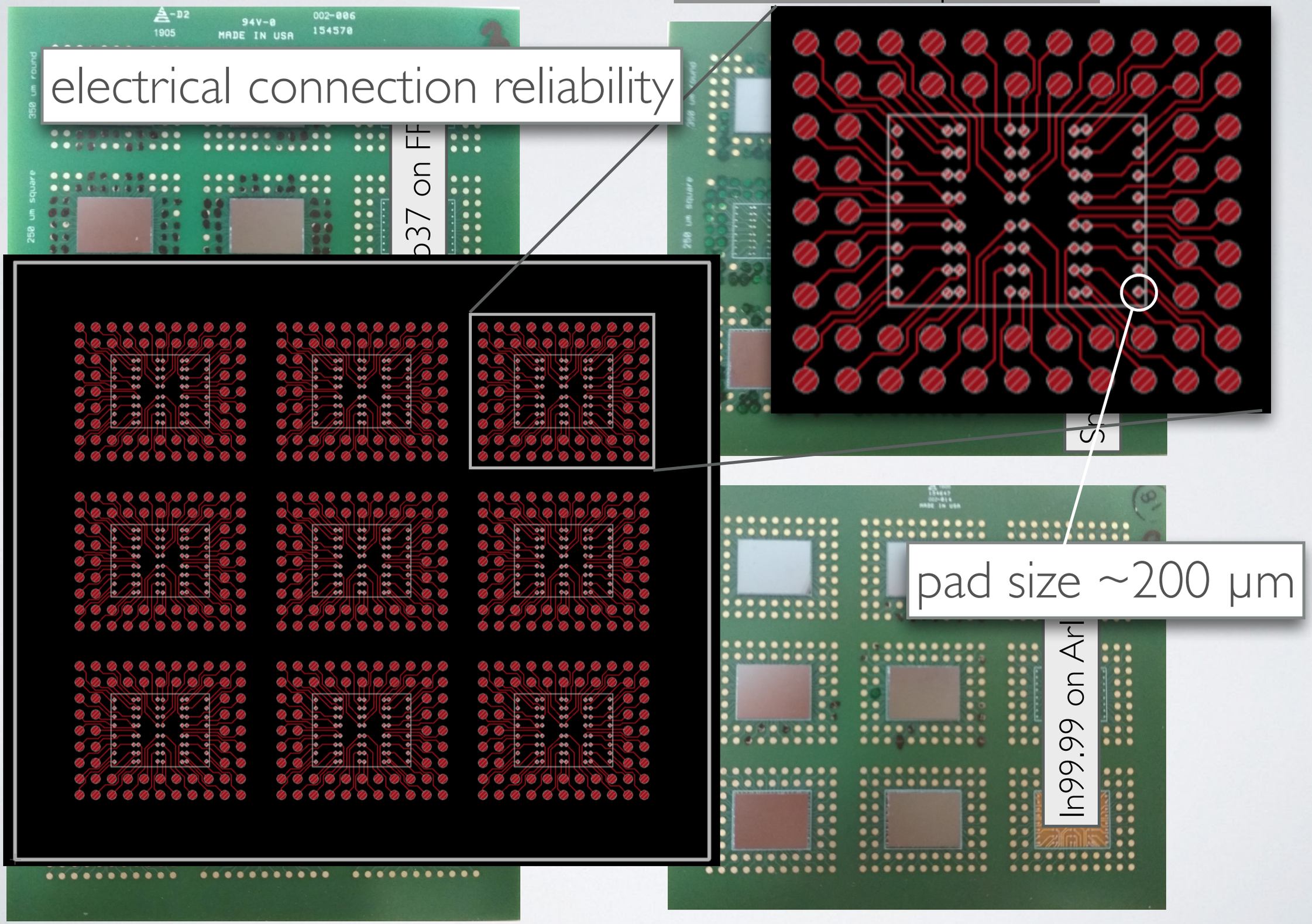
indium bonding

PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

CTE of substrate | Radio-Purity | Bonding strategies | Anode contact

- thermo-compression

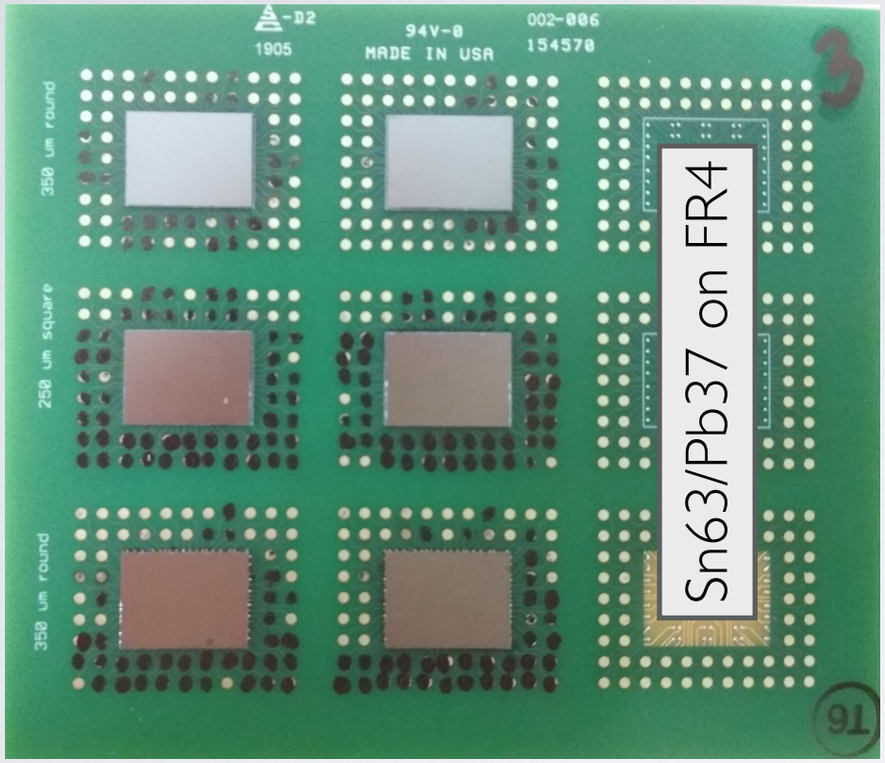
electrical connection reliability

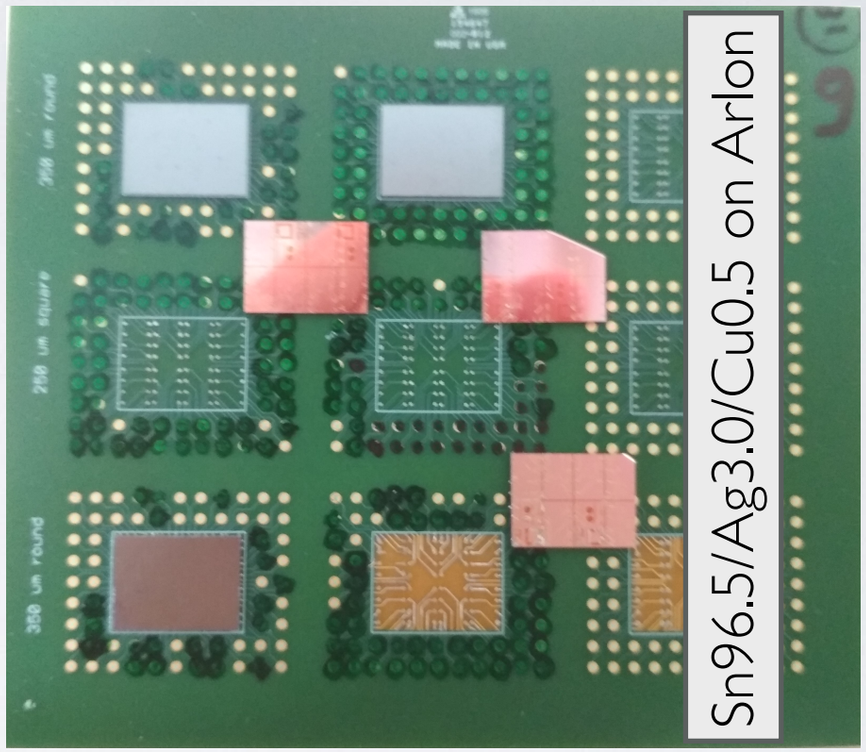


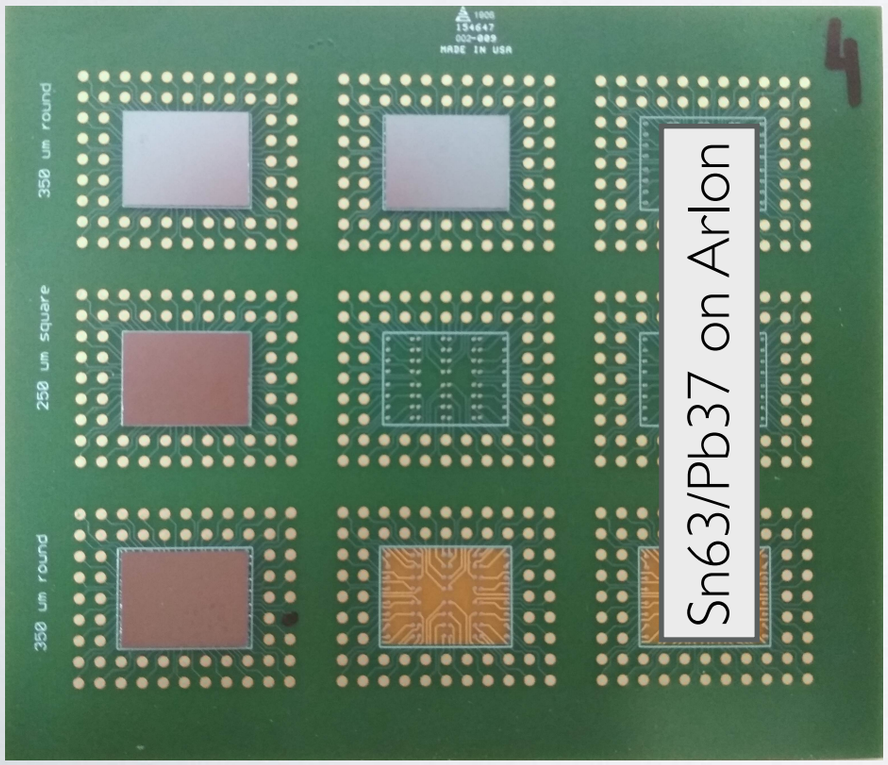
PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

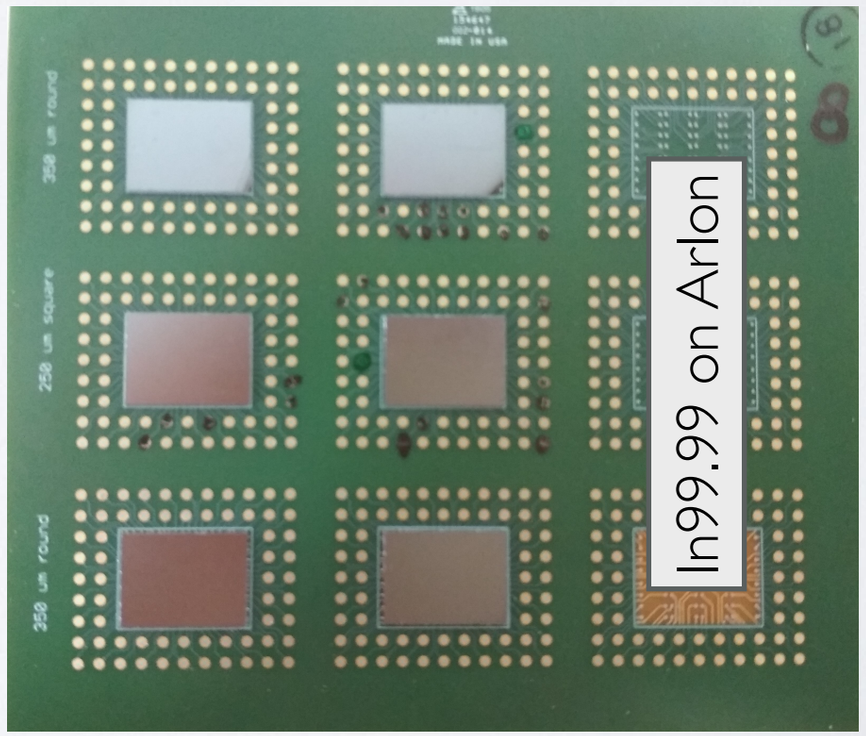
CTE of substrate | Radio-Purity | **Bonding strategies** | Anode contact

- thermo-compression





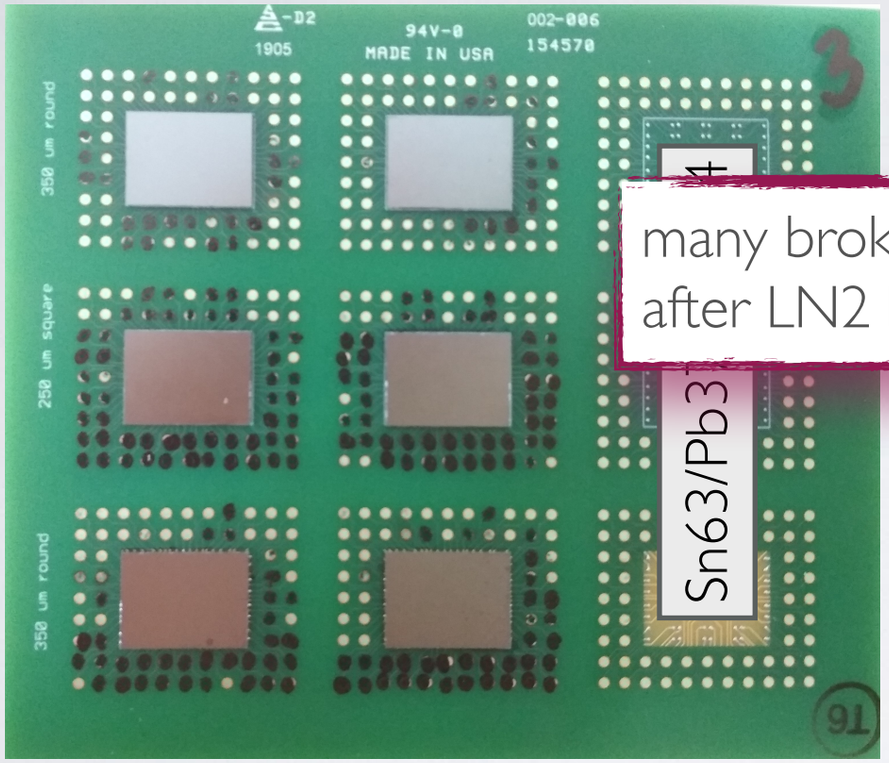




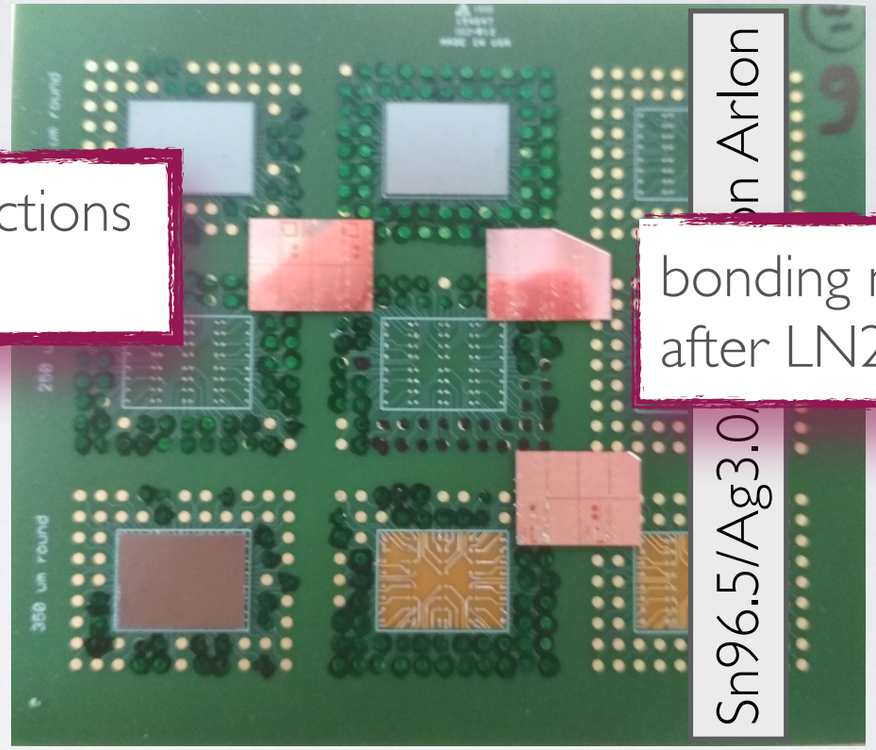
PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

CTE of substrate | Radio-Purity | **Bonding strategies** | Anode contact

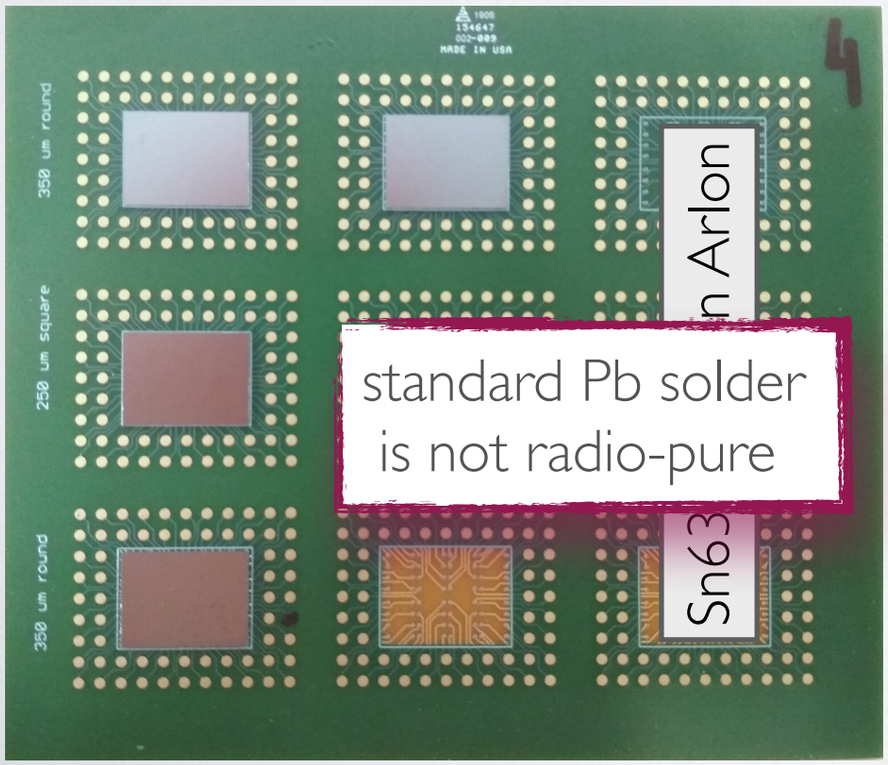
- thermo-compression



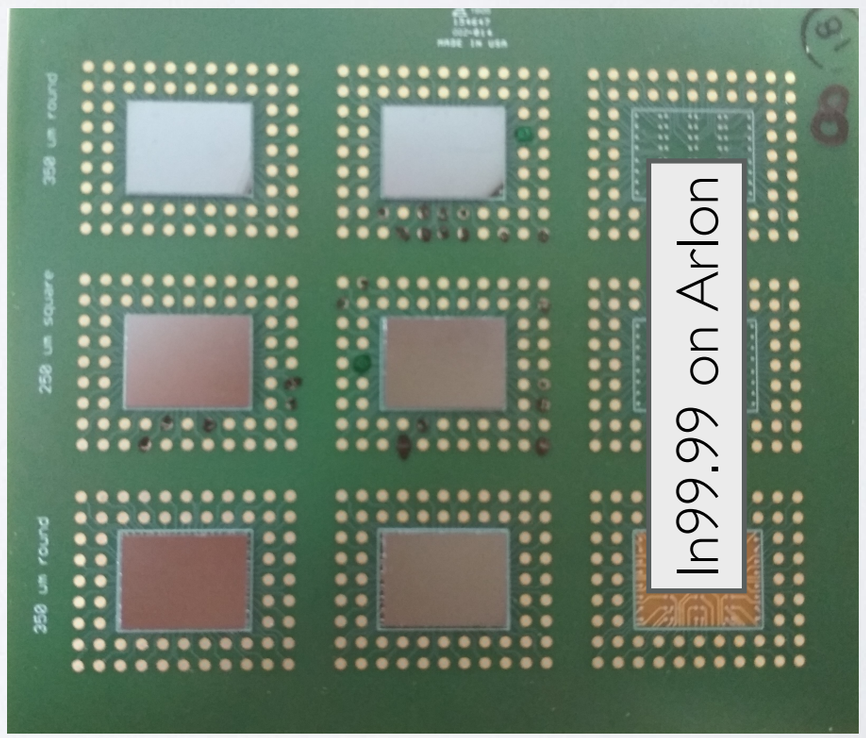
many broken connections after LN2 bath



bonding not reliable after LN2 bath



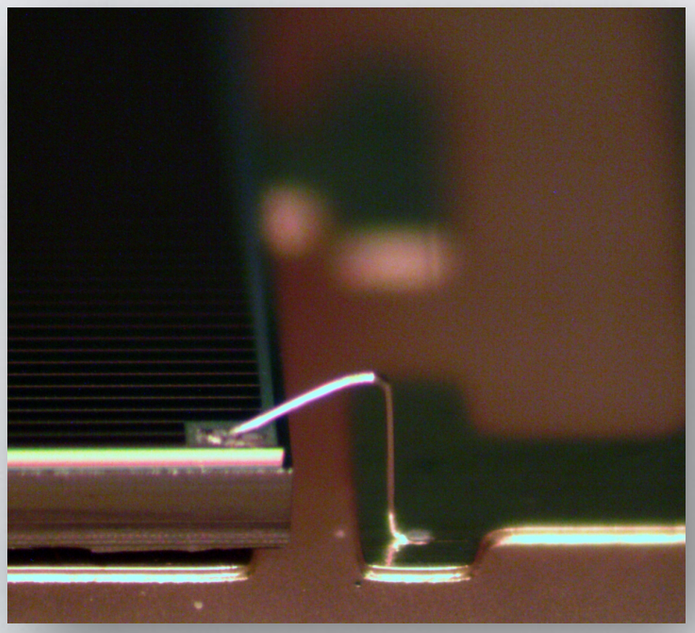
standard Pb solder is not radio-pure

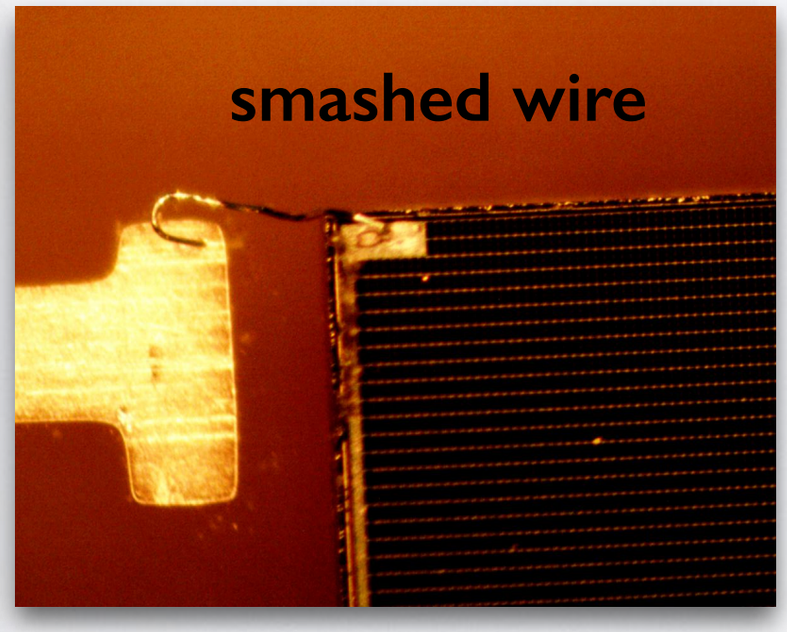


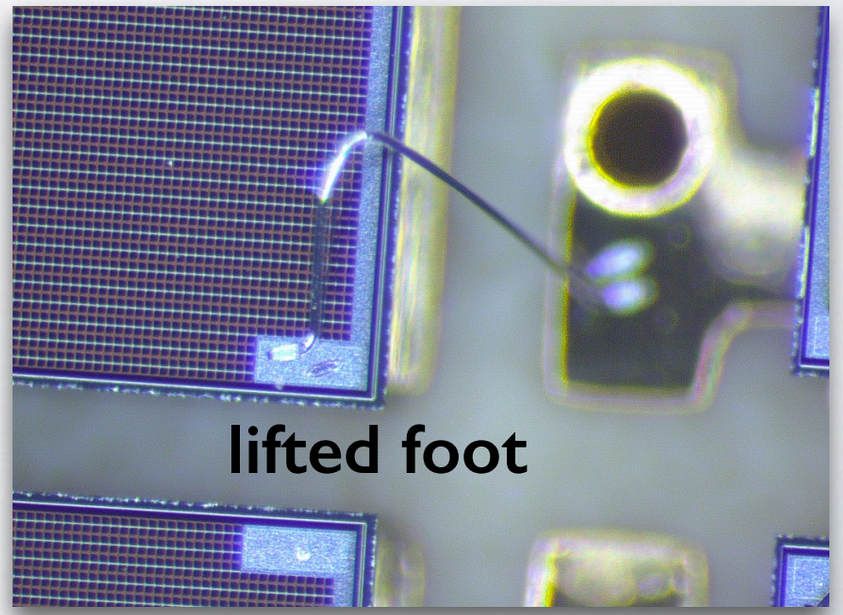
PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

- 25 μm aluminium wire
- 24 wires per PDM

Very fragile during manipulation:
- Complicated installation of the experiment



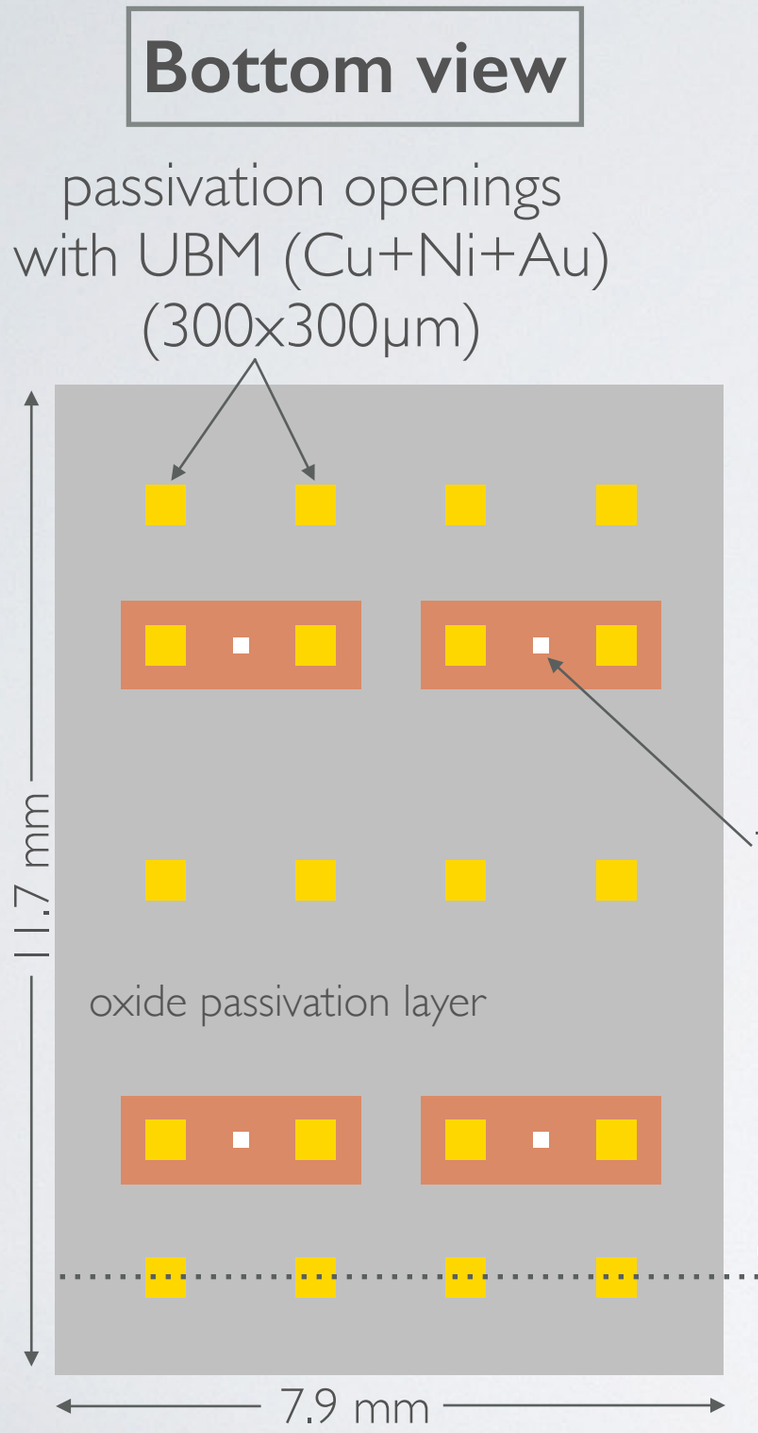




PACKAGING SOLUTIONS FOR CRYOGENIC APPLICATIONS

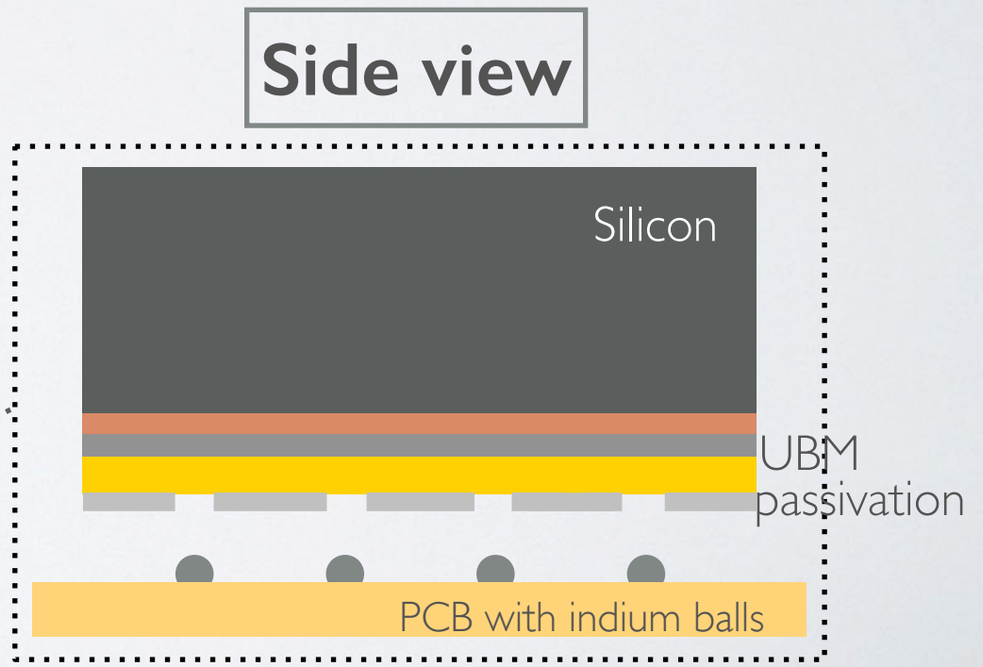
CTE of substrate | Radio-Purity | Bonding strategies | **Anode contact**

- **TSV**



LFOUNDRY
Solutions
for great visions

- robustness and higher fill factor (97%)
- die backside and PCB topside modification
- thermo-compression bonding



* not to scale

MASS PRODUCTION

NOA is a project funded through the RESTART program which aims to re-launch the economy and advanced training in the 2009 earthquake region.

NOA is using top quality equipment for the packaging of silicon devices

NOA proposal starts in the framework of DarkSide-20k.

SiPMs will be produced by LFoundry and delivered to NOA CR.

NOA will include the following processes all available for wafers up to 8":

- cryogenic and room temperature wafer probing
- dicing
- fully automated flip-chip bonding

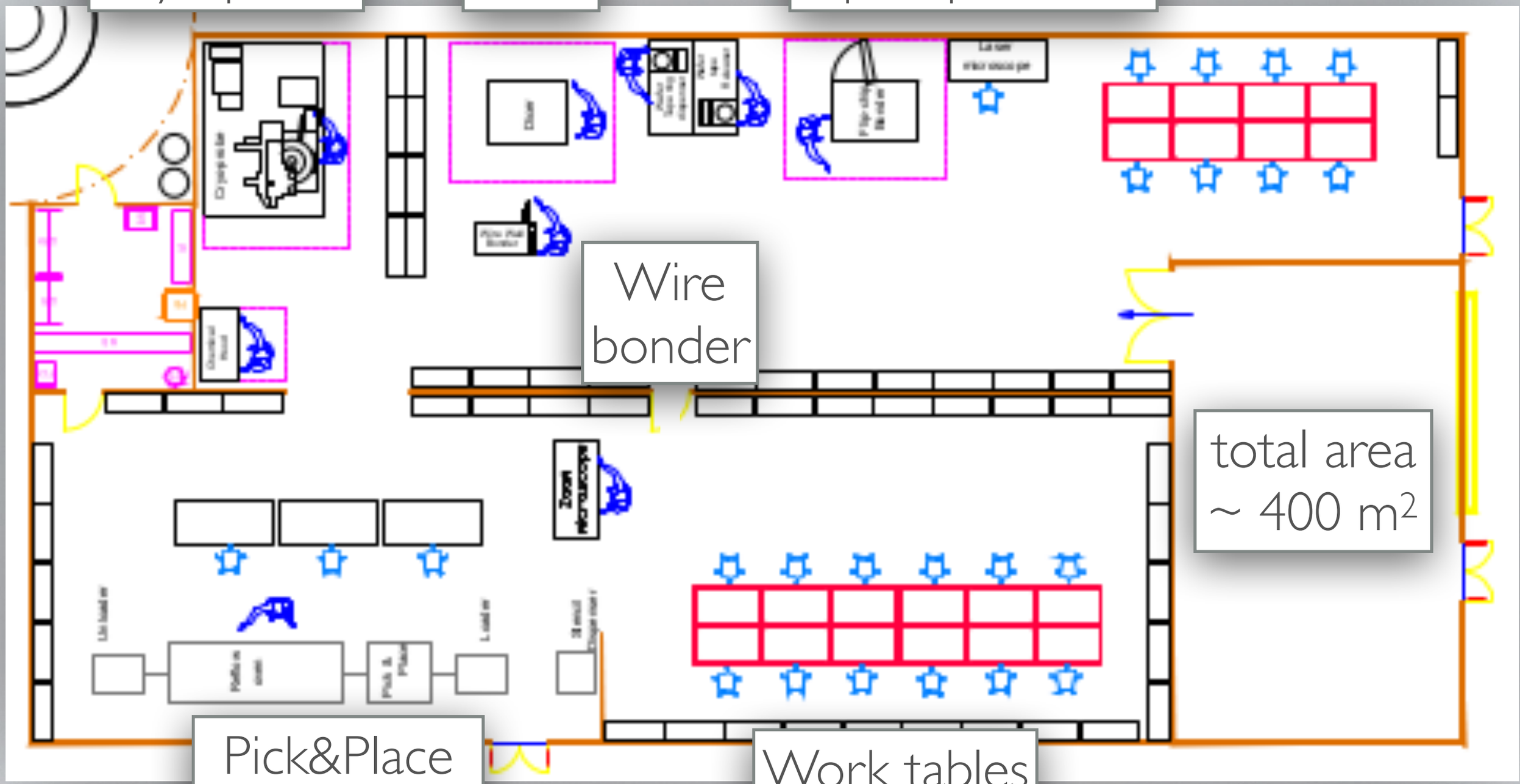
Moreover, NOA will include radio-pure processes for SMD PCB productions and an advanced electronic testing facility.

MASS PRODUCTION

Cryo probe

Dicer

Flip chip bonder



Wire bonder

total area
~ 400 m^2

Pick&Place
+
Reflow oven

Work tables

SCHEDULE

NOA will be commissioned next summer

- The cleanroom will be installed September 2020.
- The machines will be installed soon after.
- People have been hired and getting trained.

After that, DarkSide will start the production.

The tuning of the process will take few months.

The first MBs will be ready by the end of 2020.

The production of 360 MBs will last ~1.5 years.

CONCLUSIONS

DarkSide-20k succeeded in an ambitious R&D program to deploy radio-pure cryo-graded, SiPM-based, large photodetector.

The hot topics include:

- development of a specific technology of SiPM within FBK for LAr
- development of an extremely low noise preamplifier board
- selection of radio-pure components
- identification and use of the most advanced silicon packaging techniques
- deployment of a cutting edge silicon packaging facility at LNGS