UCLA Physics & Astronomy

UCLA Dark Matter 2018

SiPM at cryogenic temperature for dark matter

Alessandro Razeto - LNGS

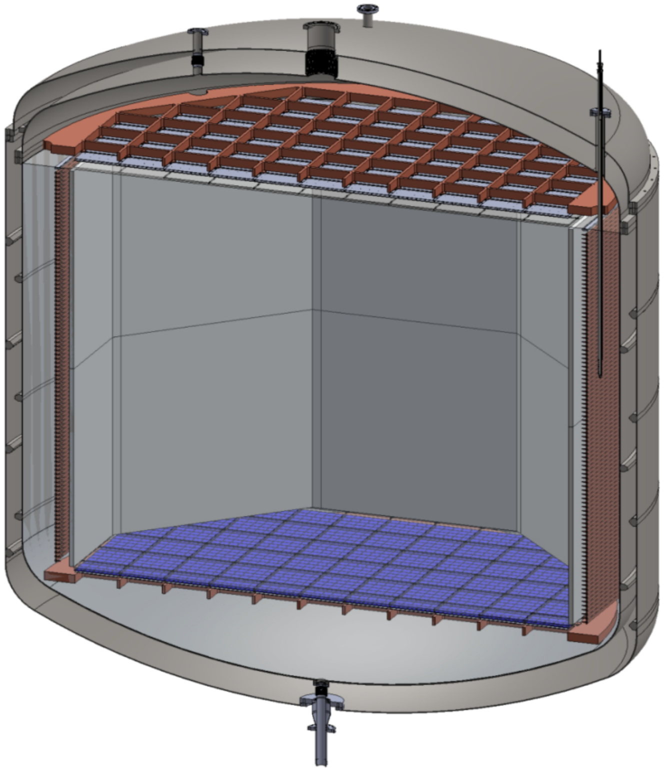
DarkSide-20k

About 14 m² of light sensitive surface

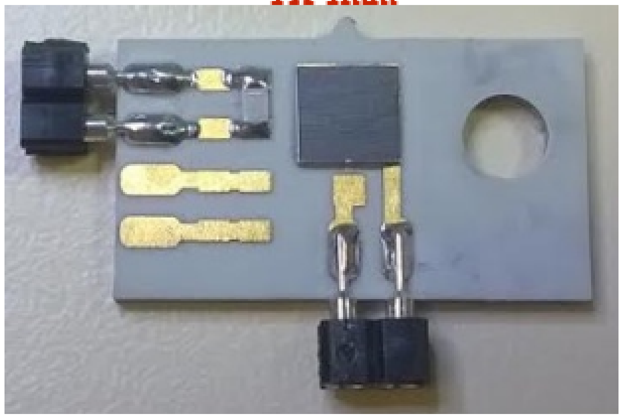
for single photon counting

at LAr temperature

with SiPM



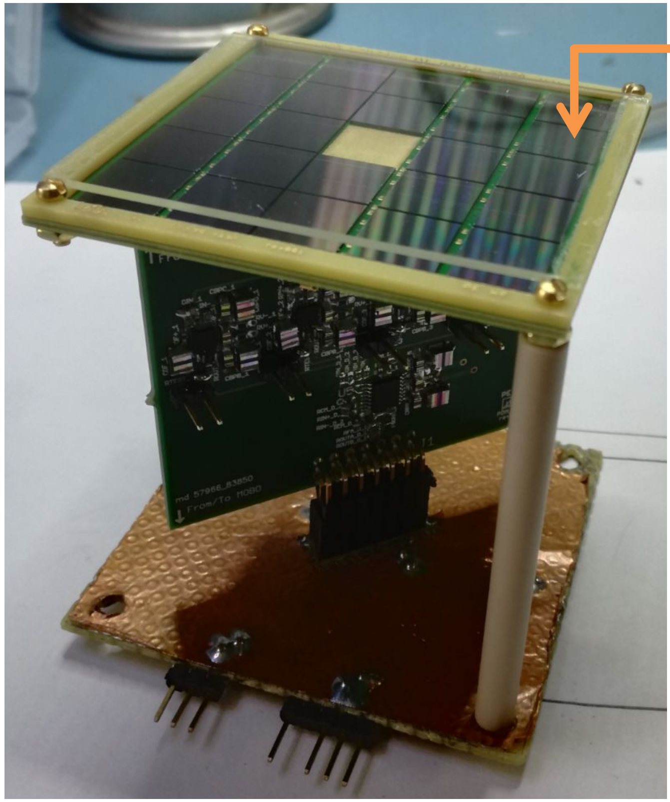
4x4mm²

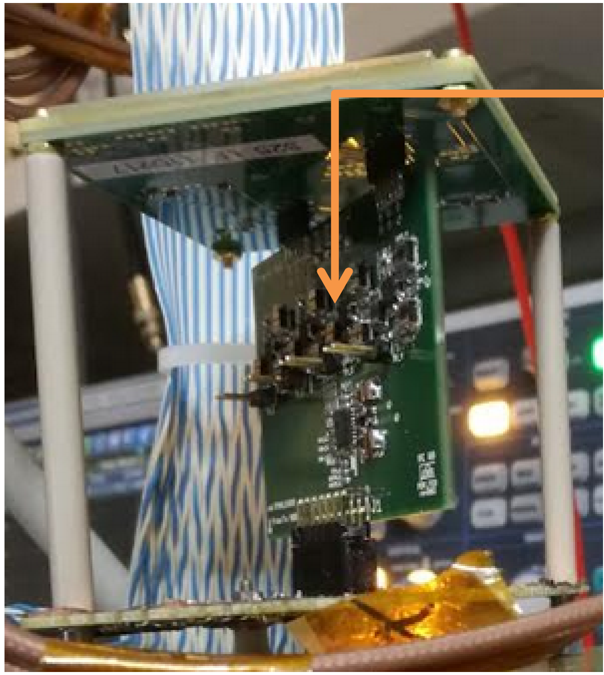


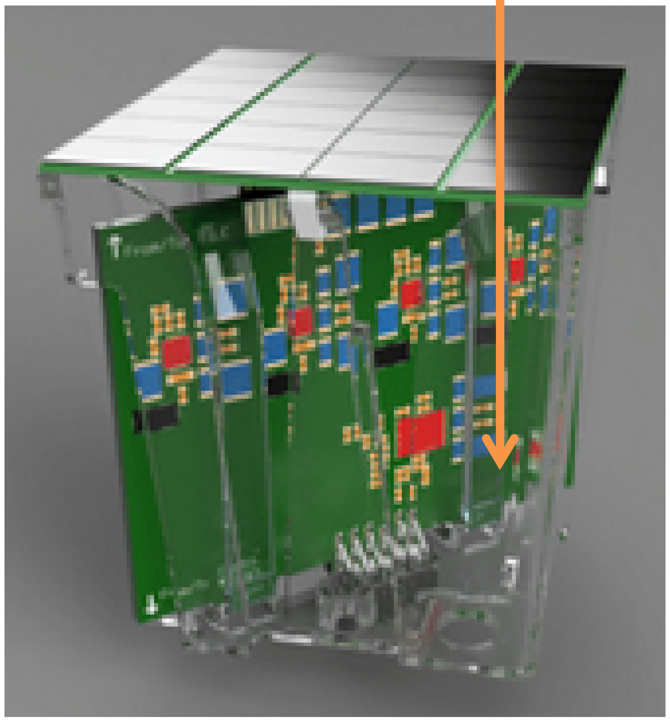
3″ diameter

Photo-Detector Module

- Silicon-based PMT equivalent
- The basic photo-detector element in DS-20k
  - One read-out analog channel per PDM
    - Aggregating all the SiPM signals
- Integrates the SiPMs (TILE) and the electronics (FEB) in a plastic cage







PDM Requirements

- Surface: ~50x50 mm²
  - Contain the number of channels

14 m² / 25 cm² ~ 5200 PDM

PDM Requirements

- Surface: ~50x50 mm²
  - Contain the number of channels
- PDE of a PDM: ≥ 40%
  - PDE of a SiPM: ≥ 45%
  - Increased Light Yield

PDE = Photon Detection efficiency

Considering a dead space between SiPMs of 0.5 mm

~98% packing (form factor) vs <90% for circular PMTs
~ 90% of surface is active vs 70% of PMT R11065

R11065 effective Q.E. ~ 22%

PDM Requirements

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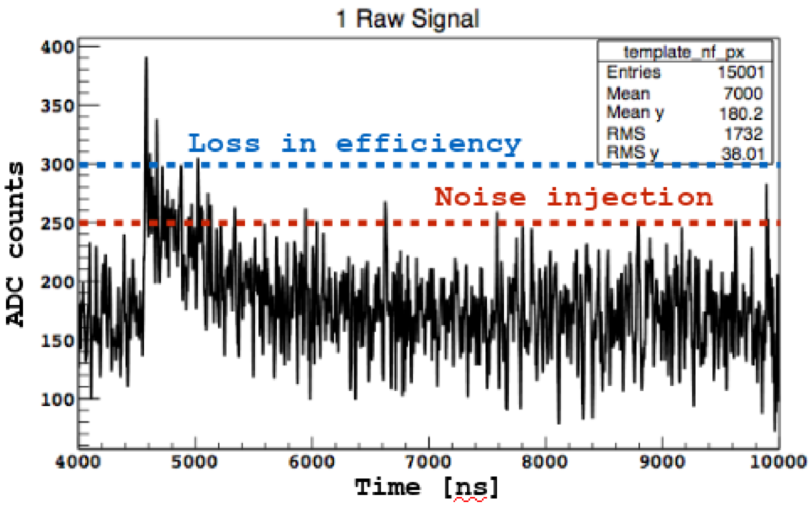
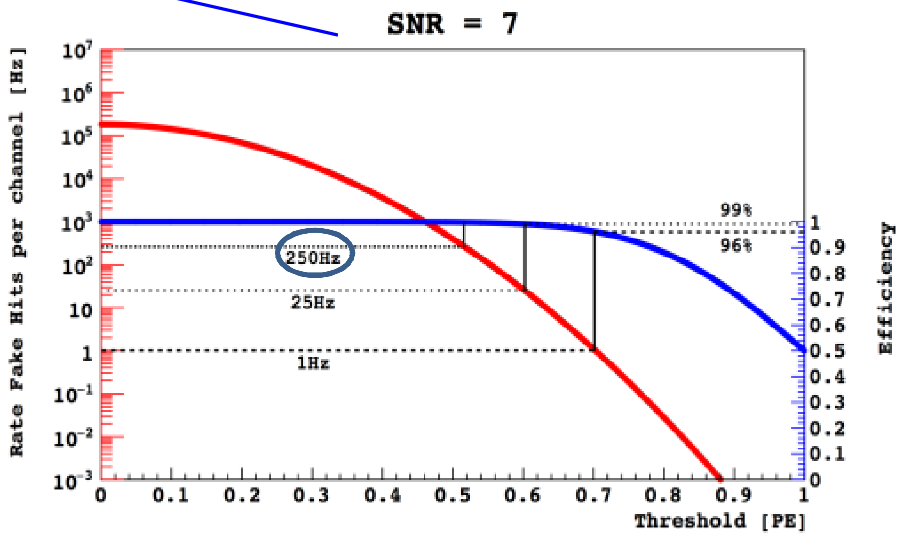
  - Increased Light Yield
- Noise: DCR + Electronic noise hits < 0.1 cps/mm²
  - Keep PSD effective
  - Avoid fake triggers
  - SNR > 7

DCR = Dark Count Rate

14 m² & O(10 μs) → ~15 pe





PDM Requirements

TCN = Total Correlated noise
Afterpulse + Cross talk

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- TCN < 60%
  - Energy reconstruction of S2

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- Time Resolution: O(10ns)
  - Keep PSD effective

Time jitter is crucial to Pulse Shape Discrimination.

High jitter allows leakage of prompt photons outside of the time window.

The effect is dramatic at 40 ns, while still acceptable up to 15 ns.

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- Dynamic Range: >50 PE
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- Dynamic Range: >50 PE
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- Power consumption: < 250 mW
  - Avoid LAr bubbling and overload on cryogenic systems

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- Radioputity: fraction of mBq (^{238}U + ^{232}Th)

SiPMs

FBK NUV-HD SiPMs

Strong collaboration with FBK

- Several technologies and their variants were studied

The NUV-HD technology was selected

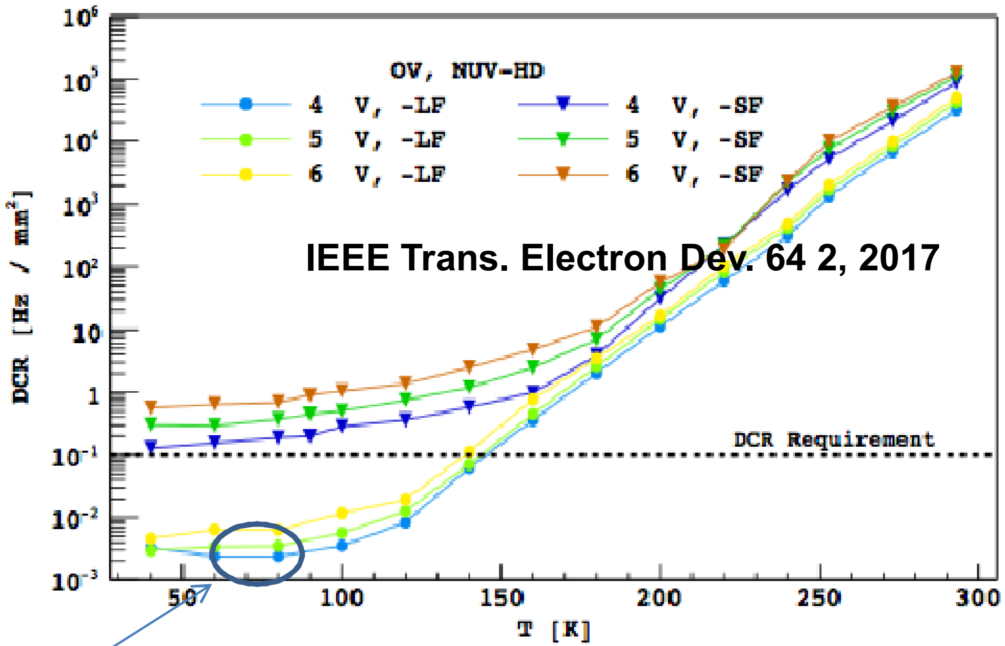
- Peak sensitivity at ~ 420 nm
- High density SPAD with high PDE

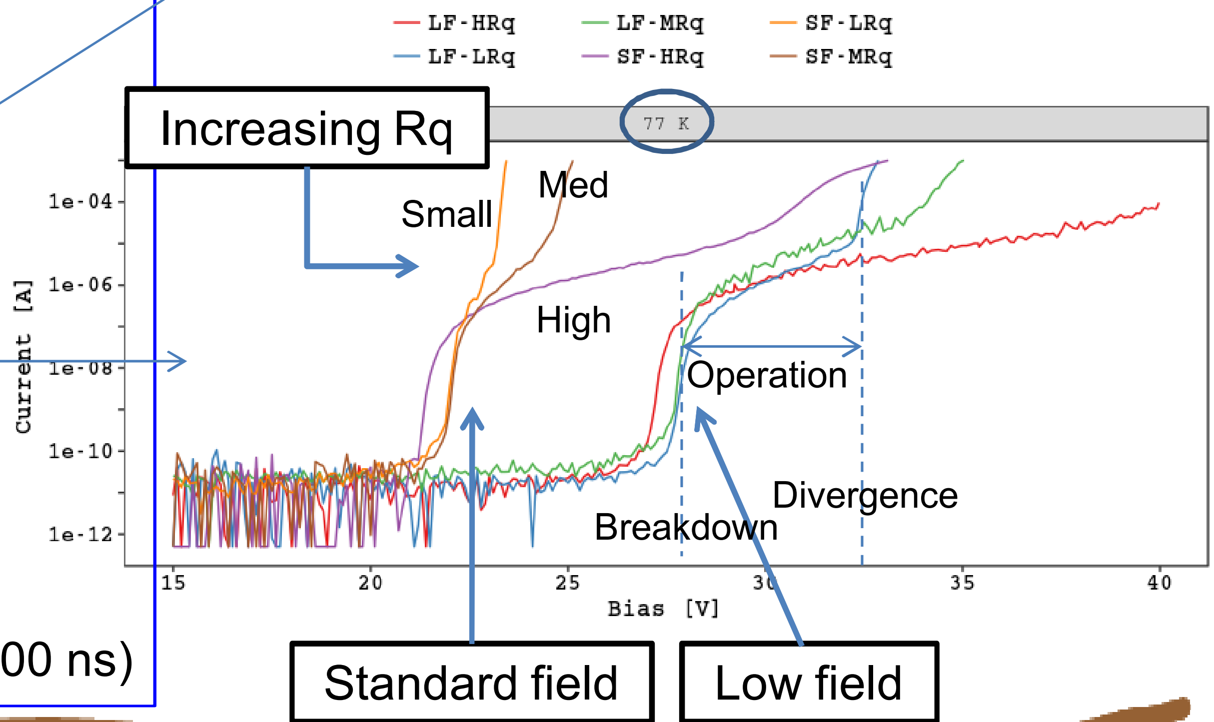
Low field variant:

- DCR ~ 5 mcps/mm² at 80 K
- Higher over-voltage operation

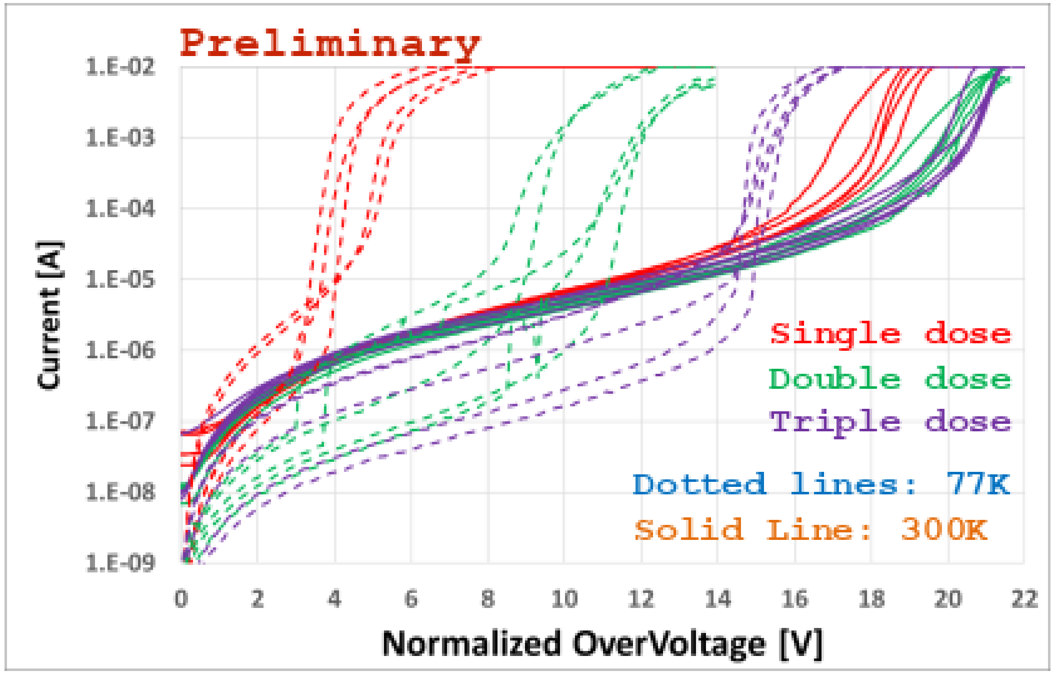
The NUV-HD technology requires high quenching resistor (Rq) at 80 K

- Resulting in long recharge times – O(500 ns)



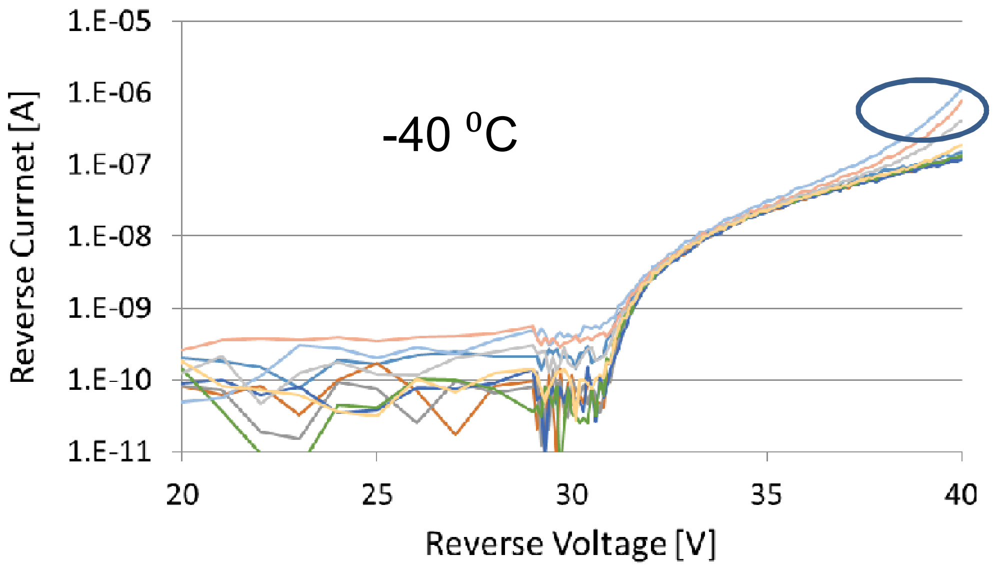


SiPM triple doping



- FBK developed a NUV-HD variant for extended gain at cryogenic temperature
  - It is based on a different (higher) doping
  - This variant allow operation of NUV-HD at 14 Volt over-voltage
  - The DCR at 80K is compatible to standard NUV-HD

- An R&D run was produced at FBK
  - It is based on NUV-HD-LF with 3x doping
  - We received the run few weeks ago
  - Initial tests show a low yield at – 40 ^{0}C
  - To be verified at 80 K



SiPM: future developments

- FBK:
  - A set of 3 scientific/R&D runs are programmed for 2018
  - The goal is to fine tune the parameters to best match SiPM with FEB
  - Produce 50 PDM

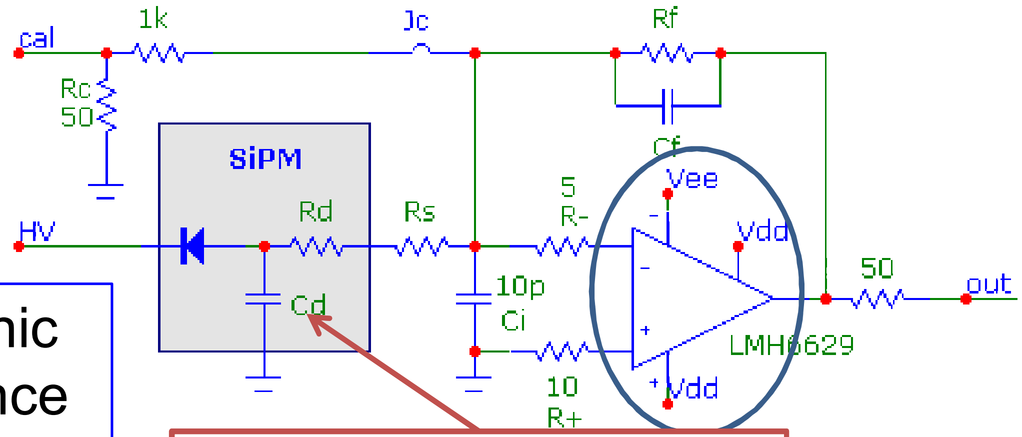
- LFoundry:
  - The contract INFN-LFoundry will be soon operative
  - The FBK technology will been transferred to LFoundry
  - Will be in charge of the mass production of the SiPM

- Through-silicon via (TSV):
  - TSV technology will allow us to reach the high fill factor required
  - Simplify the packaging and increase the robustness of the PDMs
    - By getting rid of the wire bonding
  - A R&D program between SMIC/LFoundry and DarkSide is in definition

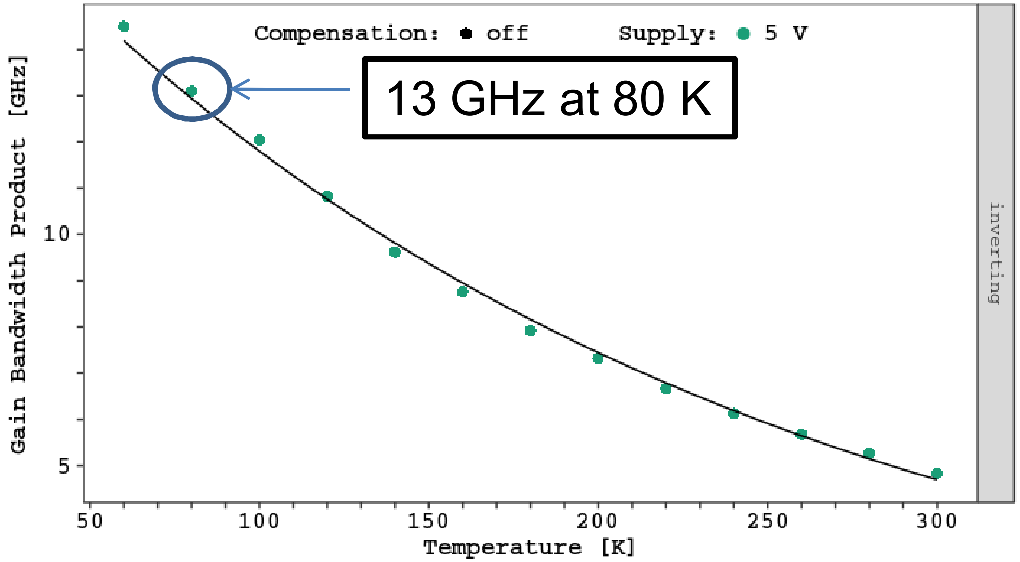
Electronics

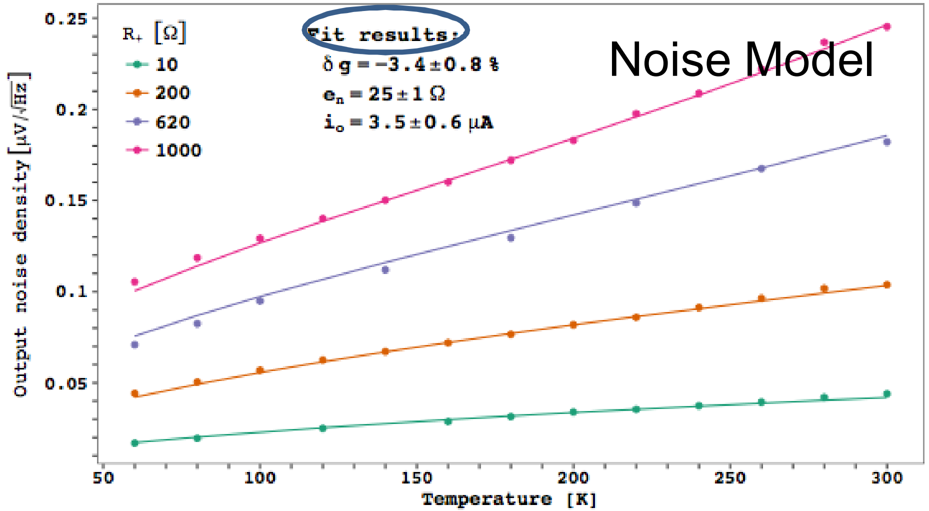
Very High Speed and Low Noise

Op-Amp based TransImpedance cryogenic amplifier for low noise and high capacitance

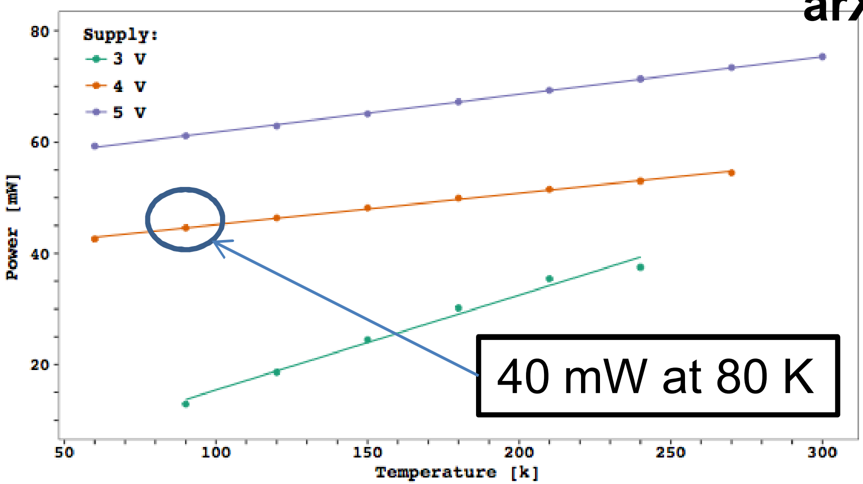


@80K: Rd ~ 60 Ω Cd ~ 6 nF





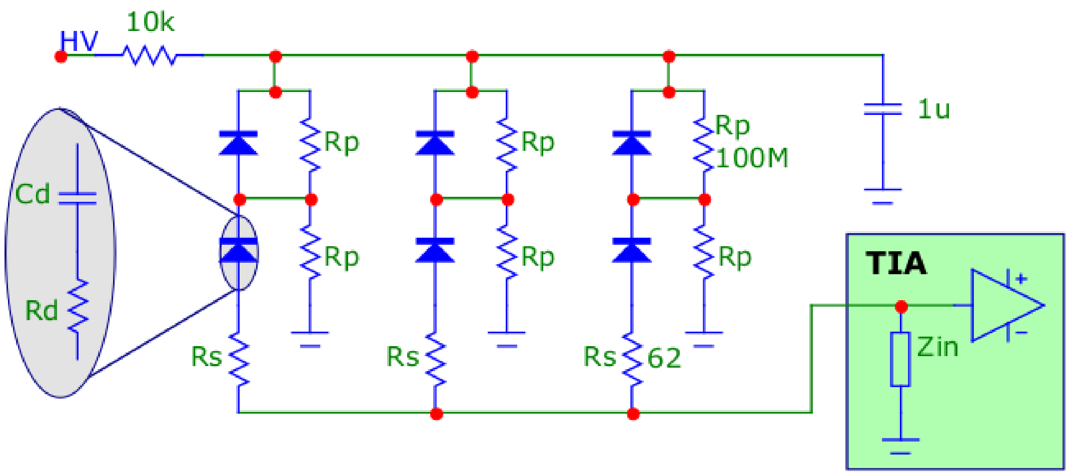
arXiv:1706.04213



Noise	300K	80K
e_n [nV/√Hz]	0.64	0.33
i_n [pA/√Hz]	2.6	1.1

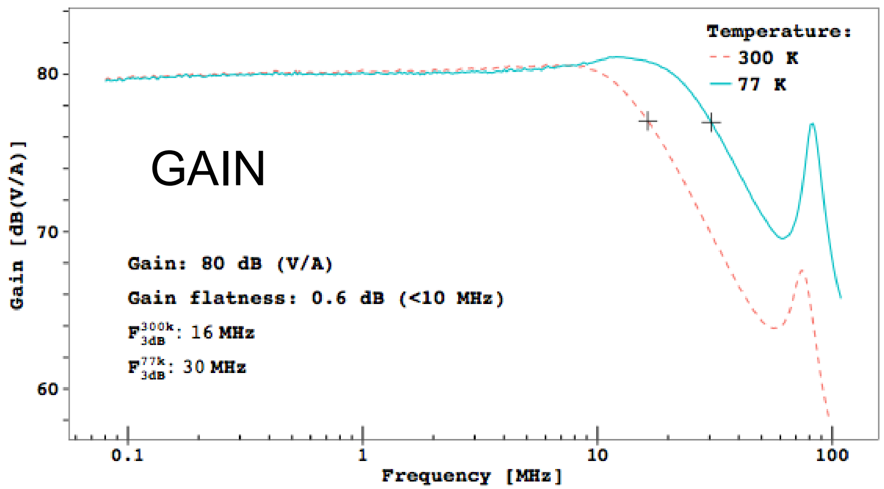
high speed required to maintain the fast peak

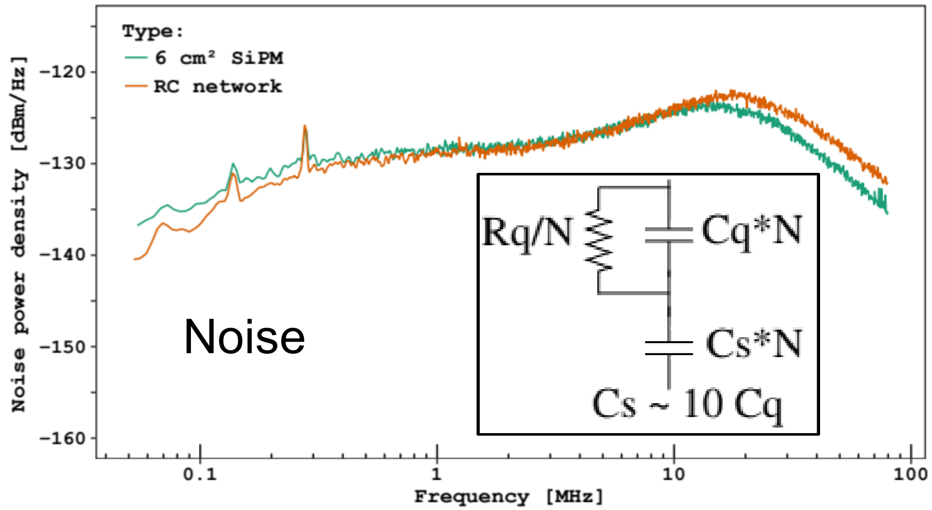
6 cm² read-out

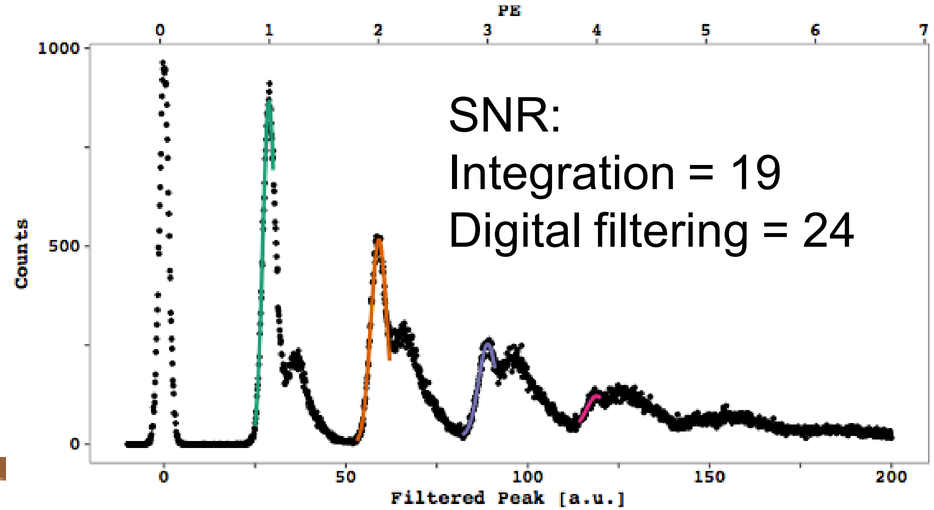


2s3p configuration optimal:

- BW sufficient to preserve the pulse fast peak
- The amplitude of the signal is halved
- The noise gain is reduced by a factor ~3
- The output noise depends on the SiPM model
  - We were able to produce a SiPM equivalent with 2 capacitors and 1 resistor







24 cm²

The signal from the 4 x 6 cm² quadrants is summed with an active adder

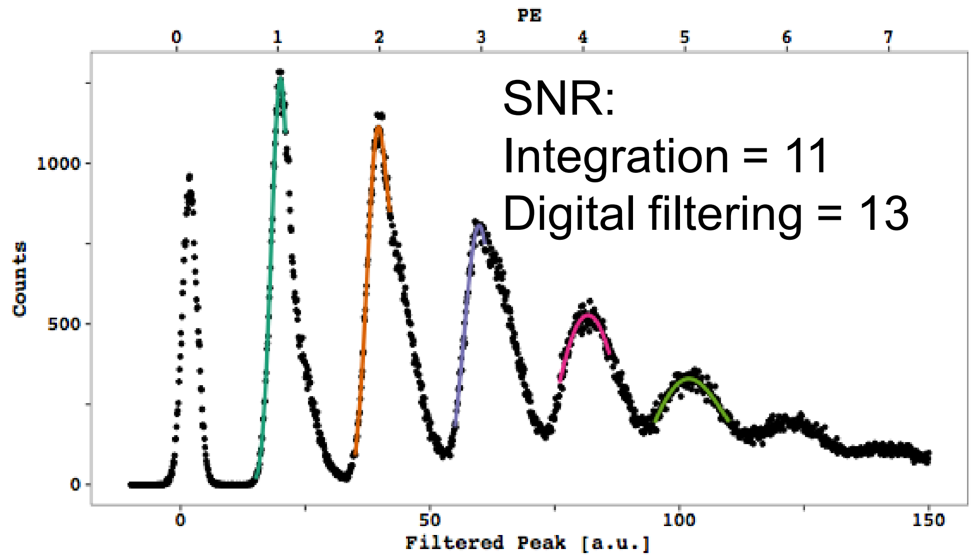
Full 24 cm² tile with NUV-HD-LF at LN2 5 V_{OV}:

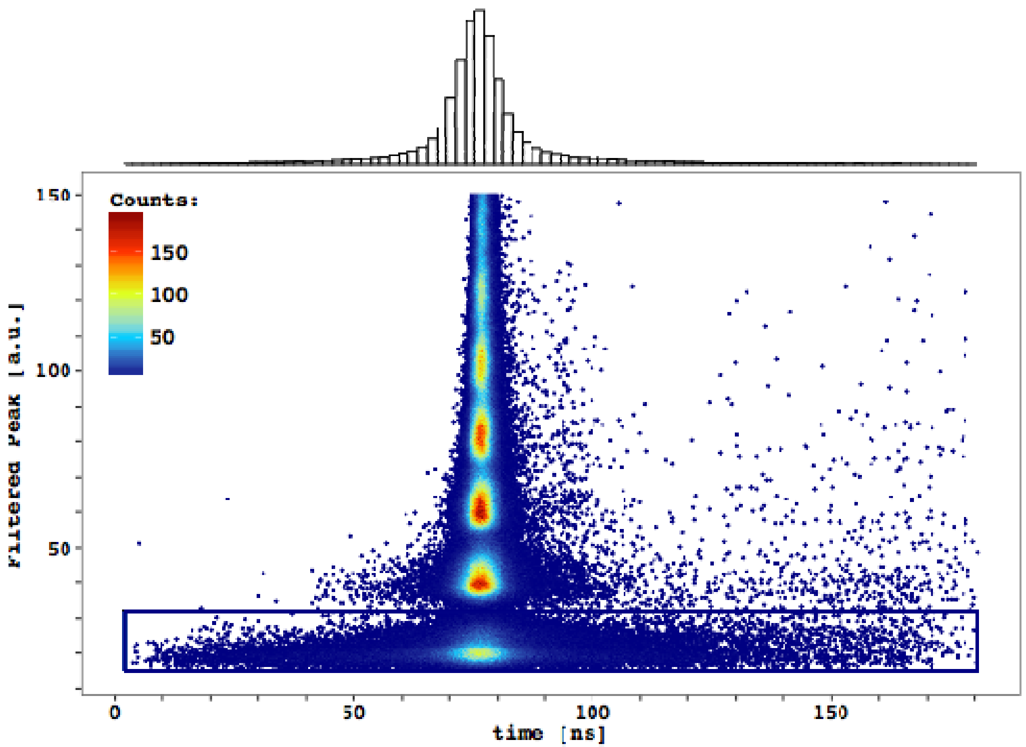
- σ_{1PE} = 9% μ_{1PE}
- SNR = 13
- 1PE Time resolution: 16ns

Total power dissipation ~ 170 mW

Dynamic range > 100 PE

- Rail to rail adder and differential driver





arXiv:1706:04220

FEB future

- Component screening
  - All major components have been screened
    - Total ~ 60 μBq/PDM (ICPMS for ^{238}U and ^{232}Th)
  - Definition of PCB substrate and connectors still ongoing
  - Signal extraction on optical fibers
    - Avoiding the activity from signal cables

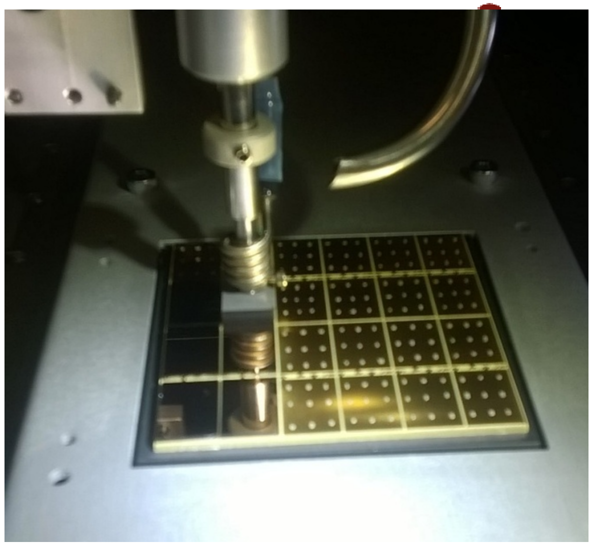
- The limiting factor on the SNR of the 24 cm² is the recharge constant of SiPMs (~ 500 ns)
  - Considering a fast recharge, O(20 ns), the SNR would increase by a factor ~5
    - This would give a SNR ~20 for the unfiltered signal on 24 cm²
    - A measurement is ongoing at LNGS with Hamamatsu SiPMs

Conclusions

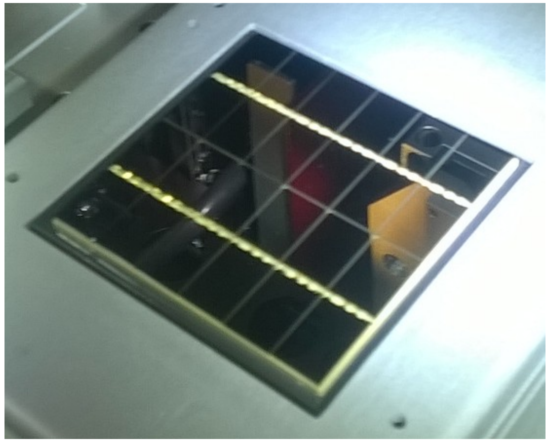
- The R&D on SiPM and front-end electronics is almost over
- We reached all the design goal for the project
  - 24 cm² SiPM based aggregate detector with SNR = 13
  - Large dynamic range
  - Low power dissipation
  - Radio-pure components
- Still some issues to be solved
  - Low CTE and radio-pure substrate
  - Radio-pure connectors
  - Finalize the SiPM parameters
- Develop and test TSV
- The next step is large scale optimization
  - And the mass production

Thank you

Packaging facility at LNGS



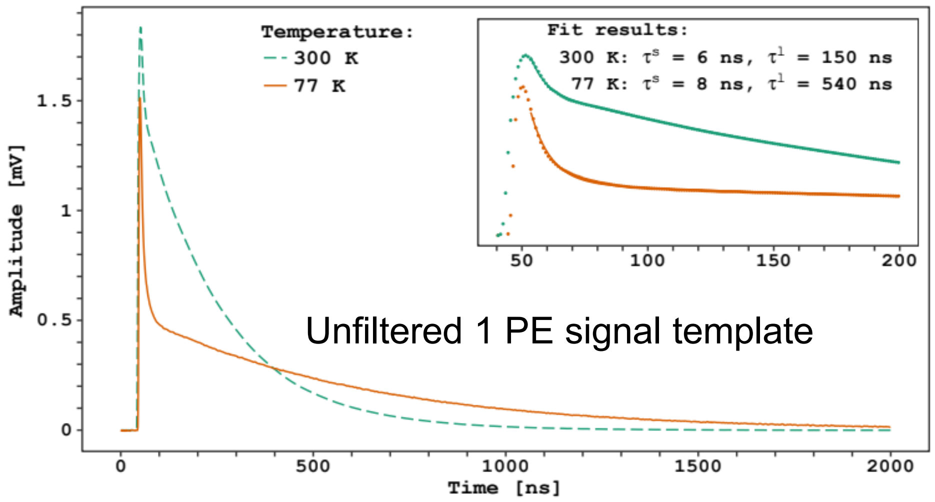
- A packaging facility (NOA) has been funded at LNGS

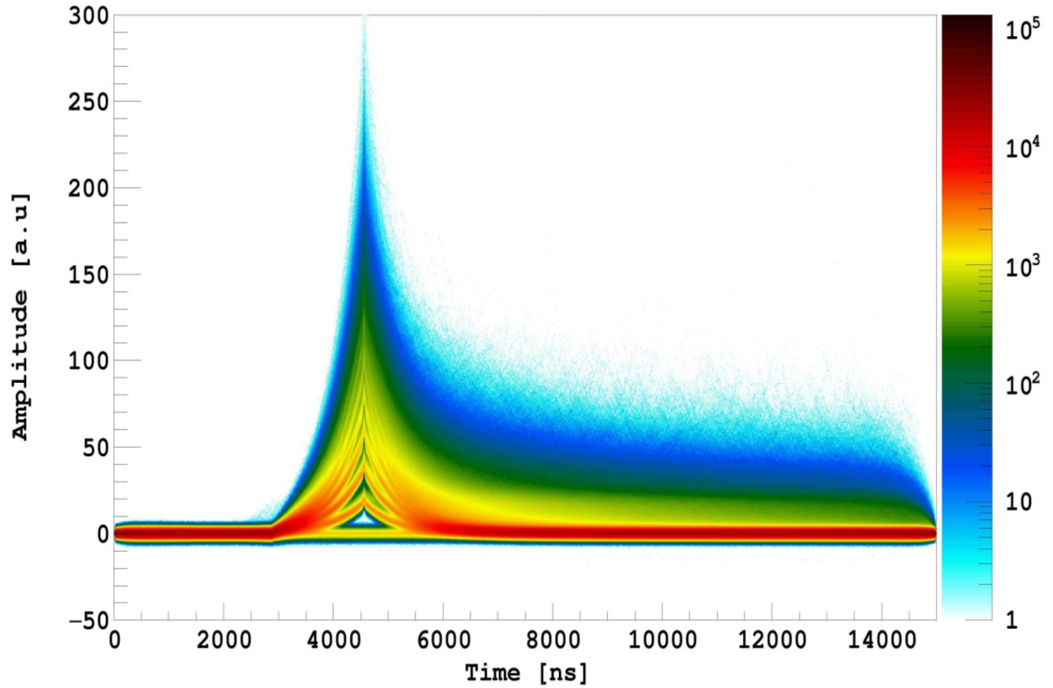


- The project includes
  - A cryogenic wafer probe
  - A fully automated die bonder for the SiPMs
    - A fully automated wire bonder
  - A radio-pure SMT reflow process for the FEBs
  - A warm/cryogenic test station for SiPMs

- The facility is designed to mount all the PDMs in 2 years

Digital filtering



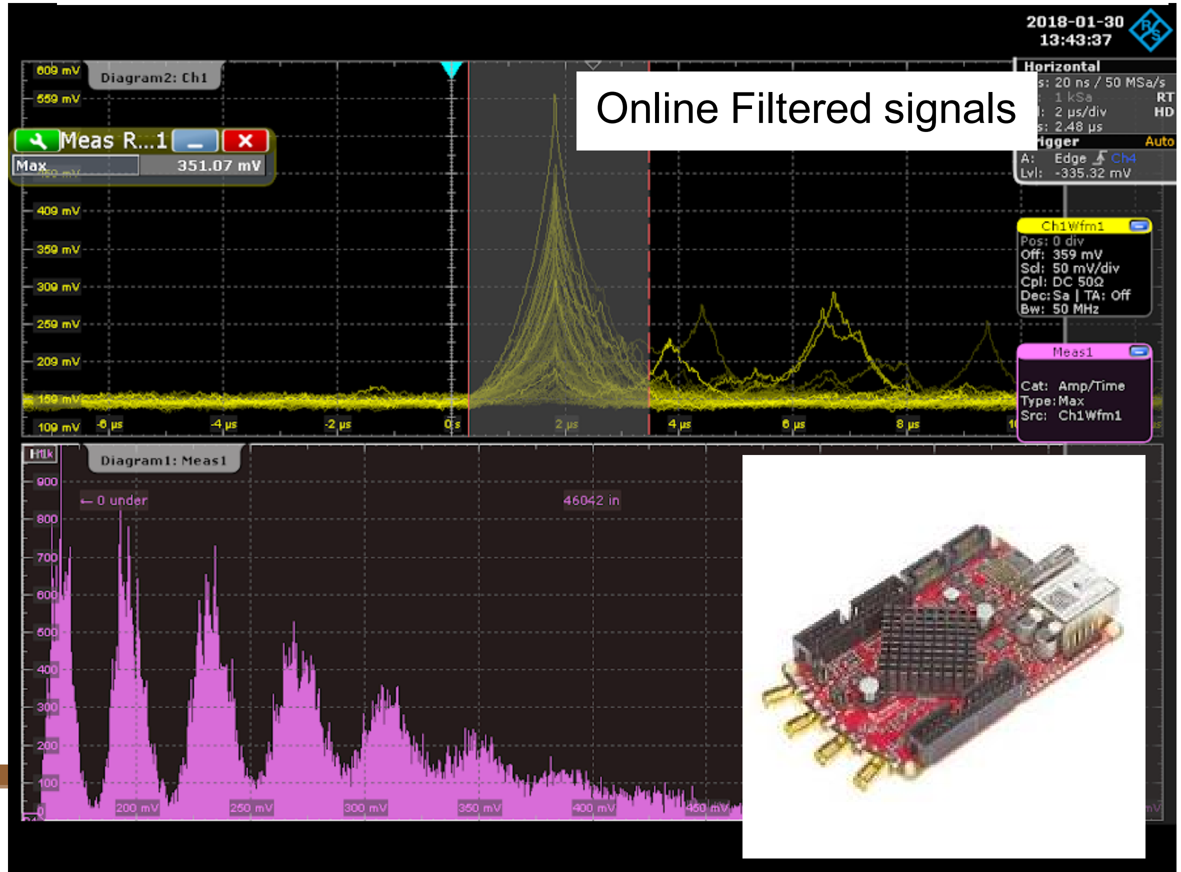


Matched filter the optimal linear filter to extract a signal of know shape in the presence of additive stochastic noise.

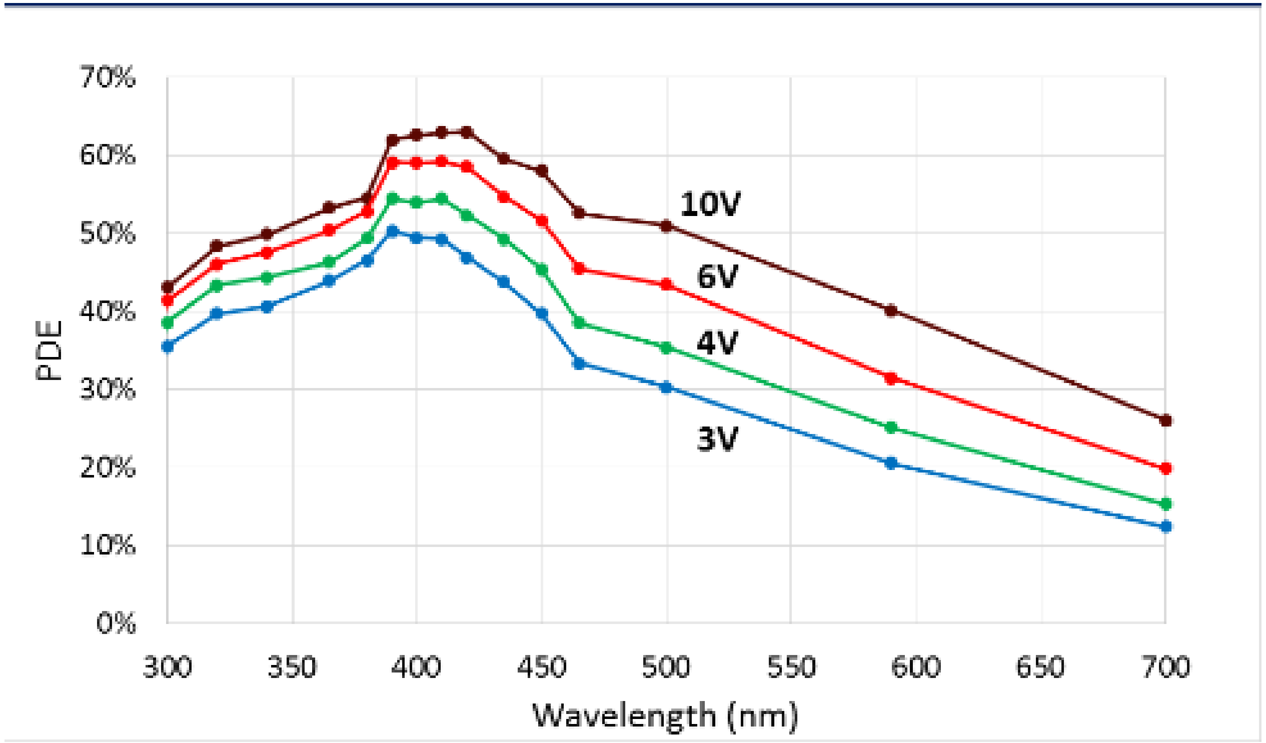
The filtered signal is obtained by cross-convoluting the raw waveform for the signal template

The output is symmetric around the peak, giving a better identification of the timing.

We successfully tested an online FPGA based implementation



PDE



70%
60%
50%
40%
30%
20%
10%
0%
PDE
300
350
400
450
500
550
600
650
700
Wavelength (nm)
10V
6V
4V
3V