SiPMs for the Photon Detection System of DUNE

SiPM workshop: from fundamental research to industrial applications

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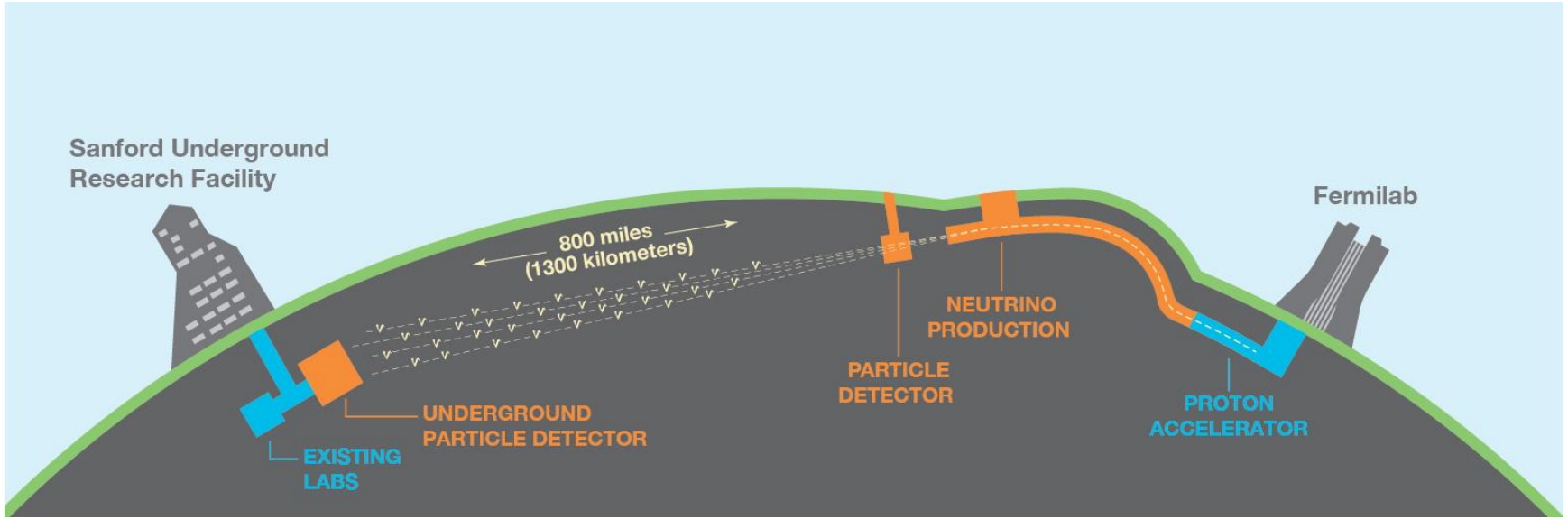
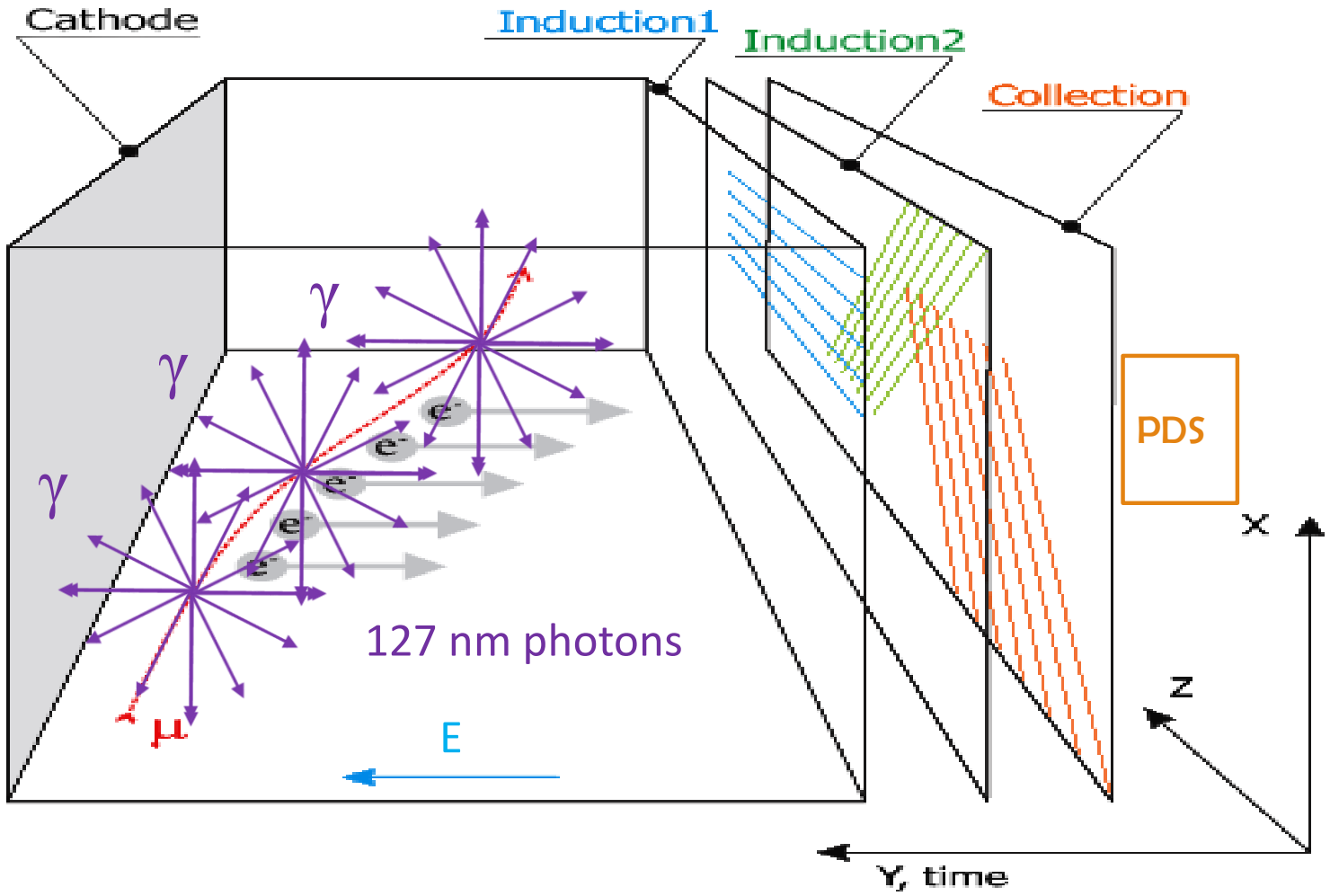
Deep Underground Neutrino Exp



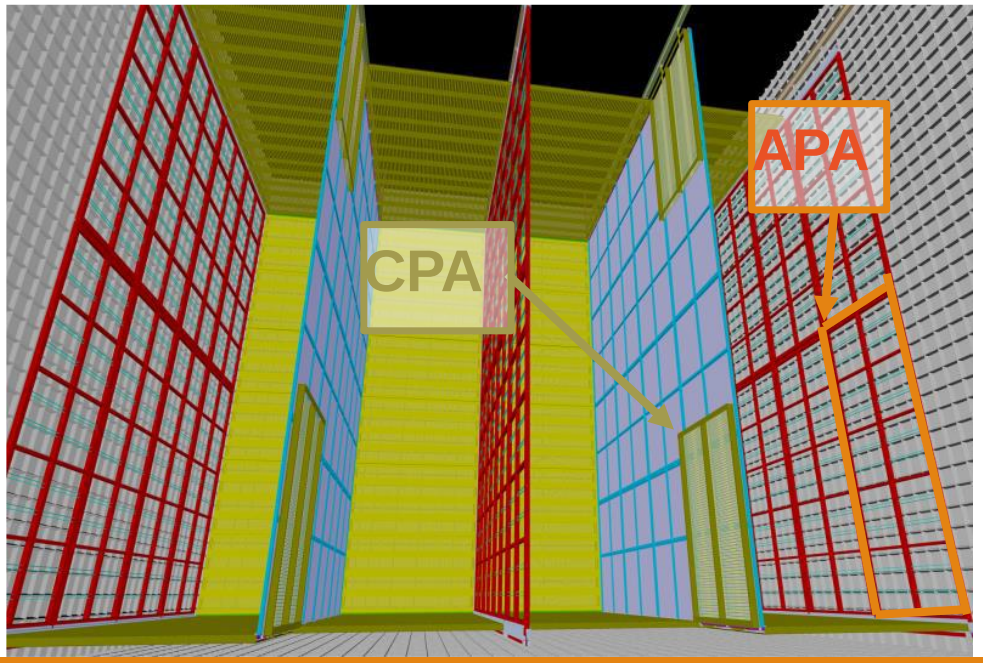
- ✓ Near + Far detectors.
- ✓ Far detector: 4 LArTPCs, 10 kton fiducial volume each, 1.5 km underground.
- ✓ CP violation, mass hierarchy, proton decay, SN neutrinos.

LAr TPC


Cathode
Induction1
Induction2
Collection
PDS
γ
γ
γ
e⁻
e⁻
e⁻
e⁻
e⁻
μ
127 nm photons
E
X
Z
Y, time

DUNE Far Detector

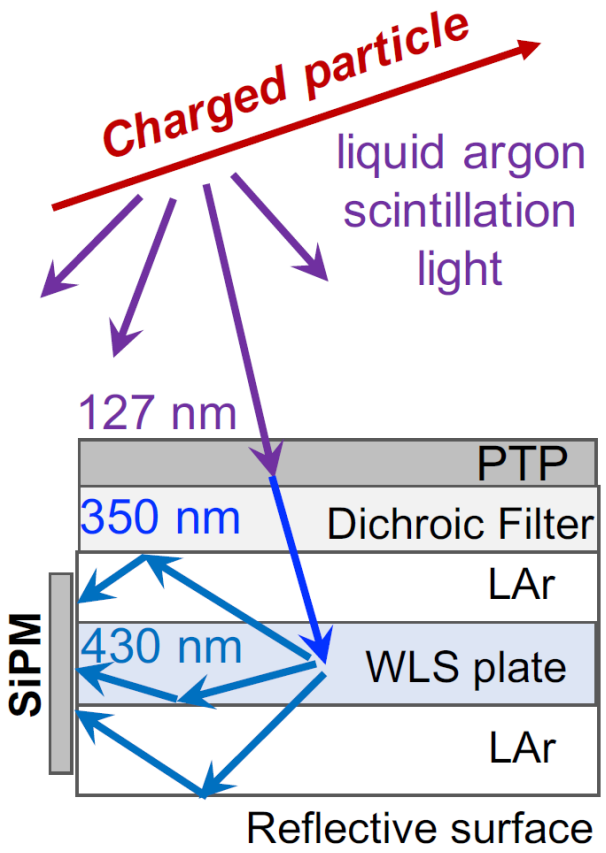
- ✓ Active volume: **12m x 14m x 58m**.
- ✓ 150 **A**node **P**lane **A**ssemblies, 6m high x 2.3m wide. Wrapped wires, 2 Ind and 1 Coll planes.
- ✓ PDS between APA planes.
- ✓ 200 **C**athode **P**lane **A**ssemblies. Cathode at -180 kV for 3.6m drift.



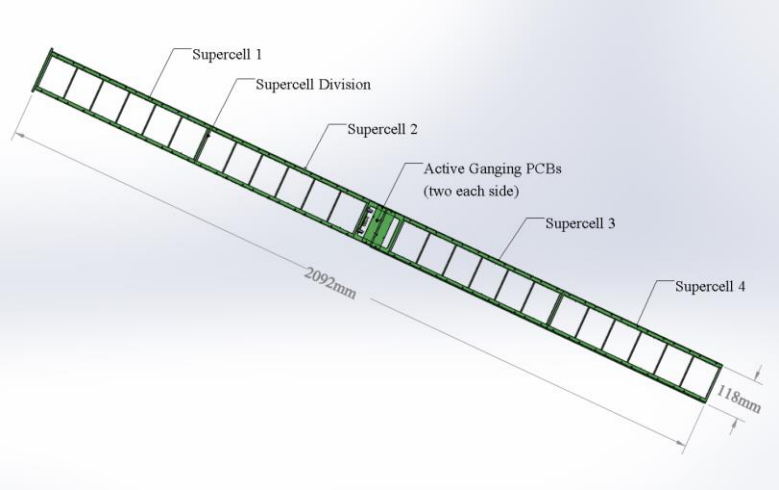
Light in DUNE

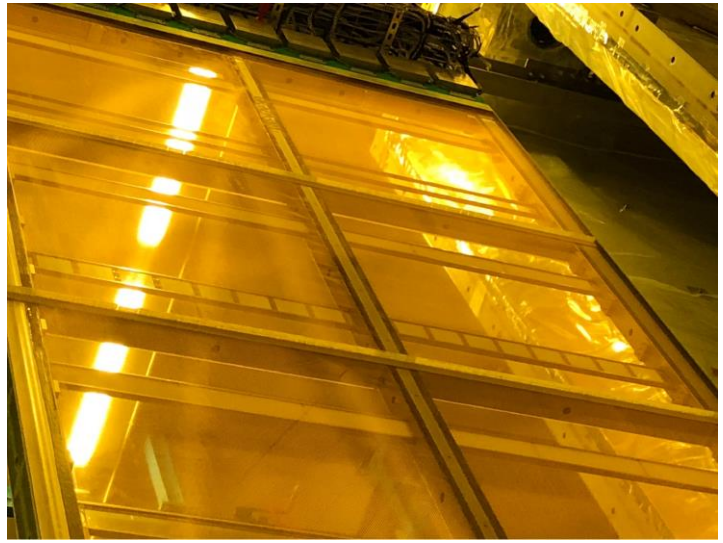
- ✓ t0 (and so third coordinate) of the event.
- ✓ Trigger for no beam events:
  - SN neutrino bursts ($\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$, with 5 – 20 MeV signal);
  - proton decay (golden channel $p \rightarrow K^+ \nu$).
- ✓ Alternative method for calorimetry.
- ✓ Help for Machine Learning technique.

X - ARAPUCA



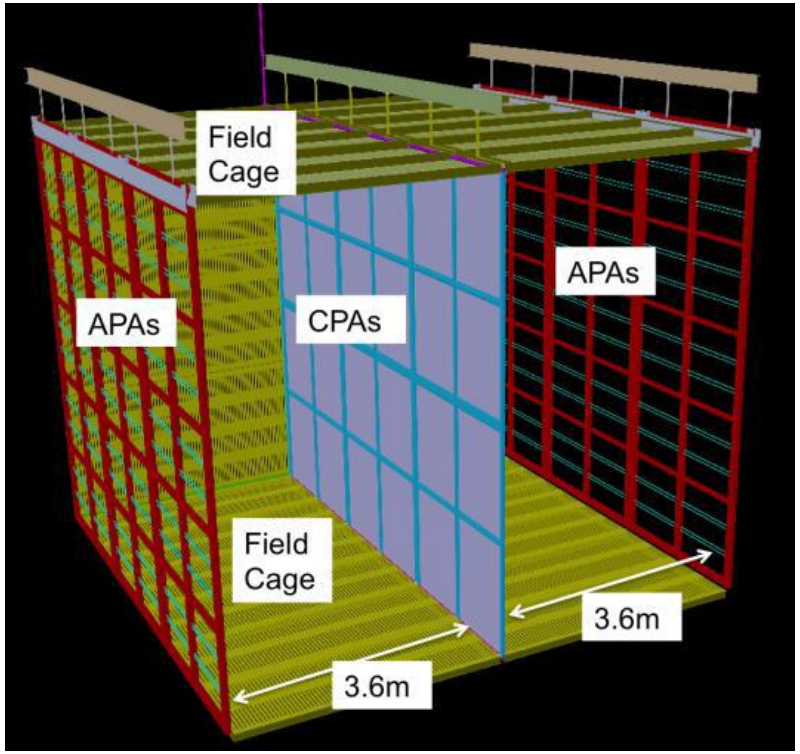
- ✓ 48 SiPM actively ganged (8 x 6 SiPMs) will read a Supercell, i.e. a channel of electronics.



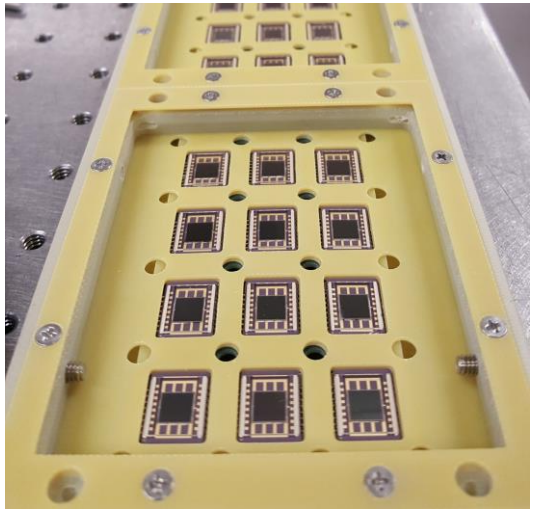


Works in the framework of DUNE Collaboration

✓ Test of the ARAPUCA concept in ProtoDUNE SP



- ✓ 1/25 of full DUNE far detector
- ✓ 6 full-sized drift cells (150 in far detector)
- ✓ First test of ARAPUCA in real experiment



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- ✓ Optimization of cryogenic amplifier.
- ✓ Preparation of ProtoDUNE Run II.

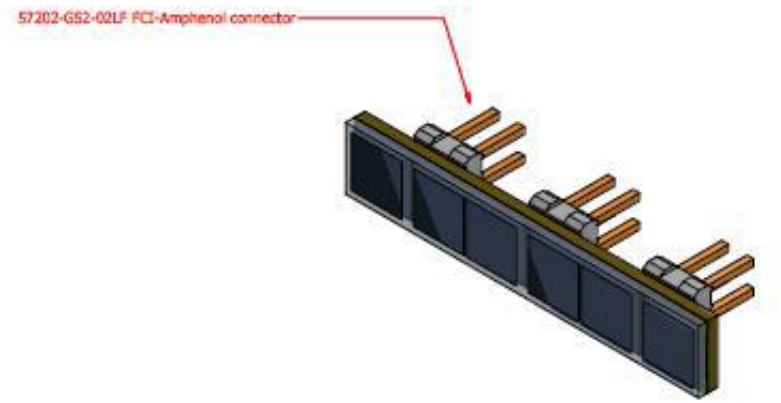
SiPM for DUNE

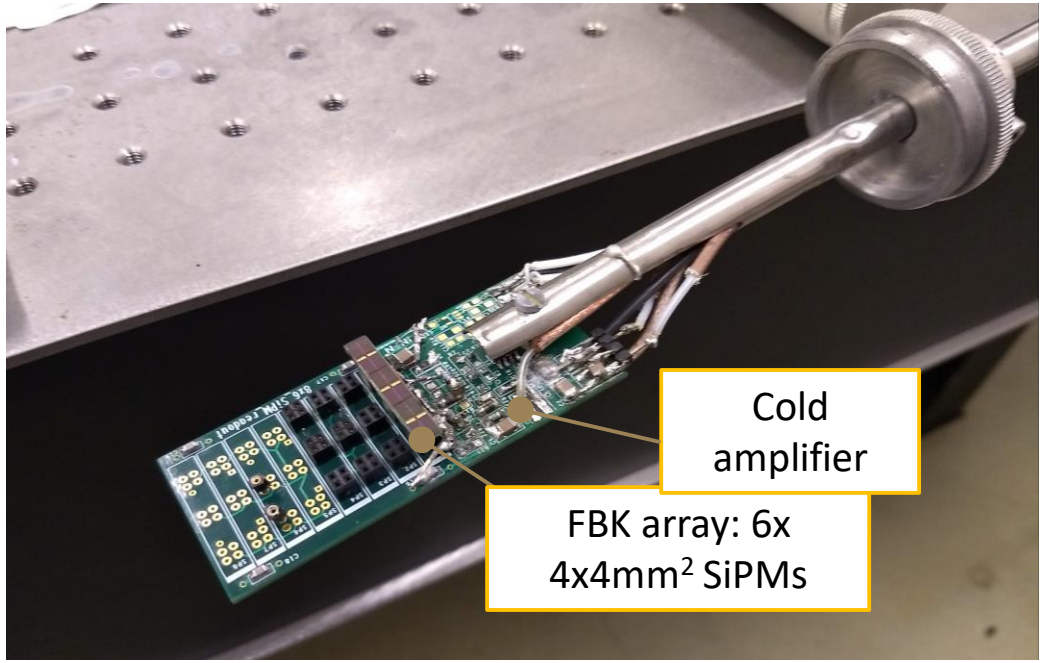
SiPM to be used in DUNE should have:

- ✓ long term cryoreliability;
- ✓ breakdown voltage < 50 V;
- ✓ PDE at 430 nm (87K) > 35% at nominal overvoltage;
- ✓ cross-talk and afterpulse < 15% at nominal overvoltage;
- ✓ recovery time of a few μs;
- ✓ dynamic range: 1-2000 p.e. per ch (48 SiPM);
- ✓ dark count rate small compared with background from ^{39}Ar contamination.

Focus on my talk

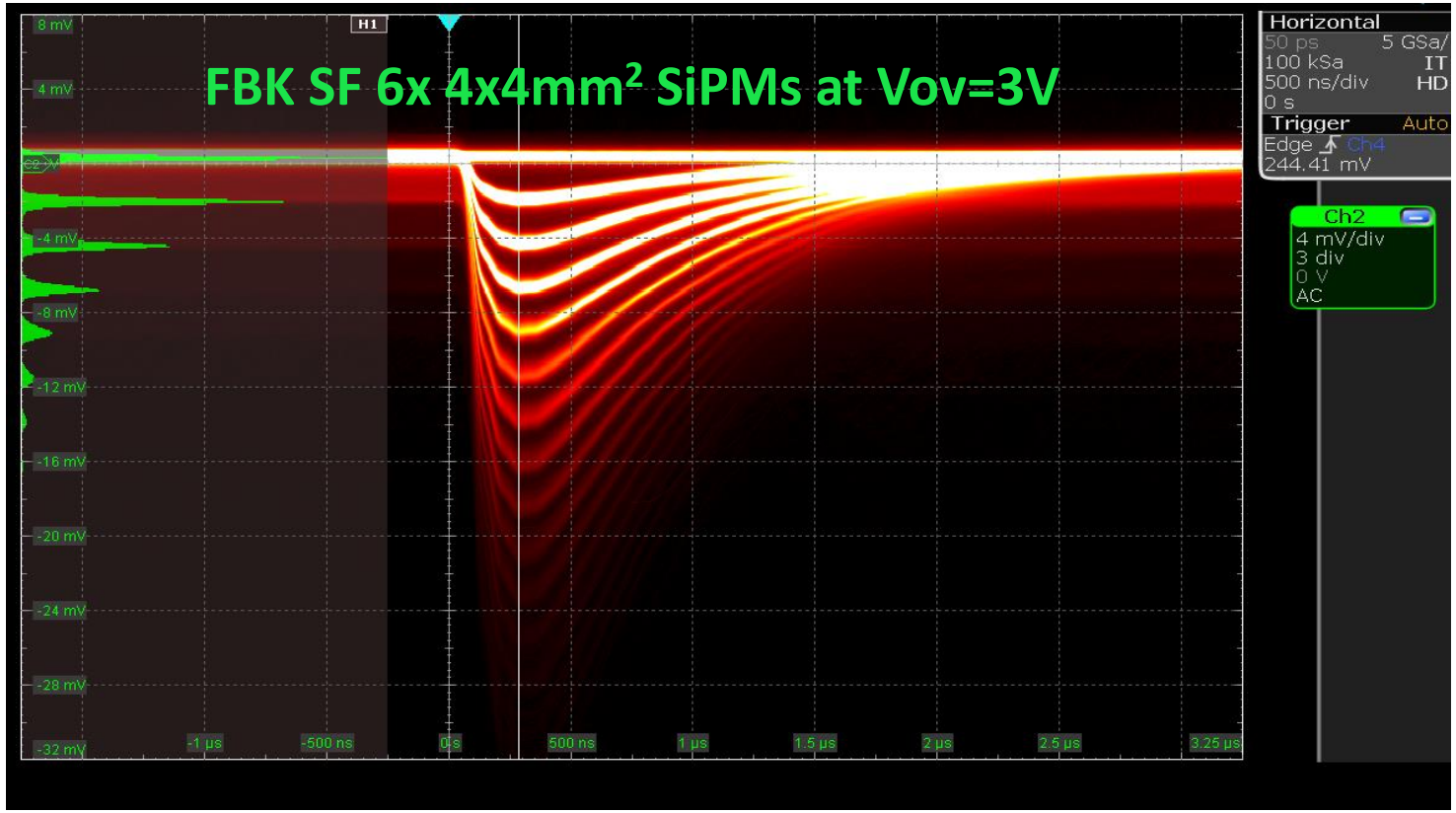
- ✓ Characterization of tiles of 6 FBK NUV-HD-SF 4x4 mm^2 as the first step in optimization and development program.
- ✓ SiPM read by mean of a 2-stage cold amplifier BJT – THS4121, with a noise of 0.4 nV/√Hz at T=77 K.





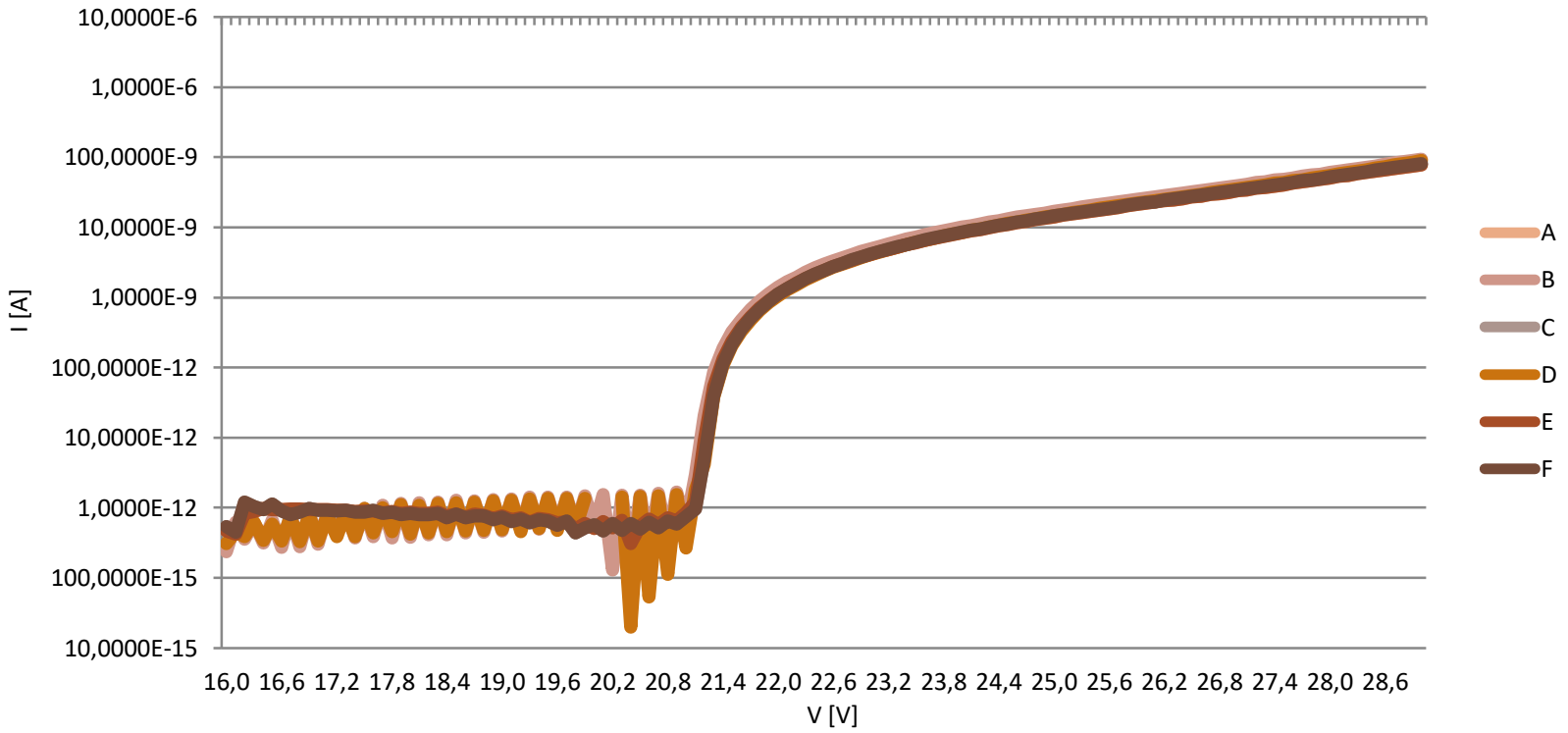
Thermal cycle

- ✓ Thermal tests: 38 SiPMs OK (>20 cycles for all of them).



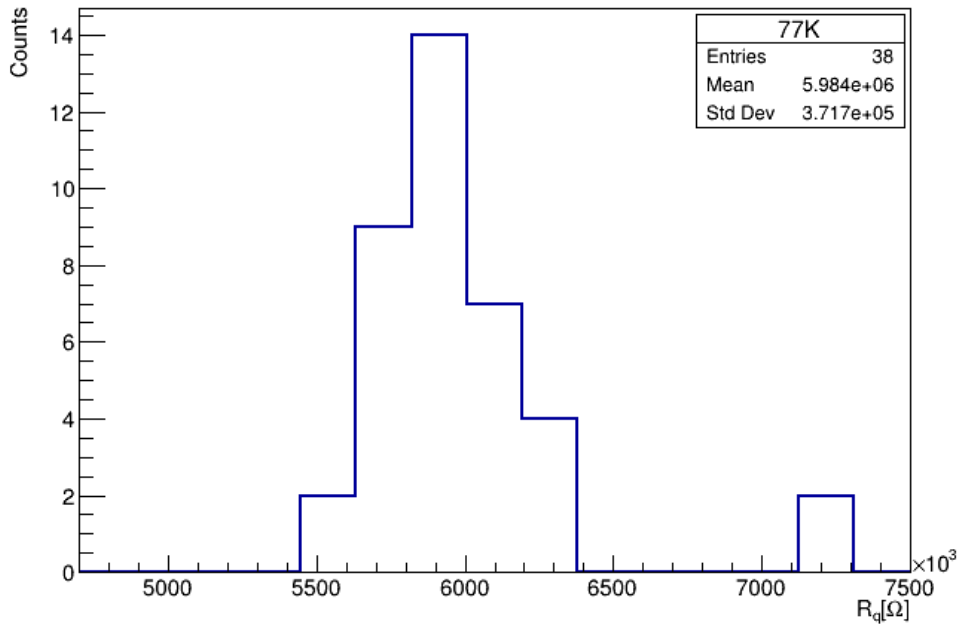
Breakdown voltage

- ✓ Breakdown voltage at 77 K: 21 ± 0.1 V.
- ✓ Max overvoltage: 21- 31 V (+10 V).

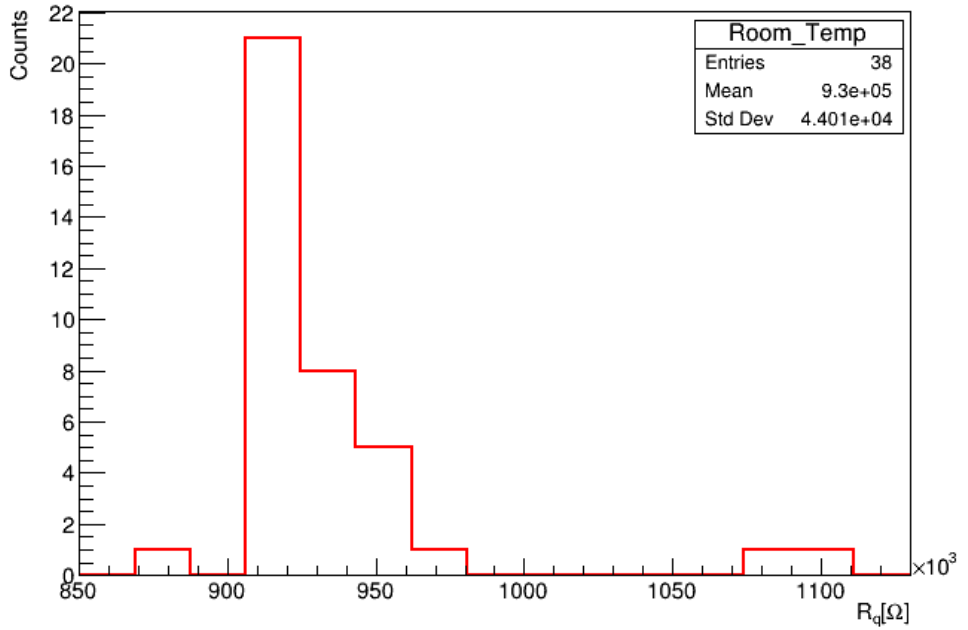


Quanching resistance

- ✓ At 77K, the quenching resistances follow a Gaussian distribution, peaked at 5.9 MΩ.
- ✓ At room temperature it is between 0.87 and 1.1 MΩ.

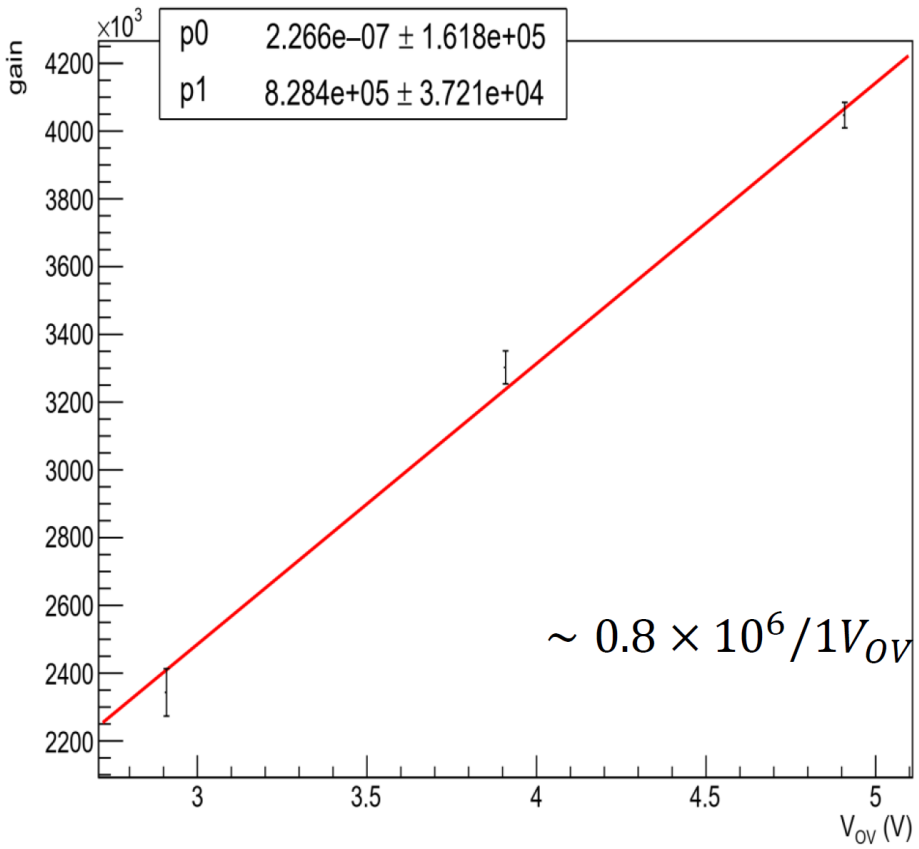


77 K

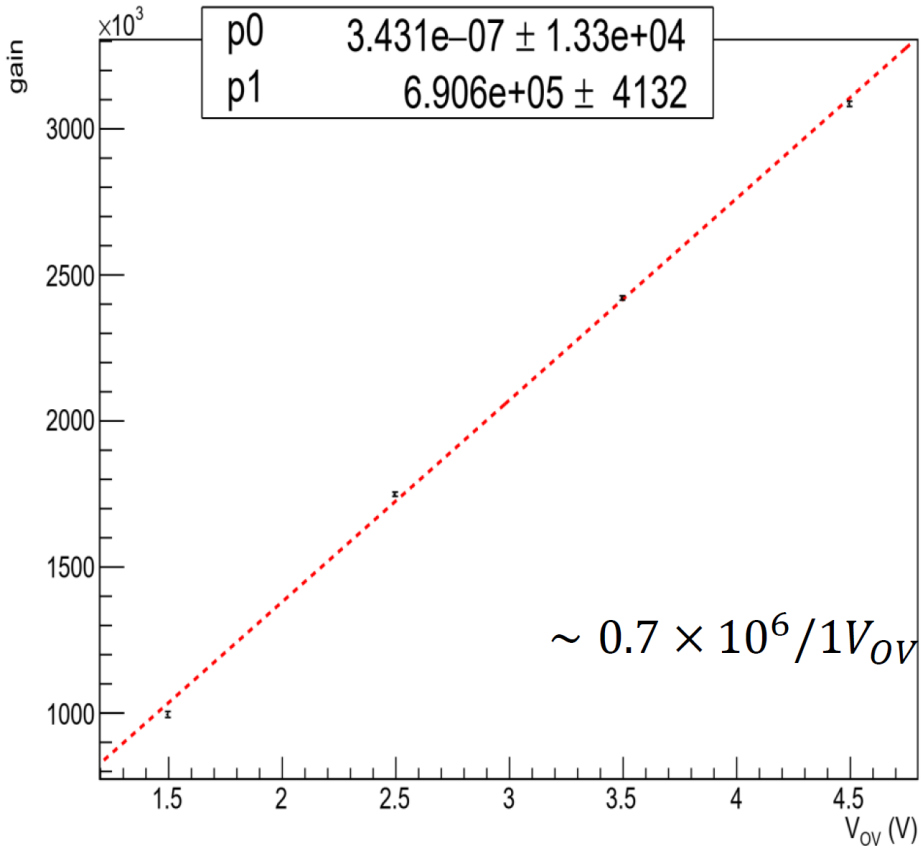


Room temperature

Gain

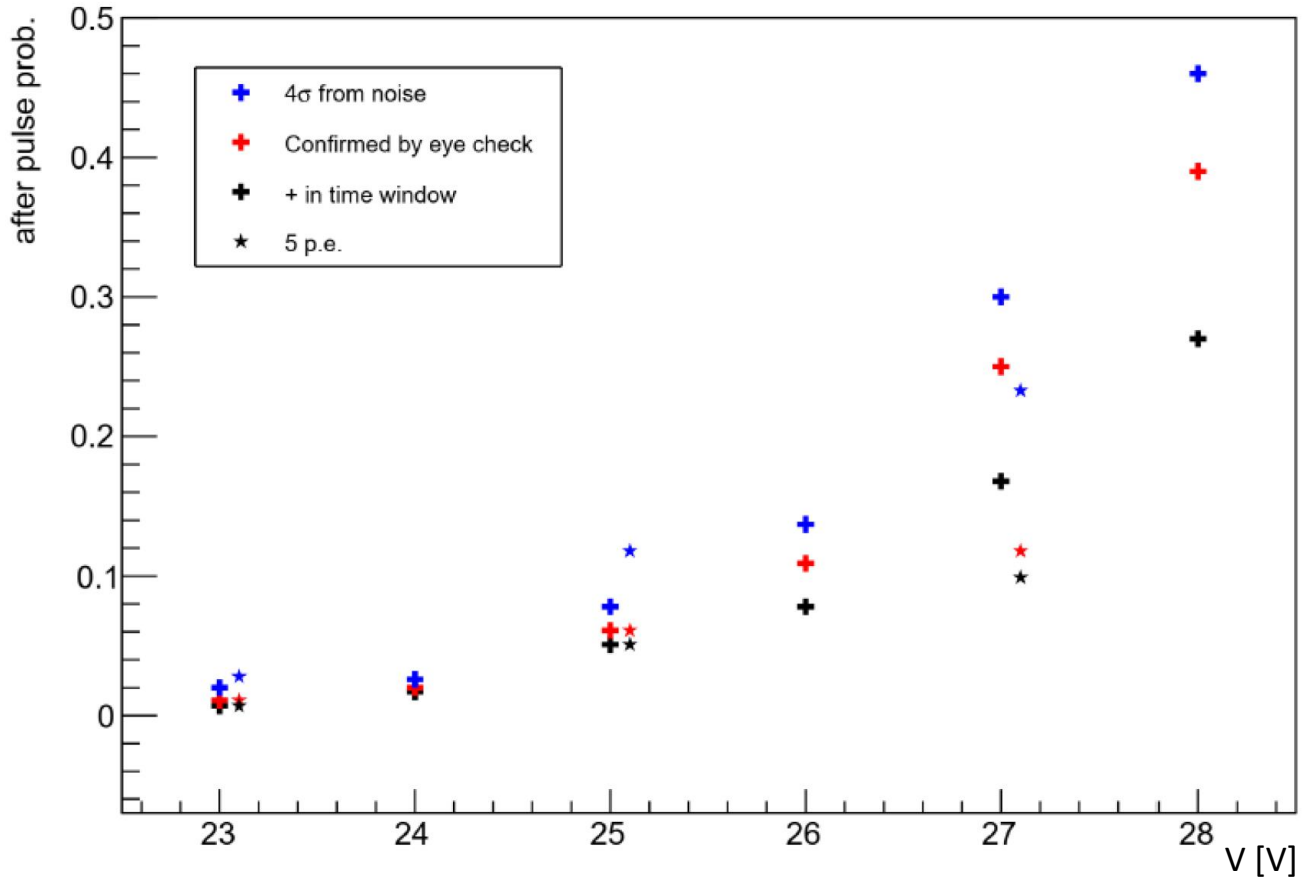


77 K



Room temperature

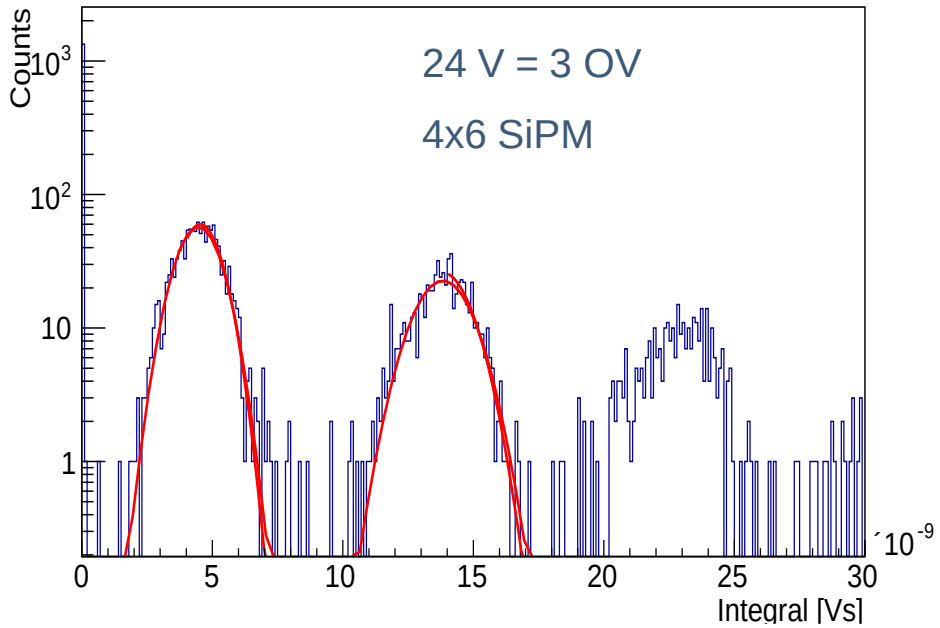
DCR and afterpulse



OV (V)	DCR / mm^2 (Hz)
3	0.135
4	0.229
5	0.520

✓ Afterpulse(+delayed cross talk) <10% at +4 V overvoltage

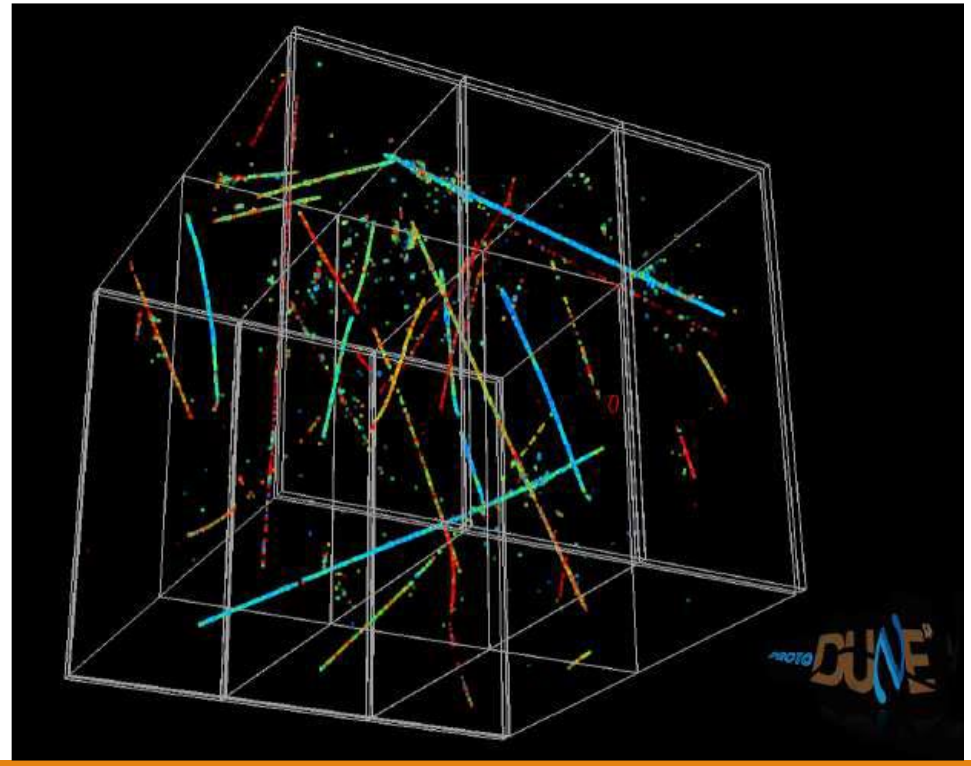
S/N vs Ganging



OV	Number of SiPM						
	1	2	4	6	6x2	6x3	6x4
3 OV	14	14	12	12	10	7	7
4 OV	17	17	14	14	12	8	7
5 OV	19	19	16	16	12	9	/

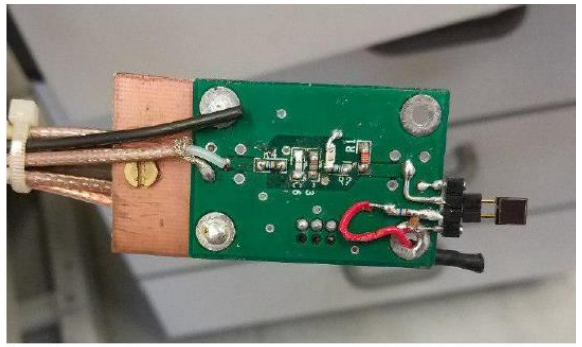
Toward Run II of ProtoDUNE

- ✓ ProtoDUNE SP: beam data (10/10/2018 → 12/11/2018 data taking period) and data from cosmic runs (12/11/2018 → end of 2019).
- ✓ Test and characterization of the various detector subsystems for DUNE.
- ✓ Choice of ARAPUCA configuration as best one for DUNE.
- ✓ In Run II (start in Summer 2020) we'll test the final design of X-ARAPUCA and of the whole DUNE PDS.

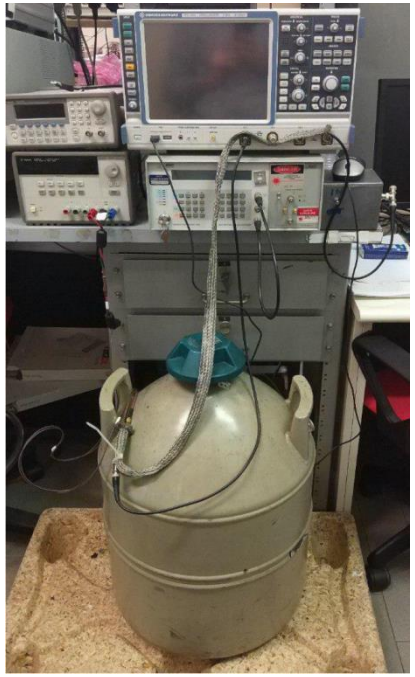


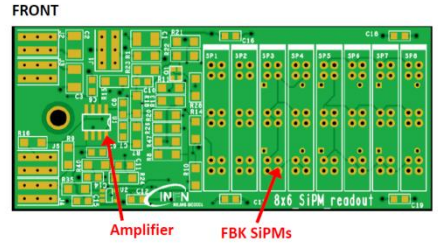
The DUNE PDS in INFN

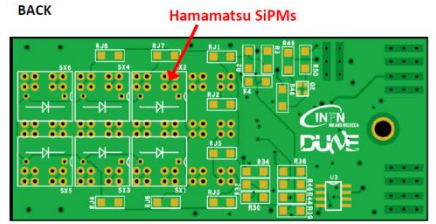
- ✓ The DUNE PDS activities of the INFN groups in DUNE have just started but… we are ramping up quickly!
- ✓ Development and characterization of **photosensors** (Bologna, Genova, Milano, Milano Bicocca).



- ✓ Development of the **cold amplifier** optimized for the DUNE sensors (Bologna, LNS, Milano, Milano Bicocca).
- ✓ Cryogenic **test facility** for the SiPMs and the X-Arapuca (Bologna, Ferrara, Genova, Milano Bicocca).







Conclusion

- ✓ The DUNE Photon Detection system is based on extensive use of cryogenic SiPMs.
- ✓ We are optimizing the sensor technologies for the needs of DUNE in close collaboration with vendors and developers.
- ✓ In my talk I focused on NUV-HD-SF sensors developed by FBK.
- ✓ These sensors show excellent performance (paper in preparation) in term of :
  - reliability against thermal stresses and operation of cryogenic environment;
  - single p.e. sensitivity in single sensor (17 at +4 OV) and ganging mode (7 at +4 OV);
  - DCR and correlated noise;
- ✓ Further improvement can be achieved employing the FBK NUV-HD-Cryo technology (in progress).
- ✓ INFN groups are contributing to the optimization process and the Run II of ProtoDUNE in a substantial manner: **a lot of new results coming soon!**

Thanks!