SiPM for ALICE 3

SiPM - Cross-Experiment discussion

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Research context

Exploring SiPM as sensors for ALICE 3 (LHC Run 5) outer timing layer

ALICE3-TOF will be part of an **extensive PID system**, together with a RICH detector, a muon identifier (MID) and an electromagnetic calorimeter (ECal)

Requirements:

- Rad. hardness
  - outer TOF: NIEL ~ $9\cdot10^{11}$ MeV n_{eq} /cm^2
  - inner TOF: NIEL ~ $6.1\cdot10^{12}$ MeV n_{eq} /cm^2
  - forward TOF: NIEL ~ $8.5\cdot10^{12}$ MeV n_{eq} /cm^2
- Time resolution of 20 ps
- Low material budget 1-3% X_0

R&D on different advances silicon technologies: LGADs, CMOS-LGADs for inner TOF, while SiPM for outer TOF (may be together with RICH)

ALICE 3 LoI: *https://arxiv.org/abs/2211.02491*

SiPMs in direct detection of charged particles: a roadmap

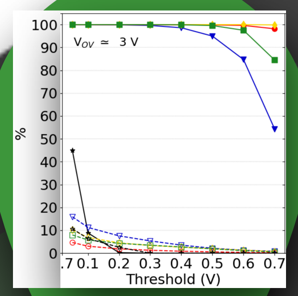
stay tuned…

recent developments

SiPMs with a ***complete front-end*** and ***readout electronics***: LIROC discriminator and pTDC, preliminary efficiency and time resolutions results are briefly introduced.

paper in preparation

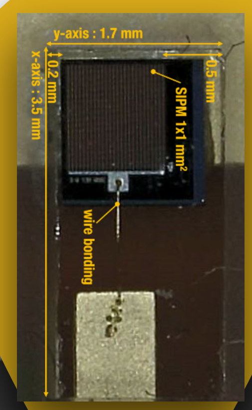
efficiency studied in detail thanks to 3x3 mm^2 area SiPMs to cover all the area subtended by the Cherenkov cone. Preliminary results indicate very high efficiencies with just 5 photoelectrons firing.

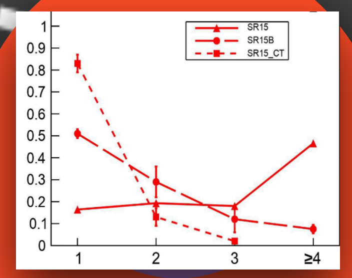


Eur. Phys. J. Plus 138, 788 (2023)

protection layers with known dimensions above single SIPMs of 1x1 mm^2: Cherenkov effect could be studied with a ***position scan***.

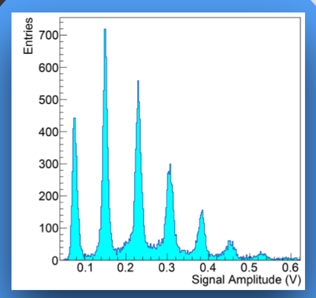
Signals and time resolution wrt number of fired SPADs (up to 8-9 SPADs) evaluated in the centre of the position scan. Resolution approaching 20 ps when >5 SPADs are firing were observed, where more than 80% of the total events lie.





Eur. Phys. J. Plus 138 337 *(2023)*

the increased response of SIPM at the passage of a MIP is due to ***Cherenkov light emission*** in the (standard) protection layer, usually placed above the sensor. A benefit in terms of time resolution as the number of fired SPADs increase was observed, going to about 40 ps when more than 4 SPADs are hit.

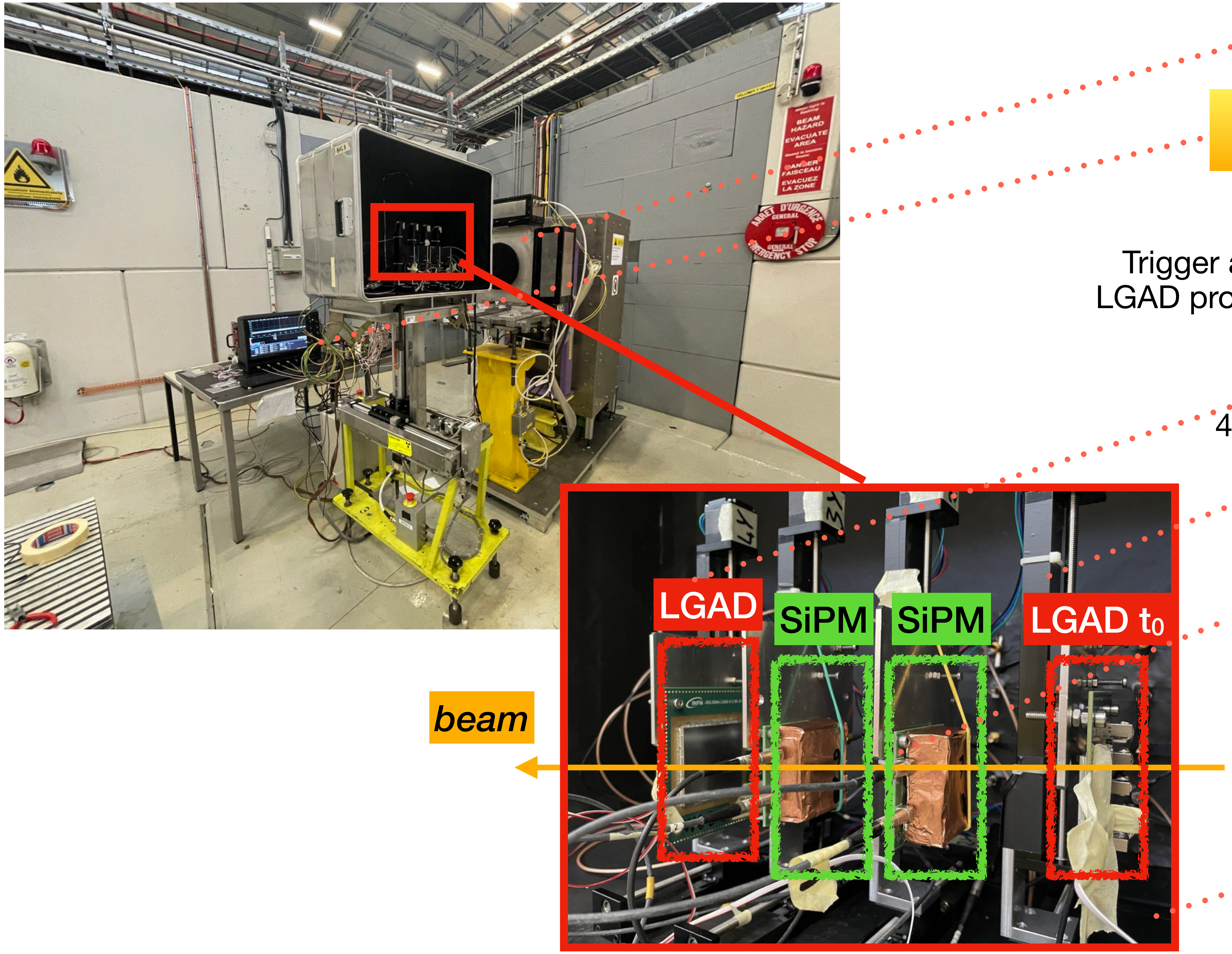


JINST 17 P06007

even if a particle should turn on only 1 SPAD per event, several SPADs are fired indicating a higher crosstalk (40-70%) with respect to intrinsic noise (10-15%) (at 6 V OV).

Cherenkov/scintillation effect in the protection layer or process inside the bulk?

Experimental setup
CERN PS T10 beamline



protons of 10 GeV/c

DAQ: Lecroy wave runner 94904M-MS
digital oscilloscope 4 GHz bandwidth

Trigger and timing reference: 25 um and 35 um thick FBK LGAD prototypes of 1 x 1 mm^2 (*Eur. Phys. J. Plus 138, 99 (2023)*)

4 independent micropositioners (10 um precision) added for (3)

Customized front-end XLEE amplifiers of **40 dB** gain

TDK Lambda Z100 power supplies for SiPMs

No cooling: T~25-28°C. Peltier cells from SiPM studied in paper in preparation.

SiPMs with know protection layer dimensions

In ***Eur. Phys. J. Plus* 138, 788**

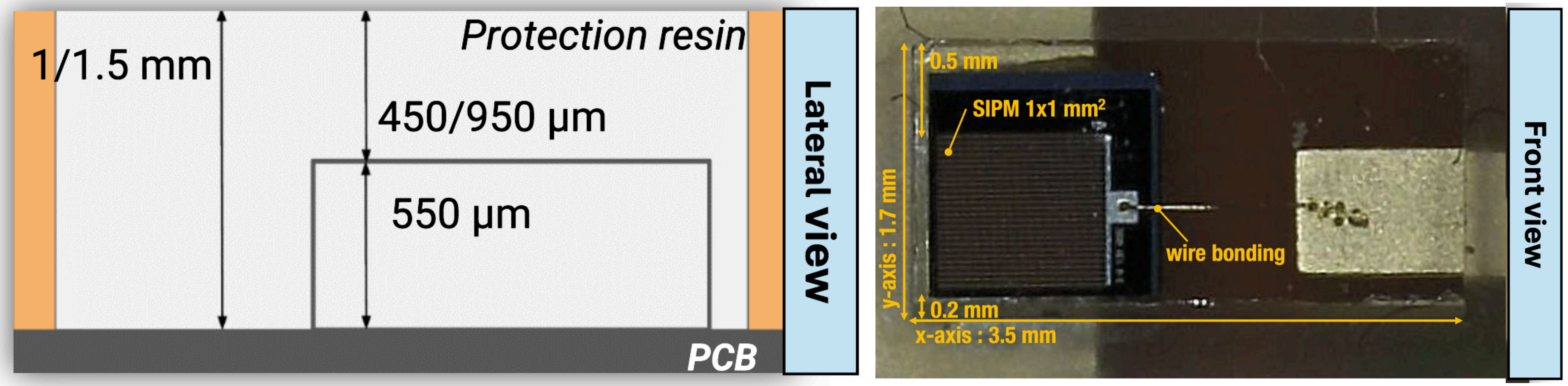
SiPM of FBK **NUV-HD-RH** technology:

- every SiPM under test on its own PCB with **protection layer of know dimensions** placed above the sensor

- Different protection layers: 1 and 1.5 mm Silicone resin, 1 mm Epoxy resin and a control sample without any protection layer

NUV-HD-RH-1x1

Active area	Pixel pitch	#SPADs	Fill Factor	V_{bd}
1 × 1 mm^2	20 µm	2444	72%	33.0±0.1 V



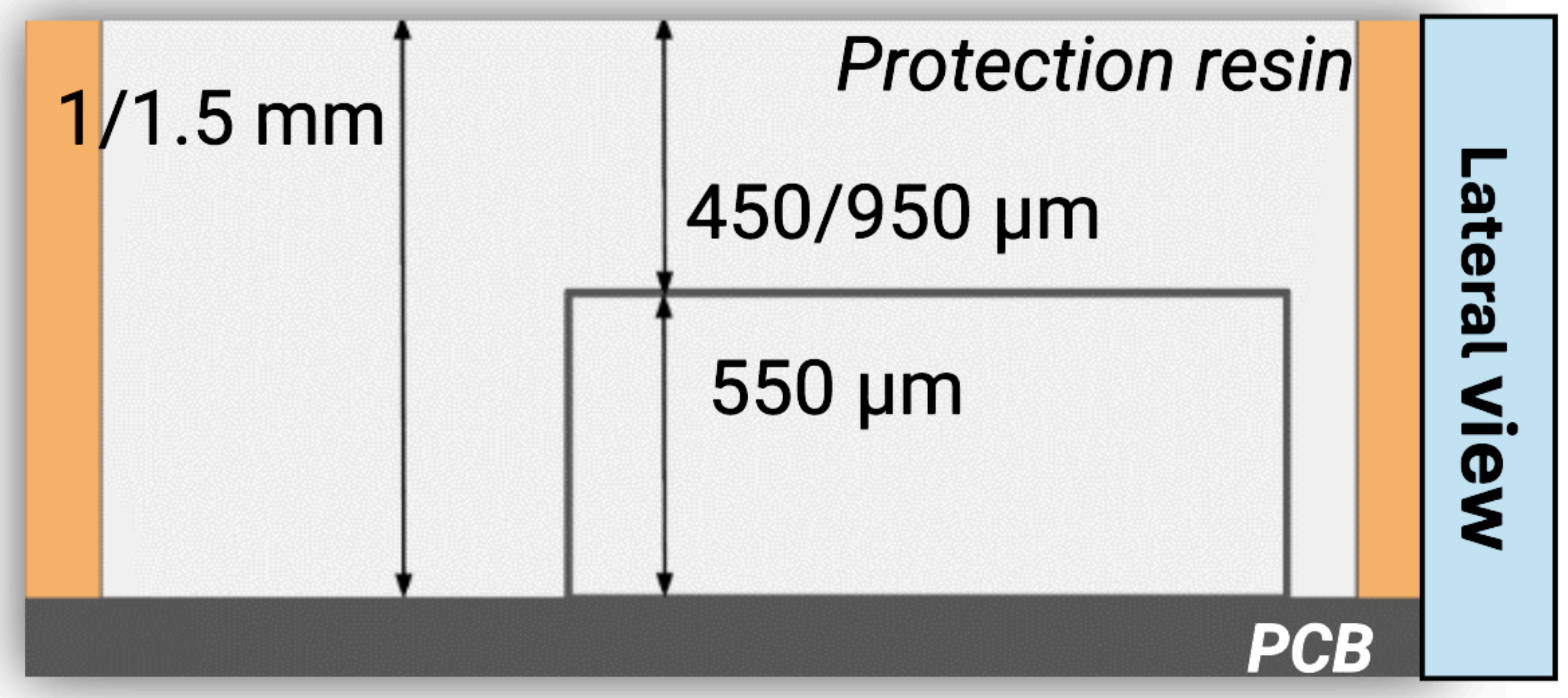
SiPM of larger area under study (paper in preparation)

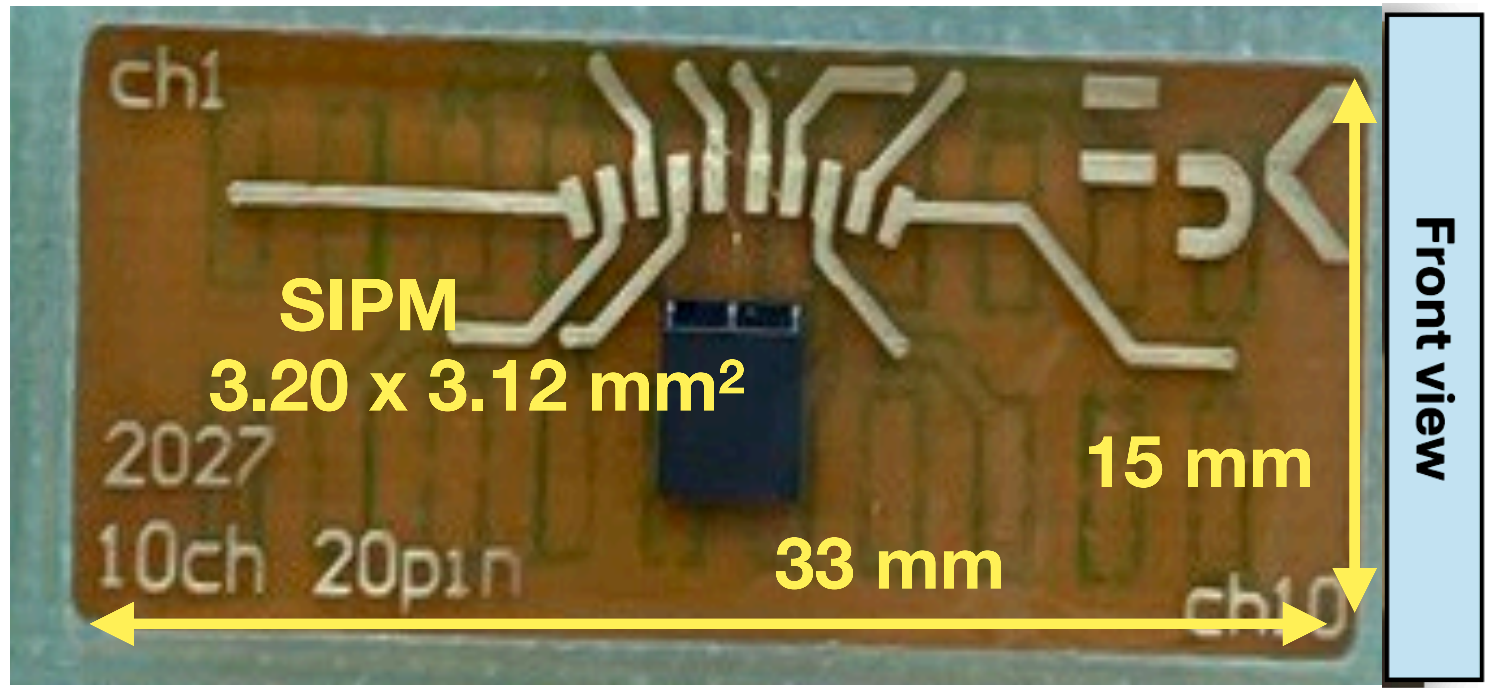
SiPM of FBK **NUV-HD-LFv2** technology with **larger area of 3x3 mm² available both in single and in matrix of SiPMs**:

- every SiPM under test on its own PCB with protection layer all over the PCB
- Different protection layers: 1, 1.5 and 3 mm Silicone resin, 1 mm Epoxy resin and a control sample without any protection layer
- Matrices are of 9 SiPMs of 1x1mm² area

NUV-HD-LFv2-3x3

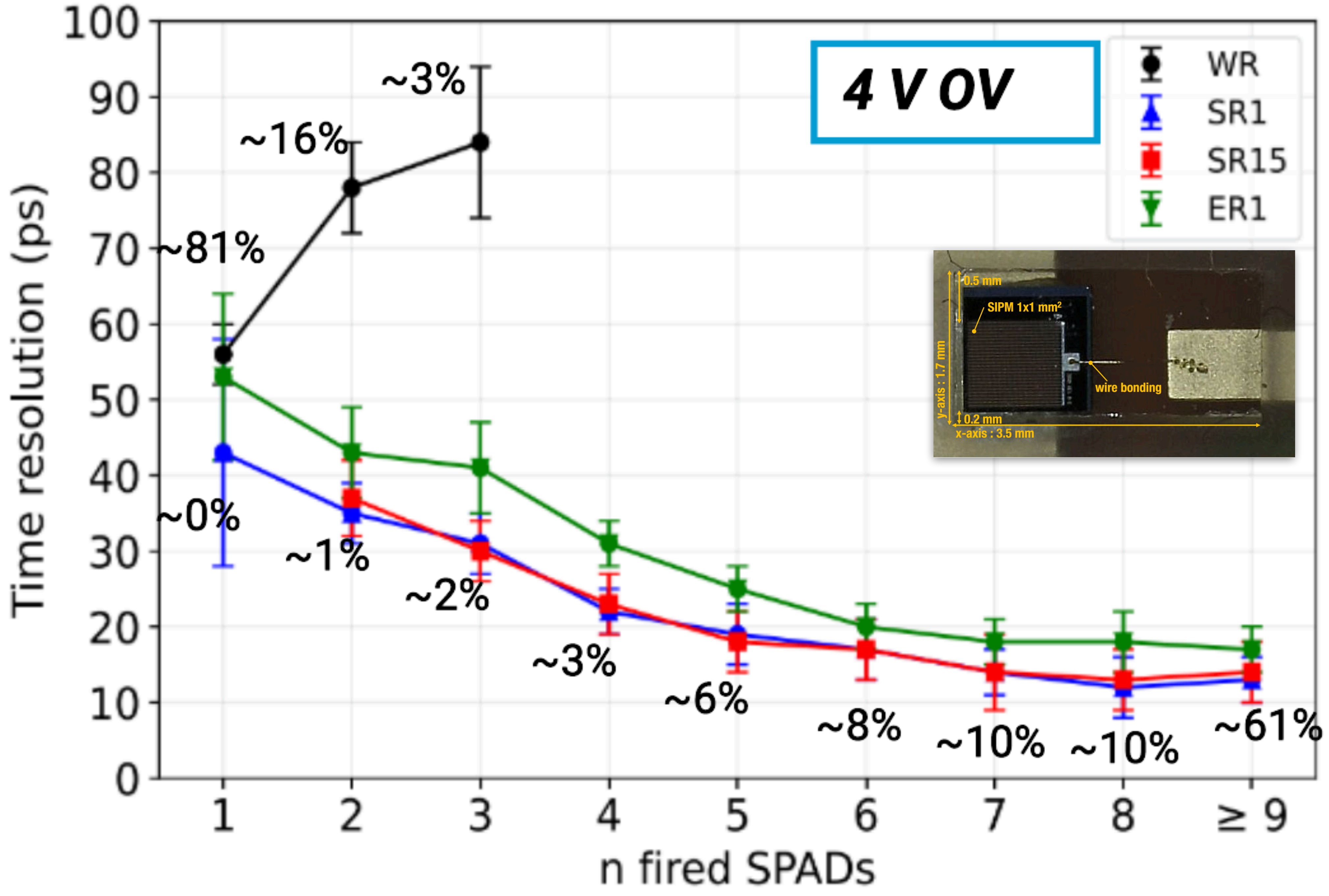
Active area	Pixel pitch	#SPADs	Fill Factor	V_{bd}
3.20 × 3.12 mm²	40 µm	6200	83%	32.2±0.1 V

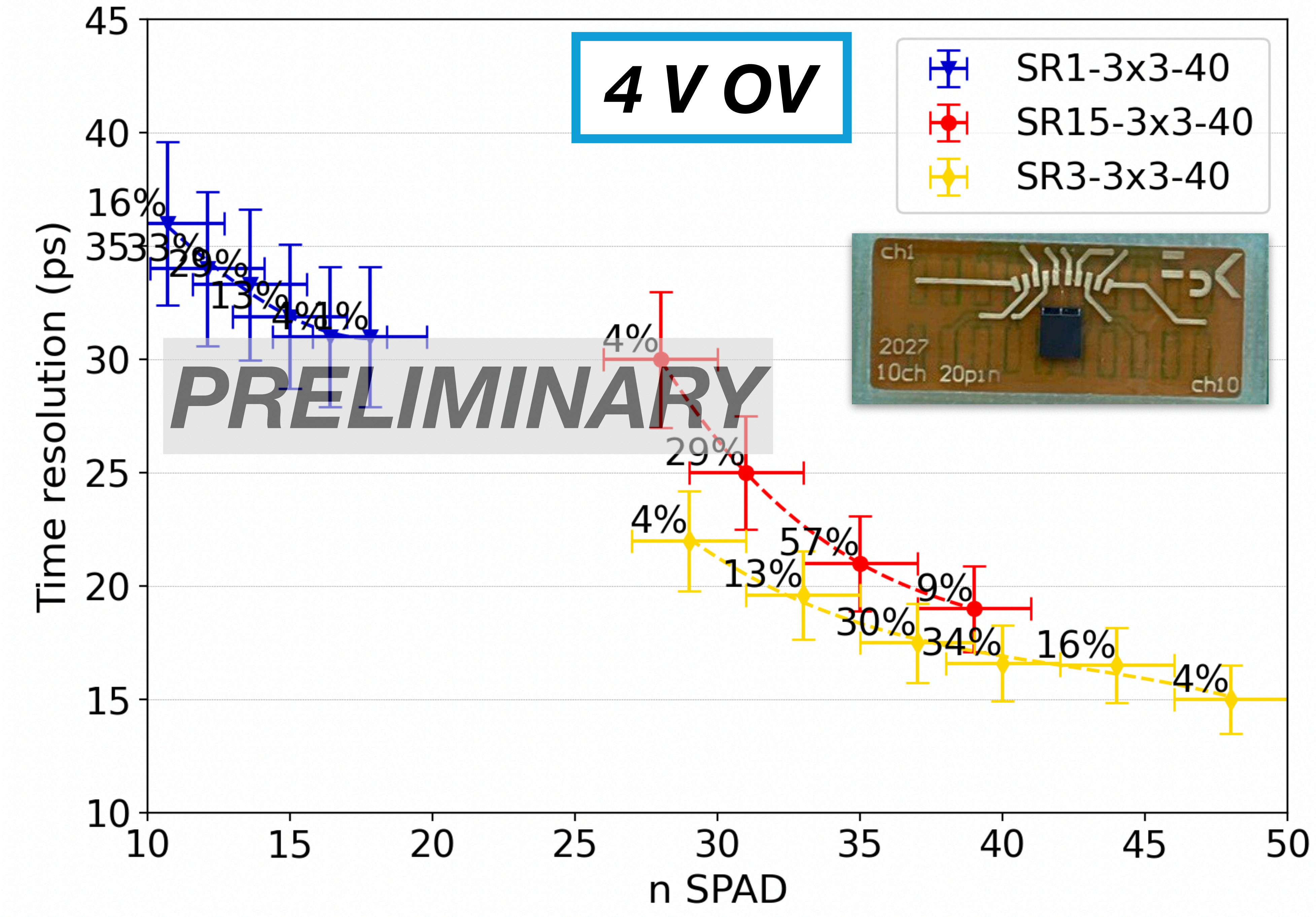




Time resolution wrt n SPADs

Study of the time resolution in the **centre of SiPM**



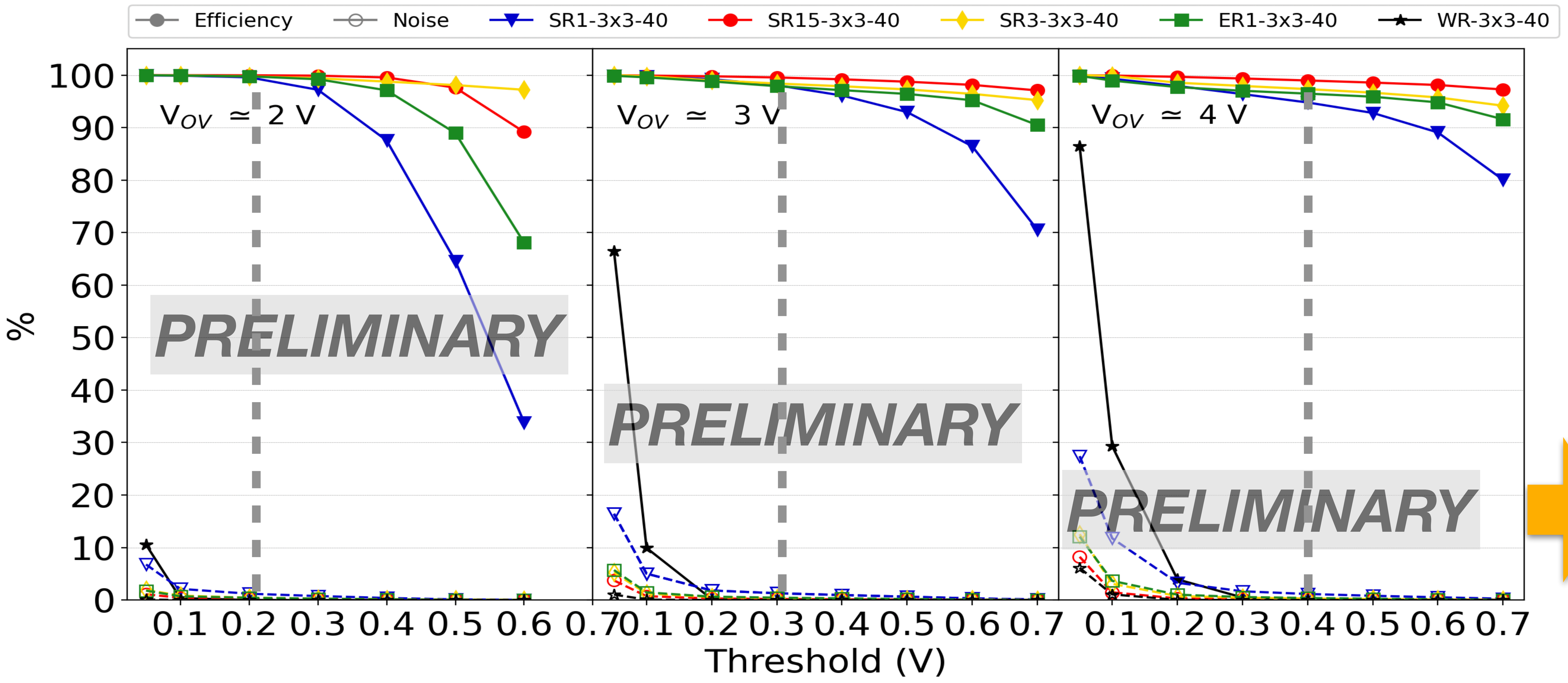


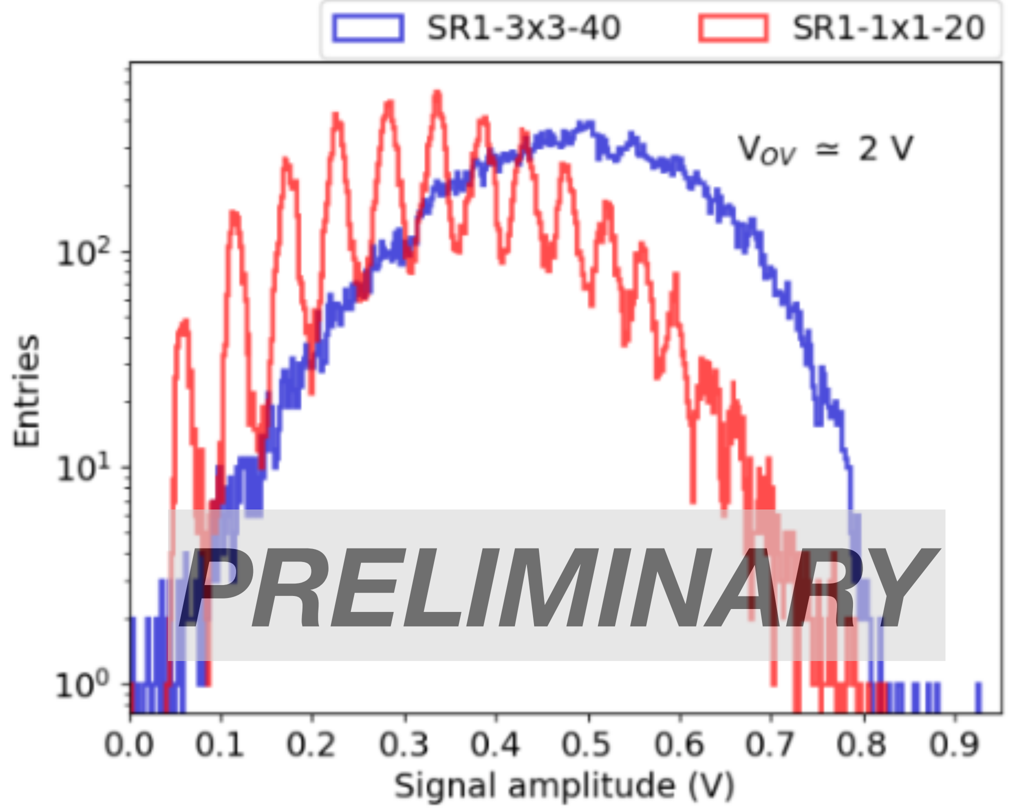
Time resolution trend improving as number of SPADs increase

Efficiency studies

- For larger area SiPM , need to account for **baseline** fluctuations: around 5 ns baseline evaluated for every waveform and threshold changing with respect to baseline value

- **Large DCR increase** after few hours (3-4 h) of beam (from kHz to few MHz!) [Peltier cells not helping]
- SPADs cannot **discriminated** for large signals
- Inohomogeinities in the samples still under study



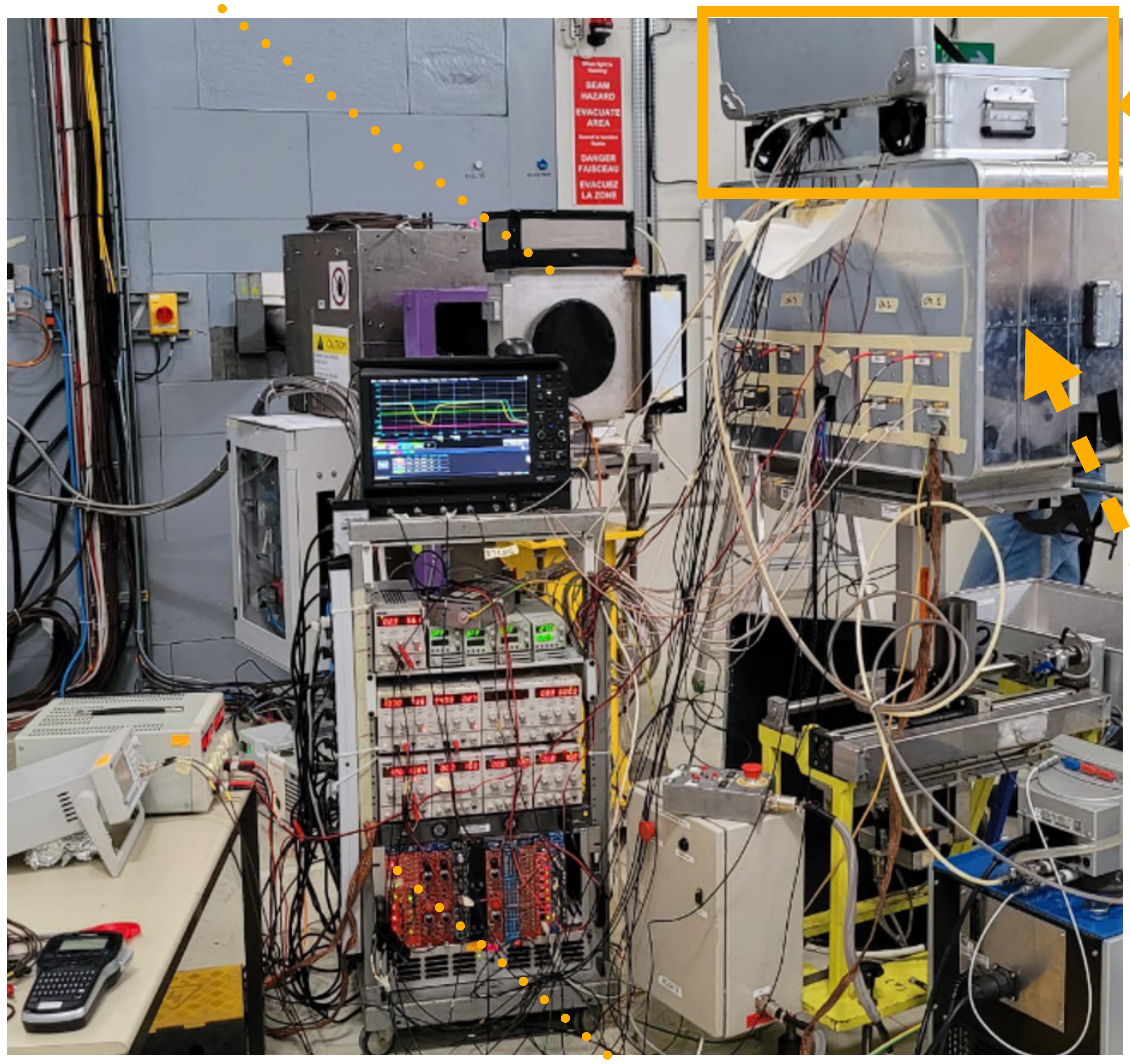


A threshold of few photoelectrons (4-5) leads to >95 % and noise <2%

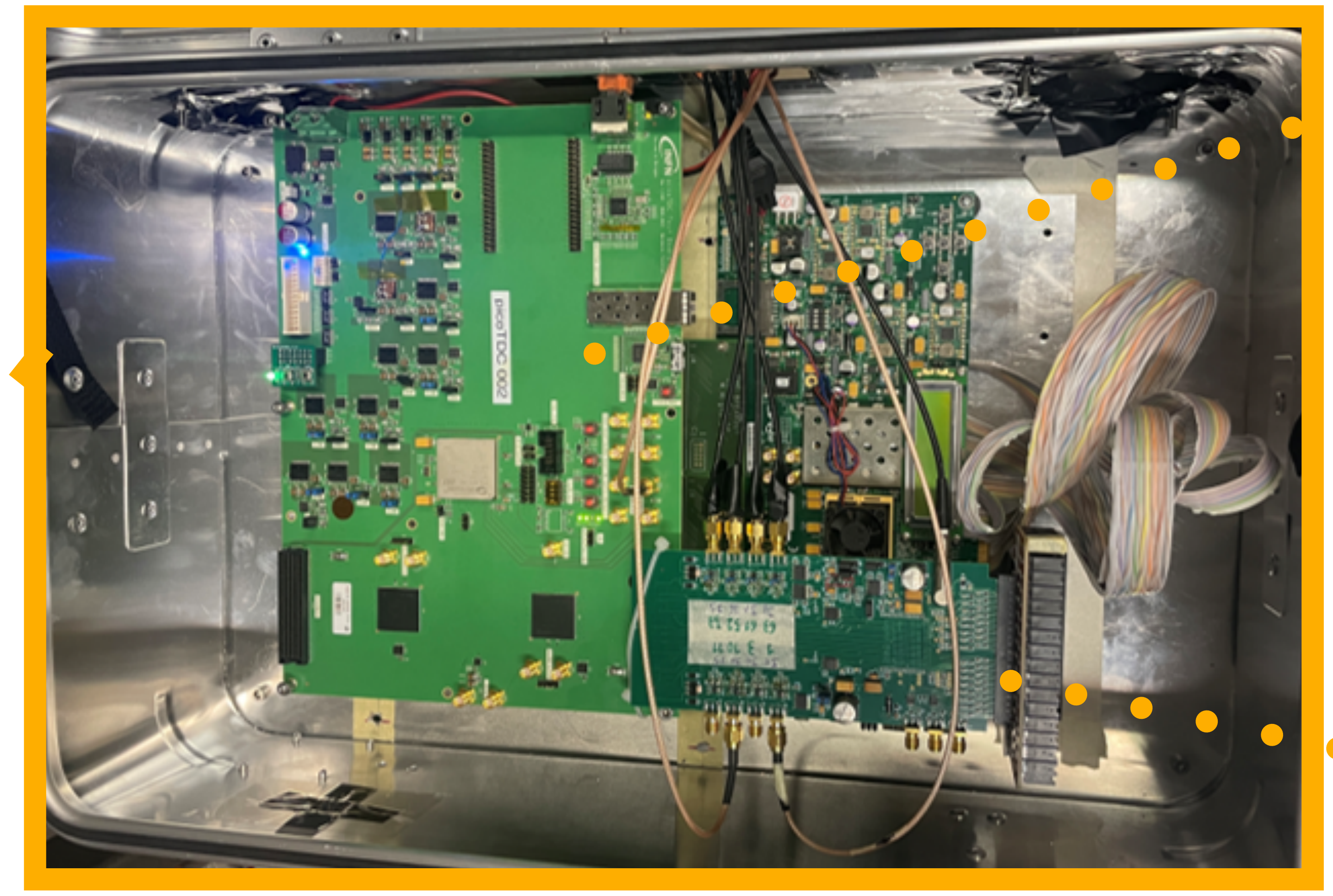
Recent development with full front end and readout electronics

CERN PS T10 beamline

protons of 10 GeV/c

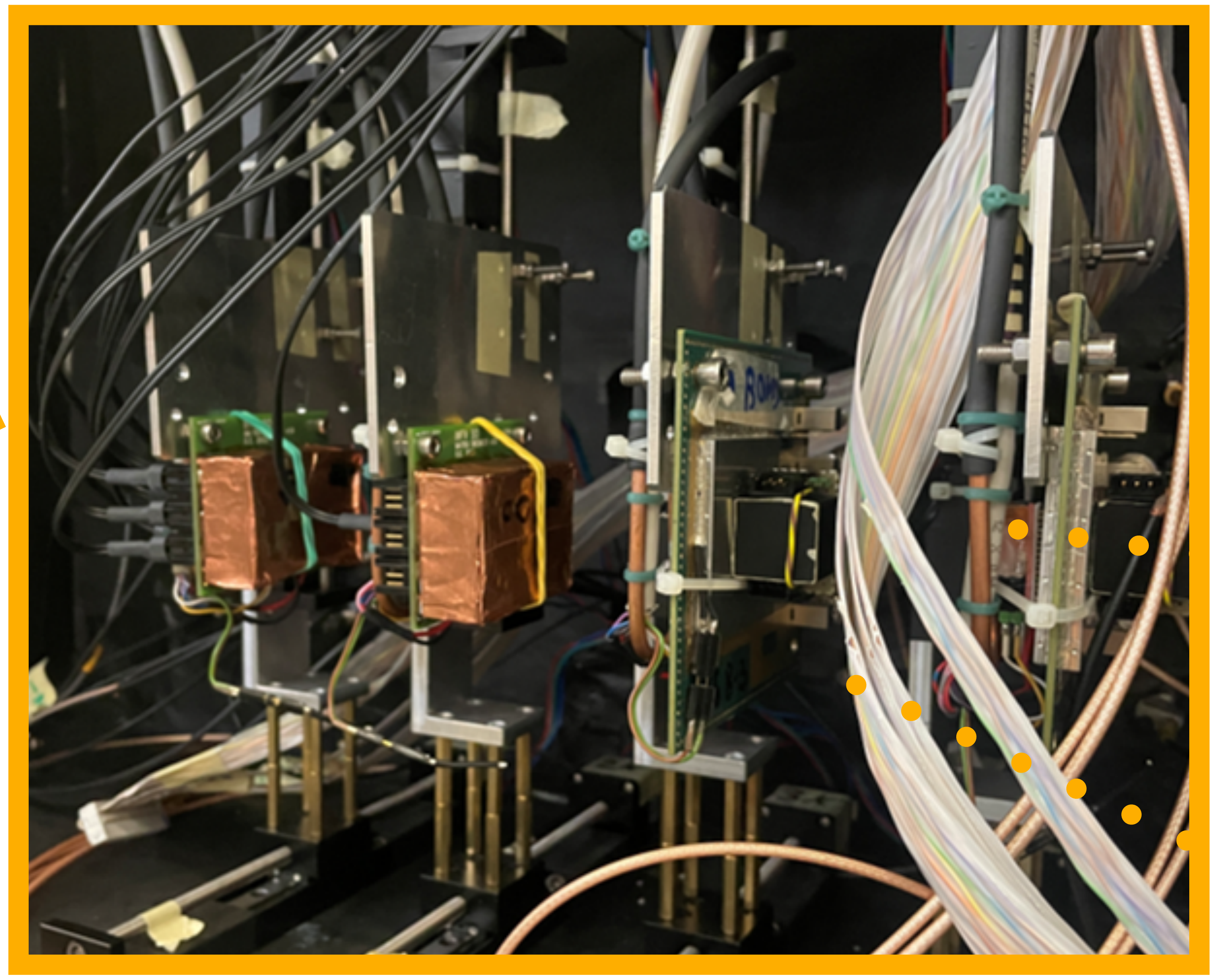


CAEN modules to manipolate signal trigger from LGAD sensor (from NIM to LVTTL)



Readout: **pTDC** (Time-to-Digital Converter) **FEB**

- 40 MHz clock, 64 channels, bin size 3.05 ps in fine resolution
- High data bandwidth towards PC with std interfaces (Ethernet and USB),
- First spill trigger from T10 line, second trigger from LGAD prototype



FEE: LIROC amplifier+shape+discriminator

- Weeroc 64 channel front end ASIC (designed for LIDAR applications)
- CAEN Adapter Board

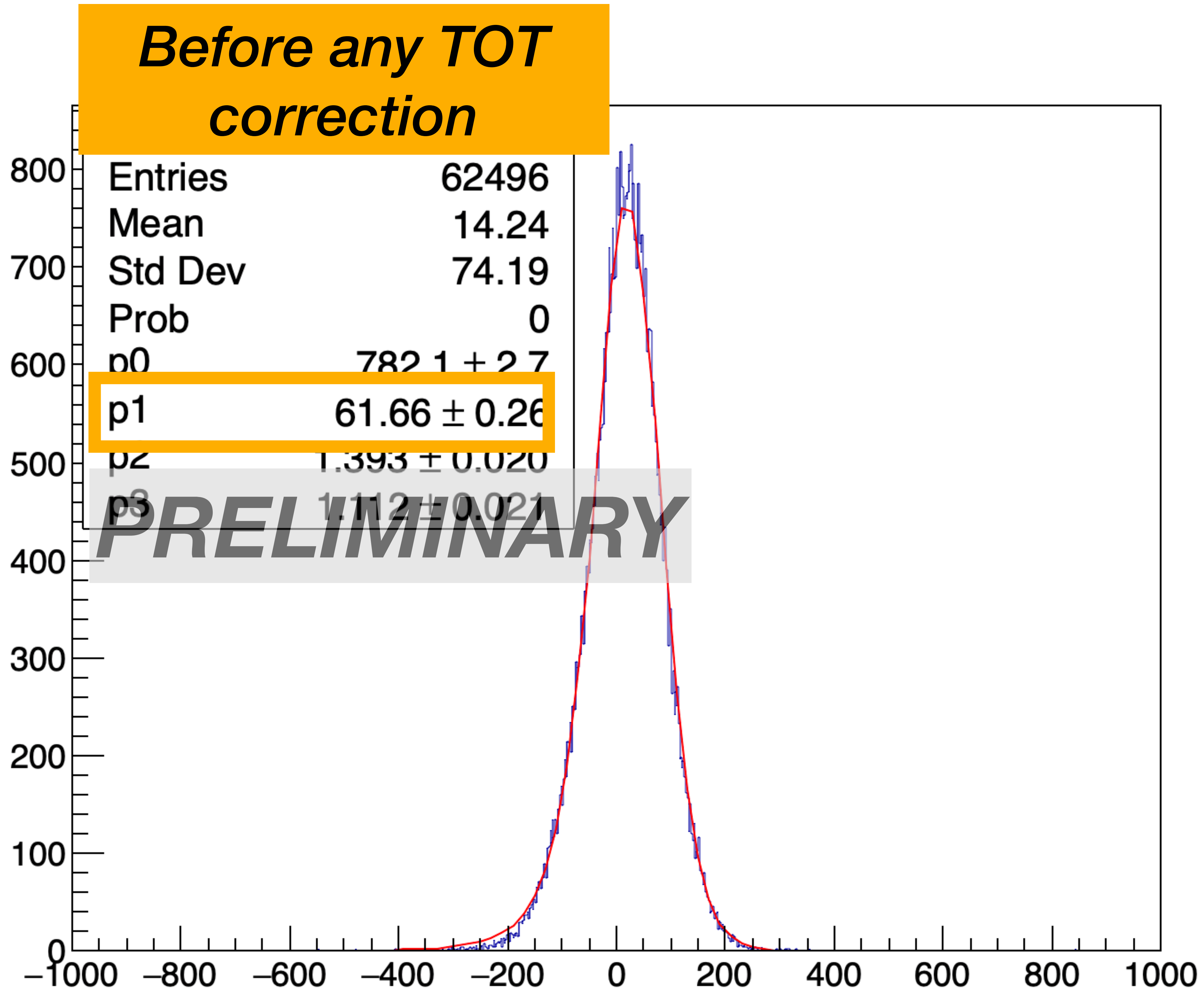
TDK Lambda Z100 power supply for SiPM (into LEMO of LIROC, then common to all SiPMs, single and of a matrix)

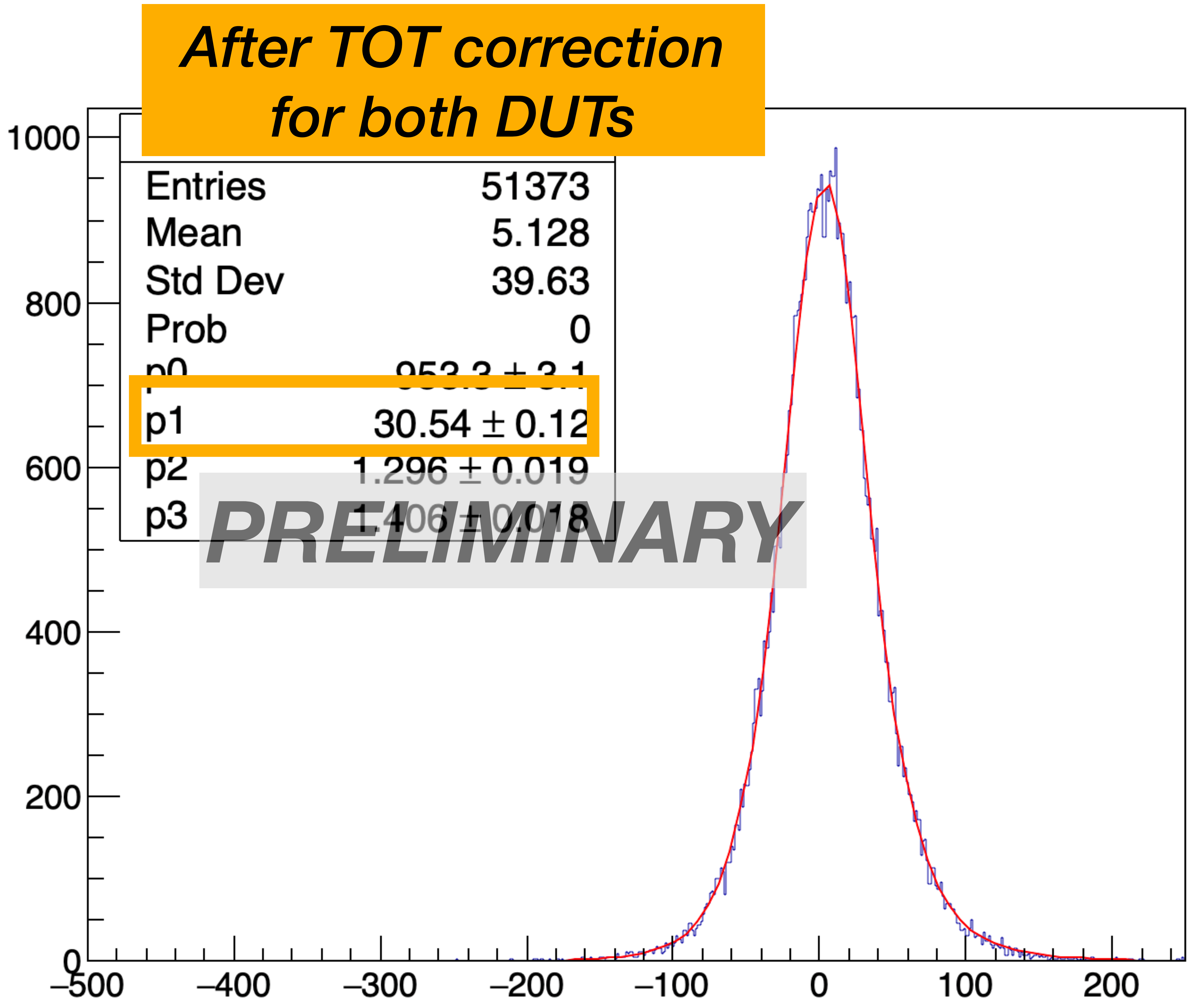
Peltier cells in order to keep Temperature as constant as possible

Different configurations (with just 1 LGAD of reference, with 2 LGADs to evaluate efficiency, with CMOS-LGADs prototypes, with LGADs only, with different SiPMs…)

pTDC analysis

SR15 at 2 OV with 30 mV threshold

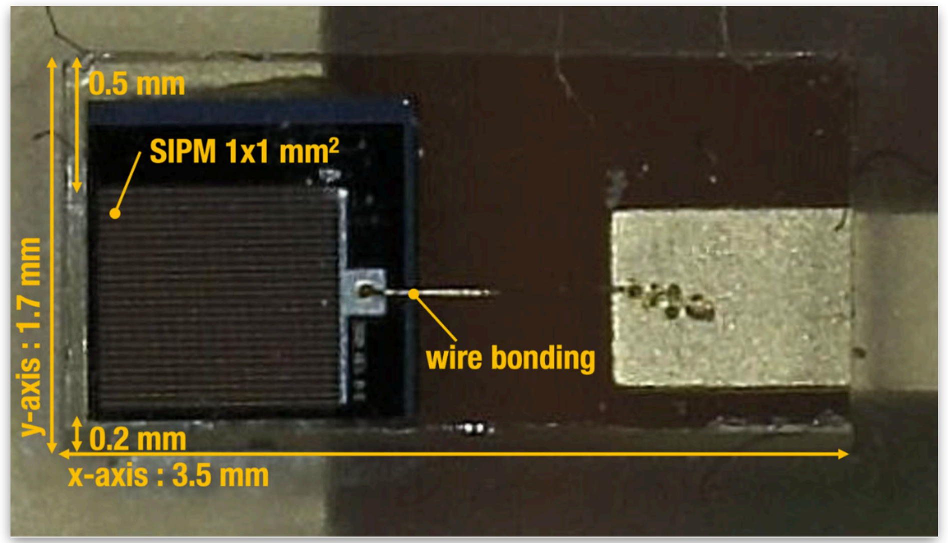




Preliminary runs studied considering Time Difference between central SiPMs:

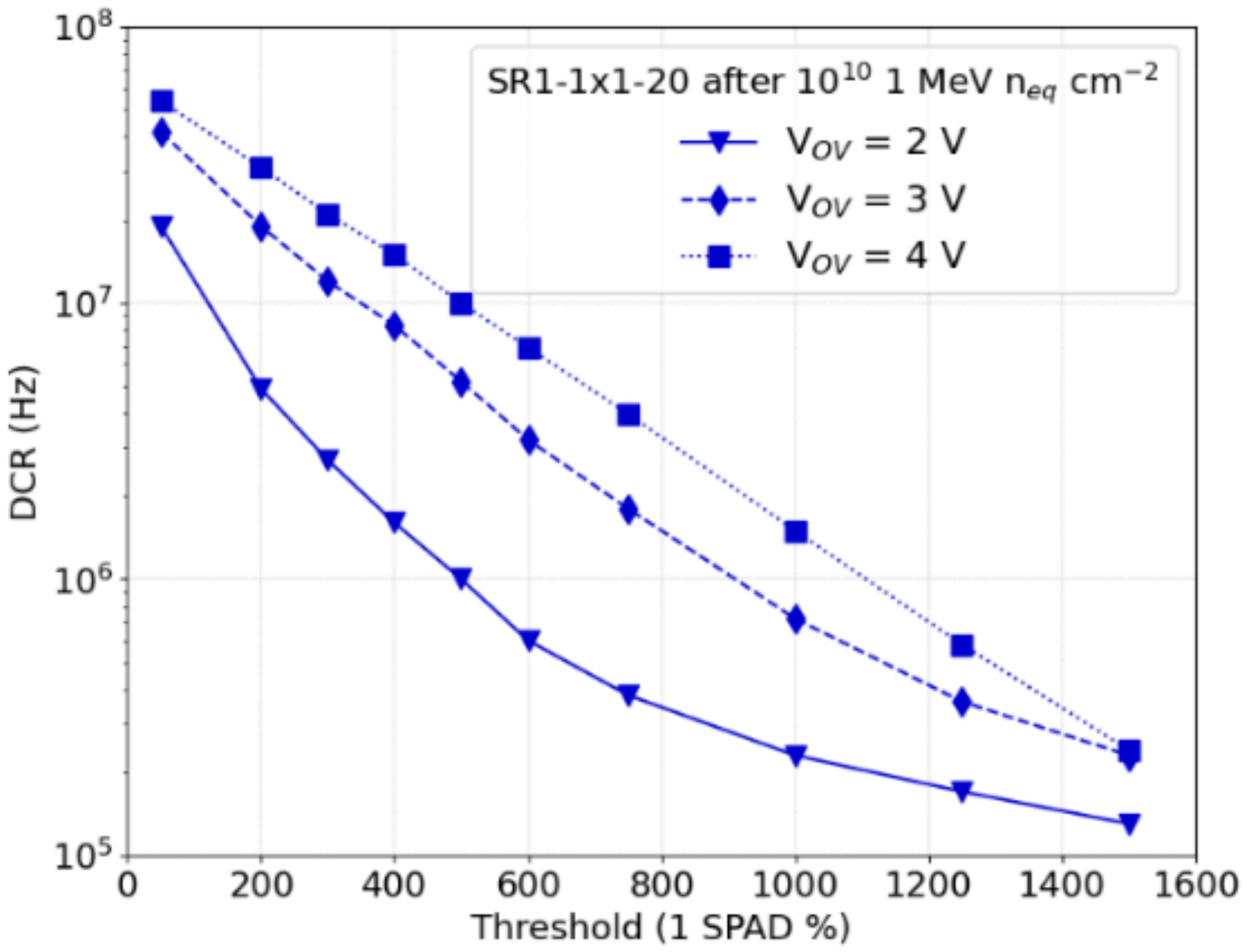
TR= 25-30 TDC counts * 3 ps single bin resolution / $\sqrt{2}$ = **50-60 ps**

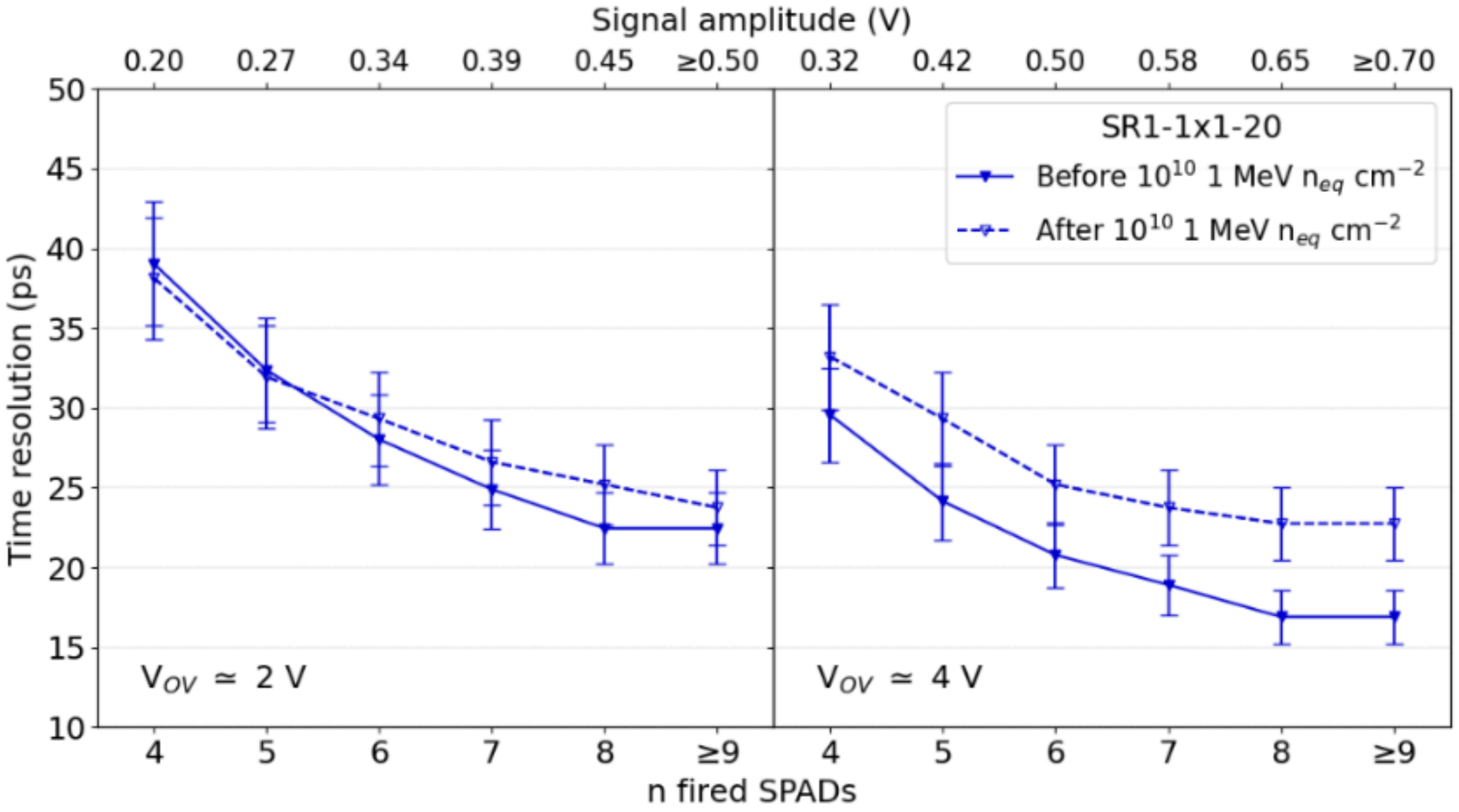
+Radiation studies



SiPMs time resolution was studied after irradiation at TIFPA of **10^{10} 1 MeV n_{eq} cm^{-2}** (lower limit as probably received already 10^9 1 MeV n_{eq} cm^{-2} during test beams):

- Before irradiation, DCR of the order of 10^4 Hz
- >5 photoelectrons, efficiency>95% at all OV and reduced DCR of factor 6-20 depending on OV
- The performance seems marginally worsened at 4 OV, negligible at 2 OV



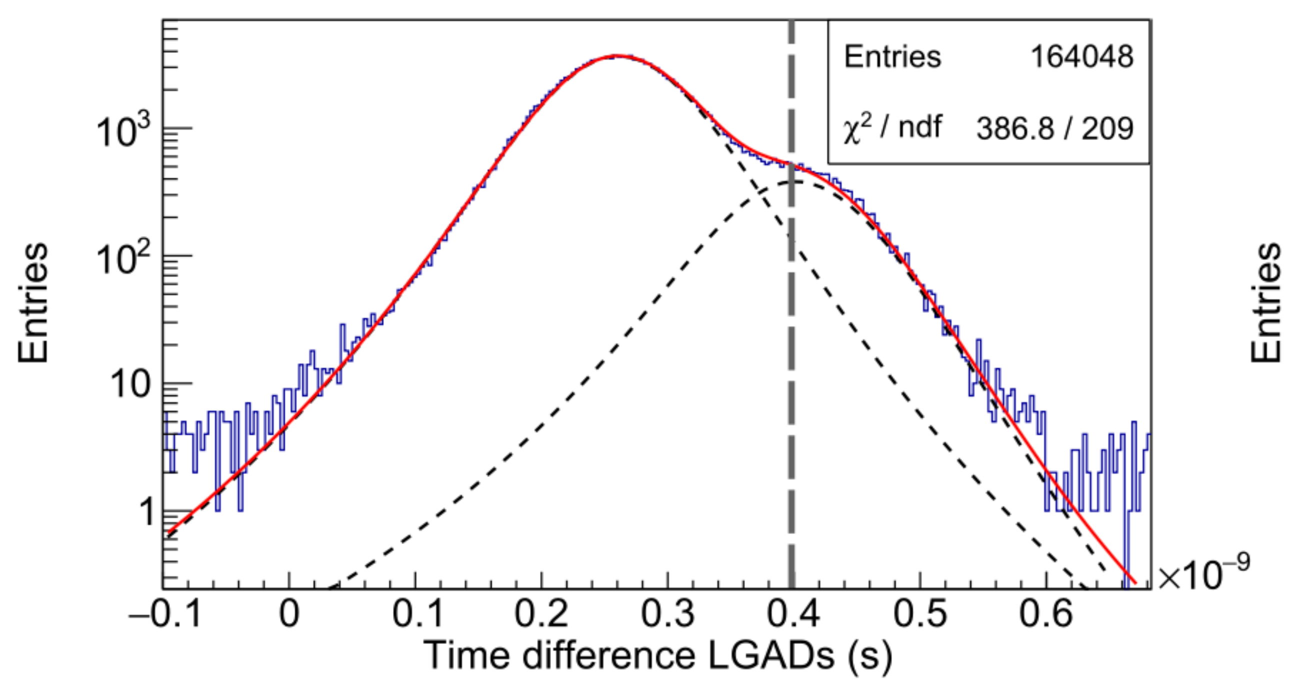


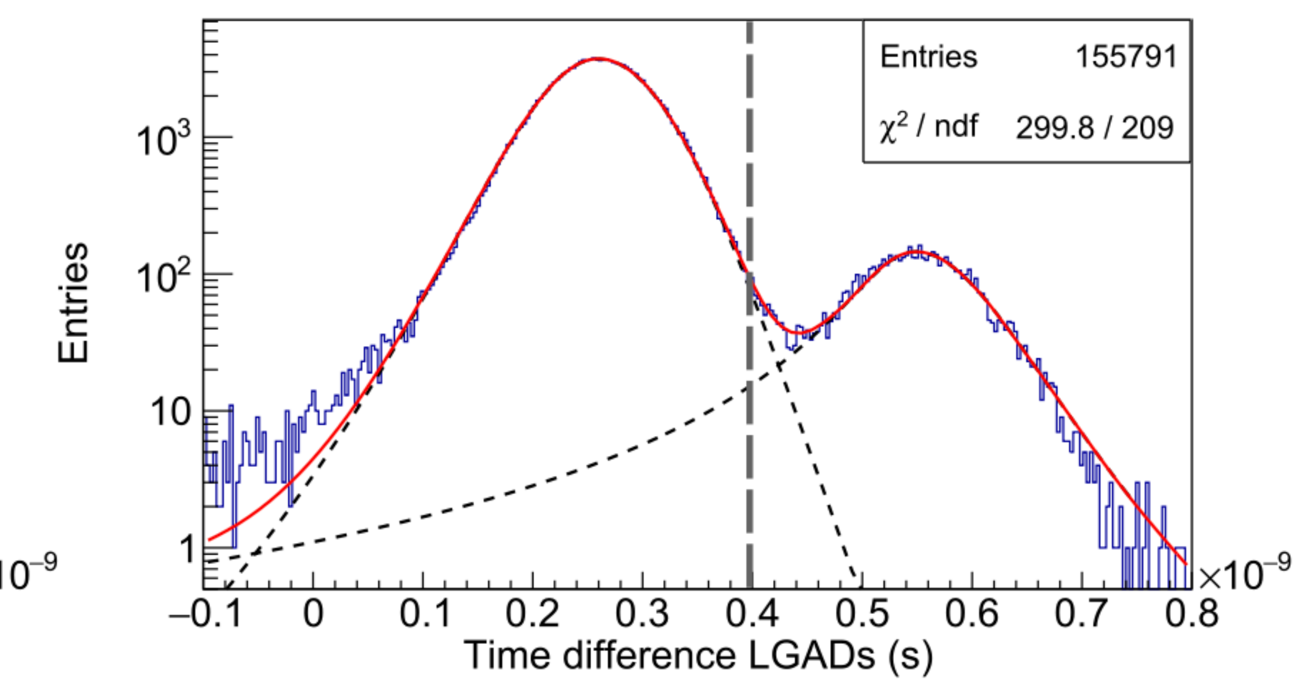
Open questions for discussion

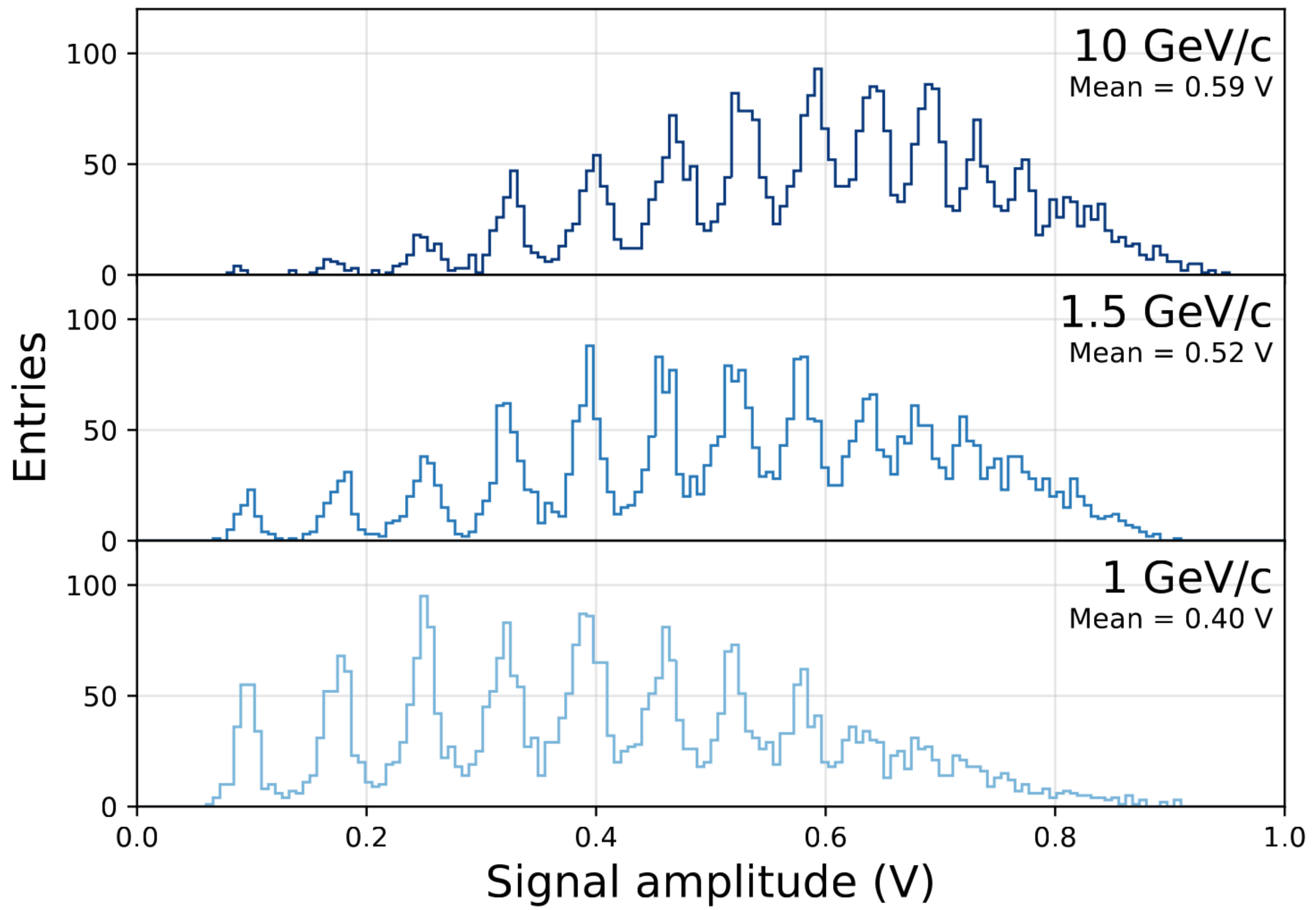
- ***Cooling system***
  - in next beam test, gaseous nitrogen in open loop on the sensors boxes to benefit both dark count rate and baseline fluctuations
- ***Effect of radiation***
  - How to mitigate it during beam time?
- ***SPADs dimension***
  - Timing between SPADs on same SiPM?
- ***Simulations***
  - Code to simulate our SIPM+Cherenkov with proton beam+other effects … availability?

Backup slides

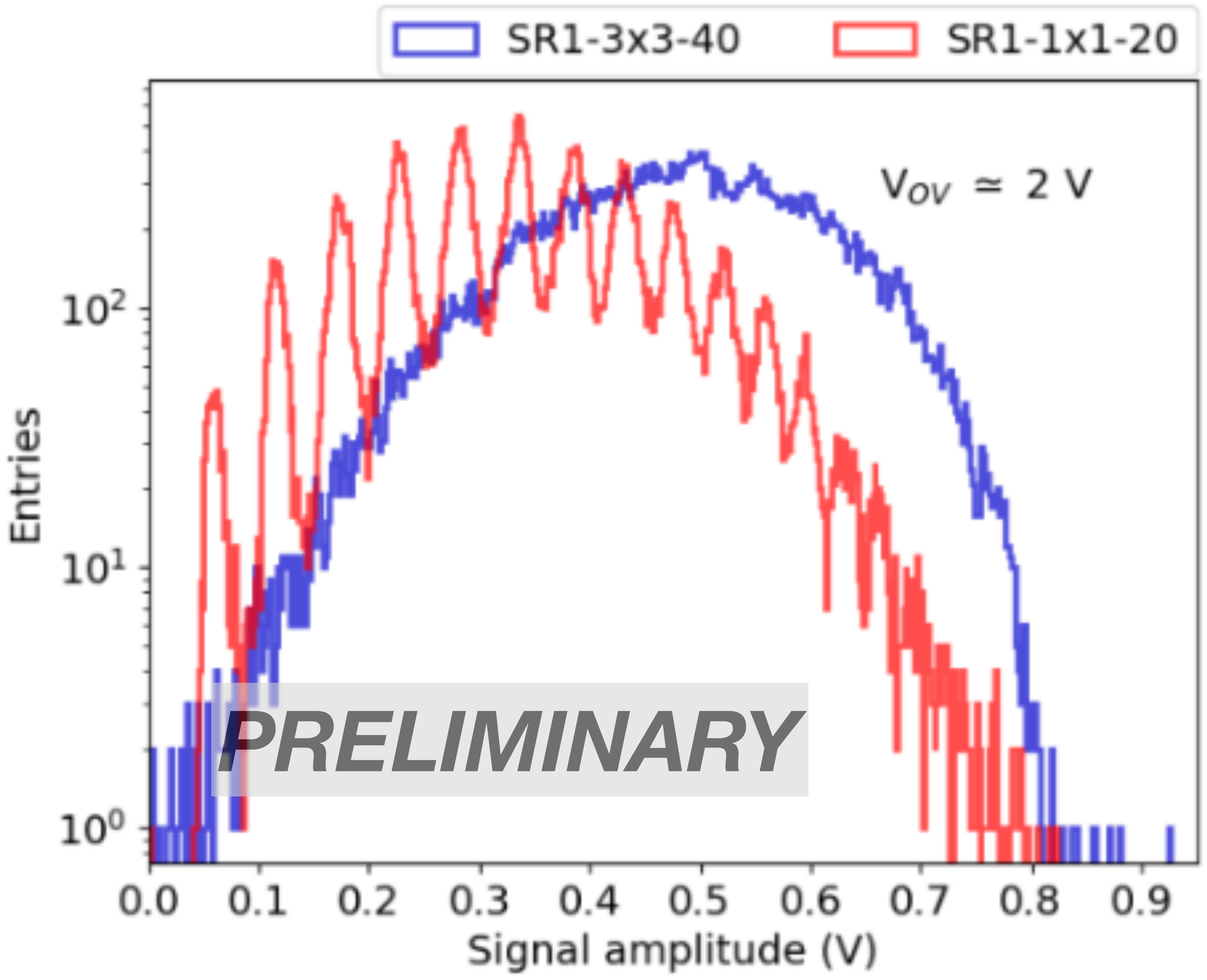
Lower energies studies







Different signals amplitude 1x1 VS 3x3

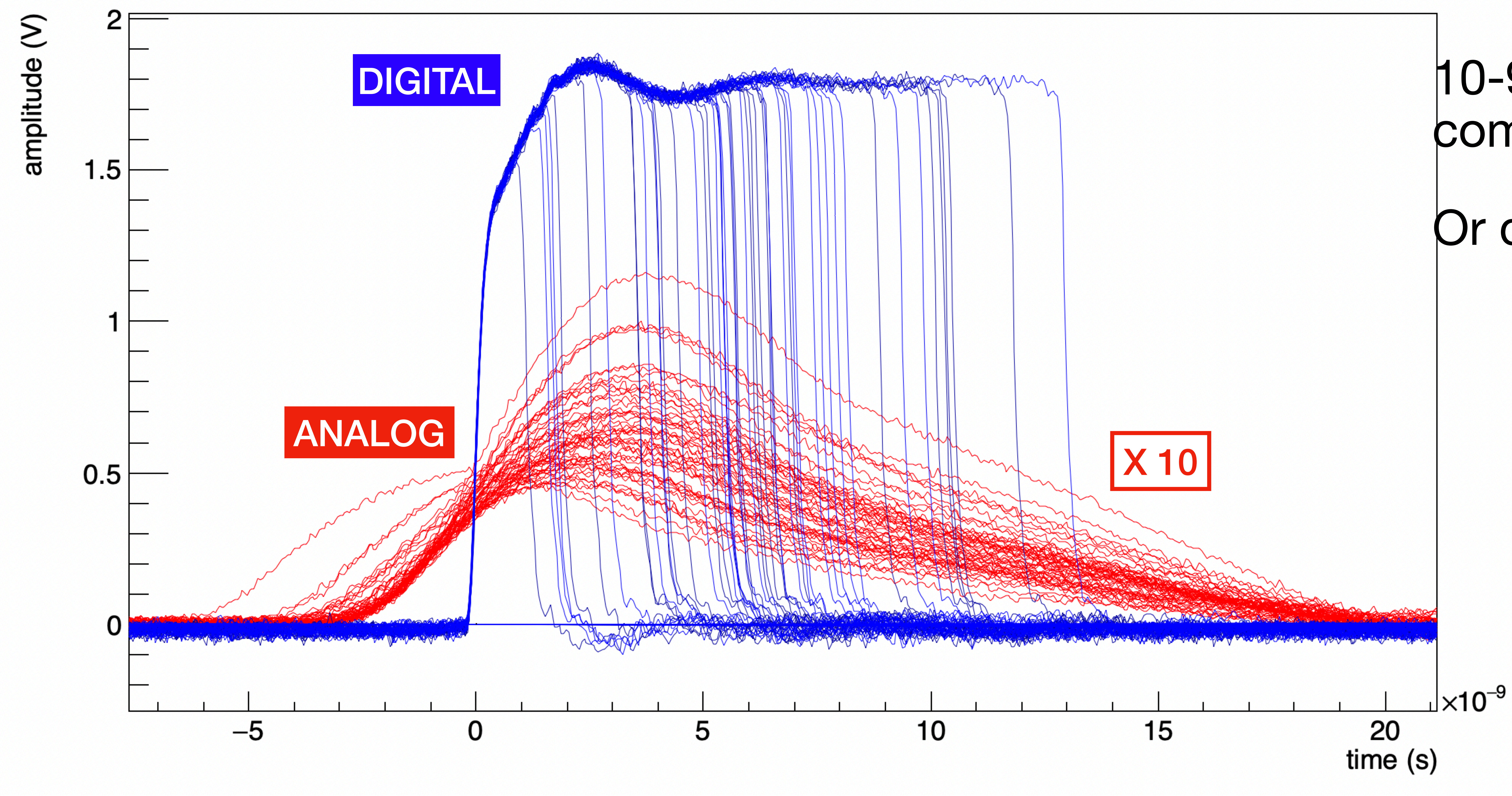


Dark count rate

1) DCR (2023)	SR1-A DCR per mm2 before any test beam
2 ov	60 KHz
3 ov	80 kHz
4 ov	100 kHz

3) DCR (2024)	SR1-A DCR per mm2 after test beam
2 ov	2.4 MHz
3 ov	2.8 MHz
4 ov	3.1 MHz

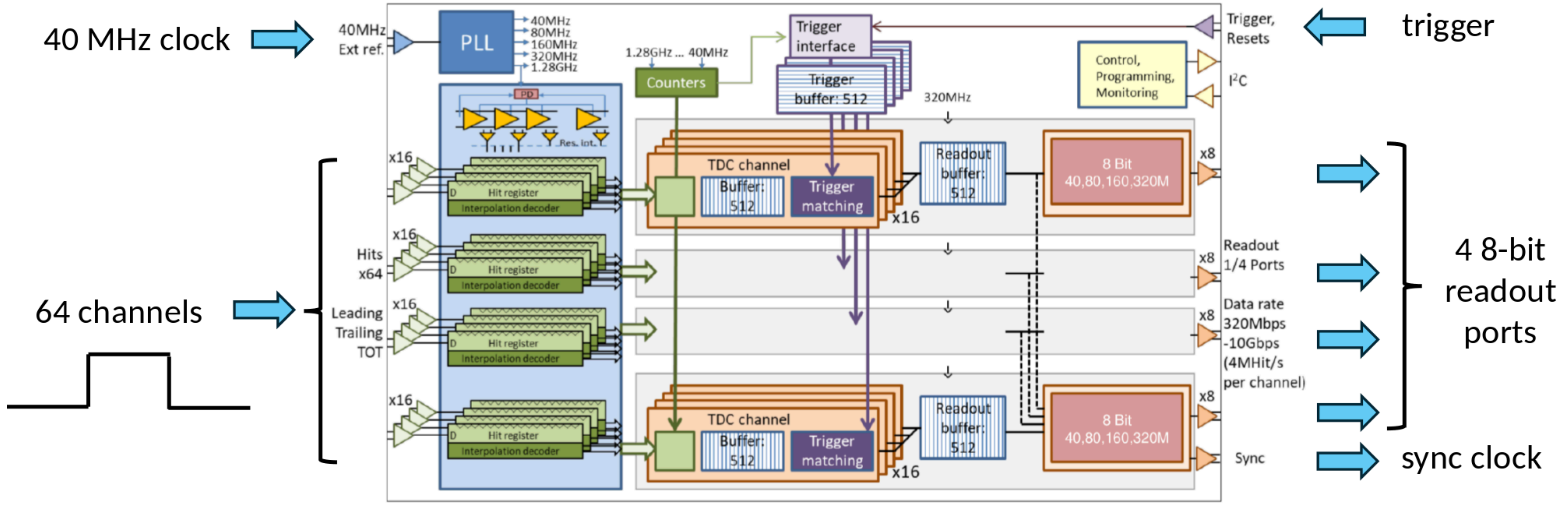
50 triggers of analog (input in LIROC) to digital (output to pTDC) for a SiPM of matrix (1 mm resin) with threshold 60 mV



10-90% signal comparison

Or dV/dt

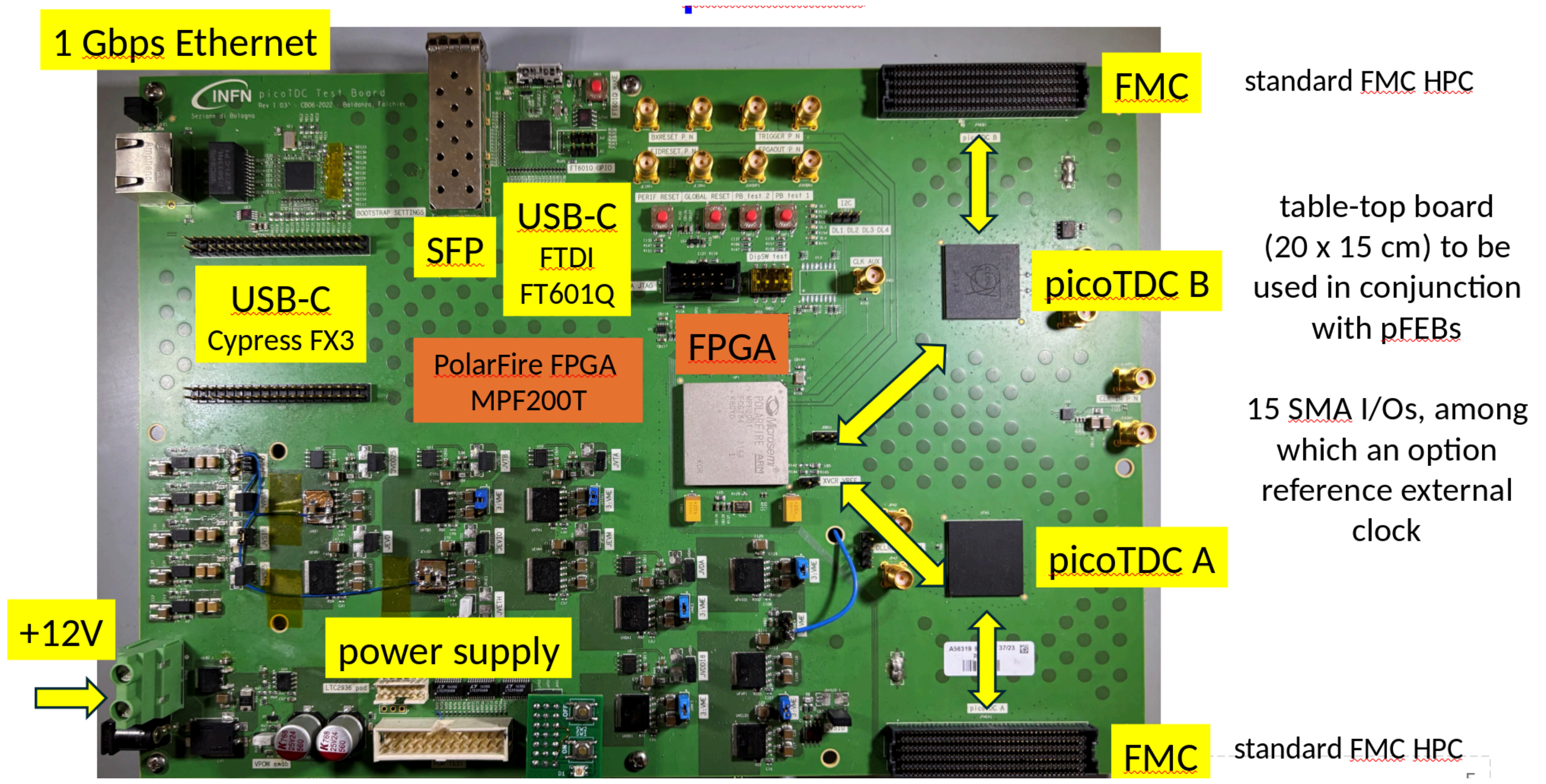
pTDC from CERN

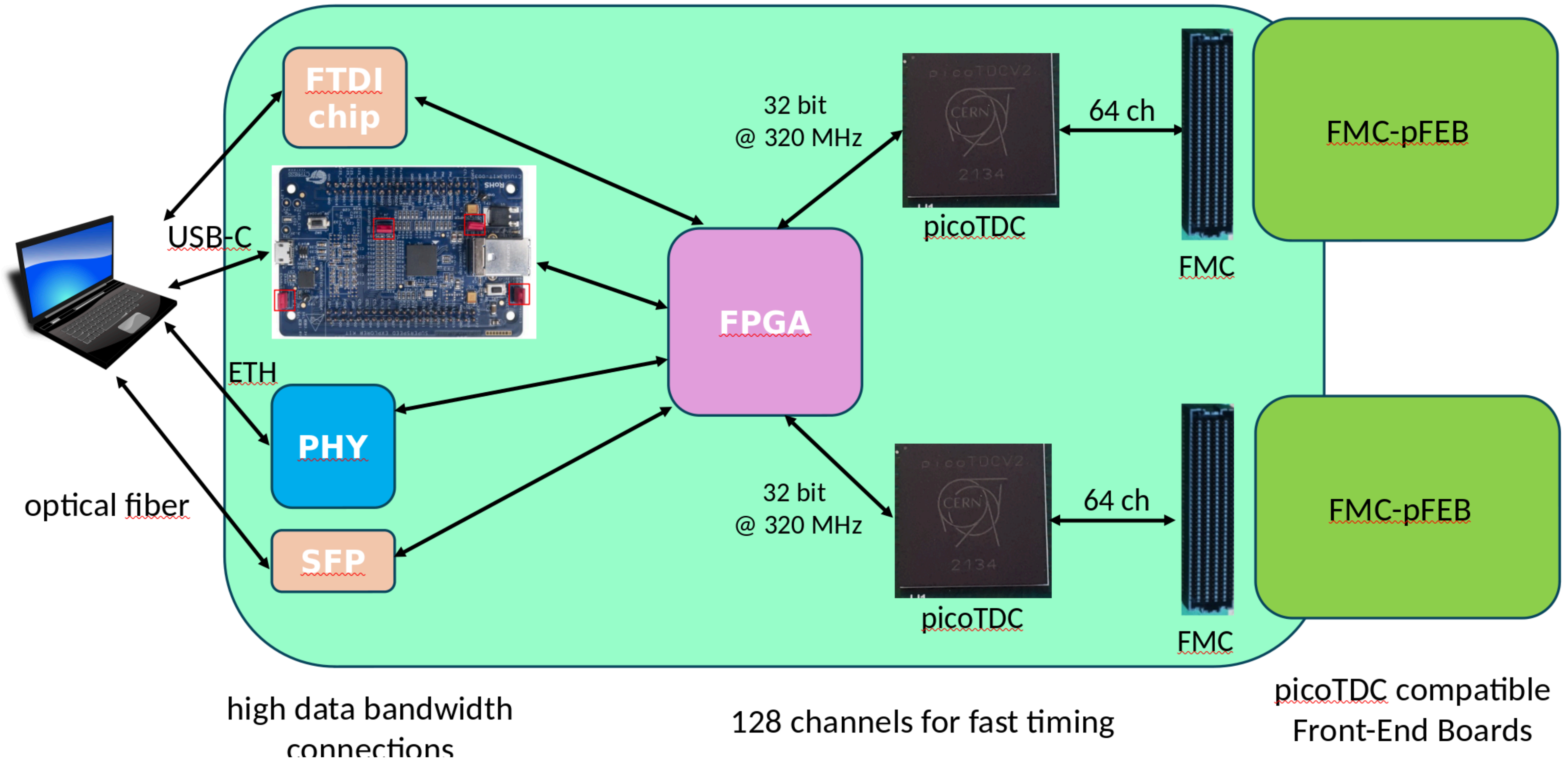


pBoard from INFN Bologna

Davide Falchieri [a], Pietro Antonioli [a], Casimiro Baldanza [a], Daniele Cavazza [a],
Sandro Geminiani [a], Marco Giacalone [a], Jacopo Succi [ab], Carlo Veri [c]

INFN Bologna [a], University of Bologna [b], INFN Lecce [c]





Fast analysis during test beam measurements