Cryogenic temperatures

7.4: EXTREME ENVIRONMENT AND LONGEVITY

IMPLEMENTING DRD7:

AN R&D COLLABORATION ON ELECTRONICS AND ON-DETECTOR PROCESSING

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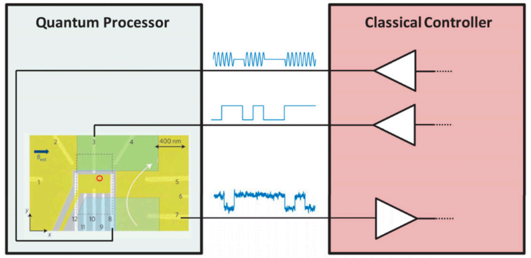
“Deep Cryogenic” electronics for Quantum technologies

- Future R&Ds will propose the development of novel quantum sensor technologies through the consolidation and scaling up of existing and emerging technologies;
- provide advanced enabling infrastructures and key capabilities for the development of cryogenic electronics in order to solve “the wiring bottleneck” on quantum computers (*see talk from Patrick Vliex*);
- cryogenic CMOS operating <4K and down to the mK will pave the way for scalability into the million qubit realm.

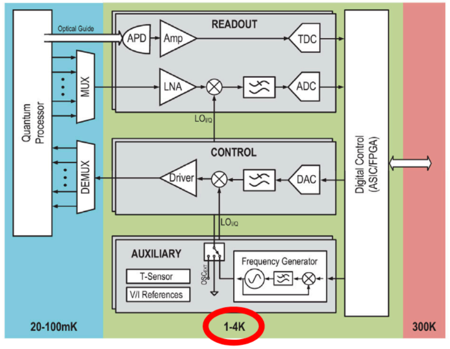
Classical Controller



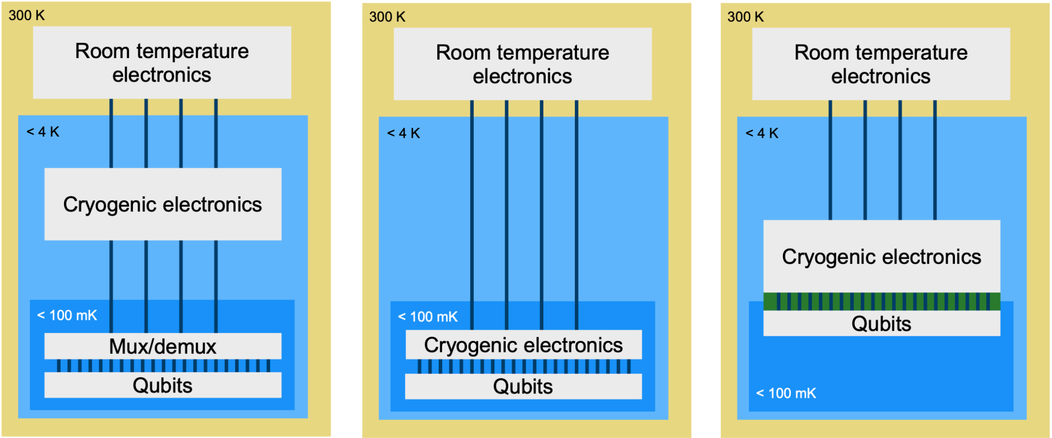
- Electronics to control and read-out the quantum processor mostly operated at room temperature (RT)
- Does not scale with the number of qubits

E. Charbon, ESSCIRC 2019.
B. Patra, *et al.*, JSSC, vol. 53, no. 1, 2018.

CMOS Integrated Controller



- More scalable approach by moving the control and read-out electronics closer to the qubits and operate it at cryogenic temperature (around 4 K)



C. Enz, A. Beckers and F. Jazaer, “MOSFET Compact Modeling down to Cryogenic Temperatures”

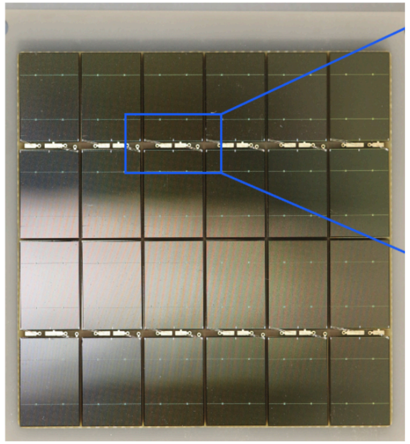
C. Degenhardt, “Cryogenic QUBIT Control – The Tyranny of numbers, self-heating and everything“

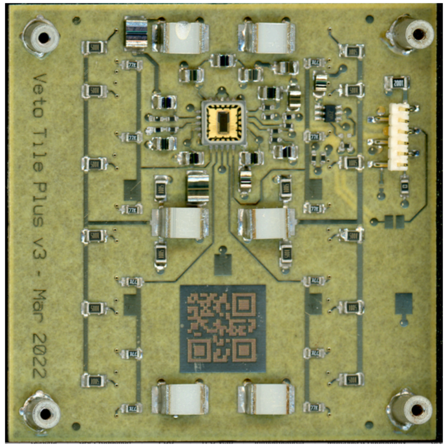
“Mild cryogenic” electronics for Liquid Detectors

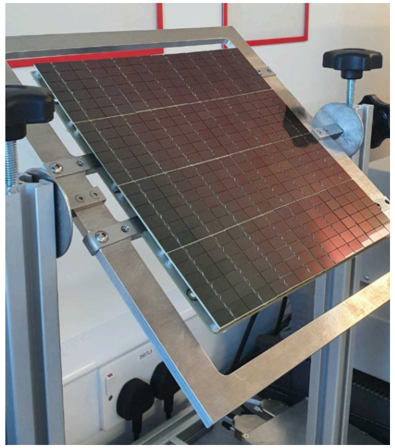
- Rare-event search on astroparticles: neutrino physics and direct dark matter detection using liquid scintillators e.g. Liquid Xenon (LXe) and Liquid Argon (LAr);
- Single and dual-phase detectors employing (solid-state) photon sensors require front-end readout electronics operating at 165K (LXe) or 88K (LAr).

Darkside-20K Veto Tile: Arlon-55NT substrate, hosts 24 SiPMs on front, front end QFN-20 packaged ASIC electronics on back;

Motherboard hosts 16 vTiles, sums signals from each quadrant; Outputs 4 differential analogue channels.







Experiment	Type	Photon detector	Area (m^2)
nEXO	LXe	SiPMs (FBK [Ch2-18], Hamamatsu [Ch2-19]), digital 3D-SiPM	5
DARWIN	LXe	PMTs, SiPMs or Hybrids (SIGHT, ABALONE)	8
TAO	LSci	FBK SiPMs	10
DarkSide-20k	LAr	SiPMs (FBK NUV-HD triple-dopant)	30
ARGO	LAr	SiPM is baseline option	200
DUNE	LAr	Light guide or trap + SiPM	10-1000

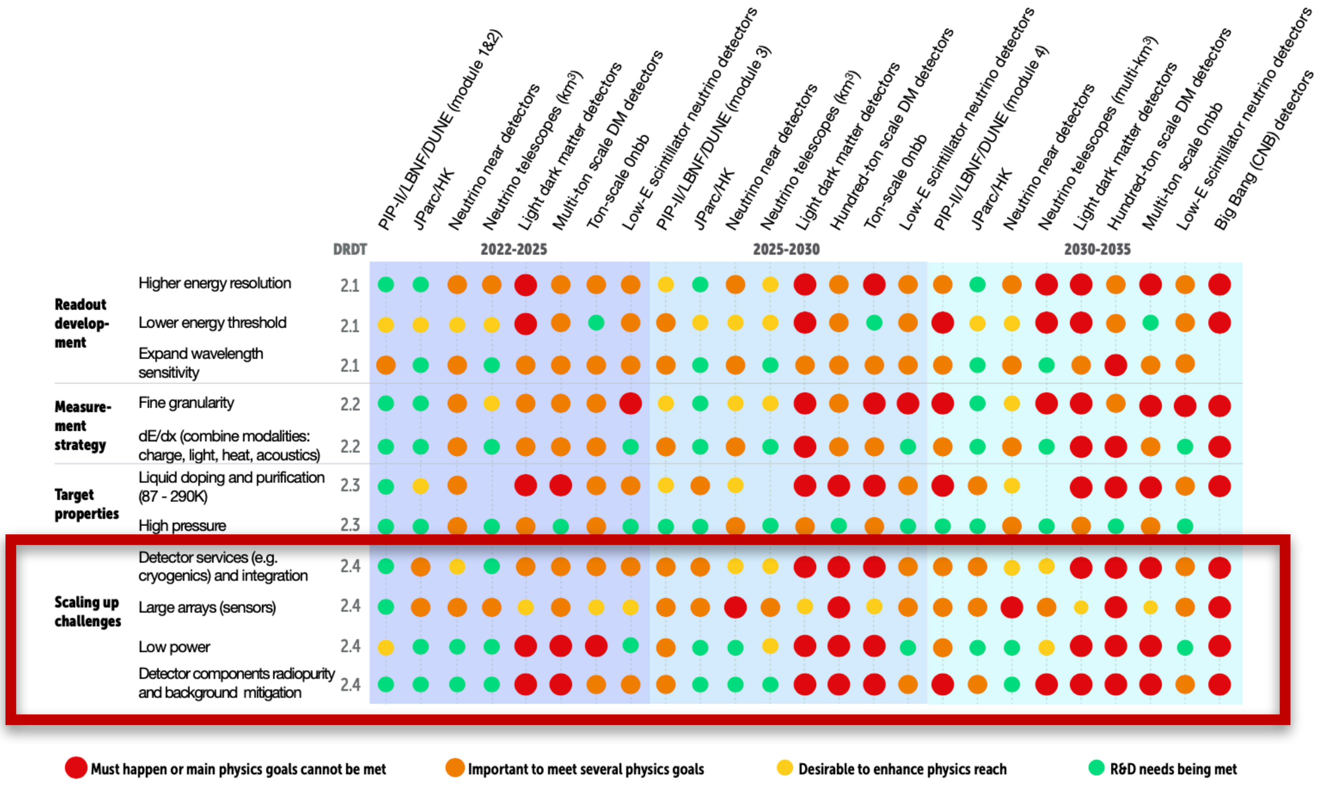
Need to commit to strong R&D programs for the development and deployment of new readout schemes suitable for future large-scale neutrino and dark matter detectors; today’s solutions are not scalable.

Liquid Detectors: future facilities with cold readout and scalable DSP

Future larger scale experiments will call for innovative cold integrated readout electronics implementing digital signal processing within the photosensor detection module.

"R&D on the 5-year horizon for greater integration include (…) dedicated ASIC design; 3D-vertical integration R&D; and development of lower-power, larger-area and lower-radioactivity photodetection modules."

Scaling up with cryogenic mixed-signal CMOS based photodetector technology.



DRDT 2.1- Develop readout technology to increase spatial and energy resolution for liquid detectors → achieve readout of more highly pixelated detectors with greater photon collection capabilities.

DRDT 2.2- Advance noise reduction in liquid detectors to lower signal energy thresholds → future liquid detectors requires R&D to achieve lower sensor and electronics noise.

DRDT 2.4- Realise liquid detector technologies scalable for integration in large systems → detectors with sensor areas reaching 10, 100 and ultimately 1000 m2.

Outlook for Cryogenic (CMOS) Electronics and future R&D

- CMOS Process Design Kits typically valid down to 233K (-40°C), although models scale relatively well down to 77K. This was verified with VDSM bulk and FDSOI technology nodes.

- Cold CMOS PDKs are fundamental for the development of complex mixed-signal ASICs allowing for innovative detector architecture and concepts, data transfer, readout and control. A future **collaboration R&D** will certainly focus **on infrastructures for device parameter extraction and modelling and development of cold PDKs**.

- The sweet spot around LN boiling temperature (where we get the best of the MOSFET characteristics with still no saturation effects) opens promising prospects on the development of **innovative readout concepts** both for neutrino and dark matter detectors with noble liquids and, in general, for calorimeters and photo detectors operating at 77K.

- The growing interest on the use of CMOS for Quantum Computing and Quantum Sensing could open new opportunities for collaborative efforts with selected silicon foundries on the optimisation of solid-state sensors and CMOS processes for operation at cryogenic temperatures.