Attivita’ italiane su FD-HD

Nov 12, 2021

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Remainder of the strategy

DUNE is pursuing a «two vendor scheme» for the procurement of the SiPMs for FD1-HD (288,000+spares) because of:

- Risk mitigation (retirement/disappearance of a vendor, as it happened with SensL a few years ago)
- Cost reduction (multiple bids)

We call it a «two vendor» scheme because in the preparatory phase we identified two vendors able to produce such an amount of cryogenic SiPMs and certify them at 87 K

Hamamatsu Photonics (HPK)
A Japanese company with satellite distribution companies in US and EU

Fondazione Bruno Kessler (FBK)
An Italian company serving particle and astroparticle experiments (CTA, CMS, DarkSide, LHCb, etc.)

Timeline

Design of customized SiPMs (Q2 2019- Q1 20)

Test of 25-sensor batches (Q3-4 20)

Test of 250-sensor batches (Q2 21)

Downselection (Q2-3 21)

Production of 4k+4k SiPMs for ProtoDUNE Run II (Q4 21)

Orders for FD1 (Q2 22)

Start of production (Q4 22)

Design of customized SiPMs (Q2 2019- Q1 20)

Test of 25-sensor batches (Q3-4 20)

Test of 250-sensor batches (Q2 21)

Downselection (Q2-3 21)

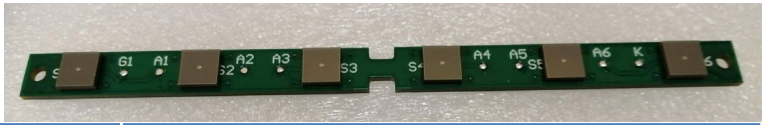
Orders for FD1 (Q4 21 – Q2 22)

Production of 4k+4k SiPMs for ProtoDUNE Run II (Q4 21)

Start of production (Q4 22)

Specifications

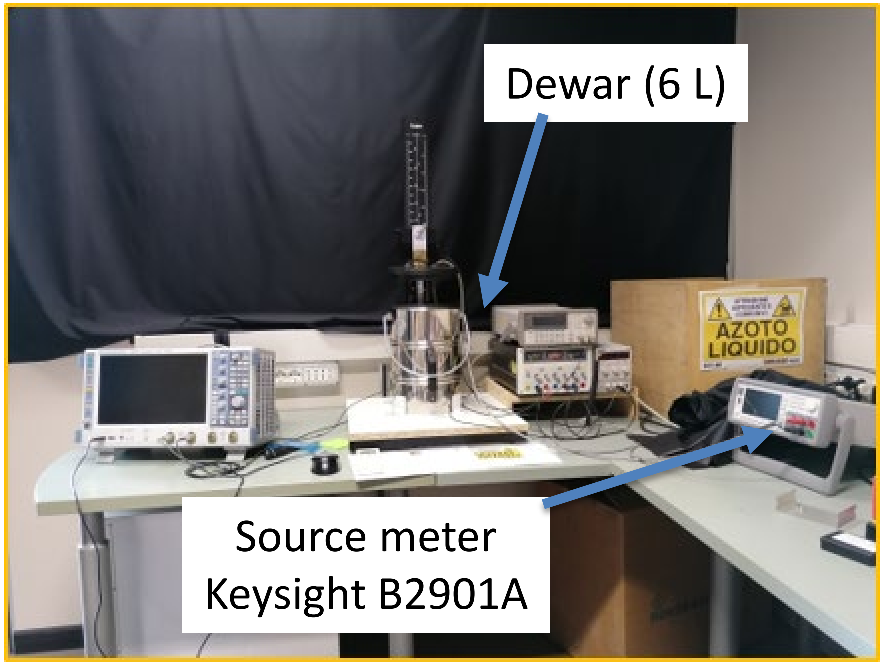
- Test 6 types of SiPMs 6x6 mm^2 developed **specifically for DUNE. «splits»**: 4 from Hamamatsu (HPK) and 2 from FBK
- 25 SiPMs per type fully characterized at single SiPM level
- 250 SiPMs per type in the DUNE SiPM board, tested at single SiPM level and in ganging



Parameter	value	note
Breakdown Voltage	<50 V	All splits
PDE at 430 nm	>35 % at nominal overvoltage	Achieved 45% for downselected splits
x-talk and afterpulse	<35% at nominal OV	Updated after the reanalysis of throughput
Rise time	<100 ns	not critical
Recovery time	a few μs	Not critical
Thermal cycles	>20	**Achieved by all splits!!**

Facilities for full test

- Bologna and Milano Bicocca setup 2 pilot stations capable to fully characterize SiPM at cryogenic temperature (Vbr, Rq, Dcr)



Amplifier
(each lab used a custom amp..good xcheck)

- After short time also the other labs built their system complying a set of requirements: Ferrara, NIU, Madrid, Valencia, Prague,

Test protocol

- Bologna and Milano Bicocca setup testing protocol
- Ferrara, NIU, Madrid, Valencia, Mi, Mib, Bologna, Prague labs were involved in the tests
- Same test procedures and compatible instrumentation to guarantee uniformity of results
- Combine all measurements

Planning for the SiPM tests in the DUNE pre-production phase

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1 The pre-production phase

In 2019, the DUNE Single Phase Photon Detection System (SP-PDS) Consortium set up an agreement with two vendors in view of the production of the SiPMs for first DUNE Module (288000 sensors). The vendors – Fondazione Bruno Kessler (FBK) and Hamamatsu Photonics (HPK) – agreed to optimize their SiPM technologies for the needs of DUNE and certify the sensors for operation at 87 and 77 K. In 2018-2019, we down-selected two technologies that will be at focus in the pre-production phase (2020-2022):

- The Hole Wire Bond (HWB) technology of HPK implemented in the S13360 chip with Silicon package.
- The NUV-HD-Cryo technology of FBK implemented in SMD epoxy resin package.

All sensors will be produced in the DUNE form factor: 6×6 mm^2. The aim of the pre-production is to down-select one sensor per vendor and produce 3000 SiPMs for FBK and 3000 SiPMs for HPK to be installed in ProtoDUNE-SP. The sensors will be installed in 30 X-ARAPUCA modules (3 APA) and tested in the Run II. The pre-production activities will culminate in the complete validation of the DUNE PDS during Run II in order to start the mass production phase.

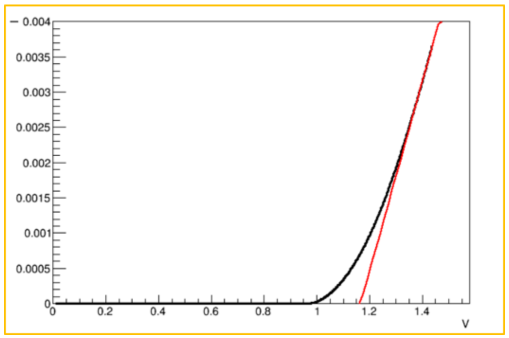
2 The FBK and HPK splits

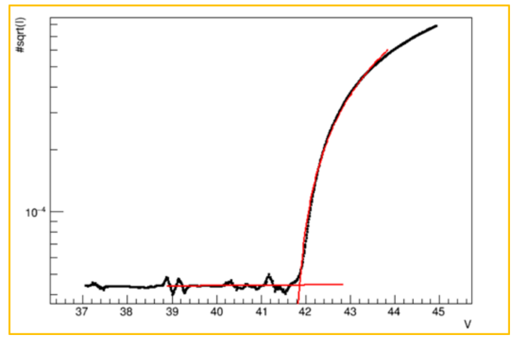
The NUV-HD-Cryo technology developed by FBK and implemented, for instance, in the Dark Side experiment, fulfills all basic specifications for DUNE. It has never been used for 6×6 mm^2 sensors and with the SMD package. As a consequence, the main DUNE production split that will be made by FBK

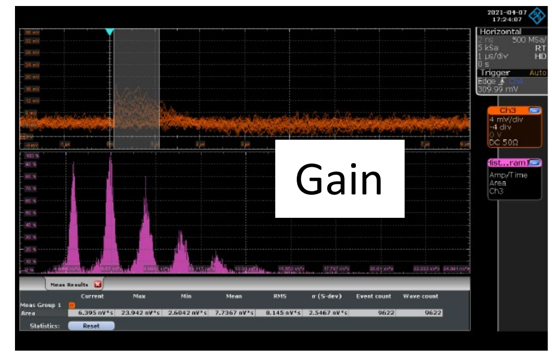
1

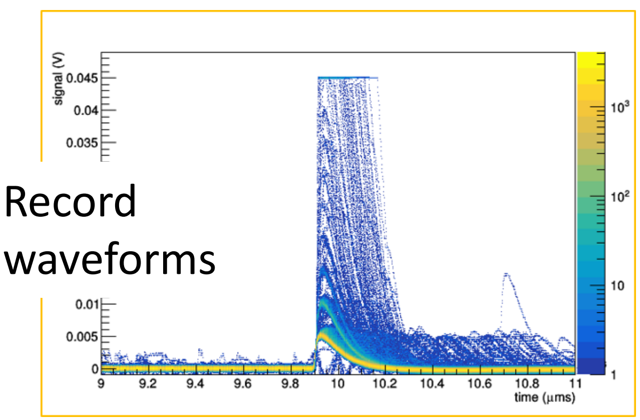
What we measure

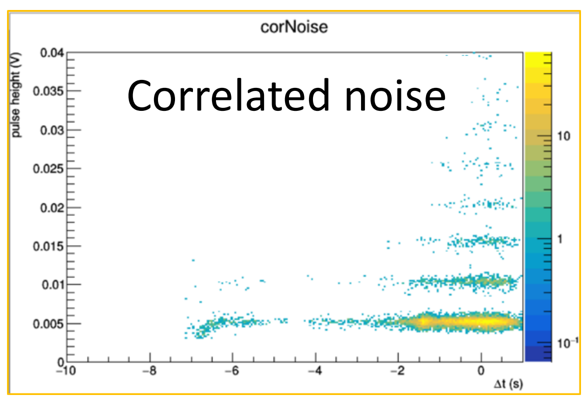
- First of all the IV curves
  - direct bias: Rq, inverse bias-> V_br

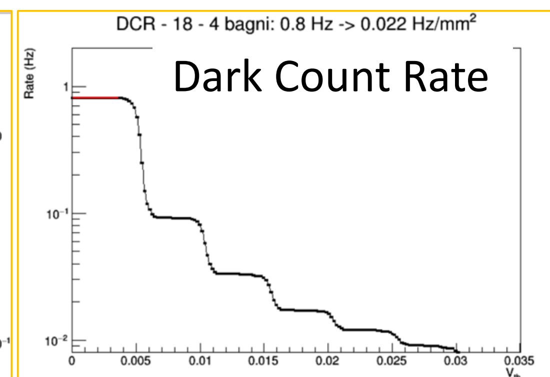












Data analysis

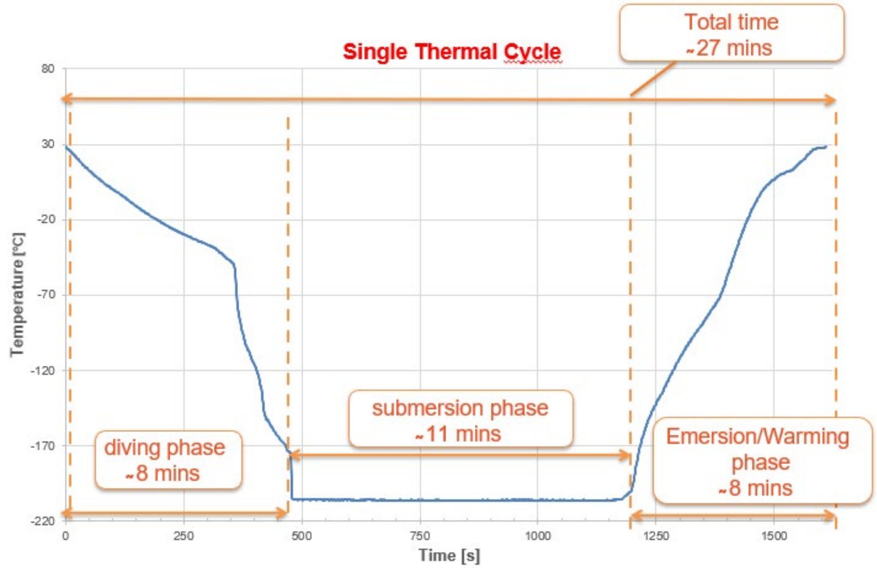
- All measurements on Hamamatsu sent to Madrid
- All measurements on FBK to Milano Bicocca
- A lot of work to check consistency of results from different labs and average all data

Example for Hamamatsu

LABS INVOLVED			Gain		DCR+B (mHz/mm²)		DCR-B (mHz/mm²)		Xtalk (%)		Afterpulses(%)	
	Model	PDE (%)	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Valencia Prague Madrid Ferrara Bicocca Bologna	50_LQR	40	2,38E+06	6,60E+03	54,08	0,96	12,79	0,67	9,96	0,47	2,15	0,15
		45	3,10E+06	8,97E+03	60,29	1,06	13,70	0,70	11,23	0,39	2,62	0,17
		50	3,84E+06	8,57E+03	71,92	1,01	16,62	0,85	13,38	0,37	5,13	0,21
Valencia Madrid Bicocca	50_HQR	40	2,25E+06	6,65E+03	38,74	0,98	7,36	0,83	7,15	0,34	2,06	0,16
		45	2,99E+06	6,79E+03	81,57	1,68	8,73	0,68	8,71	0,34	3,50	0,19
		50	3,78E+06	8,04E+03	53,25	0,92	9,65	0,46	10,92	0,36	3,95	0,21
Ferrara Valencia Bologna Madrid	75_LQR	40	3,49E+06	6,72E+03	42,14	0,65	6,10	0,32	9,47	0,32	1,41	0,15
		45	4,33E+06	6,26E+03	50,70	0,75	6,58	0,34	10,18	0,35	1,83	0,16
		50	5,16E+06	7,61E+03	50,88	0,68	9,07	0,41	11,84	0,34	2,96	0,18
Bicocca Prague NIU	75_HQR	40	3,94E+06	2,02E+05	26,40	2,12	4,60	0,24	6,16	0,05	1,63	0,44
		45	5,43E+06	2,34E+05	31,32	0,65	5,57	0,17	7,03	0,30	2,35	0,66
		50	5,81E+06	2,73E+05	32,53	4,68	6,46	0,73	9,85	0,14	2,78	0,23

Thermal tests

- For test for downselection at least 20 cycle were required for qualification.

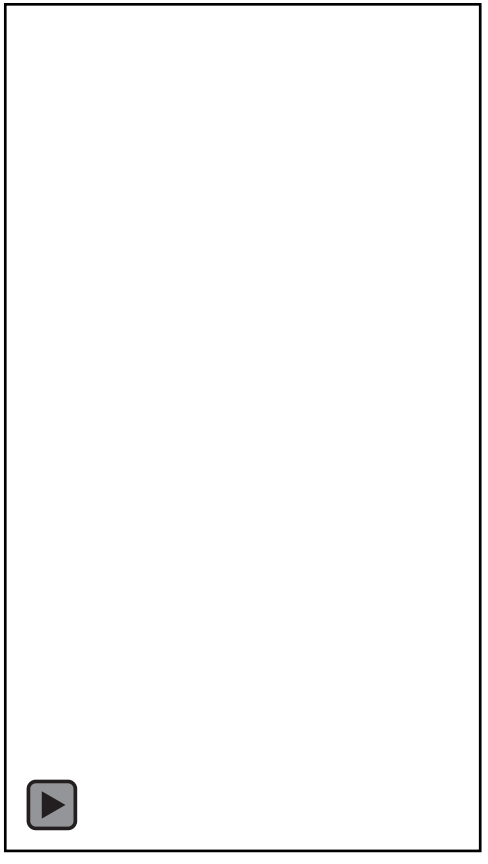


- Time consuming, risk of damage a working device. We are studying the aging factors.
- For mass production only 2 or 3 thermal cycles will be done. (time for test reduced by almost a factor 2!)

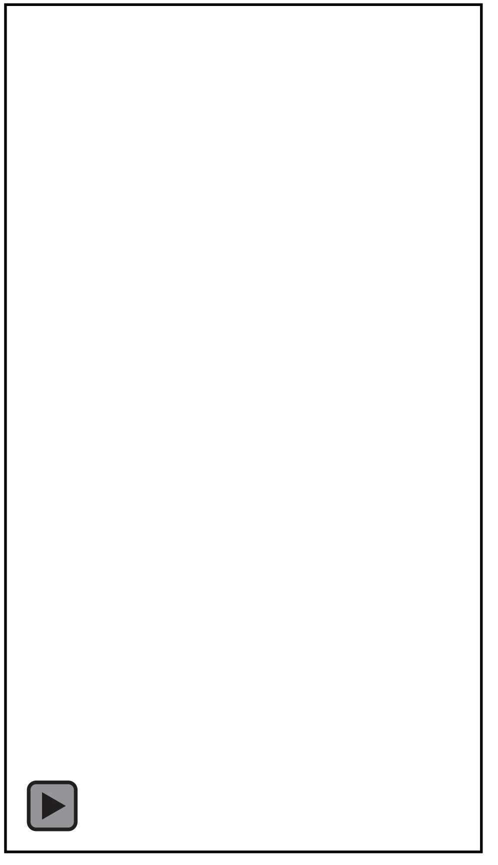
Extreme thermal tests

- We tested performances before and after extreme thermal cycles..

From room temperature to 77K



From 77K to Room temperature



High level specs

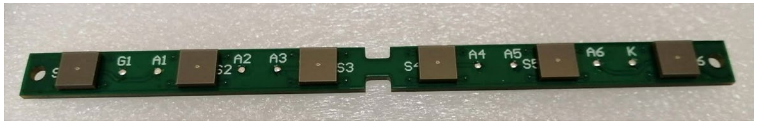
- Sensitivity to single p.e. at the level of one electronic channel and dynamic range for 48 SiPM > 2000 p.e.
- Dark count rate contribution negligible compared with background of ^{39}Ar

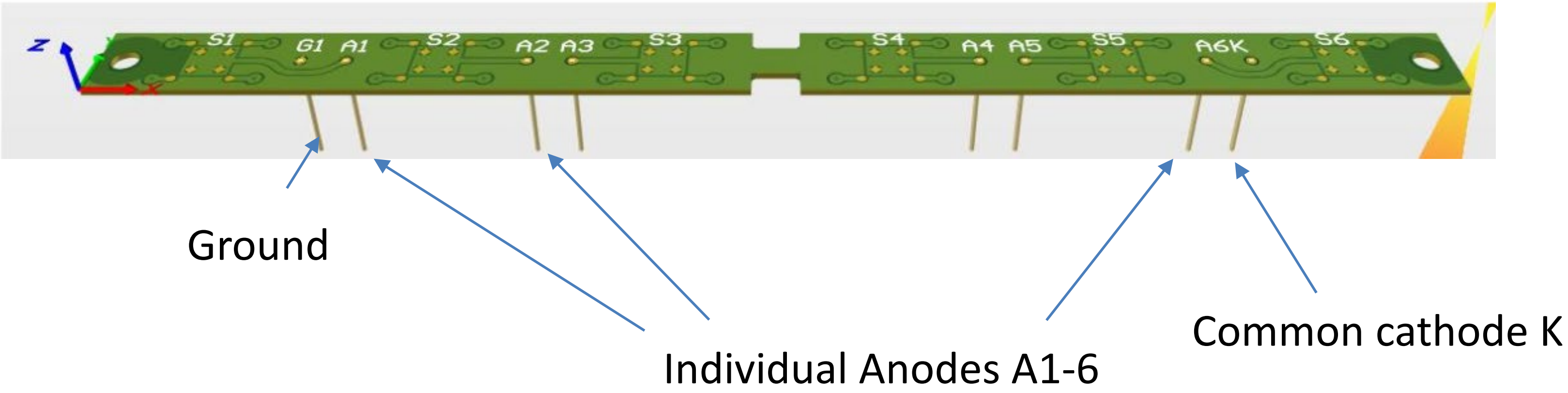
NEW! Low level specs generated by the high-level specs

Parameter	value	note
Uniformity of V_{bk}	0.1 V per channel	Achieved by both vendors Agreed on 200pcs lots for mass production
Gain at nominal OV	10^6	Cell pitch of the downselected SiPMs: 75μm (HPK) and 50μm (FBK)
S/N ratio for 1 p.e. with the PDS cryogenic amplifier	**> 4 sigma**	**OK for downselected SiPMs**
Dark Count rate	<60 mHz/mm^2 (<200 mHz/mm^2)	OK for all splits. Can be relaxed because of the 1.5 p.e. trigger
Terminal capacitance	<0.060 nF/mm^2	Updated after the release of the PDS cryogenic amplifier

Test of SiPM mounted on PCB

- 250 SiPM per each type were produced and mounted on the carrier board:



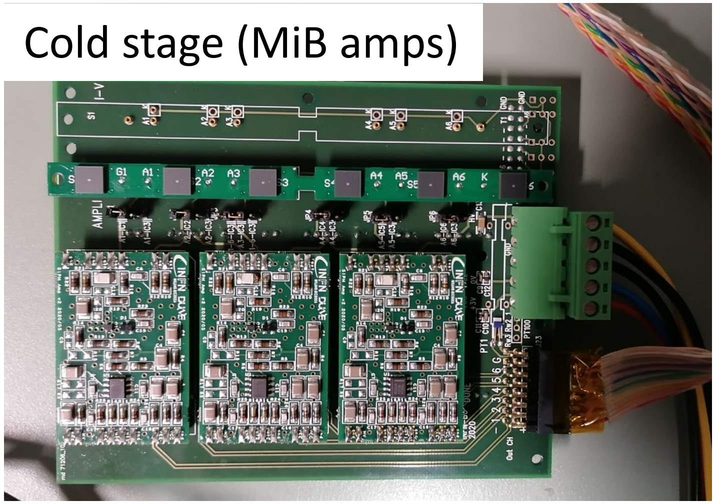


In the original design all the anodes were put together..no way to test each sigle SiPM and uniformity of breakdown voltage

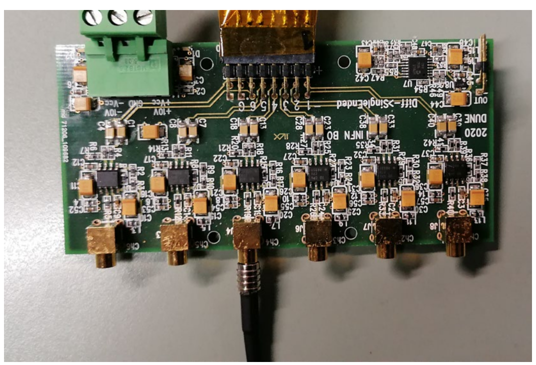
Test board with cryogenic amp

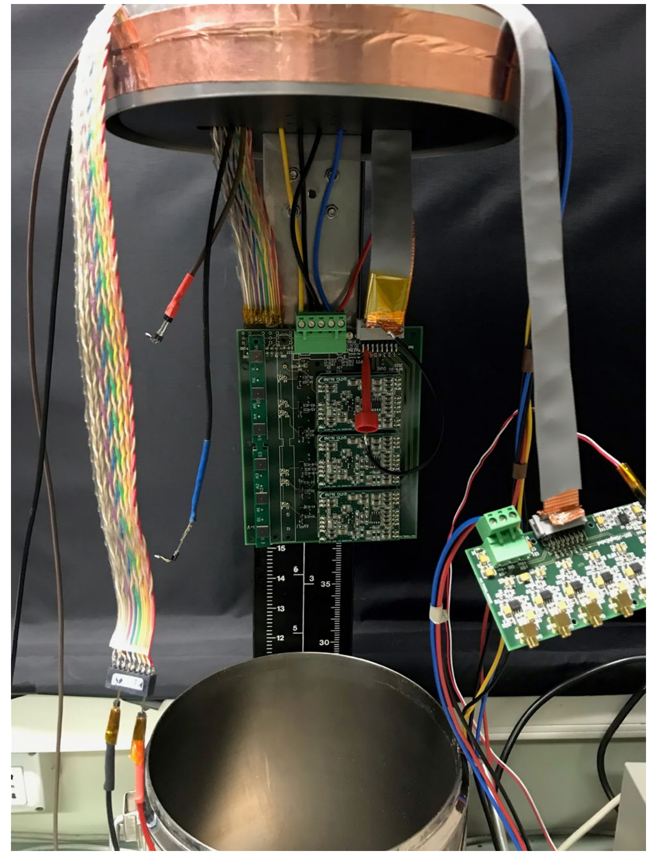
- We developed and distributed to each lab a test board for arrays

Cold stage (MiB amps)



Warm stage (diff to single)





Cold electronics

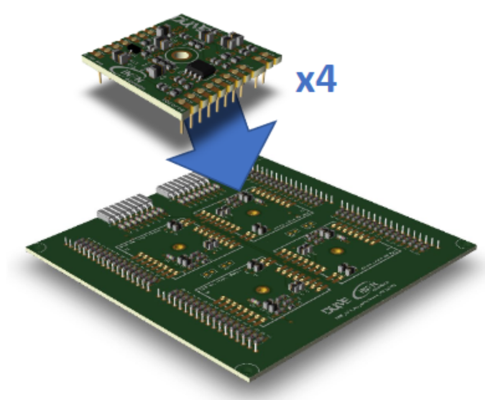
Design

Cold amplifier design based on discrete commercial components:

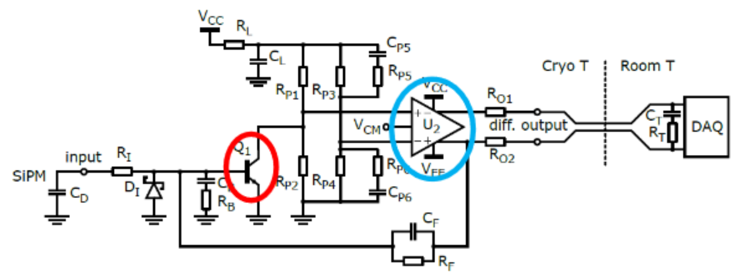
- **BFP640 SiGe bipolar transistor** at the input gives low voltage noise (0.4 nV/√Hz)
- **THS4531 differential opamp** gives high loop gain, differential outputs on 100 ohm line
- Single 3.3 V supply, ≈2 mW power consumption per channel
- 70 ns signal rise time, 2000 p.e. dynamic range*
- https://doi.org/10.1088/1748-0221/15/01/P01008

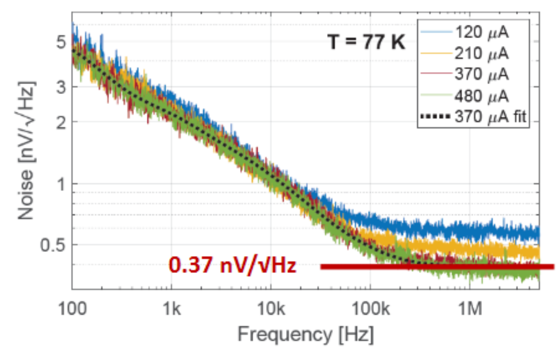
*depends on SiPM gain and overvoltage

Single channel daughter cards mounted on 4-channel motherboards



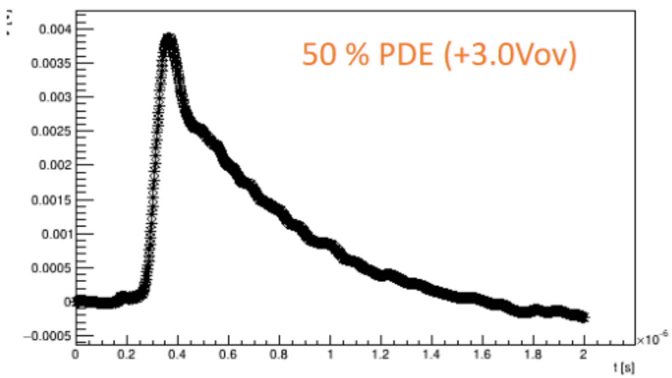
Gotti - MiB

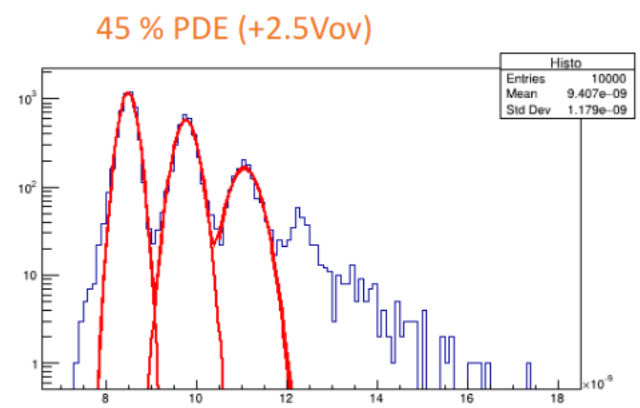




Ganging 48 SiPM Hamamatsu

Ganging results: HPK 75HR





Average single p.e. signal

- After second stage with gain x10
- Cold amp diff output peaks at ≈380uV @3Vov → ≈130uV/Vov
- Saturation at ≈750 mV → ≈5900 p.e.×Vov
  → Dynamic range > 2000p.e. if Vov<3.0 V

PDE	Vov	DR(p.e.)	SN_0	SN_1	SN_2
40%	2.0	≈2900	6.30	5.21	3.13
45%	2.5	≈2350	7.49	5.96	4.17
50%	3.0	≈2000	8.92	6.66	5.22

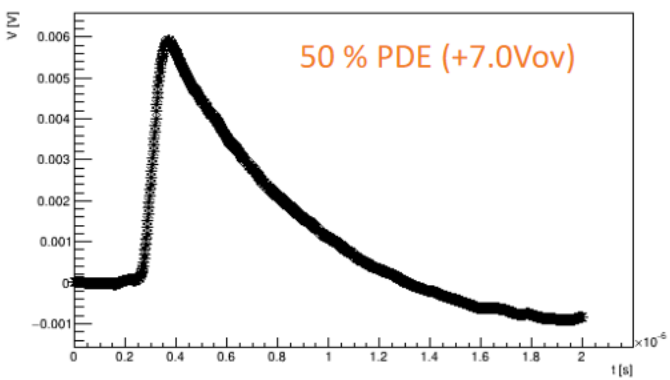
SN_x = [1 p.e. peak] / [x p.e. sigma]

Results obtained in Milano-Bicocca

Similar numbers were obtained in Madrid & Milano Statale

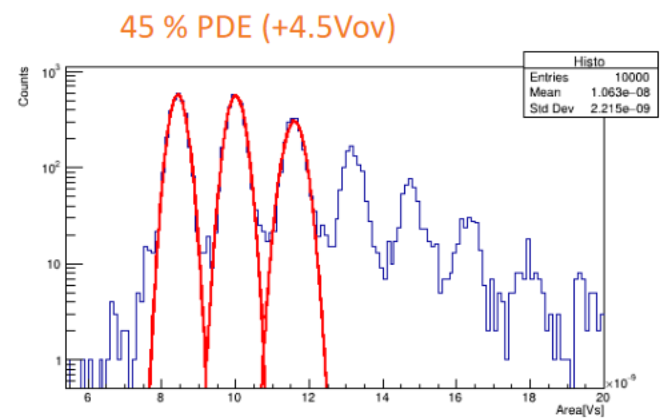
Ganging 48 SiPM FBK

Ganging results: FBK 3T (50um)



Average single p.e. signal

- After second stage with gain x10
- Cold amp diff output peaks at ≈600uV @7Vov → ≈85uV/Vov
- Saturation at ≈750 mV → ≈8800 p.e. ×Vov
  → Dynamic range > 2000p.e. if Vov<4.5 V



PDE	Vov	DR(p.e.)	SN_0	SN_1	SN_2
40%	3.5	≈2500	5.64	5.69	5.14
45%	4.5	≈2000	7.56	7.16	6.30
50%	7.0	≈1250	11.32	10.34	9.52

SN_x = [1 p.e. peak] / [x p.e. sigma]

Results obtained in Milano-Bicocca

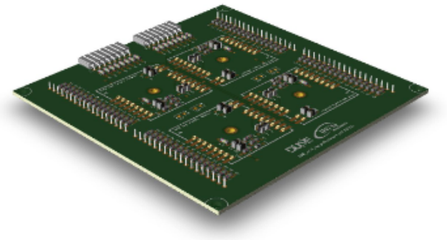
Similar numbers were obtained in Madrid & Milano Statale

Status of cold electronics

Status & numbers

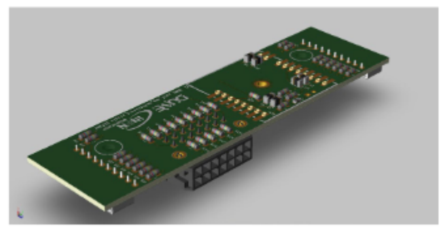
4-ch Motherboard (v02)

- 24x available
  - 10 for cold box test at CERN
  - 4 at CSU
  - 2 MiB
  - 8 to other labs / spares



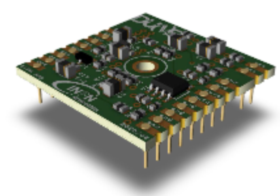
1-ch Motherboard for single supercell tests

- 40x available
  - ≈30 for SC tests at CIEMAT
  - ≈ 10 to other labs

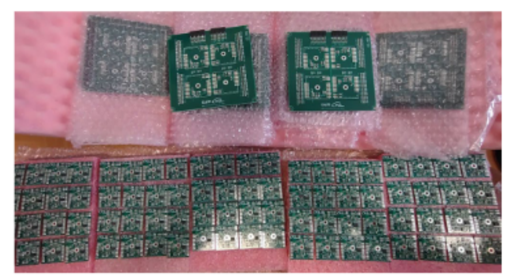


Cold Amplifier (v02)

- 80x available
  - 40 for cold box test at CERN
  - 30 for SC tests at CIEMAT, to be shared after the tests
  - 10 to other labs / spares



- Quantities required for the Cold Box Test at CERN: 10x MB, 40x amplifiers
  - Already available
- Quantities required for ProtoDUNE2: 40x MB, 160x amplifiers
  - ≈30x 4chMB and ≈100x amplifiers to be ordered in autumn



Next steps

Electrical Supercell test for FDR

- Electrical tests performed for HPK at Milano-Statale
- Ongoing: replacement of HPK 70μm LQR with FBK Triple Trench to validate the dowselected FBK sensors (October)
- [supercell test with LAr: see **C.Cattadori's talk**]

SiPM for ProtoDUNE Run II:

- We already have 250+250 SiPMs that will be used for the two modules of November's Cold Box Test – critical: complete the supercell test in October/November
- FBK: 4000 sensors will be delivered by the end of November
- HPK: 4000 sensors will be delivered by December (uncertainty of a few weeks due to an issue experienced by HPK with the quenching resistors – may be critical for January's cold box test where we need 2000 SiPMs (by any vendor). Start test in December with FBK SiPMs
- Mass tests: see **Marco Guarise's talk**

Conclusions

- Downselection: the preproduction phase is over. It was very successful and well within schedule.
- We downselected:

S13360 75μm High Quenching Resistance from Hamamatsu
NUV-HD-CRYO 50μm with Triple Trenches from FBK

- 5/6 splits fully on specs. We chose the ones with better S/N (higher cell pitch at fixed PDE)
- We are preparing the Final Design Review (lead: Philippe Farthouat) in Spring
- On the critical path: cold box test (2 modules, 384 SiPMs) and in January (10 modules, 1920 SiPMs)