R&D on rad-hard SiPM by the INFN groups of the LHCb/RICH collaboration

TF-4 community meeting 16 May 2023

M. Guarise[1] on behalf of italian groups of LHCb RICH collaboration
(Ferrara, Genova, Milano Bicocca, Padova, Perugia)
[1] INFN & University of Ferrara

Who we are

- 5 INFN groups located in:
  Ferrara, Genova, Milano Bicocca, Padova, Perugia;

- Part of the LHCb RICH collaboration;

- Scenario:
  - LHCb experiment is planning a future upgrade to fully exploit the potential of the High-Luminosity LHC;
  - Development of a RICH detector for running in these extreme conditions ($L \sim 1.5 \times 10^{34} cm^{-2} s^{-1}$): very challenging

See S. Gambetta talk about the requirements on the new RICH of LHCb (afternoon 16:45)

R&D program

- We are highly motivated to pursue a R&D program to develop photodetectors and electronic capable of performing in the challenging high luminosity LHC environment;

- We started an intense "wide-band" R&D program to achieve the specifications required by the LHCB/RICH detector. Strong synergy among the LHCb RICH Italian groups and external companies in order to obtain the best performances;

Design → Test → Improve → Characterize

particular attention to: radiation tolerance, time-response, light collection system,....

R&D program on SiPMs

- In particular about SiPM:
  - Improve intrinsic radiation hardness of the devices (different design);
  - keep dark count rate under control (operation of SiPM at low temperature);
  - Improve sensor efficiency and performances;
- INFN funded a production lot targeted to the development of rad-hard SiPM at FBK:
  - Plan to develop novel technology (backside-illuminated)
- Expected advantages:
  - Increase efficiency/noise ratio (decouple microcell photo-sensitive area and high electric field region)
  - Compact detector with high granularity and timing resolution
  - Easier vertical integration with readout electronics

See A. Gola talk about SiPM status and perspectives at FBK (this morning!)

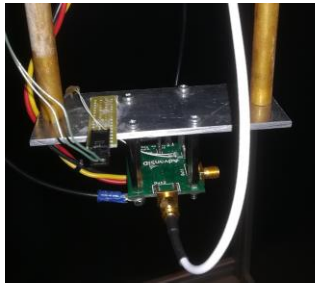
Ongoing activities

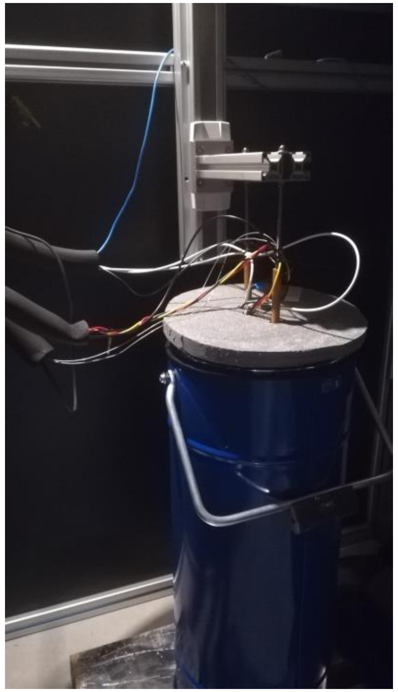
- Test campaign with commercial sensors in order to test the state of the art in SiPM technology;

- Different test systems to measure SiPMs parameters as a function of temperature, before and after irradiation & before and after annealing;

- Systems includes: low-T parts, source-meter units, ps-pulses lasers, fast preamps, wide band oscilloscopes, digitizers and other electronics

Ferrara setup
[room,-150°]



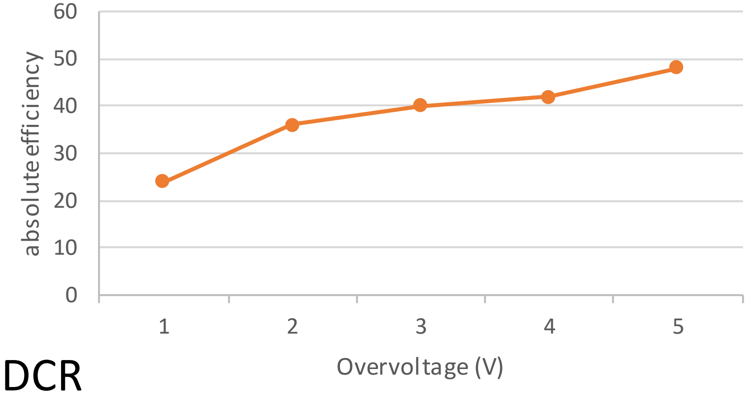


Genova setup
[room,-70°]

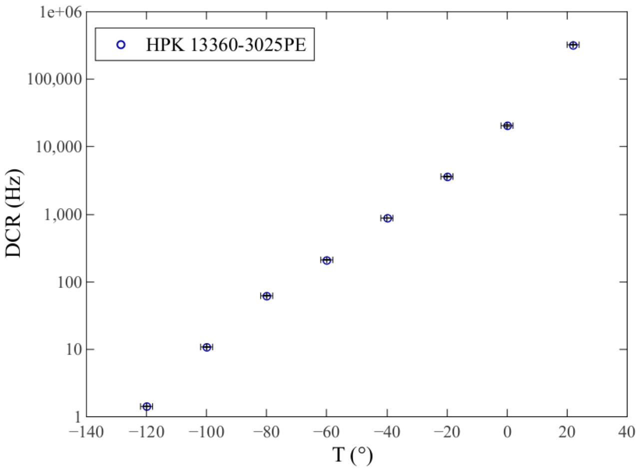
Ongoing activities

Some results:

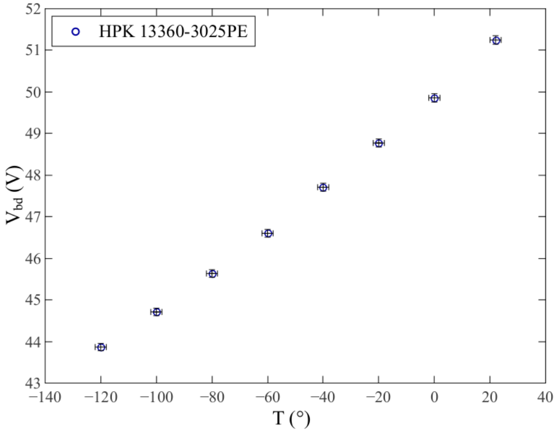
- PDE



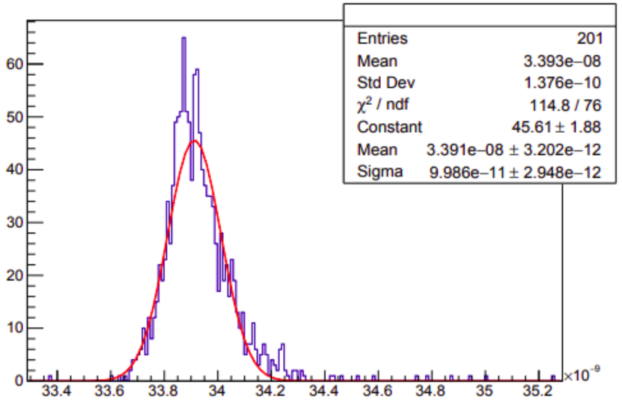
- DCR



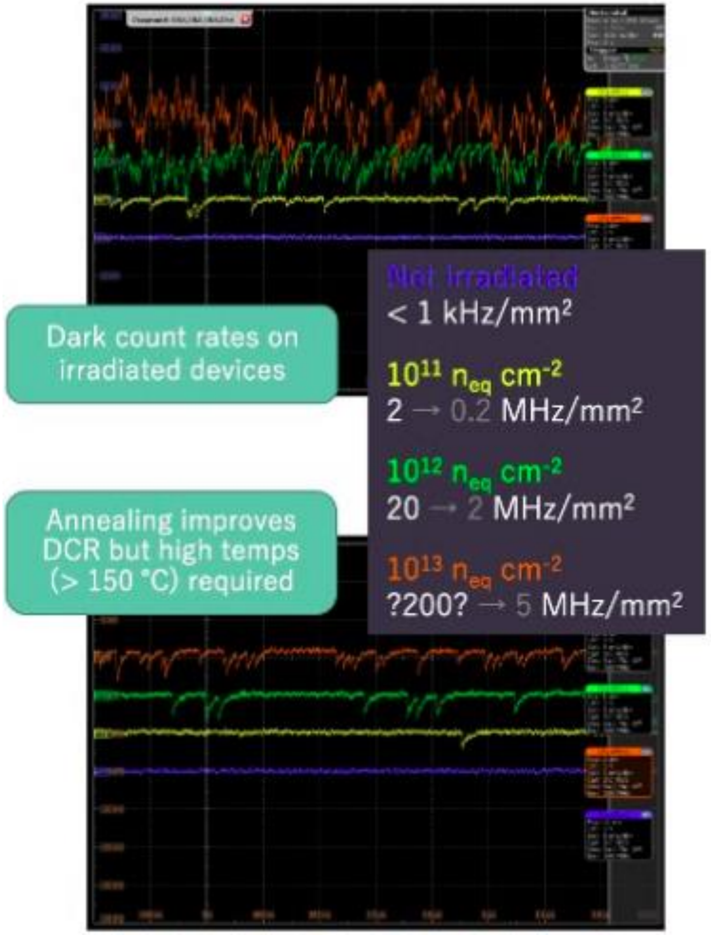
- Breakdown voltage



- Time resolution



- Irradiation



Plans for future

- Complete the equipment of a labs network with the capability to test different sensors in different conditions of operation;

- Continue the tests on commercial sensors in order to understand deeply the behavior of SiPMs in different conditions;

- Evaluate the best compromise between efficiency, time resolution, recharge decay (dead time), gain, temperature of operation, operating voltage, ...

- Develop, test and fully characterize a 1x1 mm^2 active area sensor with cell pitch of 10-20um (to be discussed) with the best possible features and rad-hard

The end

Many thanks!

The group:

M. Benettoni, R. Calabrese, M. Calvi, R. Cardinale, P. Carniti, G. Cavallero, A. Cotta Ramusino, V. Duk, M. Fiorini, C. Gotti, M. Guarise, S. Minutoli, G. Pessina, A. Petrolini, M. Piccini, A. Sergi, G. Simi

Backup slides

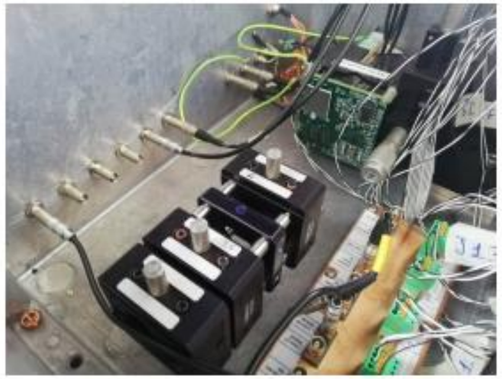
Genova

Setup for SiPM characterisation @Genova

- A setup has been built up for SiPM characterisation and it is currently operational
- It includes a pico-second (∼50ps) laser system at 405 nm (Taiko PicoQuant system), neutral density filters and sensor holders (CAEN or custom PCB called Baseboard (BB) for SiPM matrix characterization) installed in a light-tight box
- Climate chamber down to -75°C

BBv1.0 houses various SiPM types (including Hamamatsu and FBK SiPM) for test purposes

Box with laser fibre, optical filters and BBv1.0

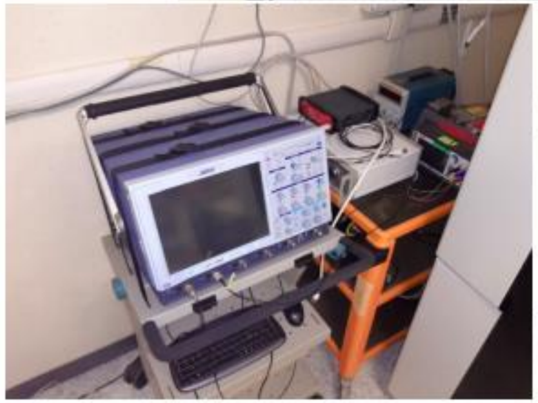


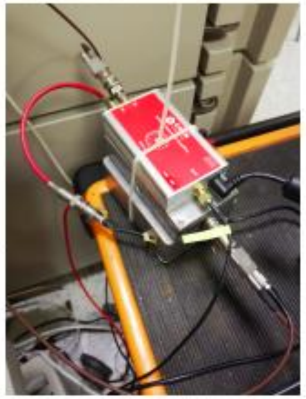
Box with laser fibre, optical filters and sensor holder

Climate chamber

Genova

Setup for SiPM characterisation (III)



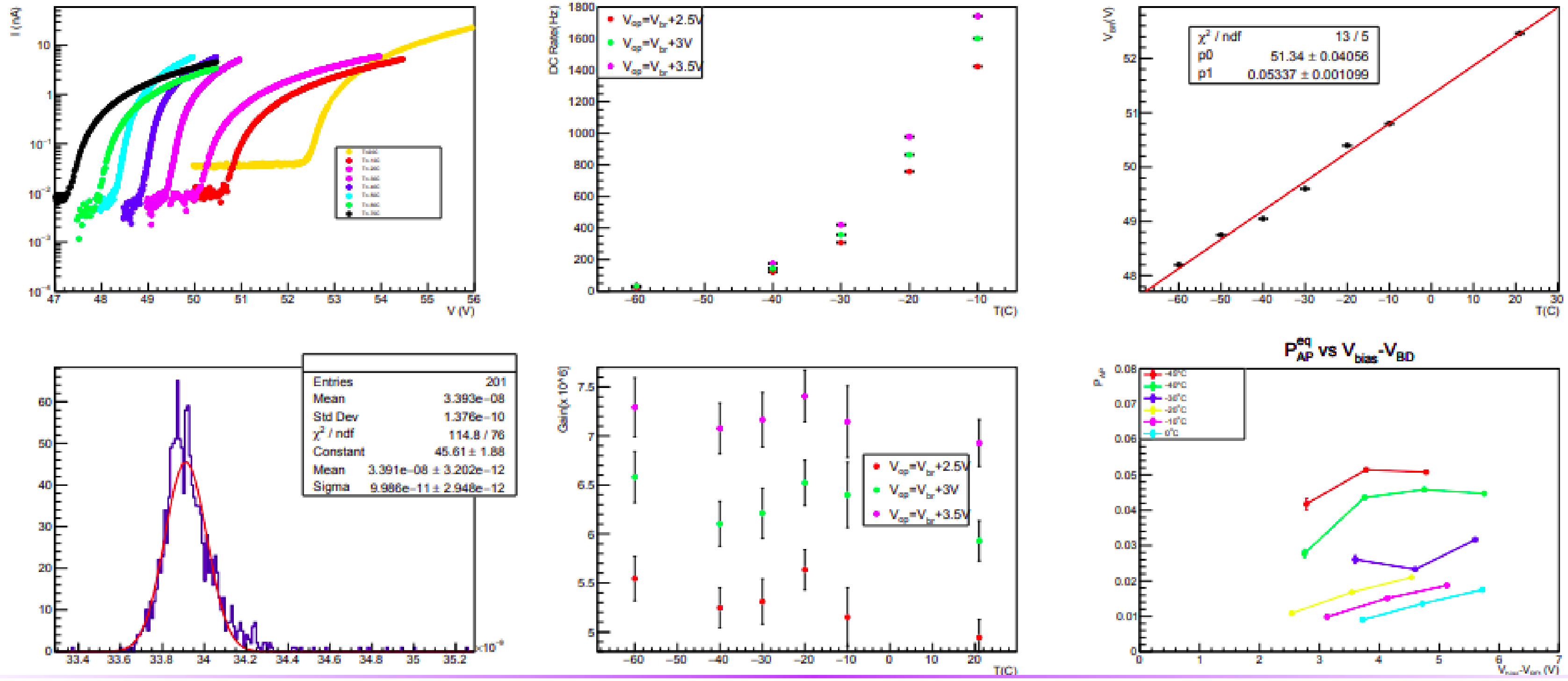


- Measurement of I-V curves acquired with an automated system with multimeters (8 channels)
- SiPM signal is amplified by a Wide-band Pre-Amp
- Automated system to readout/save waveforms by a multichannel digitizer read-out system (CAEN DT5730) for DCR and correlated noise measurements
- Lecroy 3 GHz oscilloscope, 20Gs/s + new oscilloscope, 8GHz, 20GS/s, 12-bit (WavePro 804HD Teledyne Le Croy) for fine measurements (i.e. time resolution)

Genova

Preliminary results

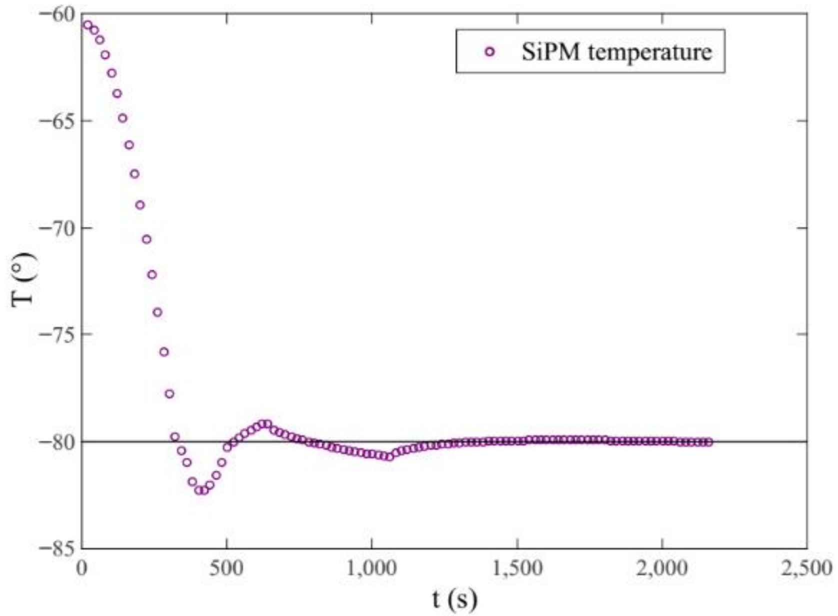
- I-V curves analysis (V_{BR}, uniformity of matrix pixels, ...)
- Waveform analysis (DLED algorithm, waveform template, Δt vs Amplitude method)
- Full characterization of the SiPMs at different temperature down to -$75°C$ (gain, DC rate, correlated noise, ...)
- Time resolution



Roberta Cardinale, Flavio Fontanelli, Saverio Minutoli, Alessandro Petrolini, Antonino Sergi, Youhua Yang 16/05/2023 4

Ferrara

We can perform test at different temperature in liquid nitrogen (LN2) vapour (from 100K to 300K)



Example: T_{set}=-80°, start from T=-60°

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INFN FERRARA

Setup:

- liquid nitrogen cryostat (LN2) 14l;
- source meter unit (Keithley SM2450) resolution <1pA, triaxial cables ;
- stabilized power supply (Keysight E3630);
- oscilloscope (Tektronix MSO 64) 12bit res., 2.5GHz bandwidth, sampling 25GS/s;
- mechanical linear stage, software controlled ;
- cold amplifier not designed for fast signals ;
- led system at 470nm;
- pulsed UV laser;
- fast amplifier

PYTHON SCRIPT

MECHANICAL STAGE

PT100 TEMPERATURE SENSOR

SIMPLE FEEDBACK CONTROL

LN2 VAPOUR

Ferrara

- We can peform SiPM carachterization down to LN2 temperature in LN2 vapour through a dedicated custom system;
- We tested so far 4 different HPK models:

	13360-3025CS	13360-3025PE	14160-3015PS	13081-050CS
Pitch(um)	25	25	15	50
Area(mm^2)	3x3	3x3	3x3	1x1
DCR @-120, +5OV (Hz/mm^2)	0.77	0.15	0.47	2

- DCR behaviour with burst effect (random train of pulses at kHz);
- DCR decreses from MHz at room temperature down to Hz at -120°;
- We are currently testing other SiPM models.

For the near future:

- We plan to test these sensors after different dose irradiation;
- We plan to test the irradiated sensors after different annealing procedure;
- We are setting-up a setup for temporal measurements with UV laser pulses.

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Milano

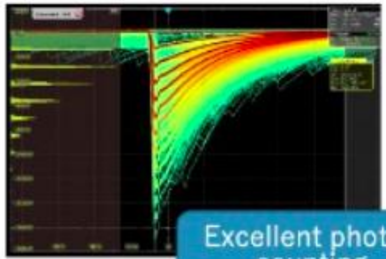
RICH: SiPM R&D

- Our group (Bicocca) selected the MaPMTs for Upg I, now shifting R&D program towards Upg II
- Currently testing both SiPMs (various models) and MCP-PMTs

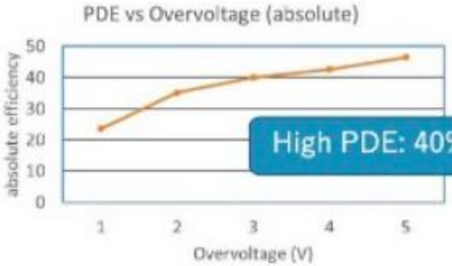
Milano Bicocca group

Pros | **SiPM** | Cons

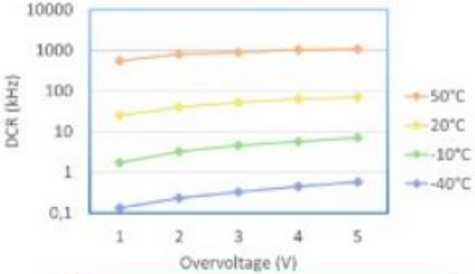
High granularity: 1.7 mm² (this model) or 1 mm² available

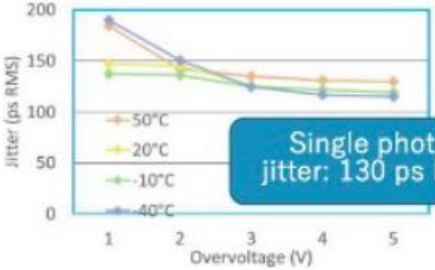


Excellent photon counting



High PDE: 40%

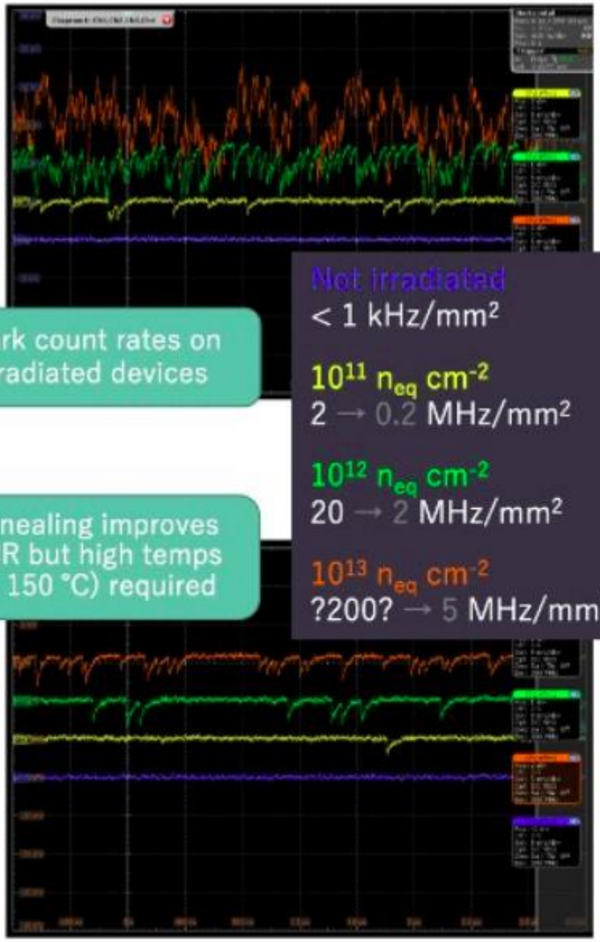




Single photon jitter: 130 ps RMS

Dark count rate strongly depends on temperature

Irradiated devices can be operated at low temperatures (<-80 °C, liquid nitrogen?) to mitigate dark count rate



Dark count rates on irradiated devices

Annealing improves DCR but high temps (> 150 °C) required

Not irradiated
< 1 kHz/mm²

10^{11} n_{eq} cm^{-2}
2 → 0.2 MHz/mm²

10^{12} n_{eq} cm^{-2}
20 → 2 MHz/mm²

10^{13} n_{eq} cm^{-2}
?200? → 5 MHz/mm²

Padova

Padova SiPM R&D interests

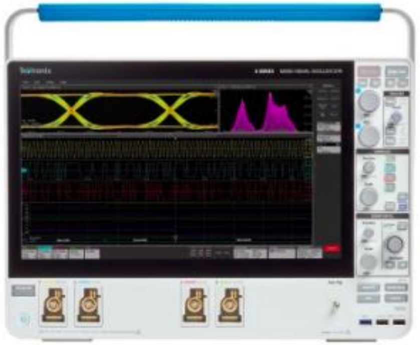
- R&D on Rad hard SiPM and study of the radiation hardness of SiPM
  - We would like to setup a characterization station for SiPM leveraging on a collaboration with the BelleII group
  - Peltier + Chiller capable of cooling down to –40C (–60C with upgraded chiller)
  - Custom bias, temperature and picosecond laser control system developed in house
  - DAQ system based on CAEN v1742 32ch 5Gs/s digitizer with time resolution O(100ps) on Hamamatsu SiPM

Perugia

LHCb laboratory in Perugia (without cooling), we can perform tests on light sensors (SiPM, PMT) measuring time resolution, gain and dark count rates

New devices:

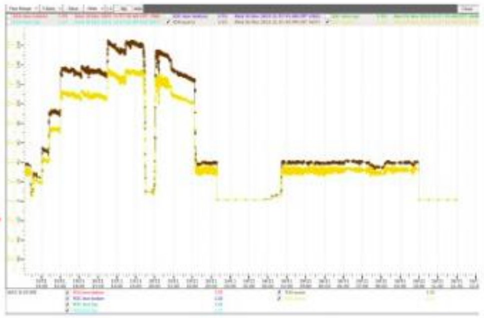
- Photon sources: Picoquant Picosecond Pulsed Driver - Taiko PDL M1 (ordered)
- DAQ: Oscilloscope Tektronix MSO64B (4 GHz bandwidth, sampling50 GS/s, 4 Ch)



Access to cooling facilities inside the department can be negotiated

Interests of our group for upgrades 1b and 2:

- Contribute to the R&D of the sensors and to the following quality tests during production
- Contribute to the development of the front-end electronics
- Contribute to one item concerning the mechanic (mirrors in acceptance, window(s) between radiator and cooled sensors, ?)
- Maintenance and upgrade (as luminosity monitor) of the LLD



18.11.2022 M. Piccini, V. Duk (INFN Perugia) 1