Cold electronics

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On behalf of the DUNE FD1 PD Photosensors & Electronics WGs

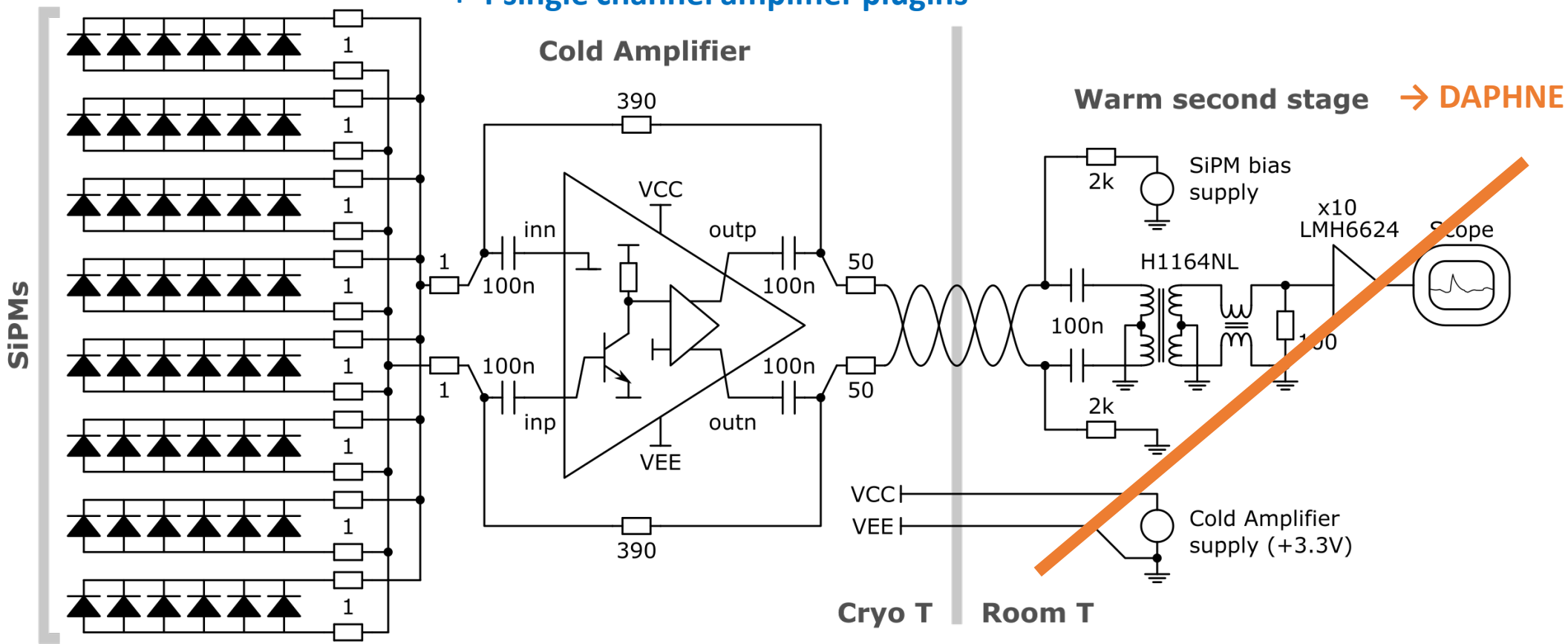
Cold electronics

SiPM boards

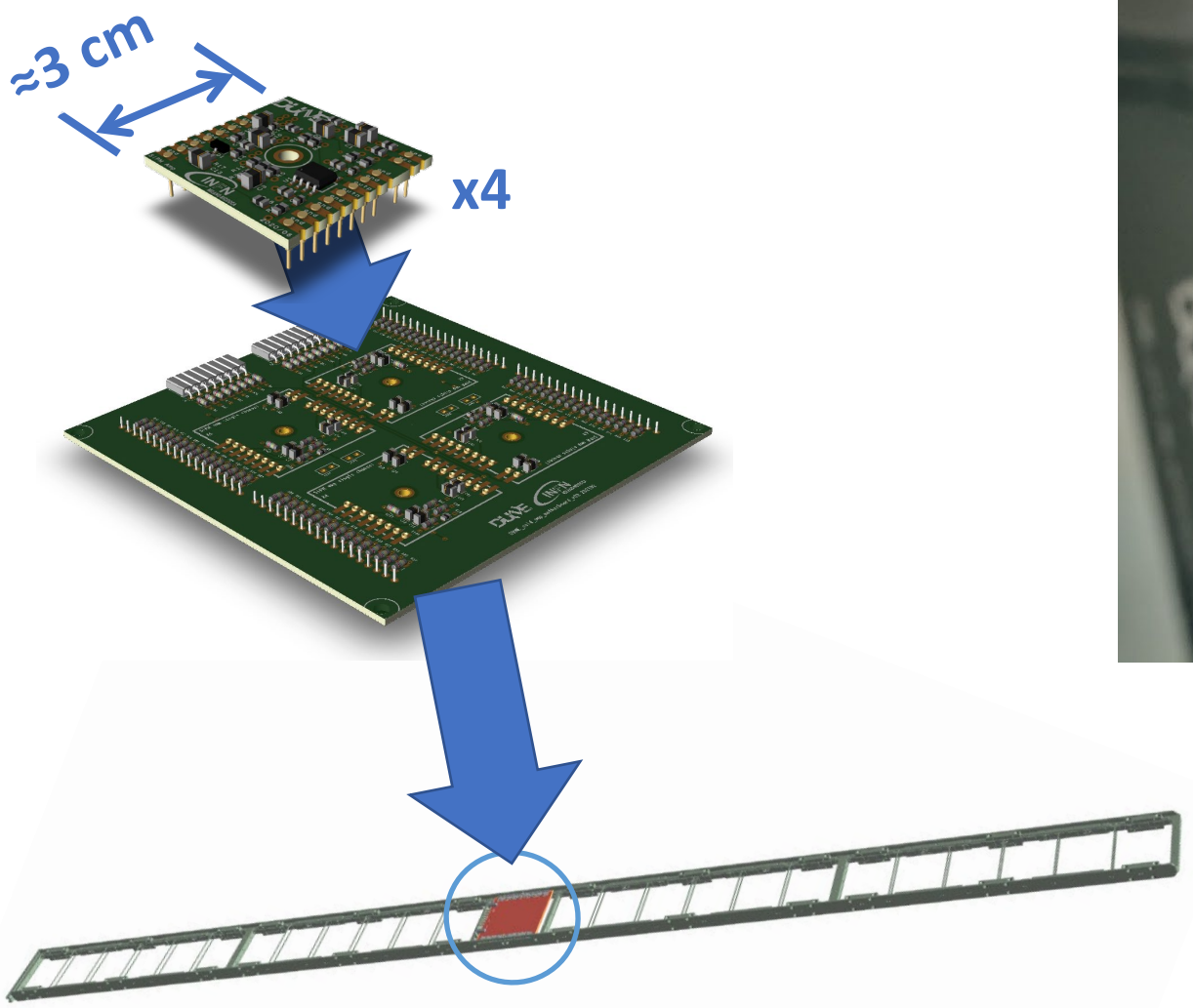
Routing aka signal lead boards

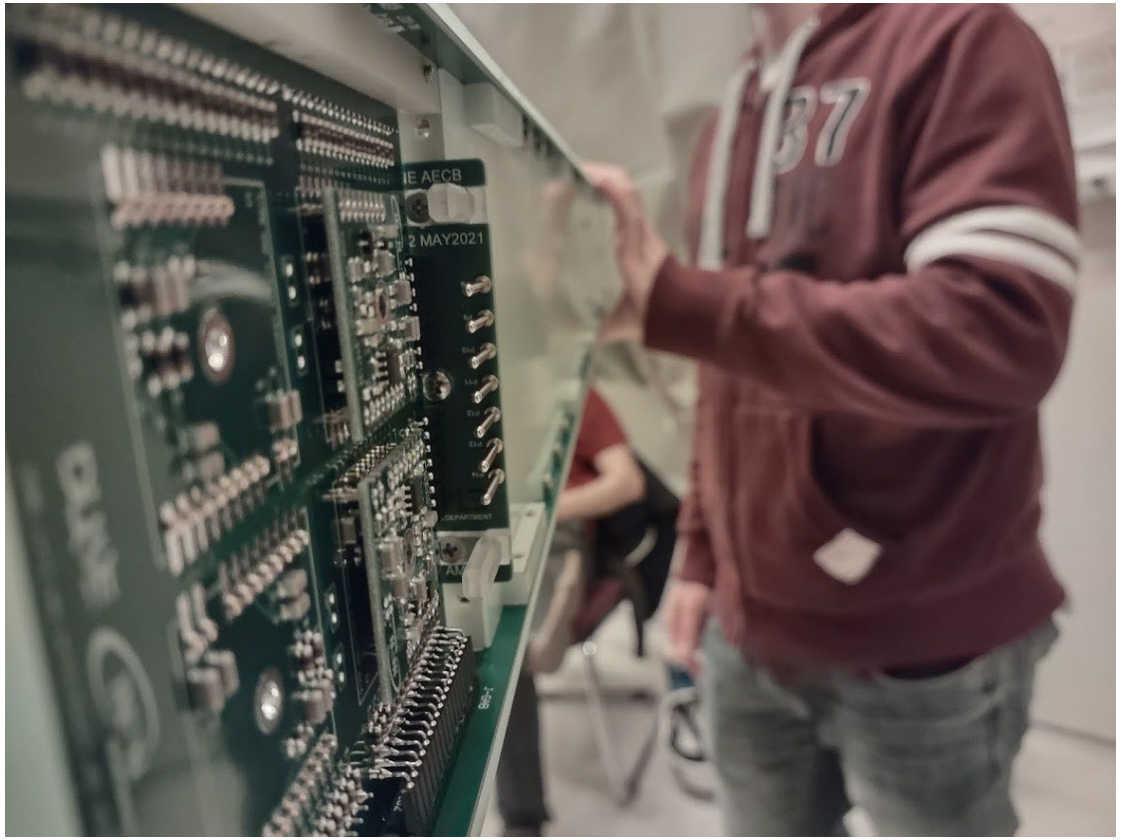
Cold amp motherboard
+ 4 single channel amplifier plugins

AECB, SASEBO, NIOBE, cables



Cold electronics





Detailed description of the cold amplifier:

Cryogenic front-end amplifier design for large SiPM arrays in the DUNE FD1-HD photon detection system

C. Brizzolari *et al* 2022 *JINST* **17** P11017

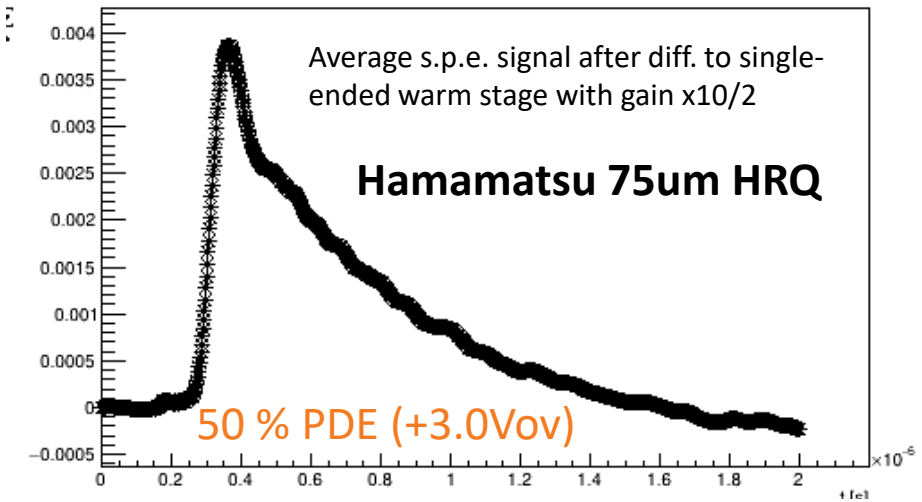
https://doi.org/10.1088/1748-0221/17/11/P11017

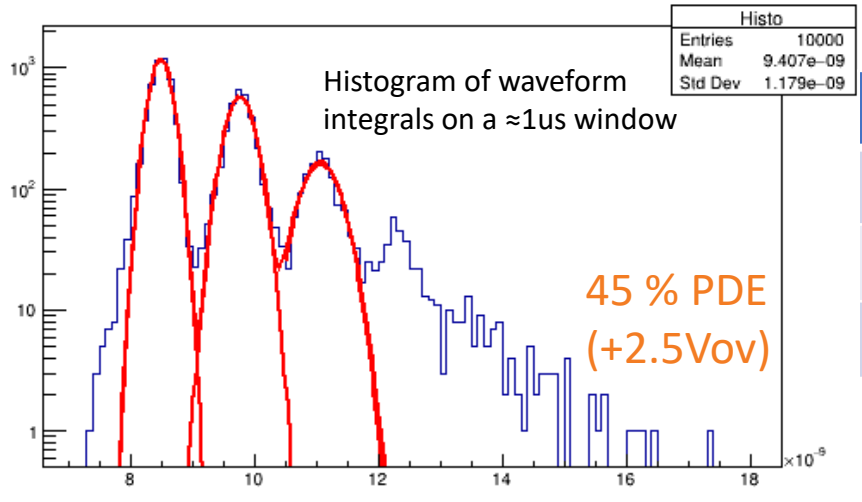
and arXiv:2207.13616

Cold electronics

- FD1-HD configuration, 48 SiPMs in parallel
- Test bench results, no supercells, no signal lead boards

Requirements:
- **≈2000 p.e. dynamic range**
- **<100 ns signal rise time**
- **S/N>4**

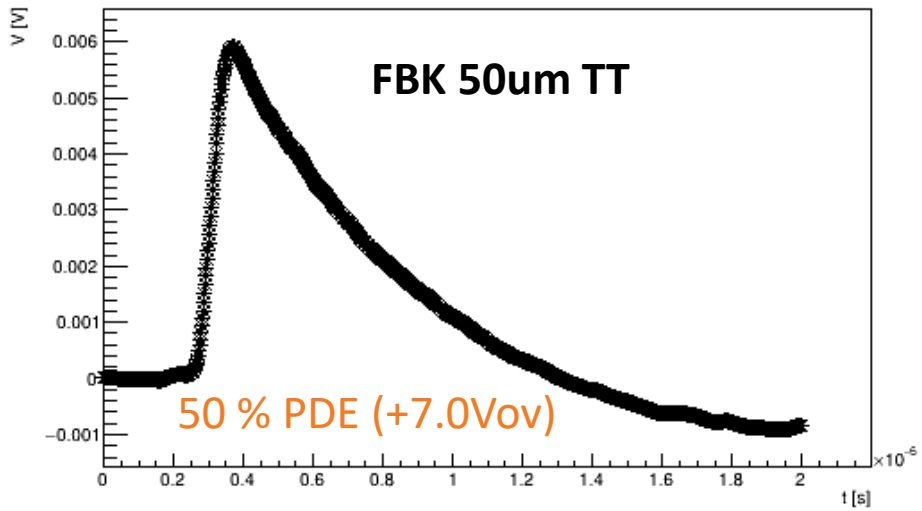


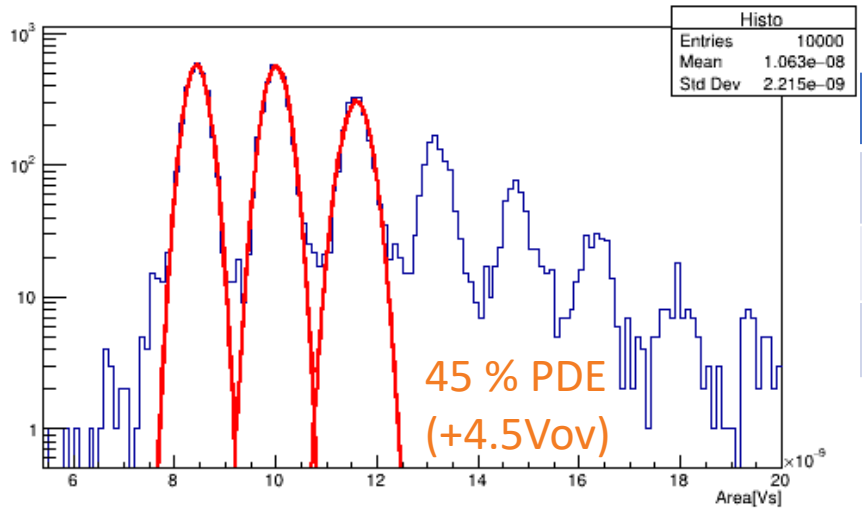


Dynamic range before saturation of the opamp output stage on 100-ohm diff. load

PDE	Vov	DR (p.e.)	S/N
40%	2.0	≈2900	6.30
45%	2.5	≈2350	7.49
50%	3.0	≈2000	8.92

Single p.e. gain divided by sigma of the baseline





PDE	Vov	DR (p.e.)	S/N
40%	3.5	≈2500	5.64
45%	4.5	≈2000	7.56
50%	7.0	≈1250	11.32

Lessons learned from ProtoDUNE2

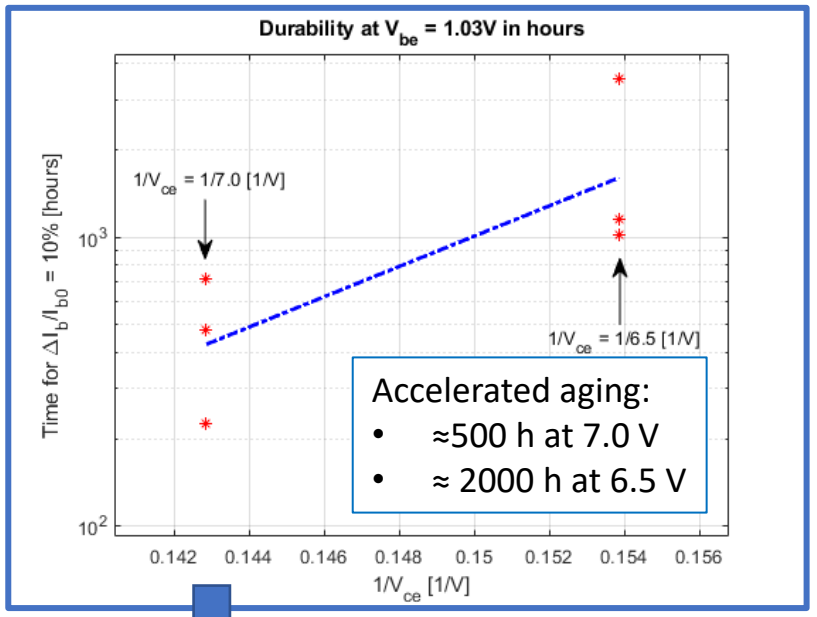
- Testing of supercells in LN2 and LAr in several labs has been very useful also for the cold amplifiers
- Allowed us to arrive at CERN with a system that was already well validated

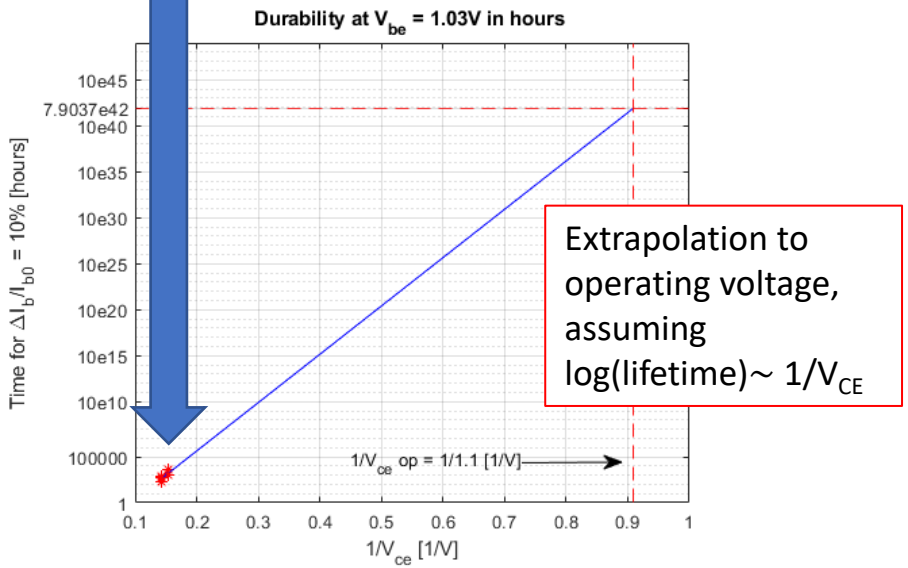
- **Electrical Integration of all components was smooth**
  - SiPM boards and routing boards are transparent
    - In particular, no issues observed from ≈1m long routing boards
      - Same signal shape, similar S/N and general performance with entire supercells compared to compact setup with just SiPM boards and cold amplifier
      - Somewhat higher sensitivity to external disturbances with entire supercells or modules compared to compact setup, but not surprising and anyway under control
  - Signal transmission looks fine also with 30 m cables
    - Matching of characteristic impedances does not look critical (≈70 ns signal rise time)
  - System grounding under control

- **Very good yield from PCB production**
  - 160/160 amplifiers produced for protoDUNE2 working out of the box
  - No failures (so far…)

Lifetime of components at cryo T

- At cryogenic temperature, increased carrier mobility can enhance degradation due to **hot carrier effects** (HCE)
- Aging accelerated by operation at high voltage (above max rating)
  → Li et al IEEE TNS doi:10.1109/TNS.2013.2287156
  → Cressler, Mantooth, *Extreme Environment Electronics* ISBN 9781138074224





BFP640 SiGe transistor

- Maximum datasheet values (room T): V_{CE}=4.1 V, I_C=50 mA
- Operated at V_{CE}=1.1 V, I_C=0.4 mA → Ample margin
- Stressed up to V_{CE}=7.0 V
- Degradation criterion: 10% increase in base current (decrease in beta)
- Lifetime at the operating point extrapolated to very high values

THS4531 fully differential opamp

- Maximum datasheet values (room T): V_S = 5.5 V
- Operated at V_S = 3.3 V → Ample margin
- Stressed for HCE up to V_S=8.0 V
- Preliminary results at INFN LNS (P. Litrico et al) indicate very long lifetime

Open issues

- Complete lifetime and reliability measurements before the final design review

- **For DUNE**: from motherboard + 4 single-channel plug-ins to a **single board with 4 channels**?
    - Lower production cost
    - Higher mechanical reliability (less connectors)
    - Lower flexibility, i.e. impossible to replace a single amplifier without dismounting the module
      → not a problem?

- Is **undershoot** an issue?
    - Study the possibility of removing it by deconvolution → no hardware changes necessary
    - If necessary, might consider modifying the DAPHNE input stage (LAN transformer)
    - If the above are not enough, increase value of AC coupling capacitors at cold
        - Possibly need to use X7R ceramics instead of just C0G
        - Synergy with vertical drift developments