# Light detection in DarkSide-20k with Silicon Photomultipliers


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*on behalf of the Global Argon Dark Matter Collaboration*

Princeton University


*CPAD Workshop 2022*

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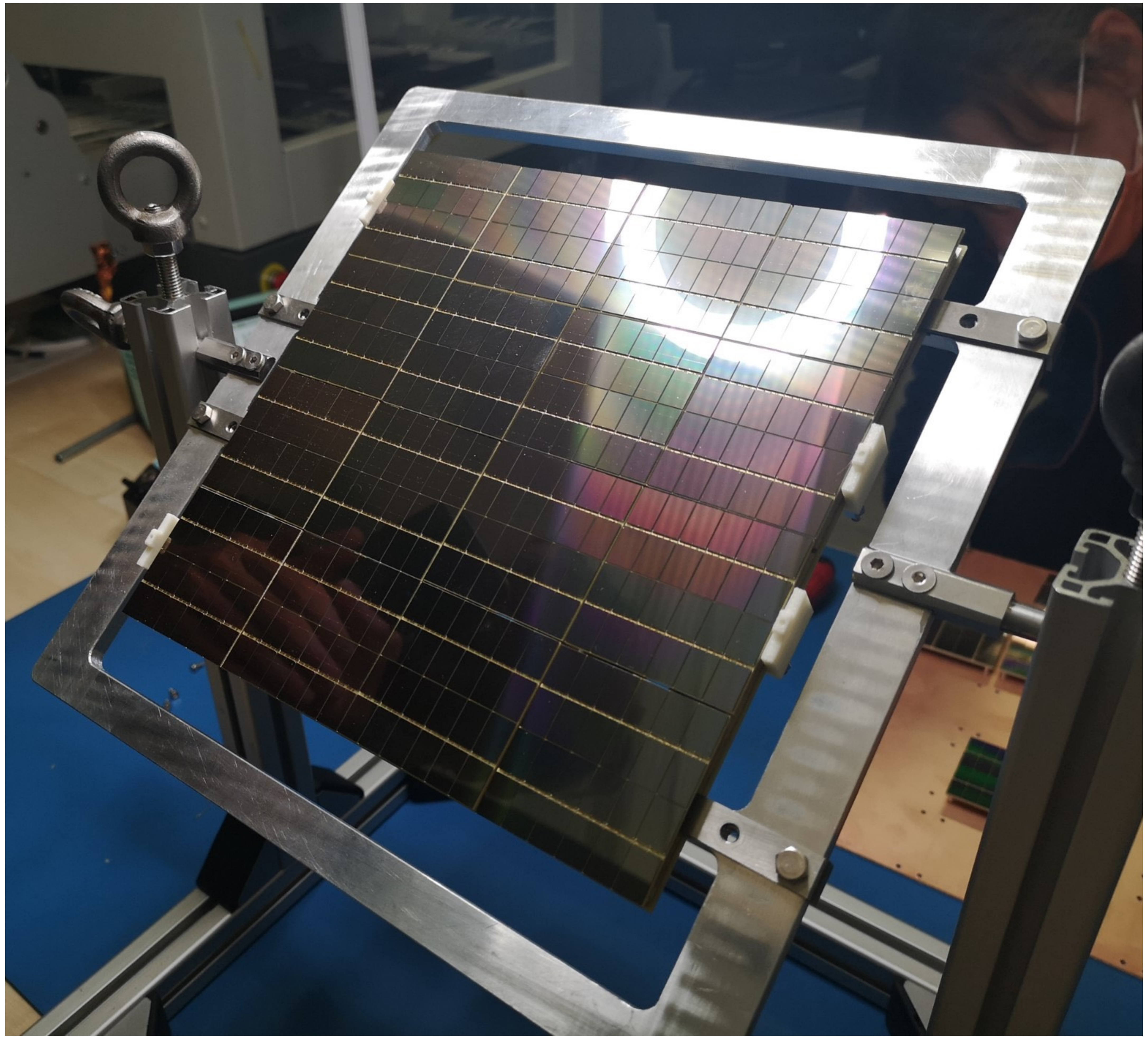
# Overview

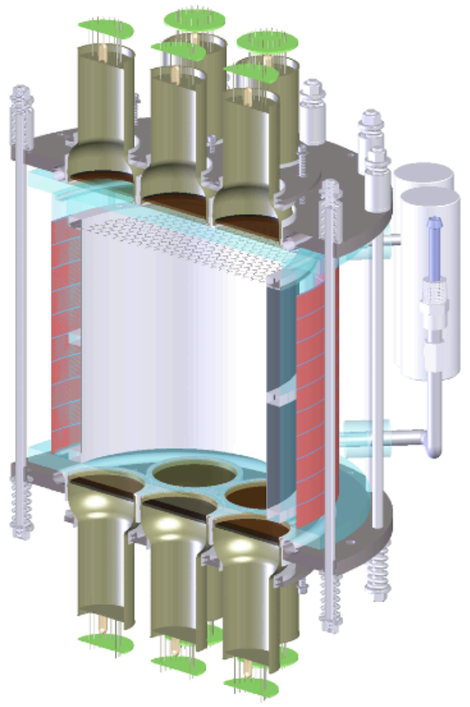


1. **DarkSide-20k**
   - The experimental program
   - DarkSide-20k overview
   - Detector design
2. **DS-20k photosensors**
   - SiPM technology
   - Figures of merit
   - Readout Strategies
   - Production

# The DarkSide-20k experiment

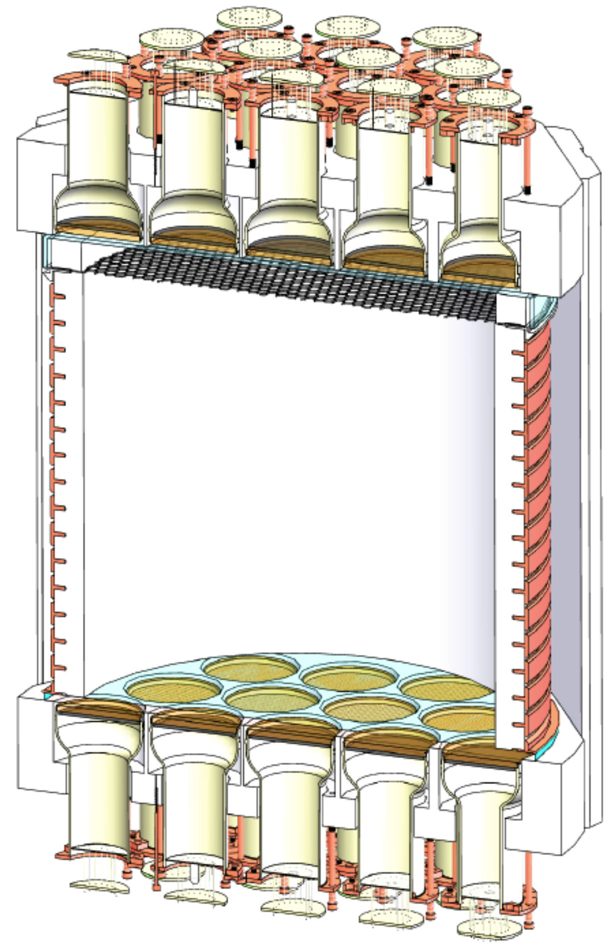
# A multi-stage approach

2012 | 2013 - 2018 | 2025 - 2035 | 2030s - ...



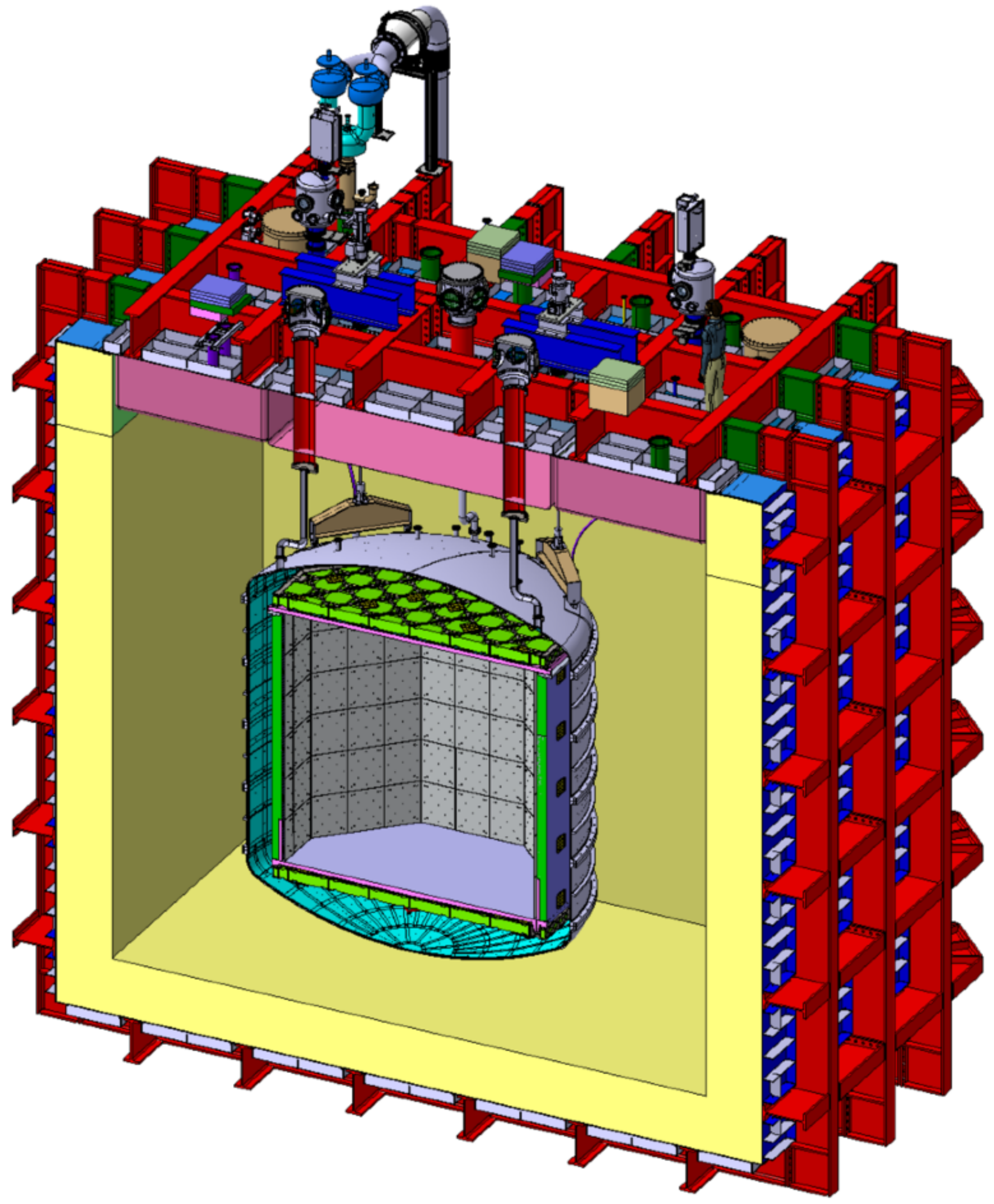
**DarkSide-10**

- First prototype
- Helped to refine TPC design
- Demonstrated a light yield >9PE/keV$_{ee}$



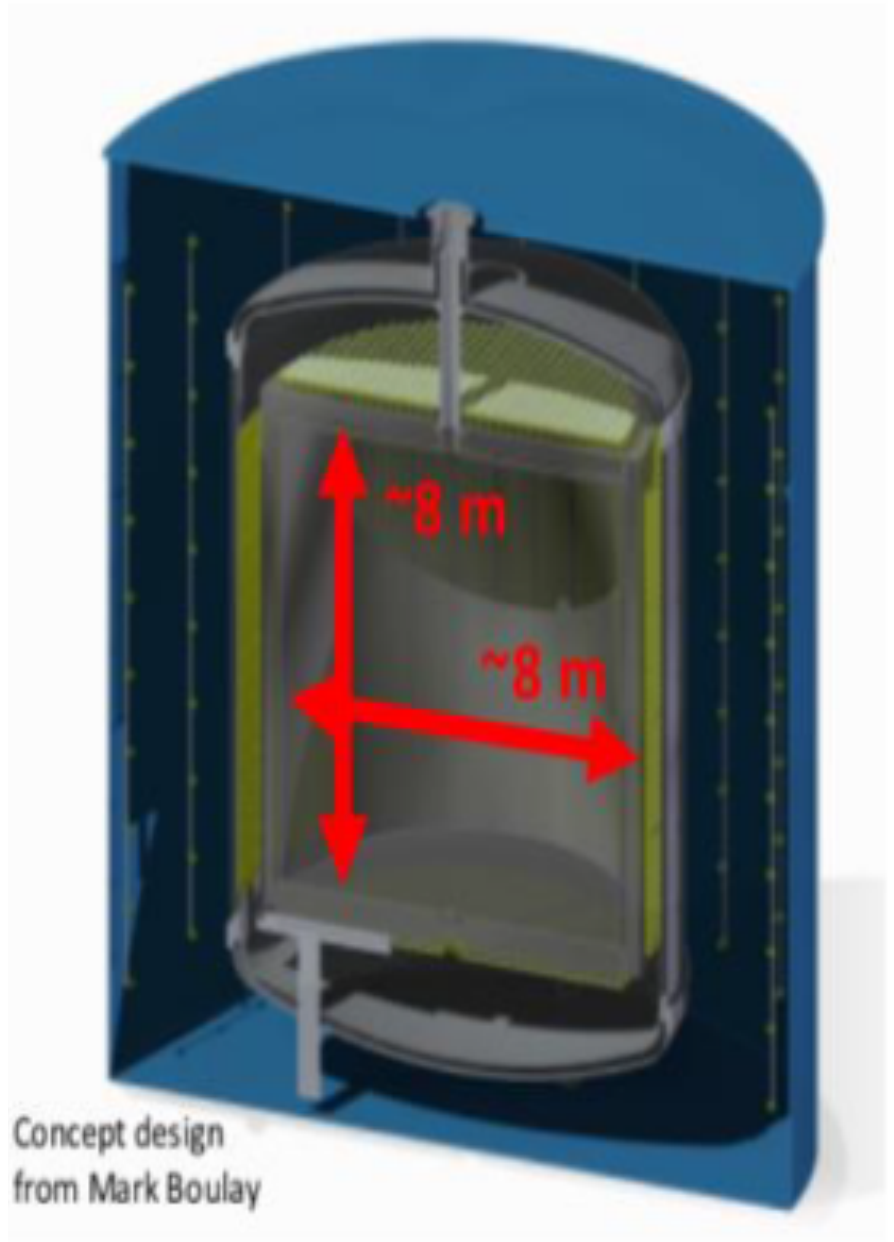
**DarkSide-50**

- Science detector
- Demonstrated the use of UAr
- First background-free results
- Best limits for low mass WIMP searches



**DarkSide-20k @ LNGS**

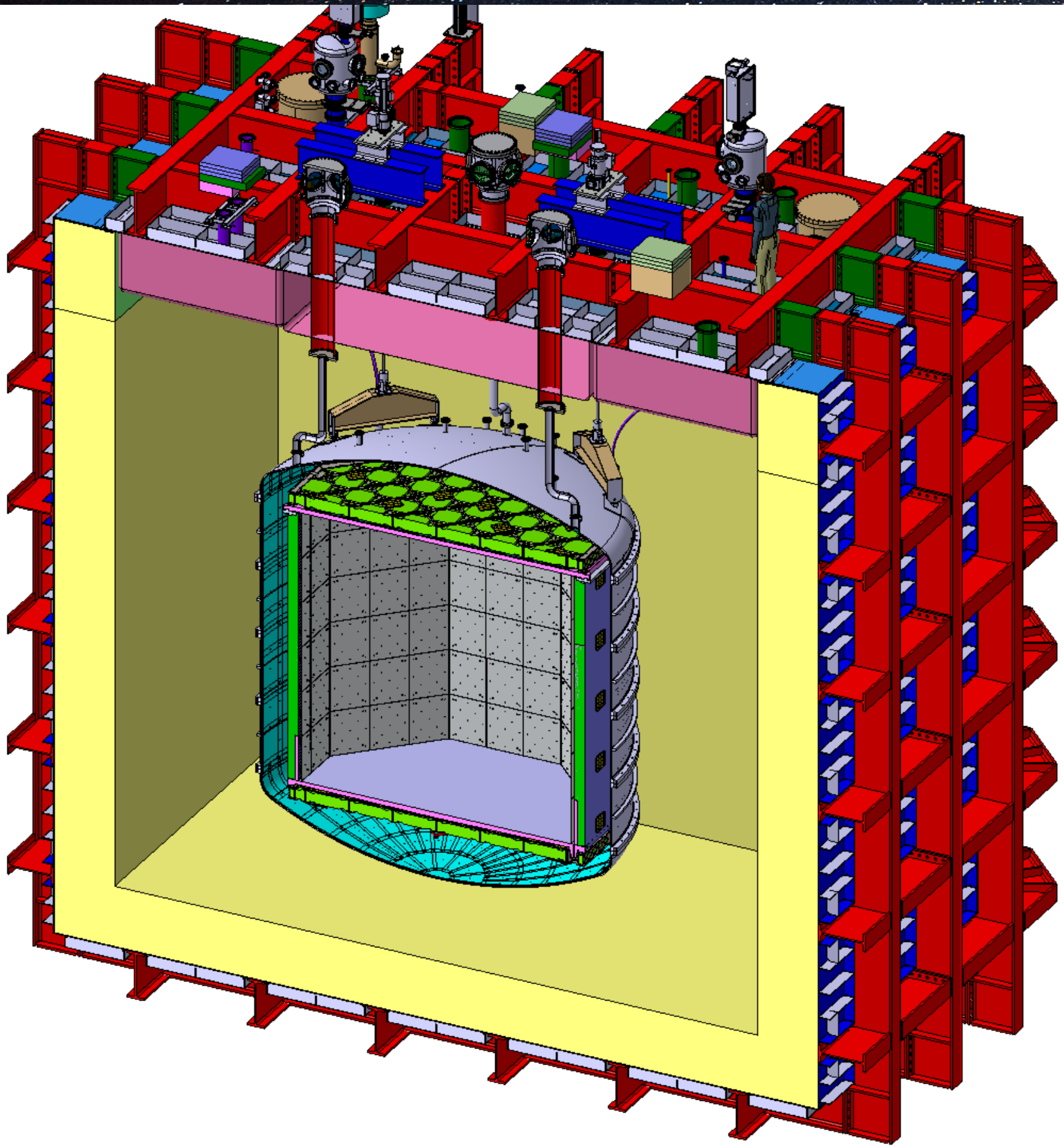
- Novel technologies
- First peek into the neutrino fog
- Nominal exposure: 200 t y




**Argo @ SNOLAB**

- Ultimate LAr DM detector
- Push well into the neutrino fog
- Nominal exposure: 3000 t y

# DarkSide-20k overview



**Nested detectors structure:**

ProtoDUNE-like cryostat (8x8x8m$^3$) - Muon veto

Ti vessel separating AAr from underground UAr.

Neutrons and γ veto

WIMP detector: dual-phase TPC hosting 50t of LAr

Fiducial mass: 20 tonnes

**Multiple detection channels for bkg supression:**

Neutron after cuts: < 0.1 in 10 y

β and γ after cuts: < 0.1 in 10 y

**Position reconstruction resolution:**

~ 1 cm in XY

~ 1 mm in Z

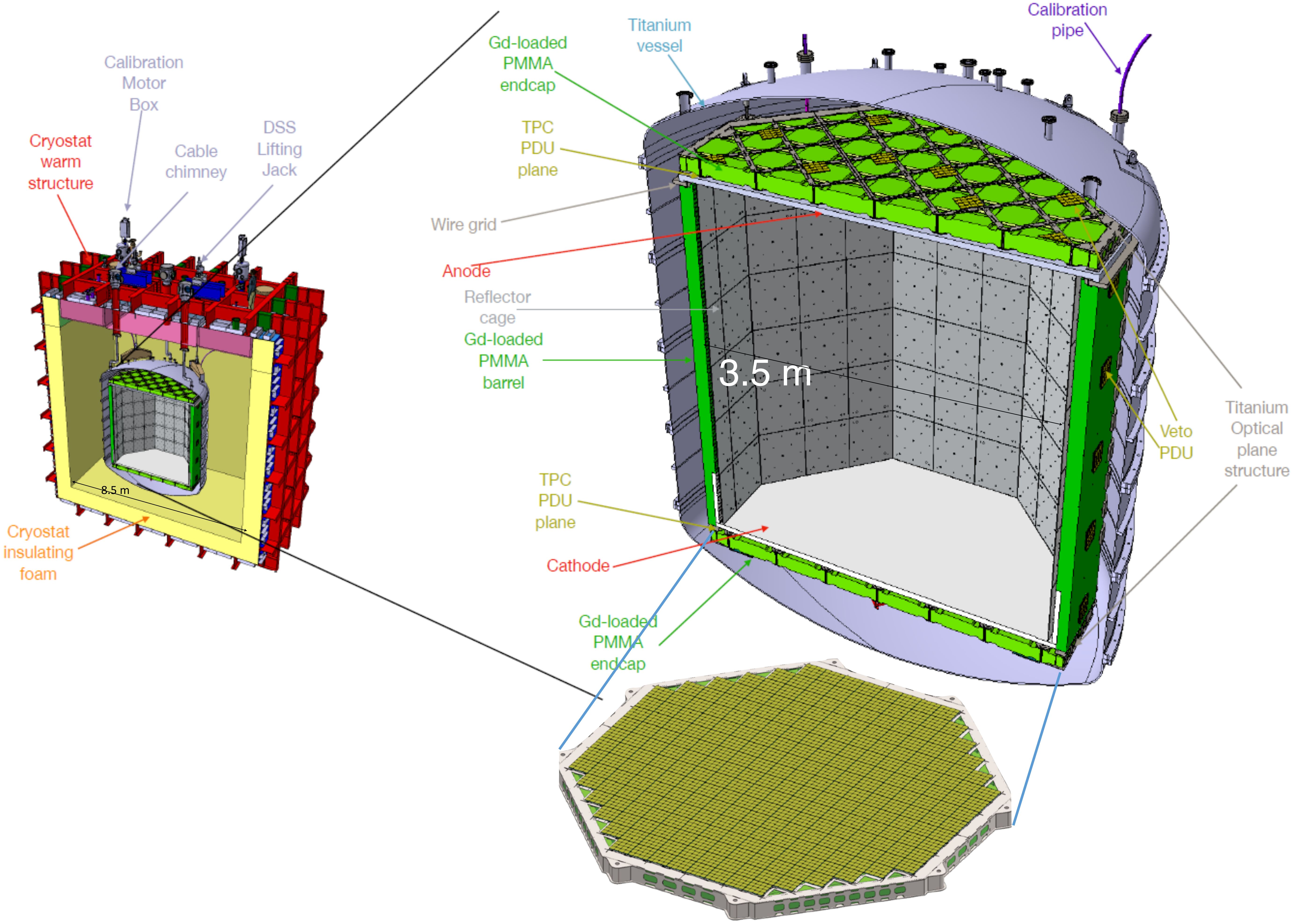
# Inner detector

- Integration of **TPC** and **VETO** in a single object

- **TPC Vessel:**
  - top and bottom: transparent pure acrylic
  - lateral walls: Gd-loaded acrylic + reflector + WLS
  - anode, cathode and field cage made with conductive paint (Clevios)
- **TPC readout:** 21m$^2$ cryogenic SiPMs

- **Veto:**
- TPC surrounded by a single phase (S1 only) detector in UAr
- TPC lateral walls + additional top&bottom planes in Gd loaded acrylic (PMMA)
  - to thermalize n (acrylic is rich in Hydrogen)
  - neutron capture releases high energy γ
- **Veto readout:** 5 m$^2$ cryogenic SiPMs

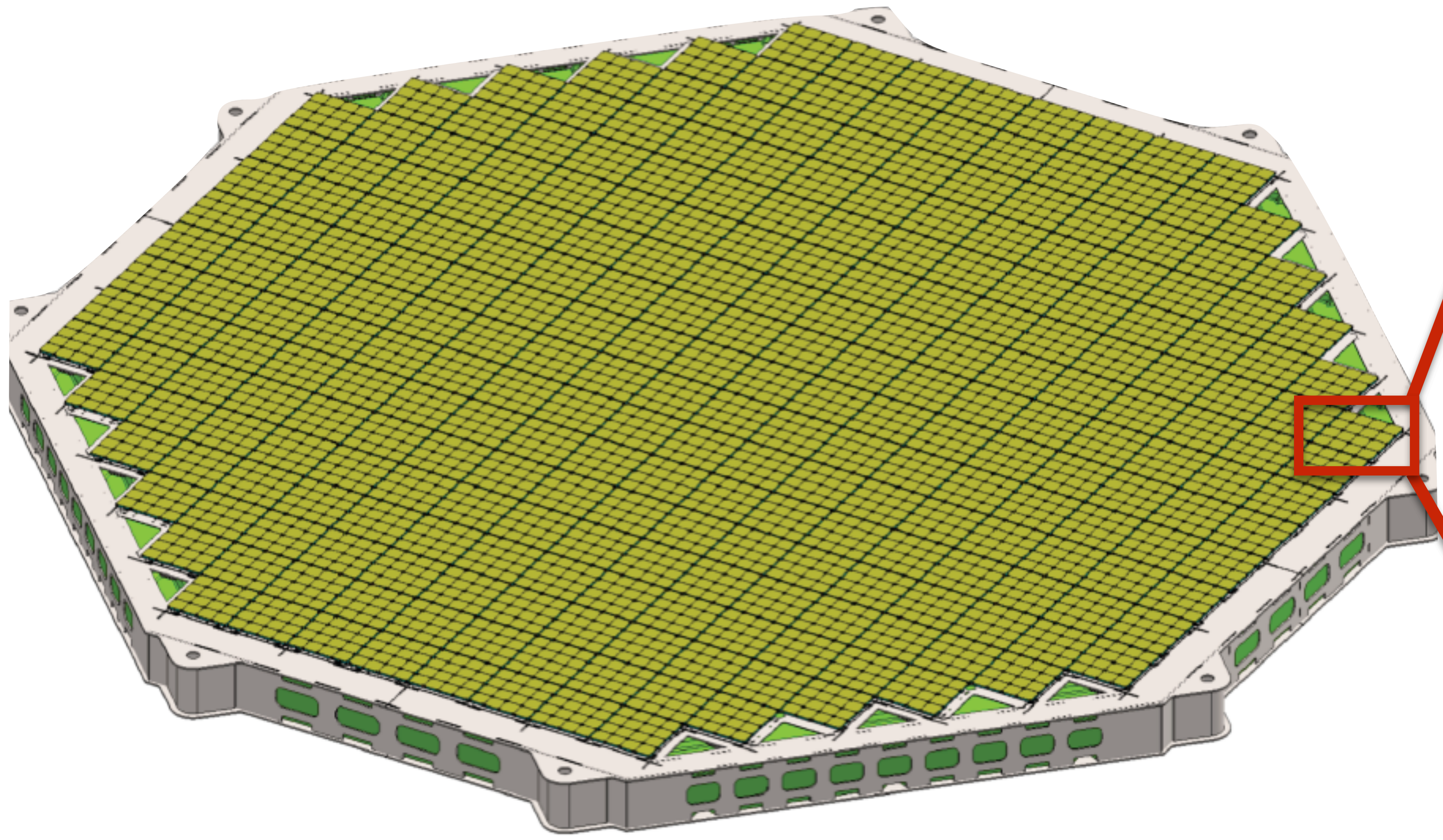
**99 t UAr held in Ti vessel**




**TPC photo-detection system**

# Photo-detection system

## TPC optical plane

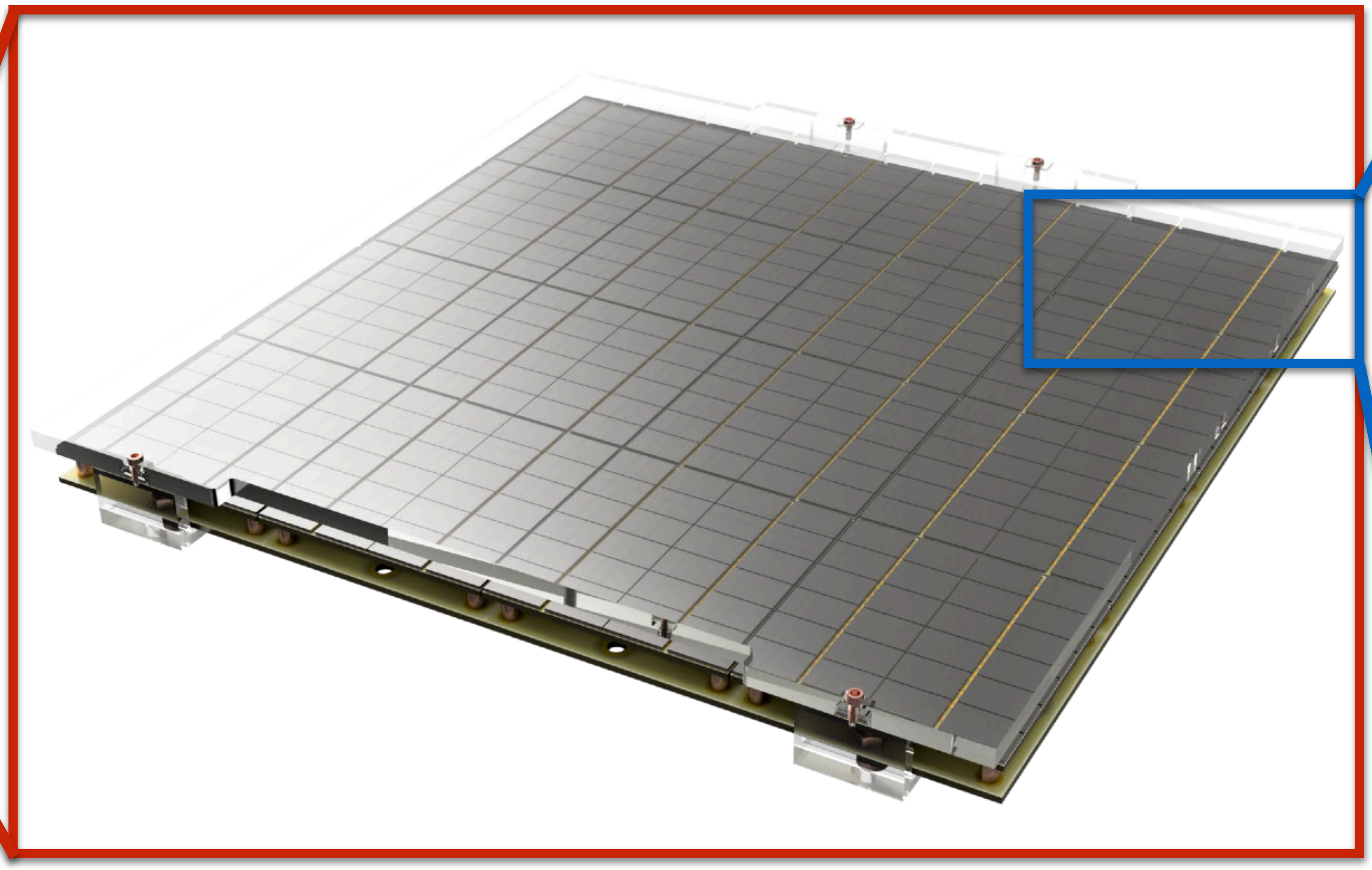


TPC planes area: ~21m²

Organized in 525 PDUs

100% coverage of TPC top and bottom

## Photo-Detection Unit



16 tiles arranged in 4 readout channels

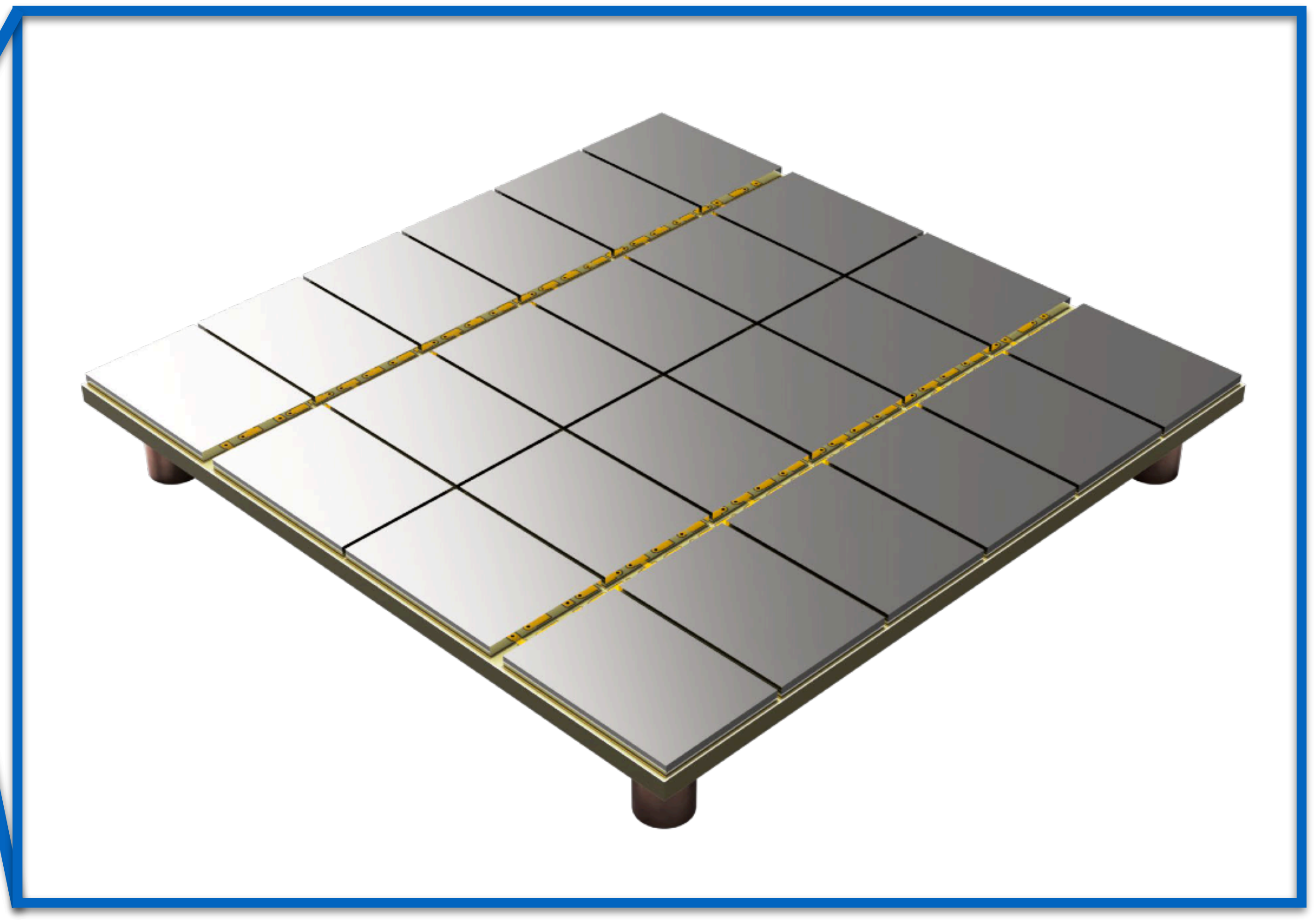
SiPM bias distribution

cryogenic pre-amplifiers bias

Signal transmission

Channels switch-on/off

## Tile

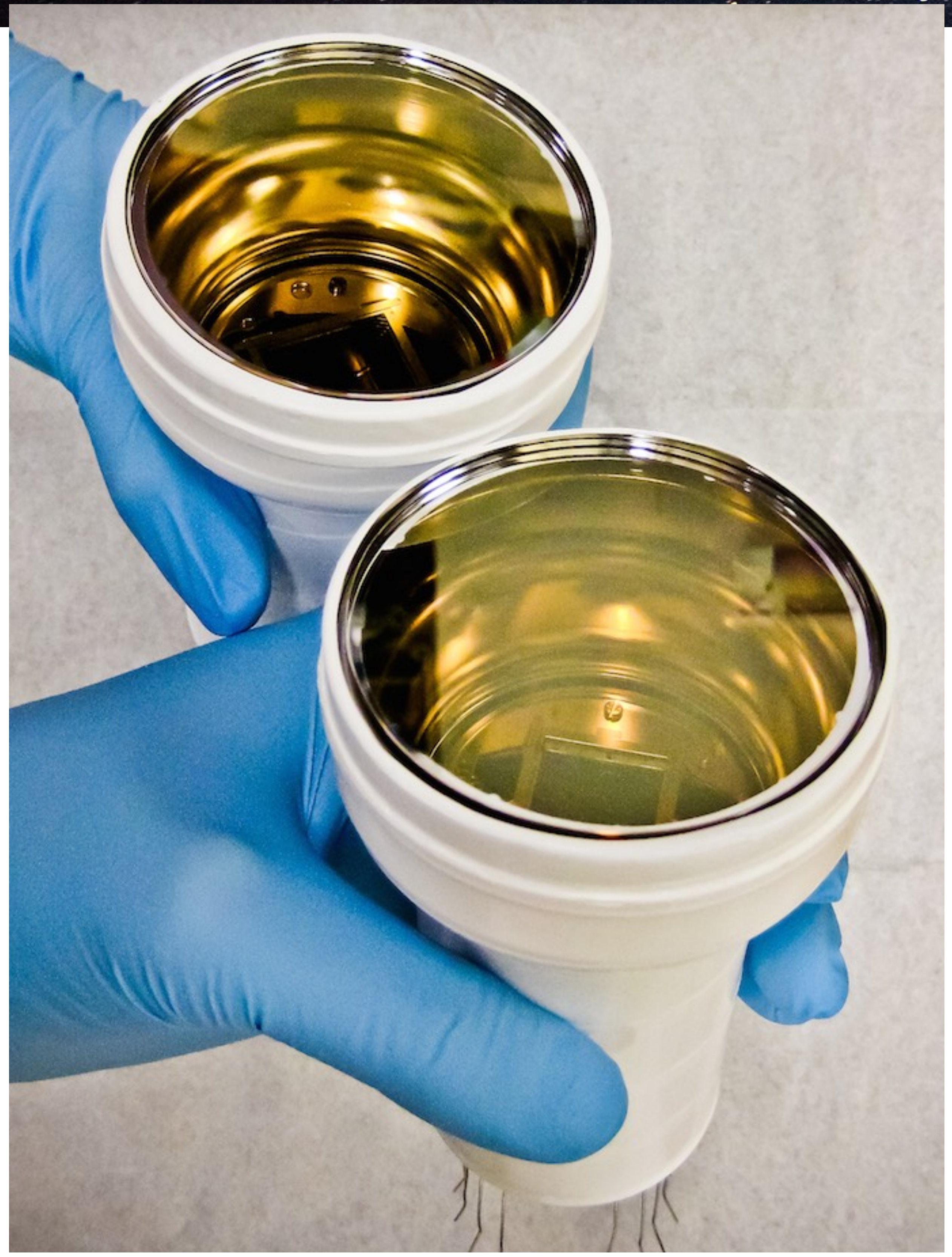


Photosensor

Array of 24 SiPMs

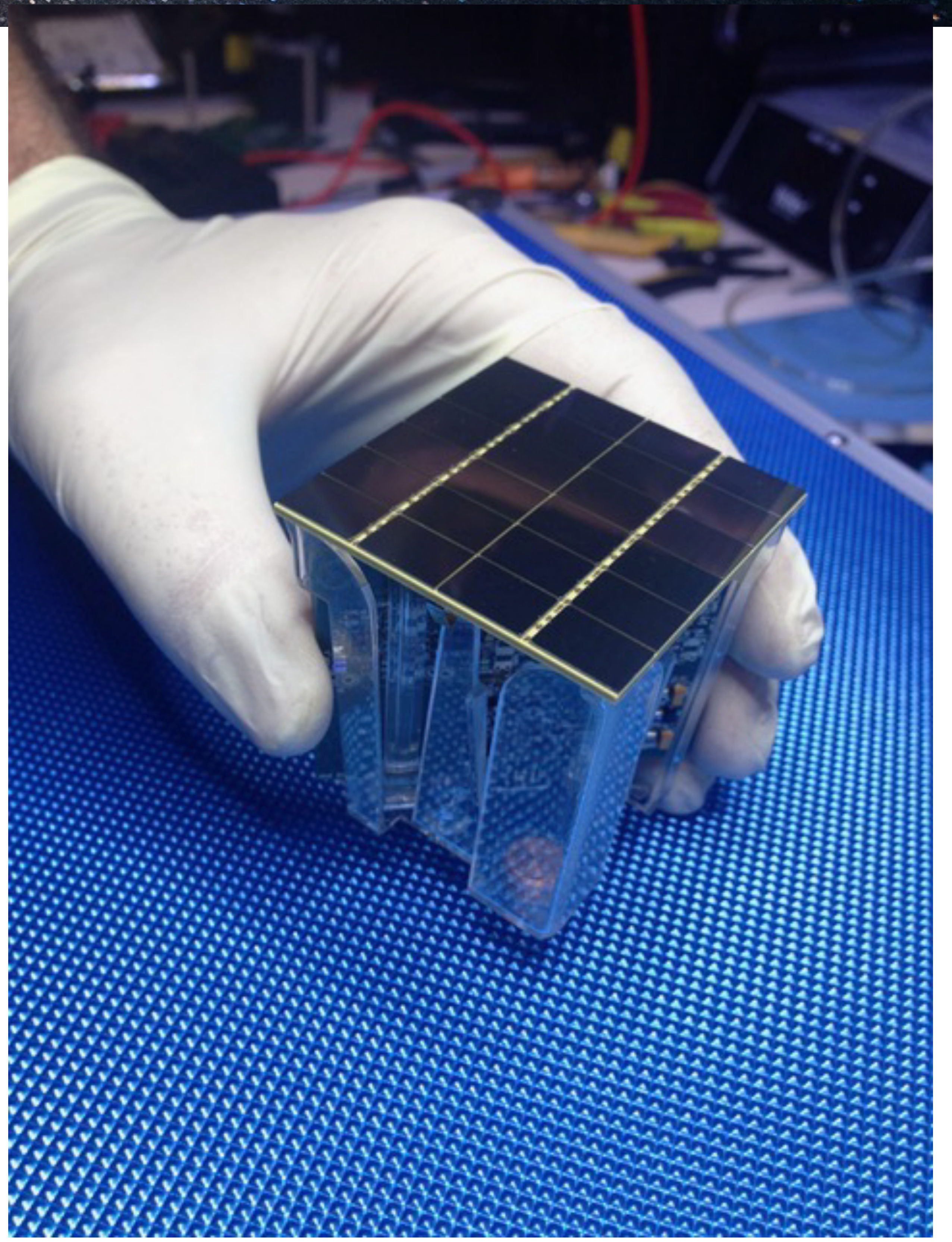
Signal pre-amplification

# Transitioning to a new technology



Why?

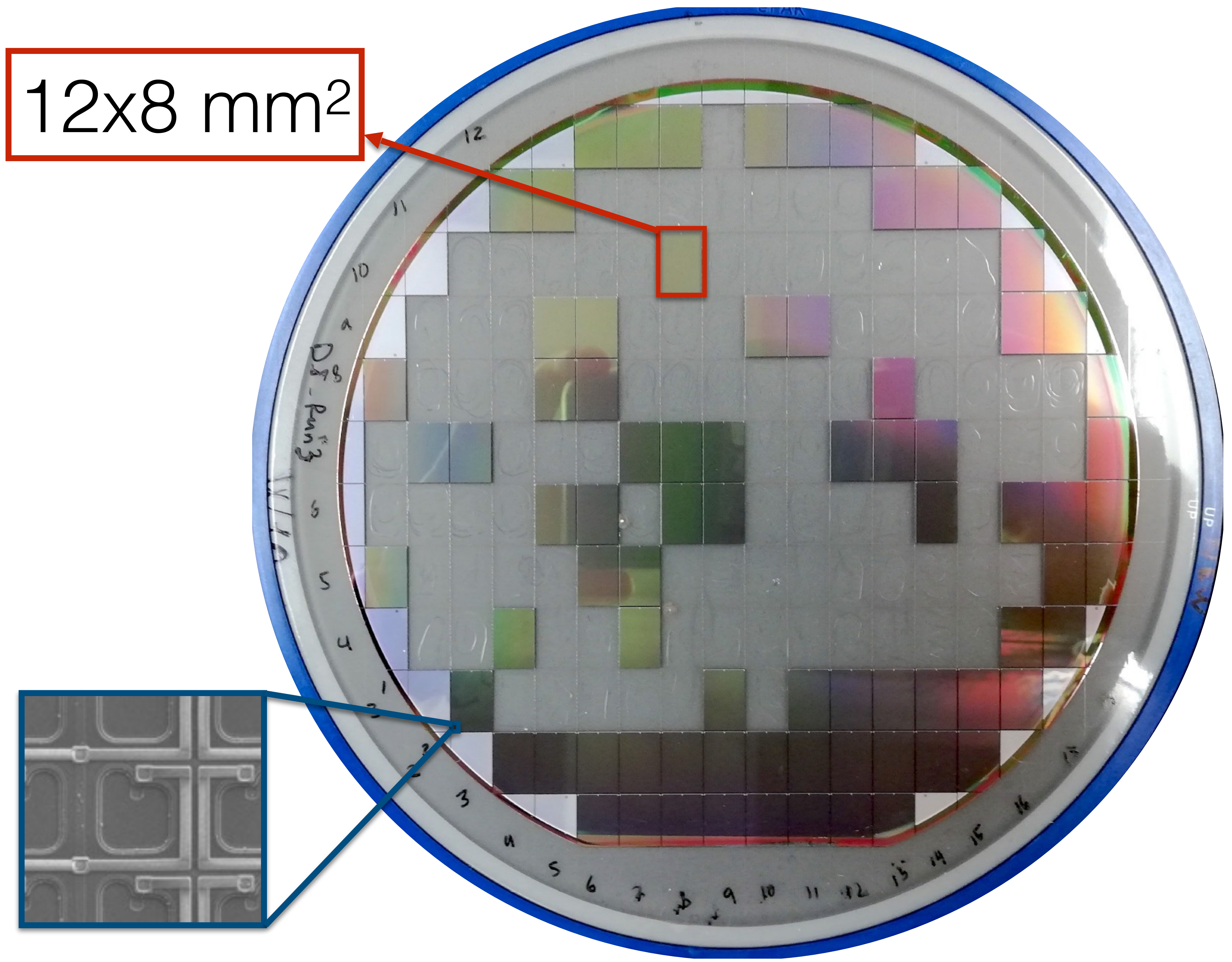
- Lower radioactivity
- Higher Photon Detection Efficiency
- Higher active area
- Operated with low bias
- Lower cost

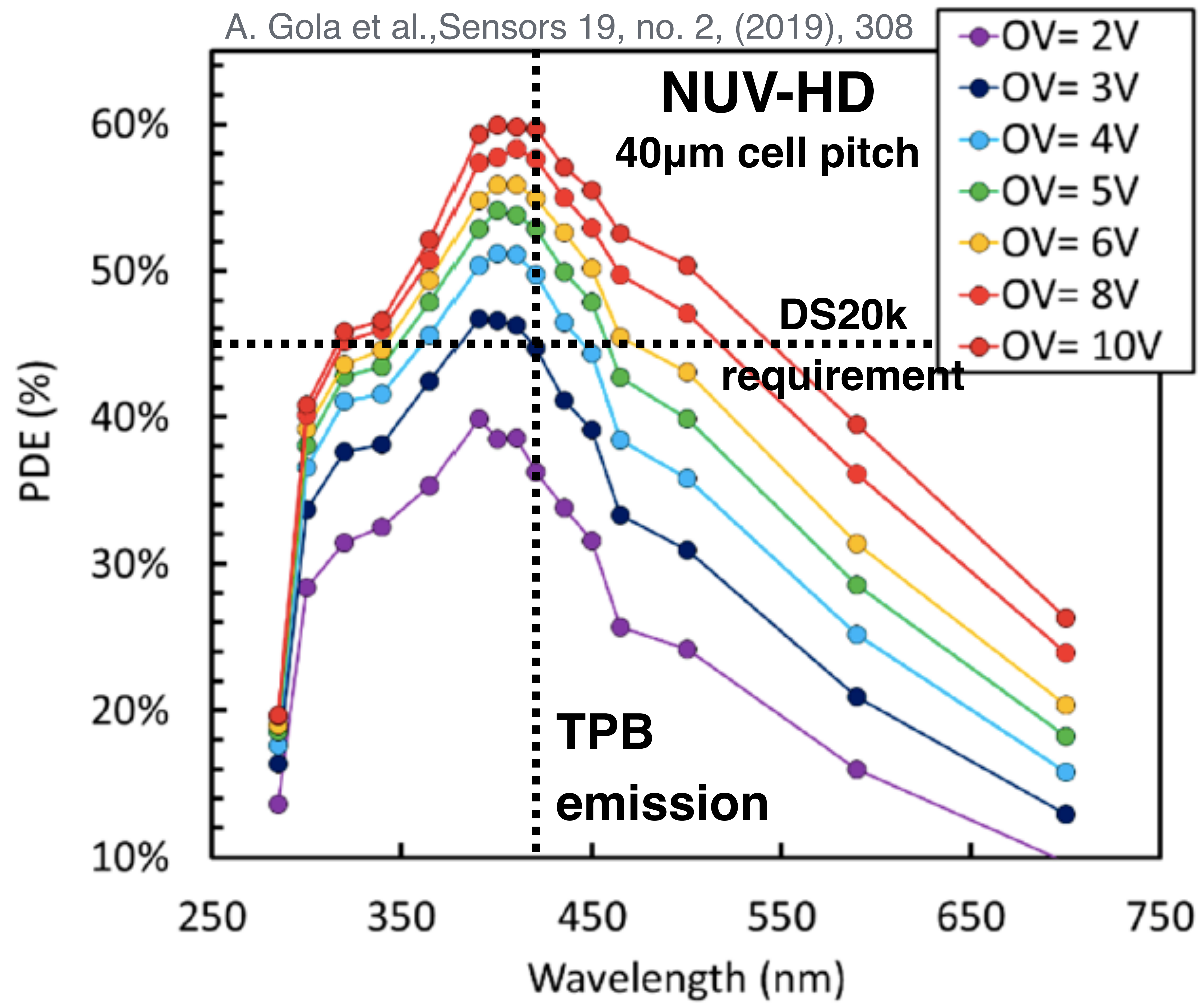


But...there's no such thing as a free meal!

- Higher dark rate and correlated noises (after-pulse, cross-talk)
- Small area (many channels)
- High output capacitance (high electronic noise, low bandwidth)

# Step 1: SiPMs development



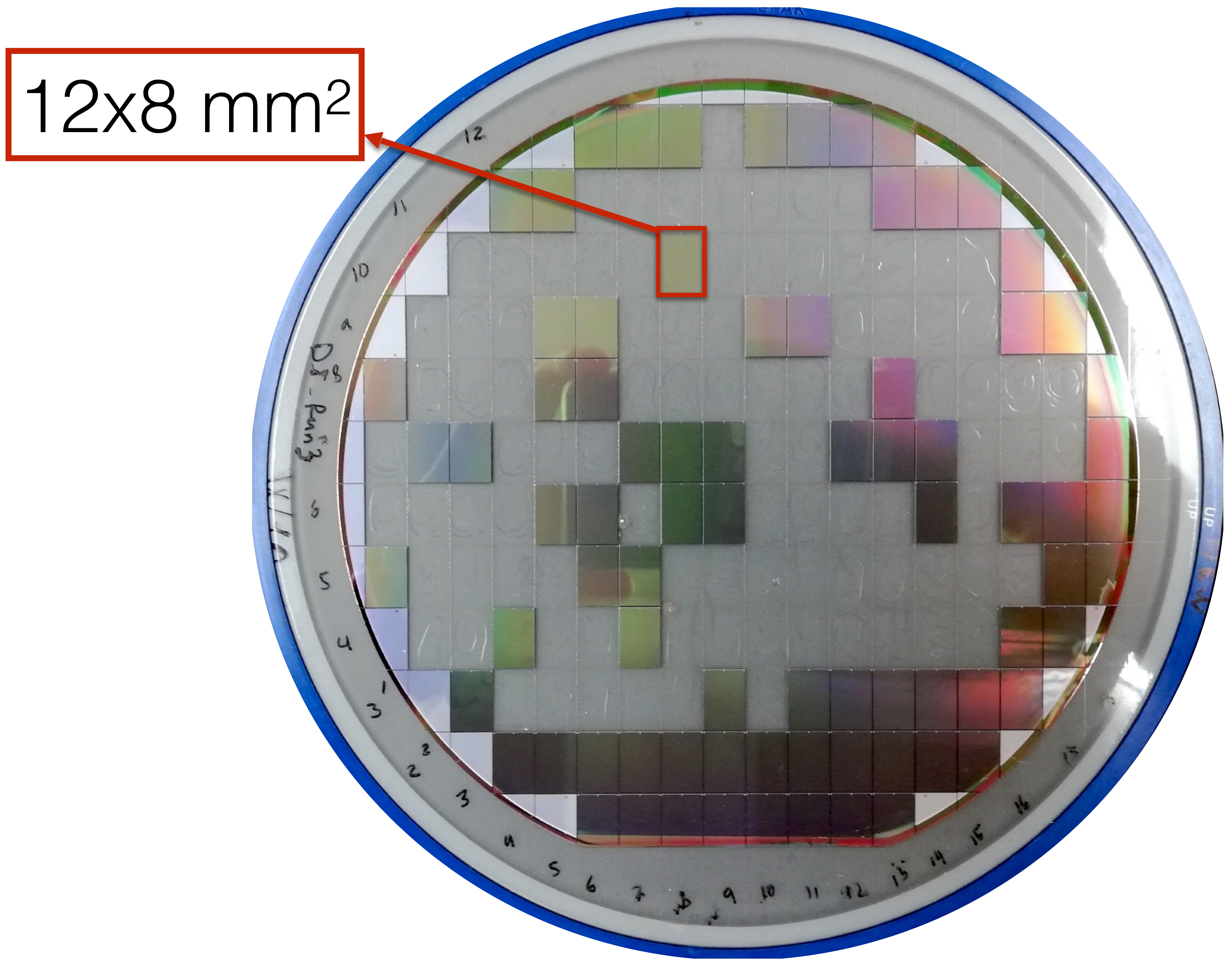



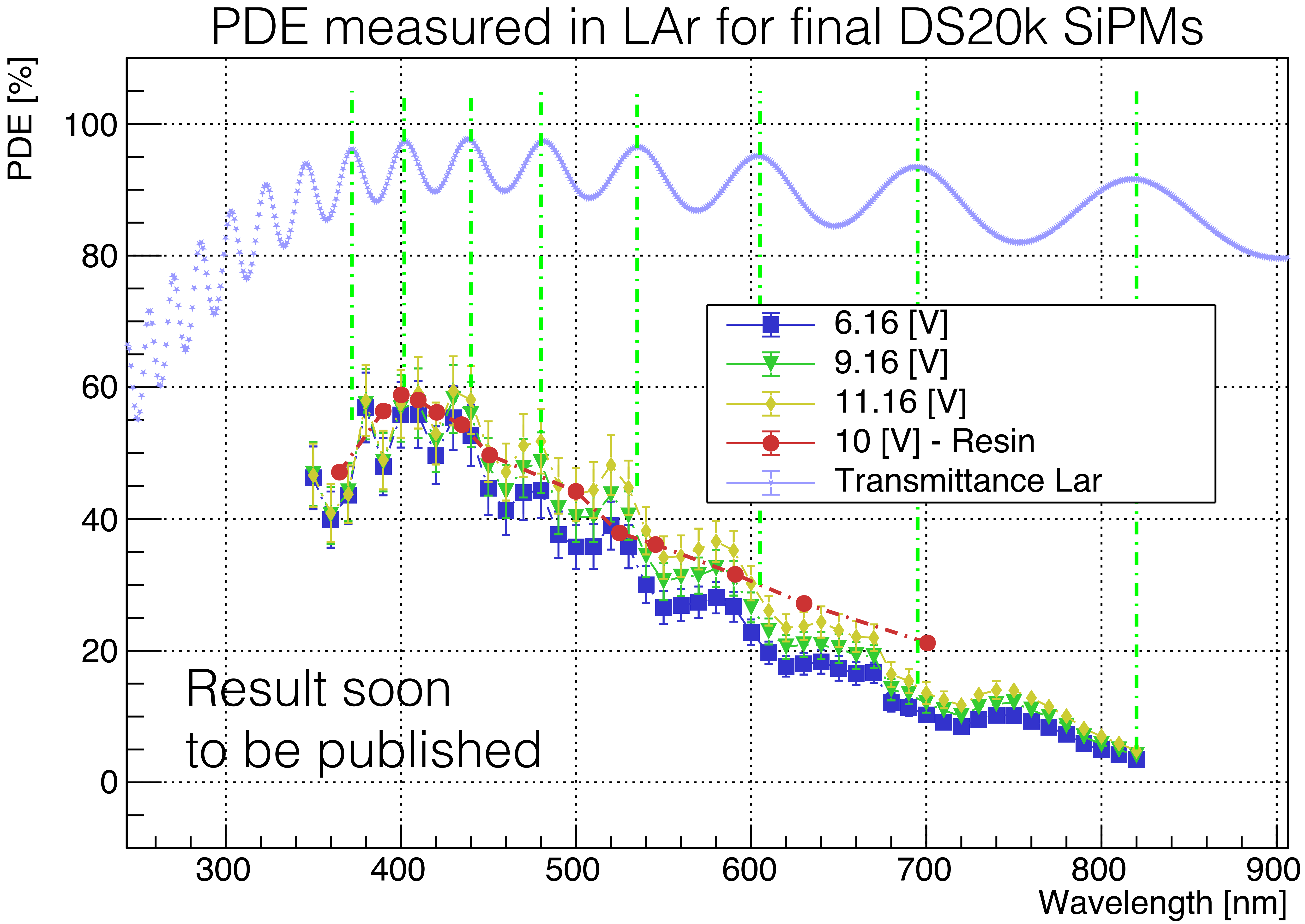

- NUV vs RGB choice ($P_{01}$)
- Cell pitch and fill factor (FF) optimization
- **E** field profile ⇒ DCR+CN reduction

$$PDE = QE \times P_{01} \times FF$$

**PDE > 55% @ 290K**

# Step 1: SiPMs development



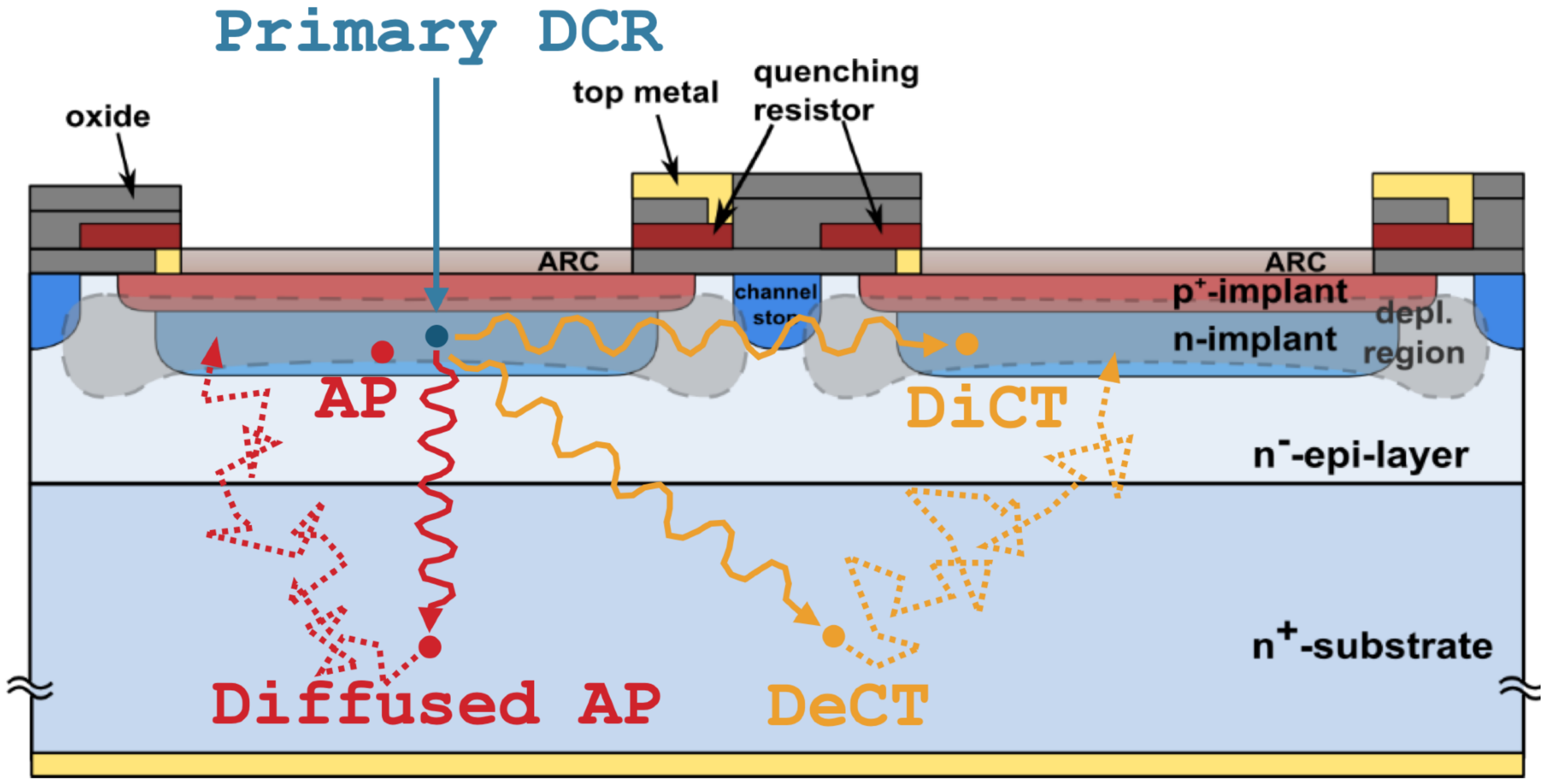



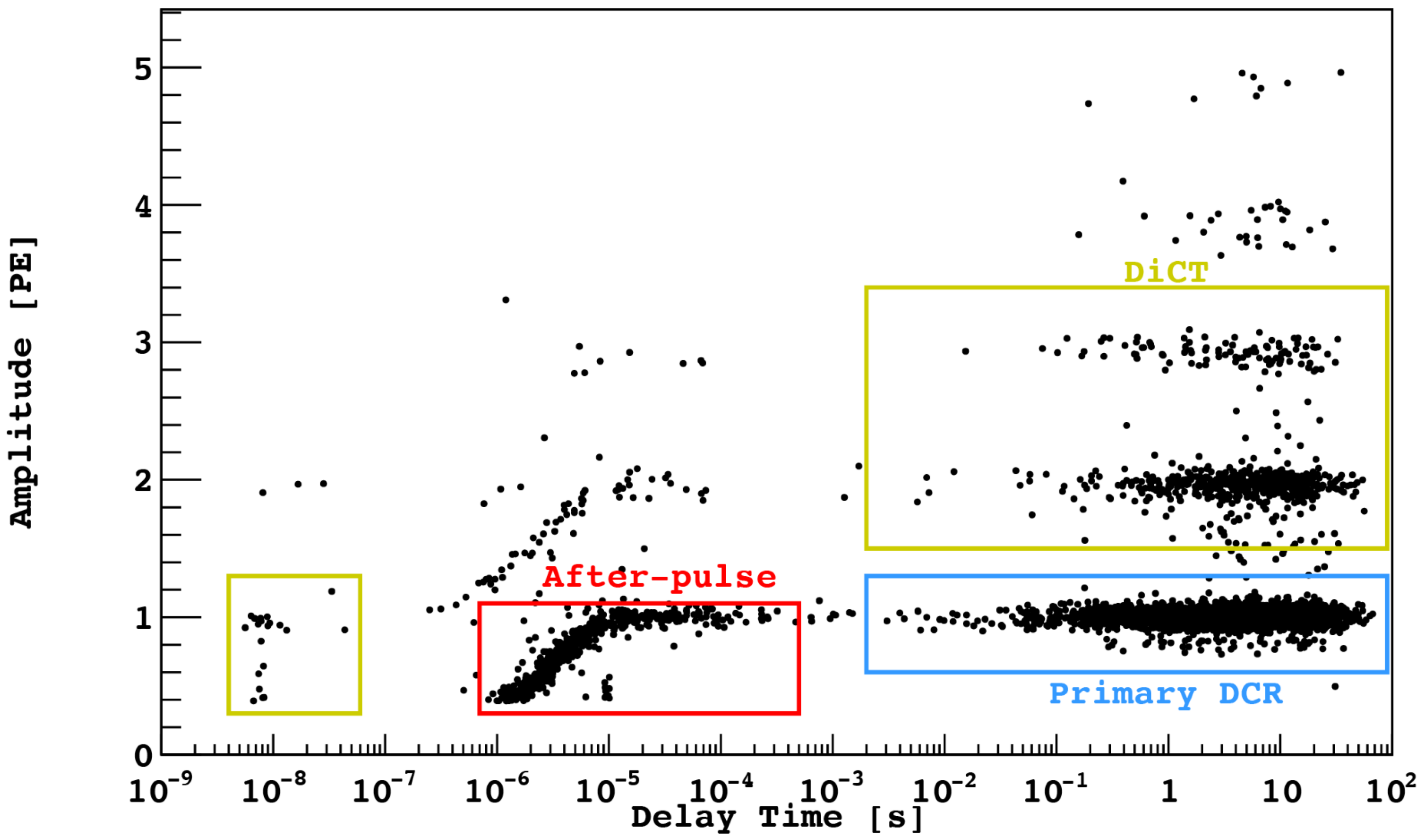

- NUV vs RGB choice ($P_{01}$)
- Cell pitch and fill factor (FF) optimization
- **E** field profile ⇒ DCR+CN reduction

$$PDE = QE \times P_{01} \times FF$$

**PDE ~50% in LAr**

# Step 1: SiPMs development



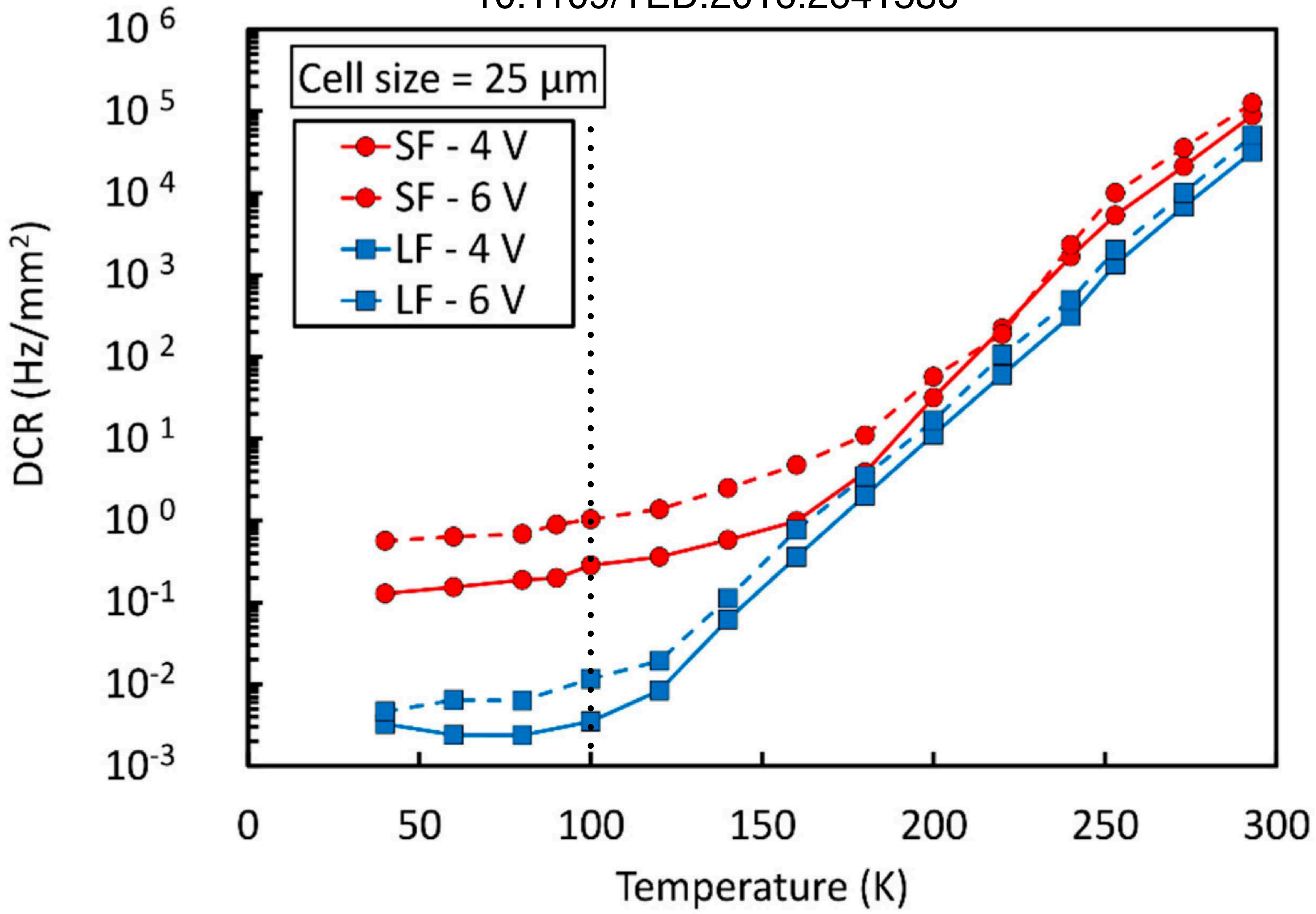




- Noises can be primary or correlated
- Primary: Dark Count Rate (DCR)
- Correlated: AfterPulse (AP), Direct CrossTalk (DiCT), Delayed CrossTalk (DeCT)

- Different generation mechanism
- Different behavior

# Step 1: Tech Breakthroughs

10.1109/TED.2016.2641586

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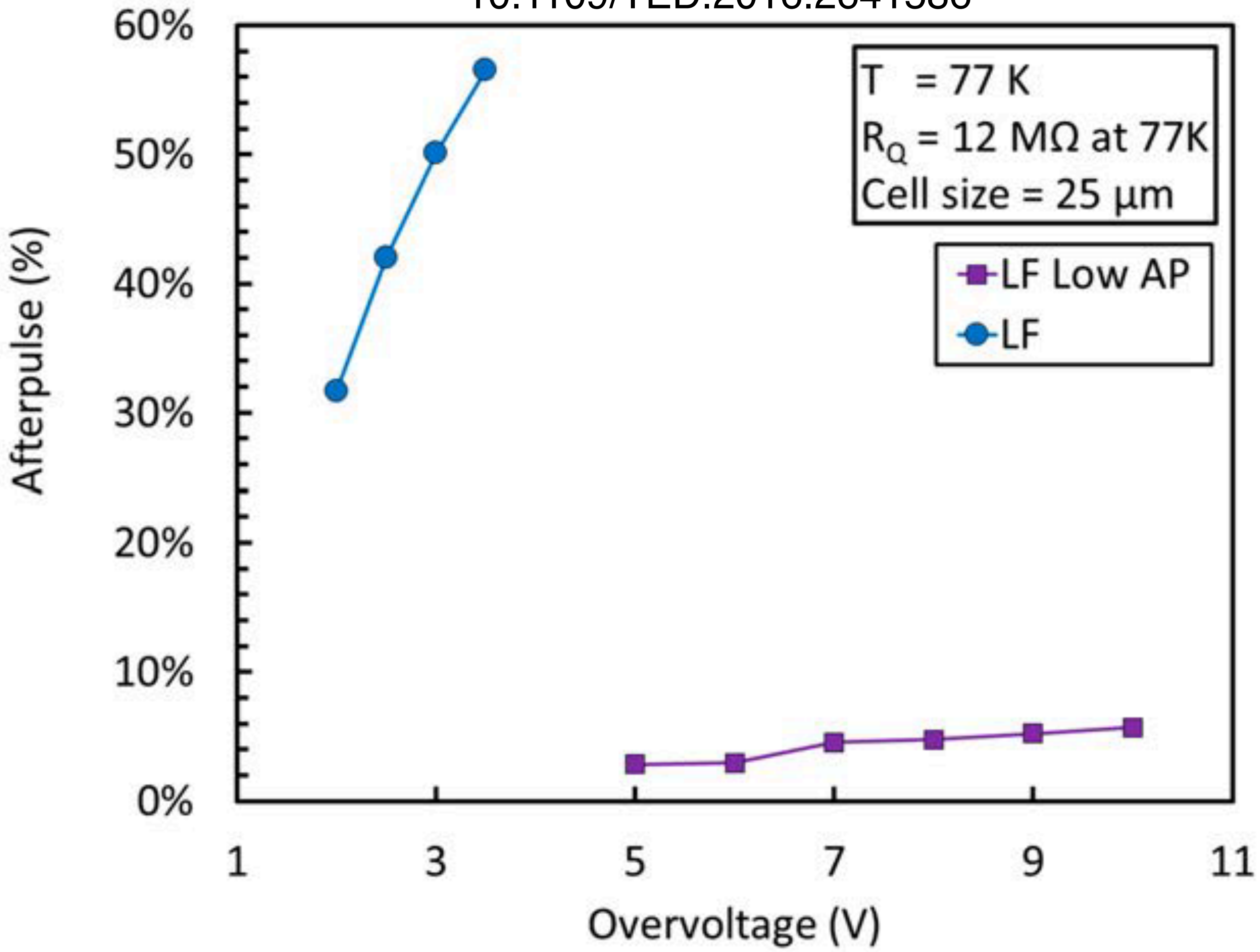


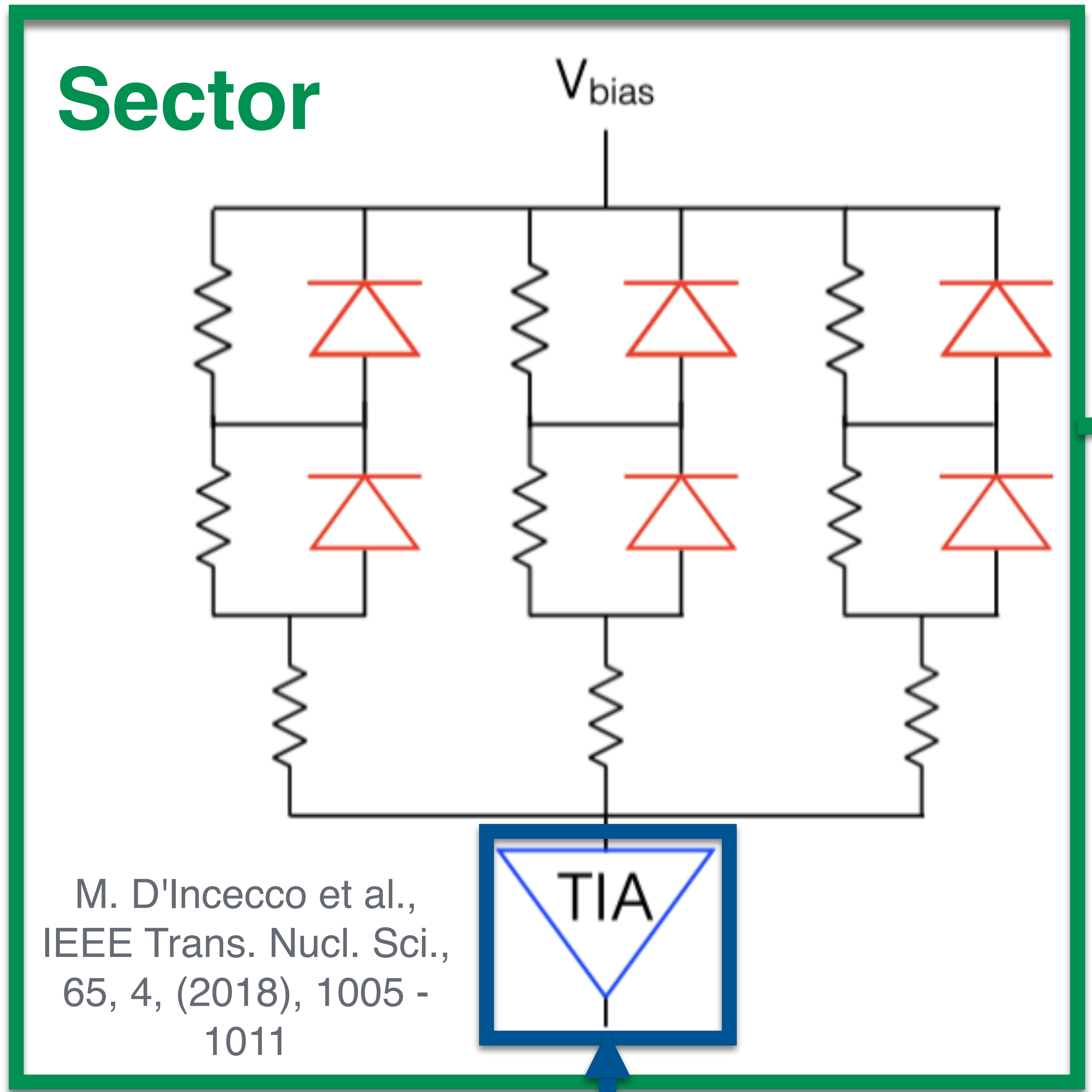

- DCR has 2 generation mechanisms
- Thermal agitation dominant @T>100K
- Field-assisted tunneling @T<100K
- **E** field profile engineered to suppress tunneling.

- AP dangerous to background rejection
- Suppressed by introducing a dopant into the active layers of the SiPMs.
- DiCT suppressed by the low **E** field

# Step 1: Current Performances


- DCR has been reliably measured by different groups. Expected at ~$1.5\times10^{-3}$ cps/mm$^2$ at DS20k chosen working point (7V over-voltage) thanks to the LF technology
- DiCT is expected to be ~30% at 7V of over-voltage, within the experiment specifications.
- AP has been effectively brought down to almost negligible levels: <2% within 5us from the primary avalanche at 7V of over-voltage.

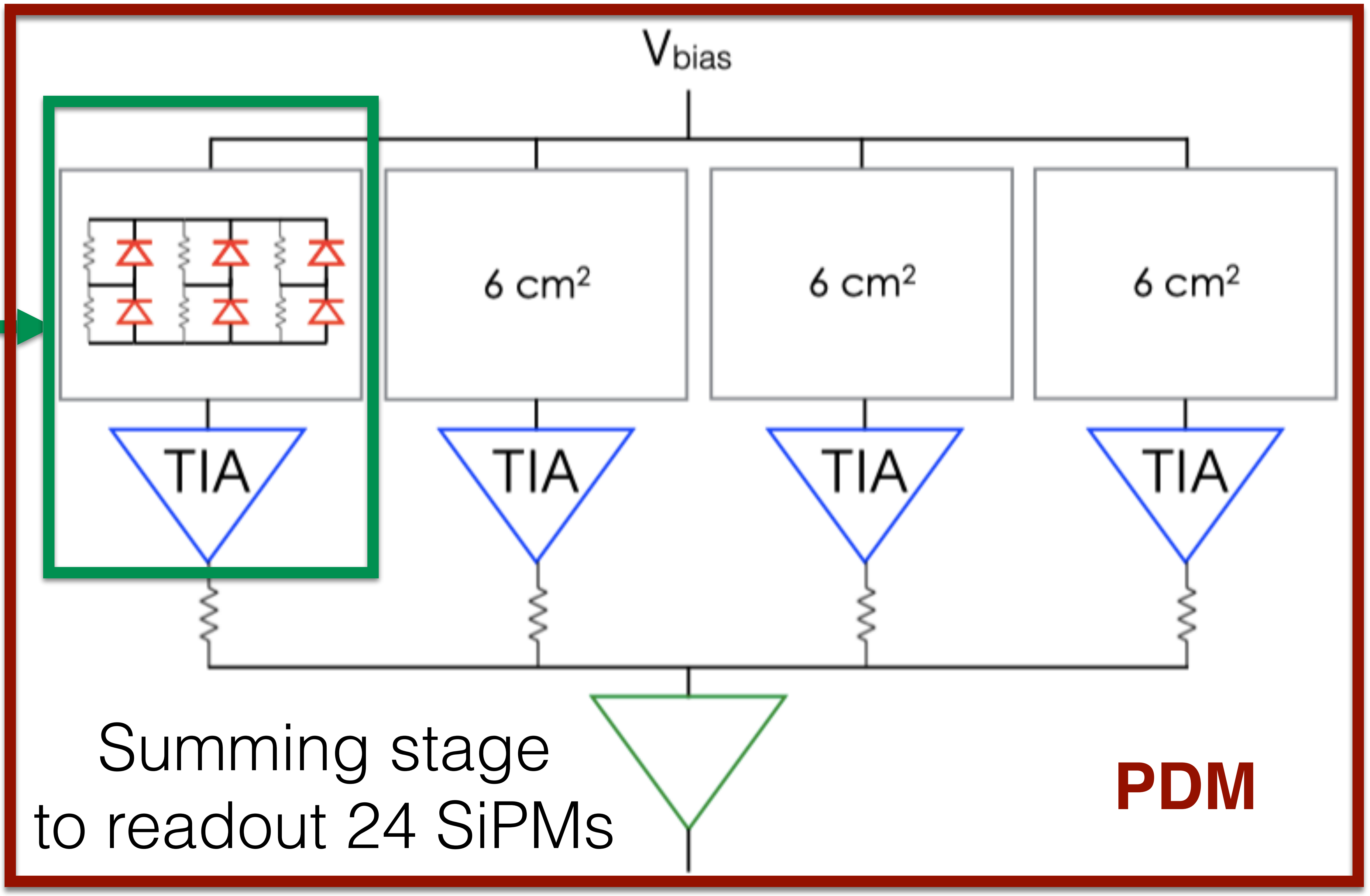
# Step 2: Readout Strategies

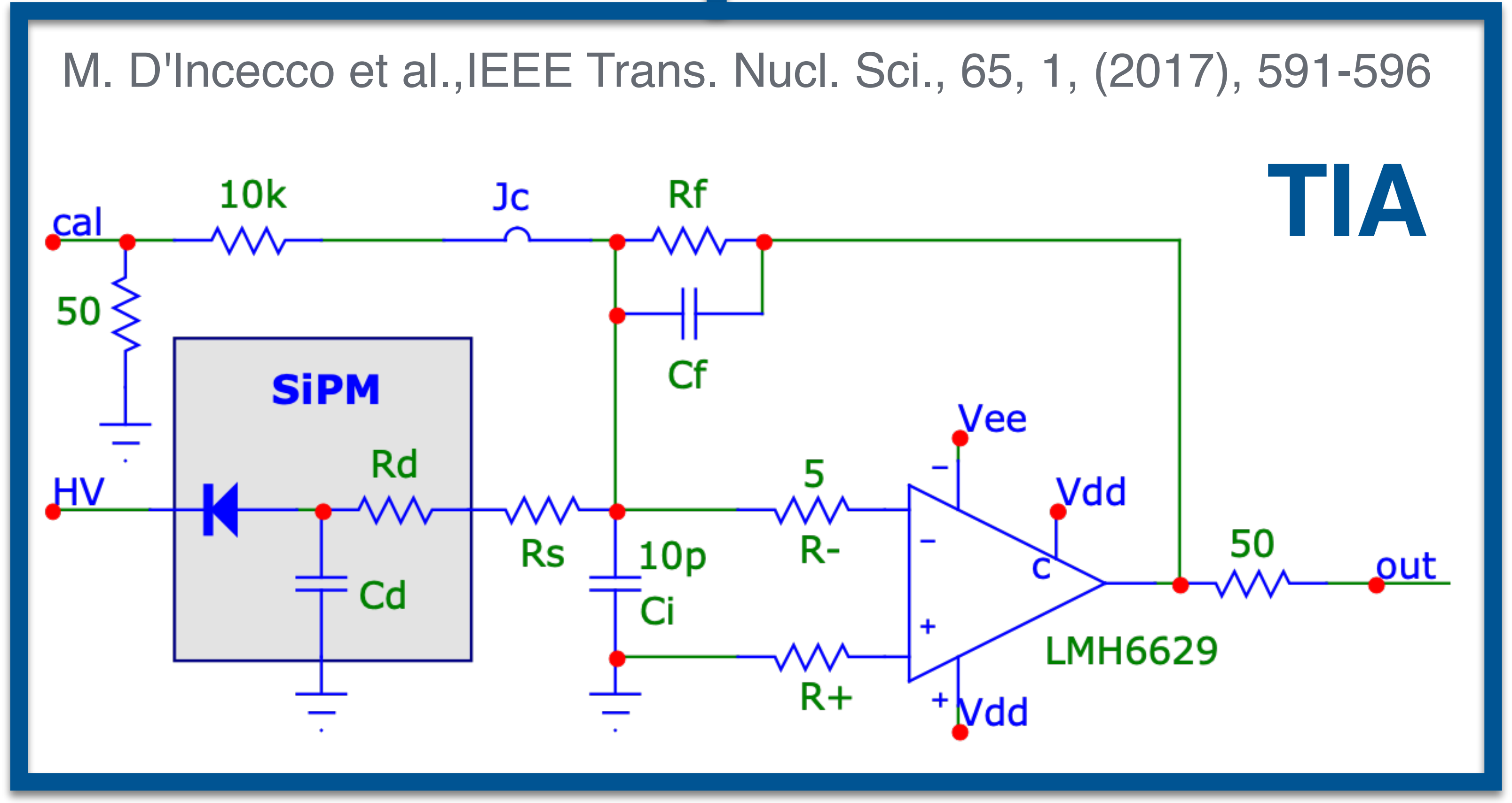



Mixed series/parallel configuration

Reduce $C_{in}$@TIA

Preserve BW



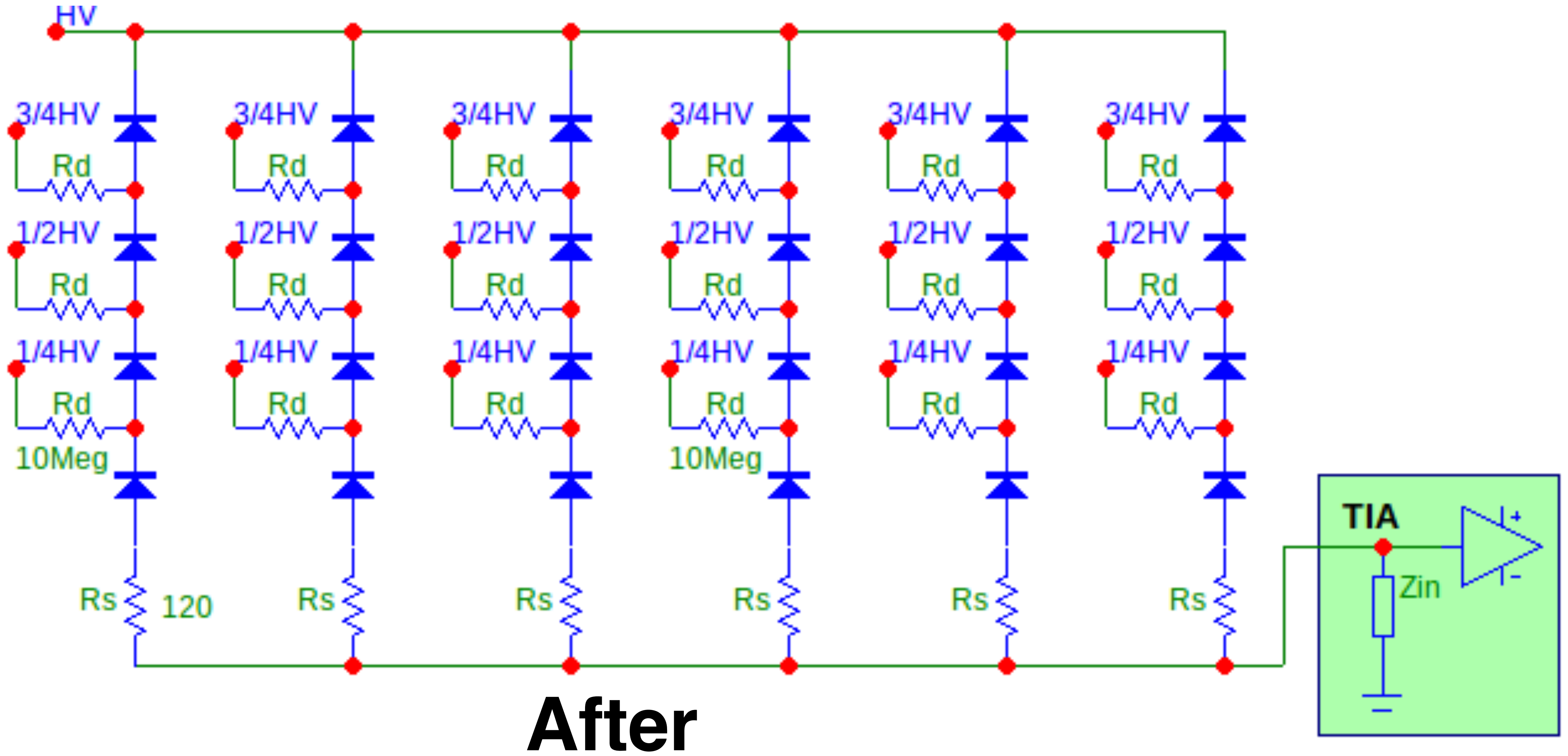

SiPM = current generators + huge output capacitance (~50pF/mm²)

Transimpedance amplifier (TIA) High Bandwidth and Low Noise

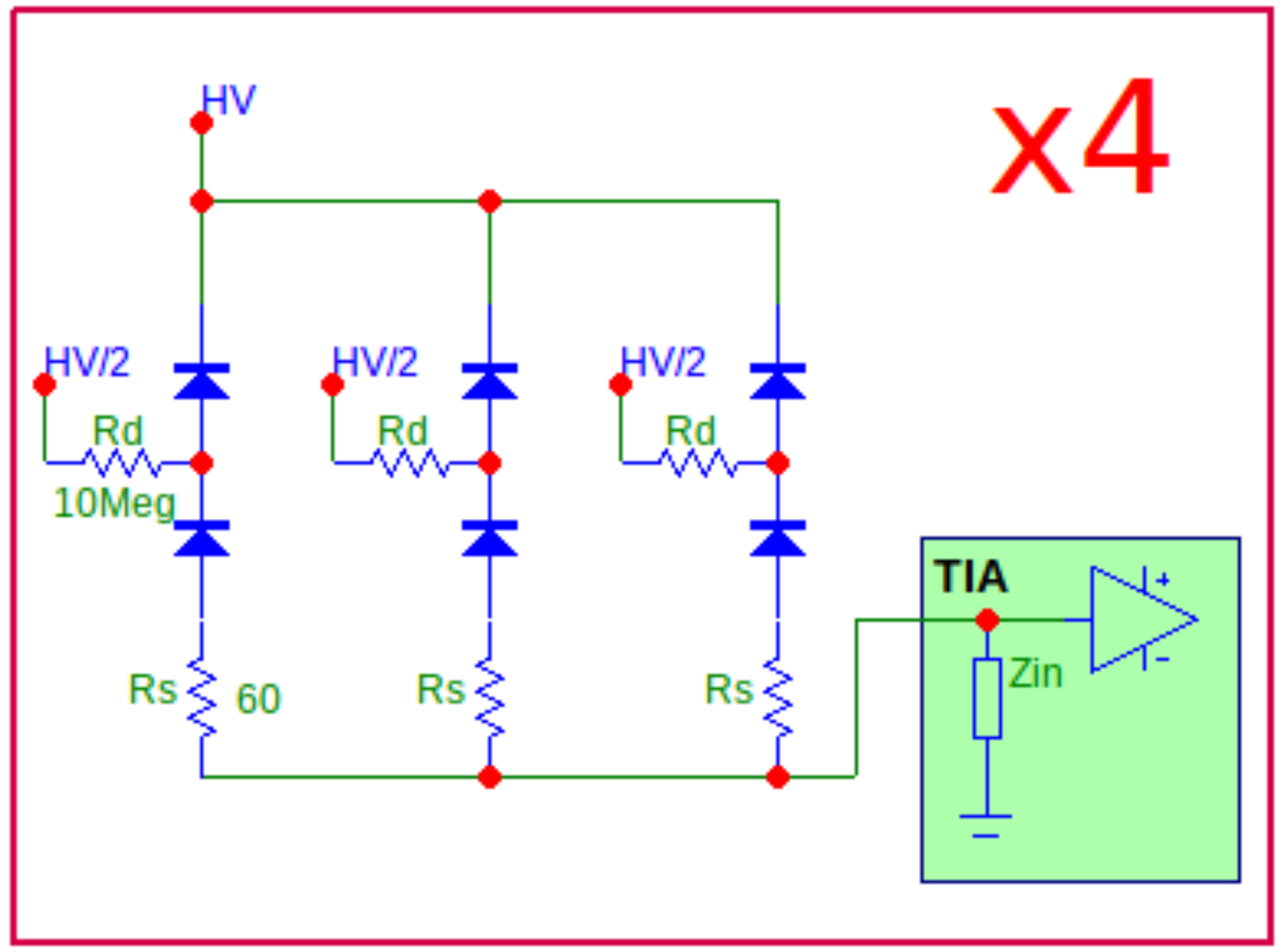
SNR is reduced wrt a single SiPM, but still very high

Power dissipation with this scheme was < 250mW per PDM

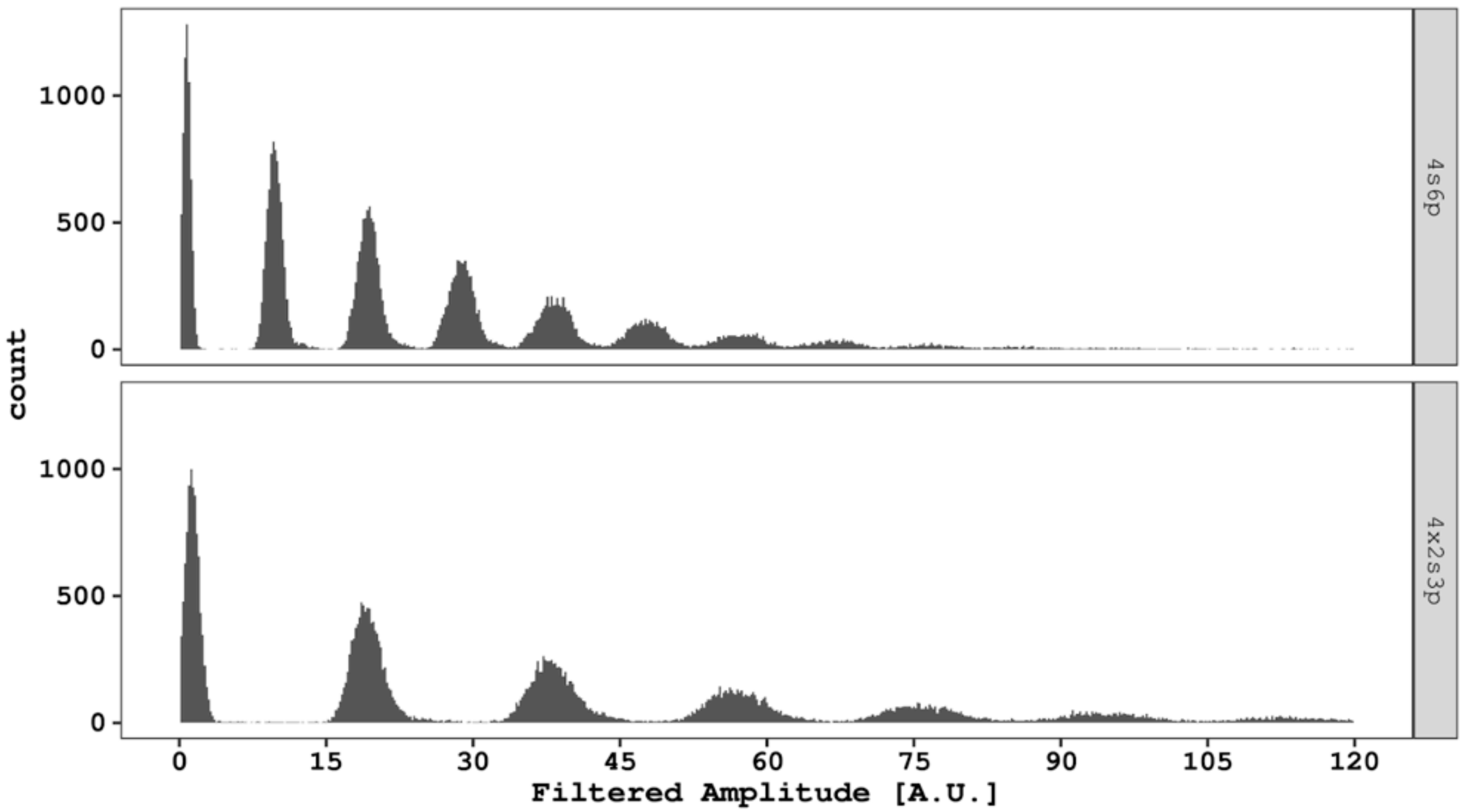
# Step 2: ...and upgrades




After




Before

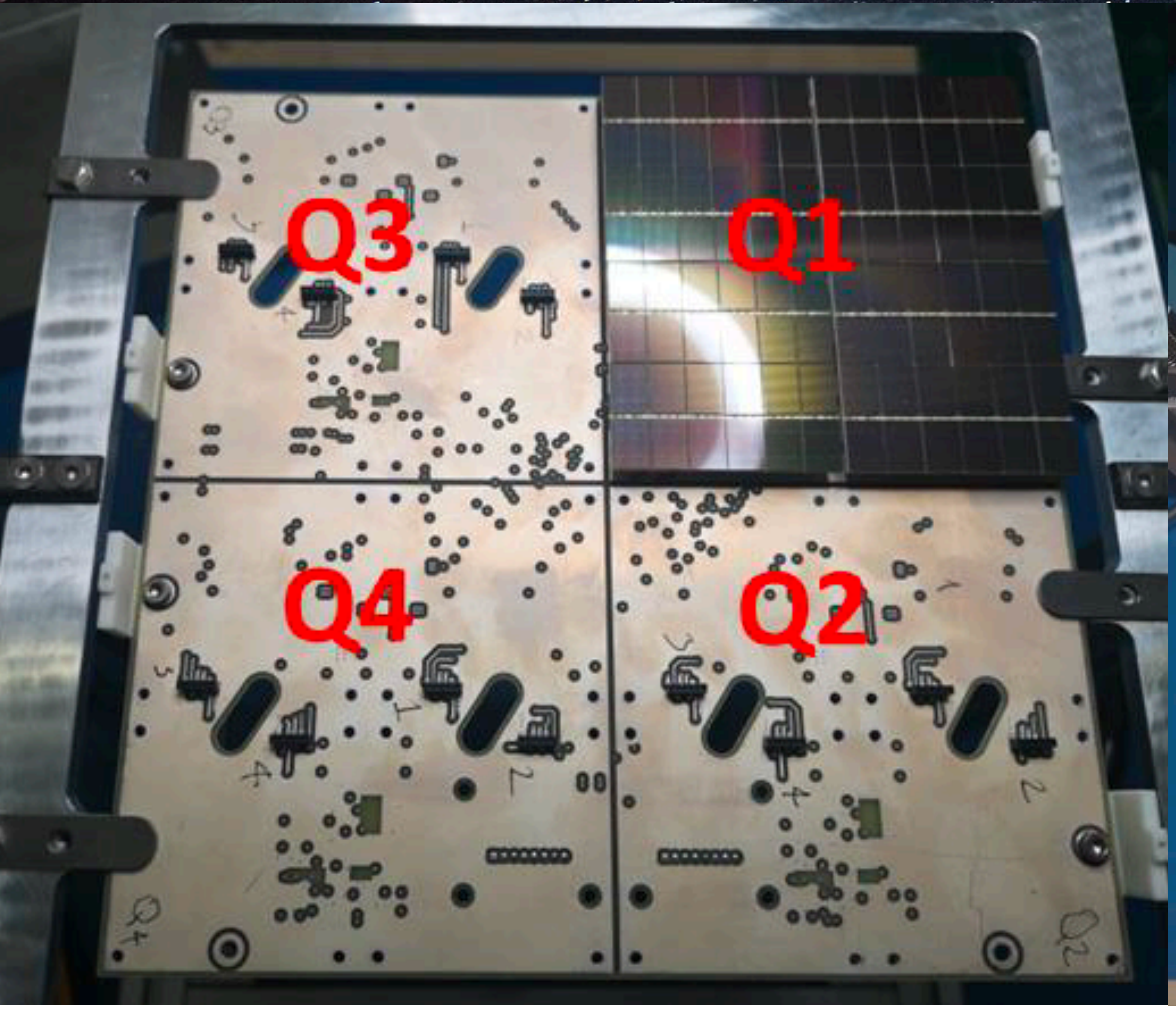



Switch from 4 sectors (6cm$^2$) to 1 single 24cm$^2$ unit

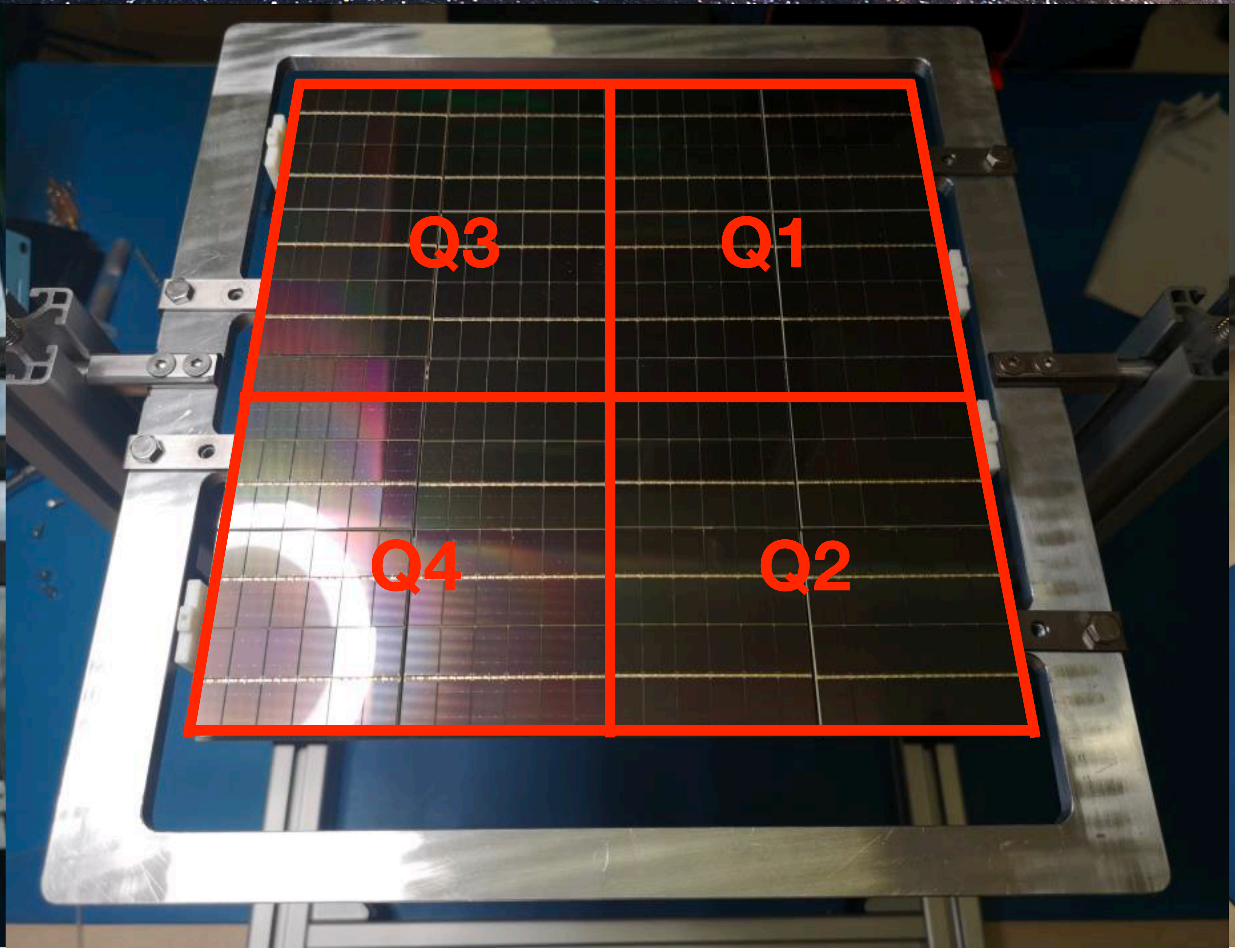
Power dissipation reduced from ~250mW to < 50mW per module

Biasing network and pre-amplification moved in a single PCB

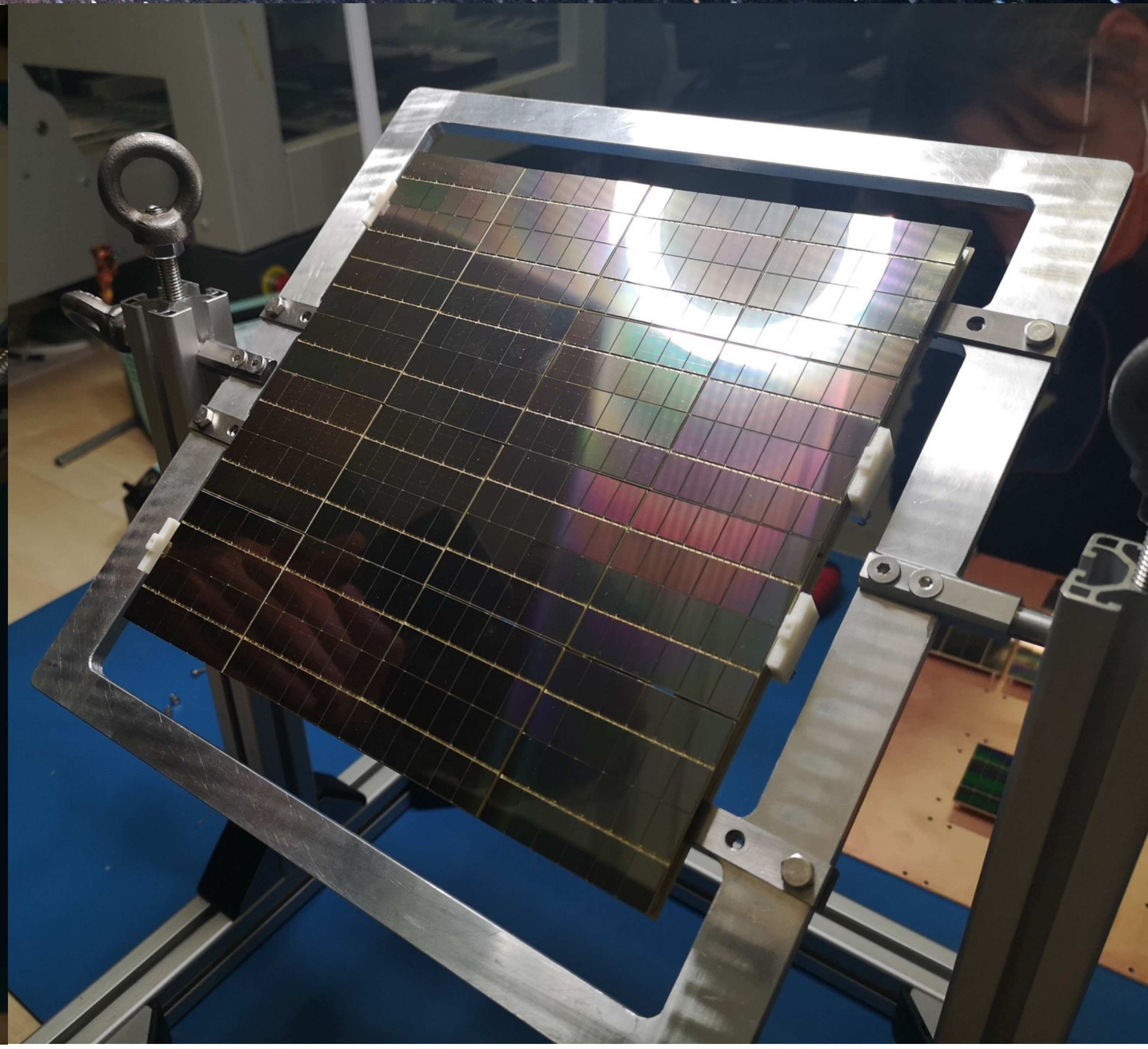
# Final photo-detection units (PDU)



Assembly phase of a final PDU

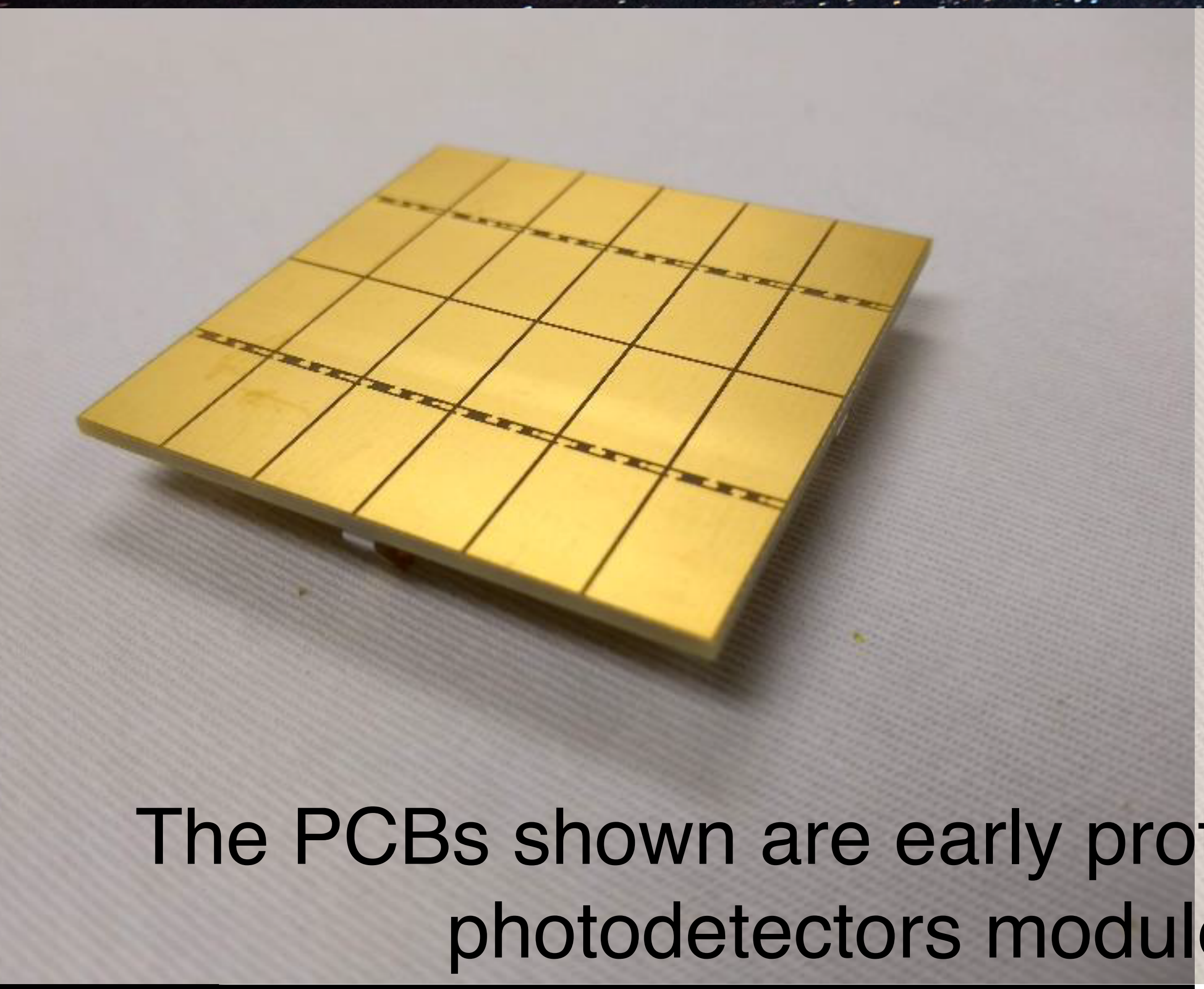


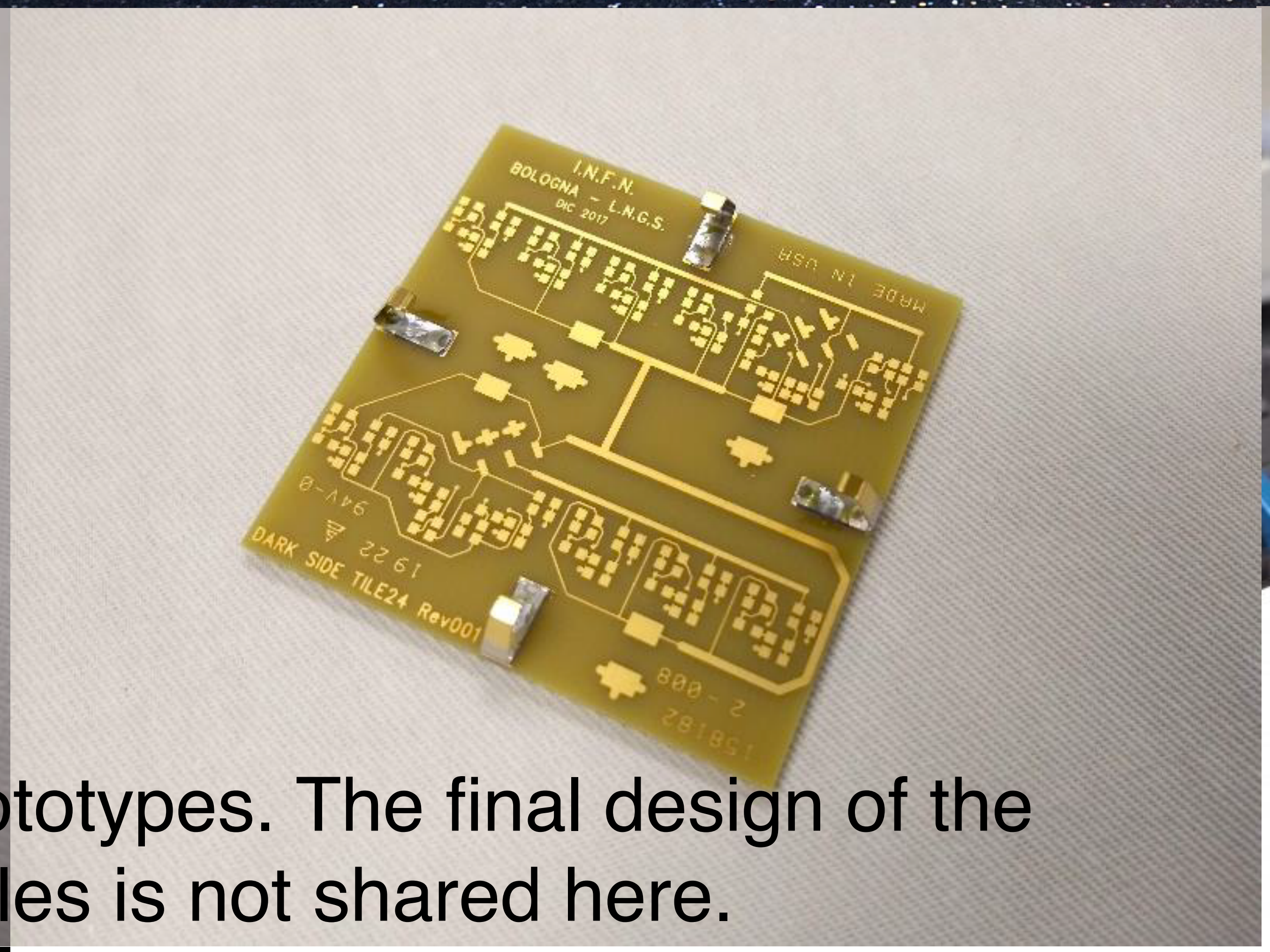
Final PDU assembled

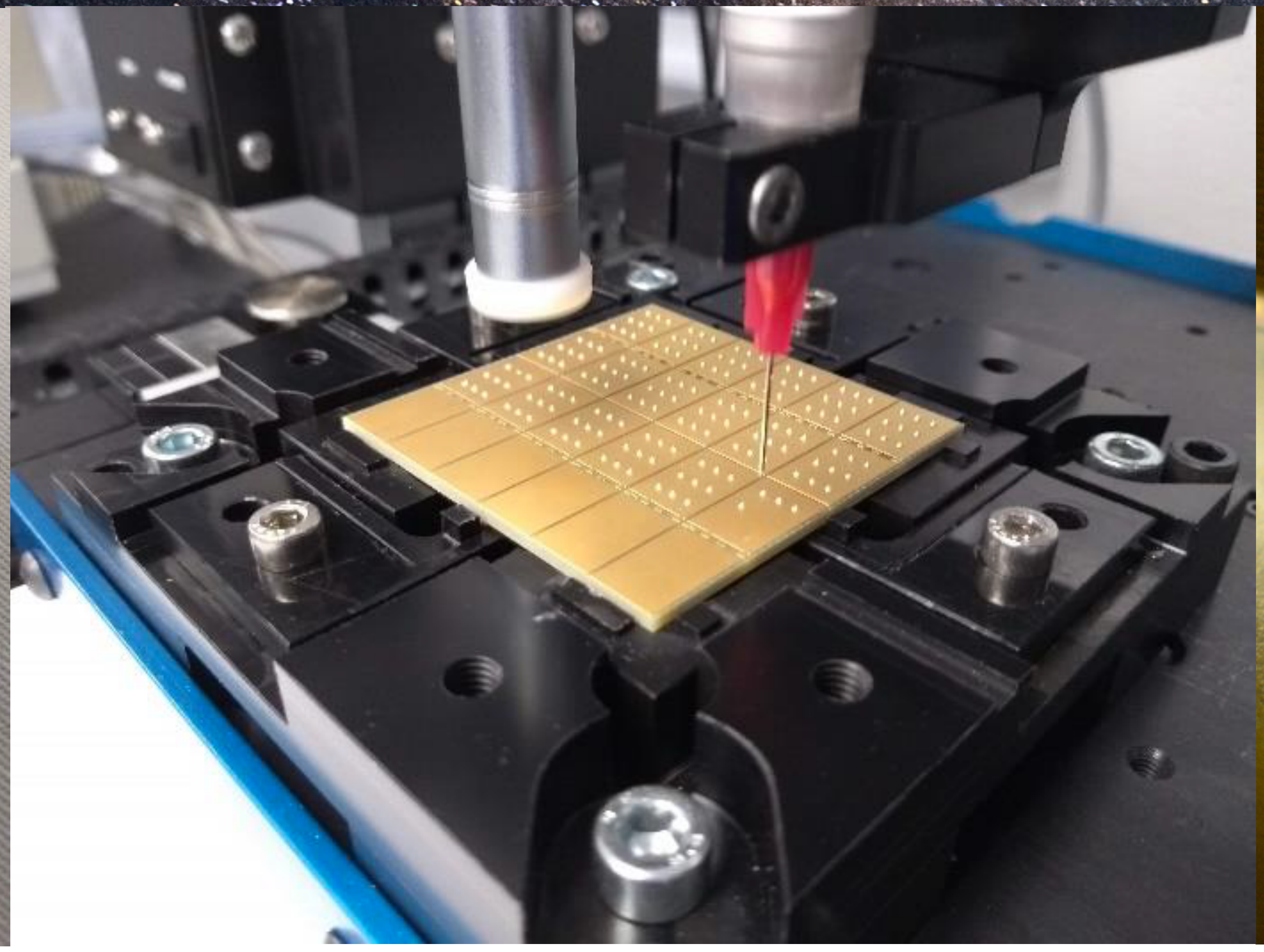

Final PDU assembled

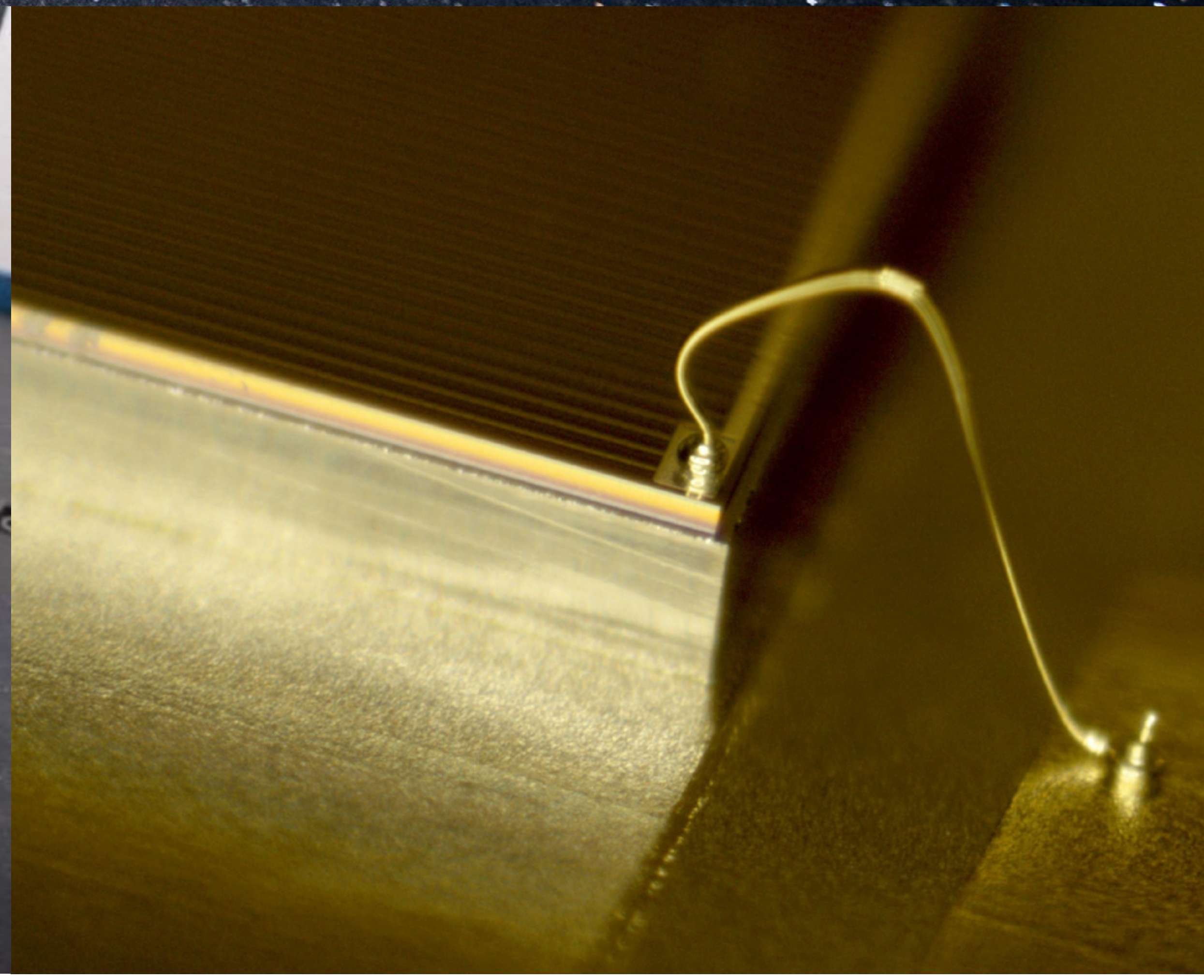
- PDU: mechanical unit of photo-detection system. Contains PDMs organized in readout channels.
- Several prototypes of Photo-Detection Units (PDU) have been produced and tested in LN and LAr.
- All the requirements on gain, SiPM noises, SNR and timing resolution are met or exceeded.
- Final DS20k PDUs contain 16 PDMs, readout as 4 analog channels.

# Step 3: Packaging

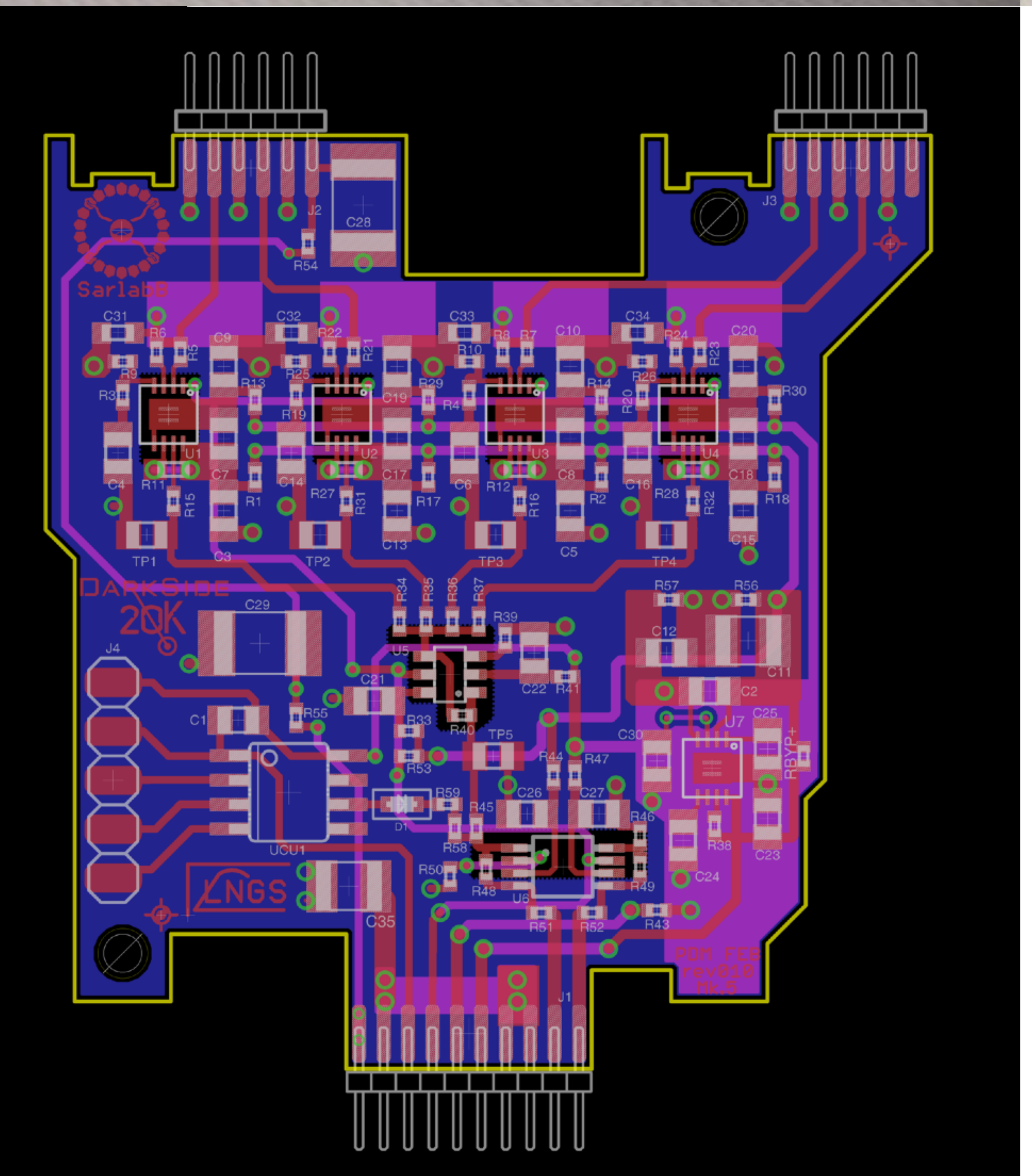






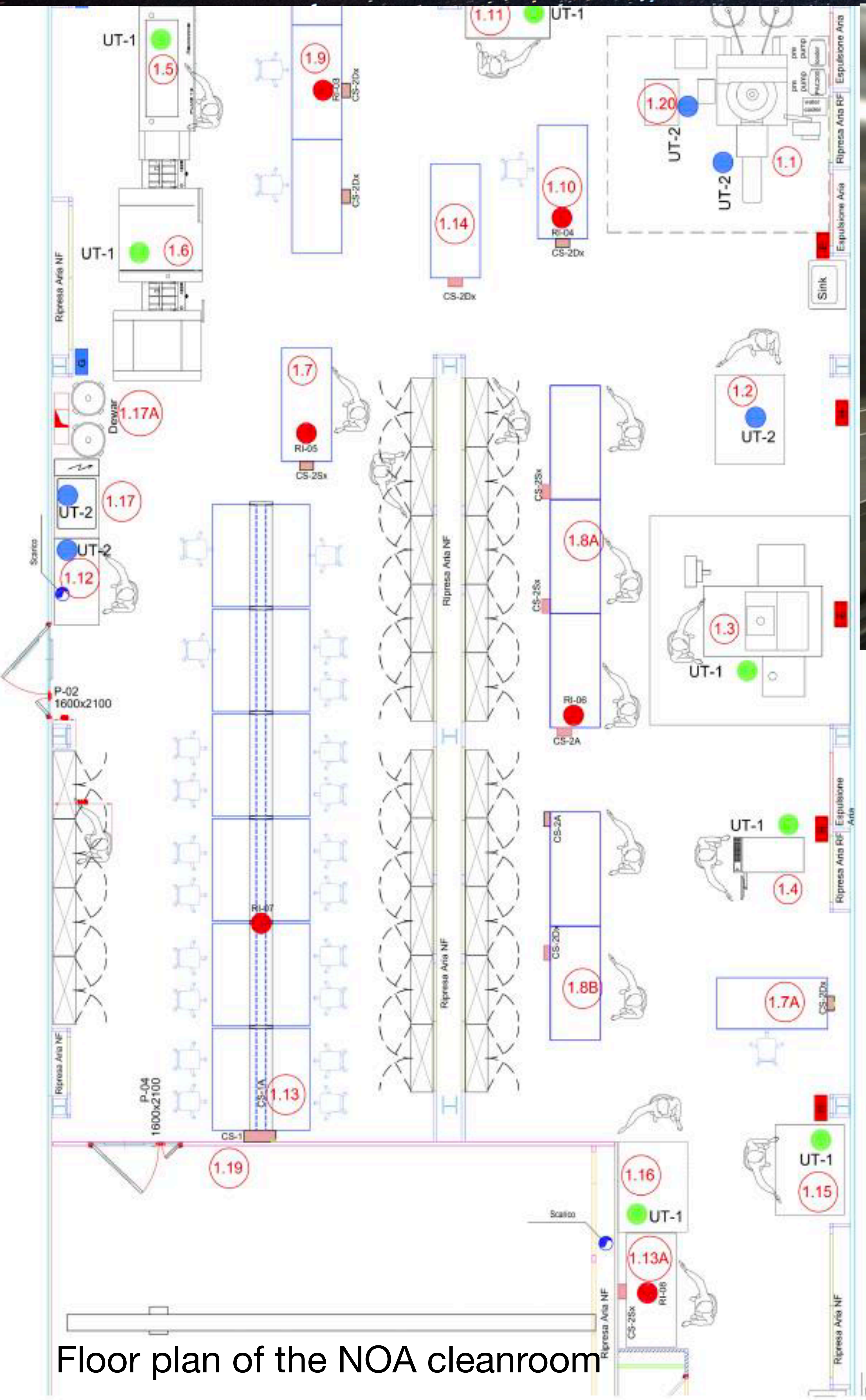


The PCBs shown are early prototypes. The final design of the photodetectors modules is not shared here.



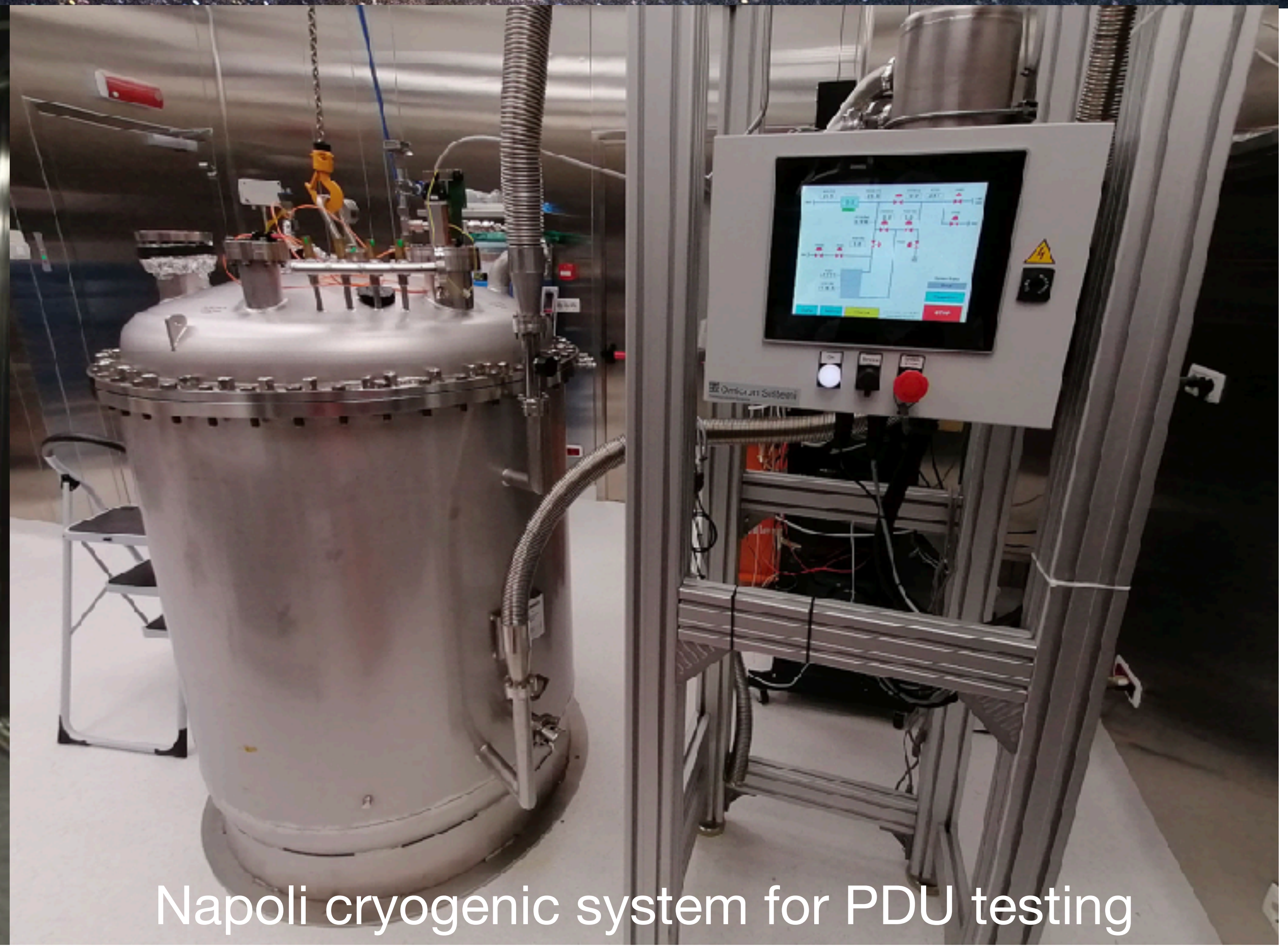
- SiPM development and readout electronics design are only the beginning of the endeavor! Packaging plays a crucial role for PDM reliability.
- Wire-bonding and die-bonding procedures finalized.
- Materials and components are continuously being assayed and selected to ensure the fulfillment of radio-purity requirements.
- Final assembly set to start soon!

# Step 4: Production and Testing



Floor plan of the NOA cleanroom

Photo of the NOA cleanroom



Napoli cryogenic system for PDU testing

- TPC PDUs will be assembled in a dedicated facility at LNGS: Nuova Officina Assergi (NOA).
- Veto PDUs (vPDU) will be assembled in UK distributed facilities.
- NOA: 421 m$^2$ clean room for packaging, test and assembly of SiPM-based detectors.
- Once assembled, all PDUs will be tested in a dedicated facility in Napoli (Italy).

# Thanks!

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# Backup slides