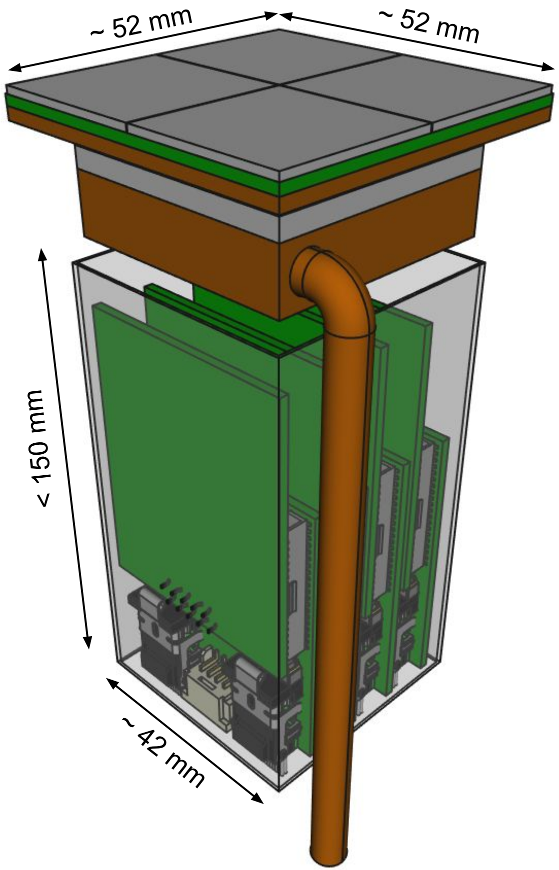
dRICH prototype readout

Roberto Preghenella
for the **sipm4eic-elettronica** group

dRICH SiPM optical readout unit (prototype)

- **large-area SiPM optical readout for the dRICH prototype**
  - based on ALCOR readout
  - milestone deadline ~ April 2023
- **SiPM sensors and layout**
  - one readout unit
    - 4 Hamamatsu 8x8 matrices
    - 256 channels
  - ~ 52 x 52 mm^2 area
- **design with layout as close as possible to needs for final experiment**
  - critical engineering exercise in view of TDR
  - place cooling and electronics on the back of the sensors
- **use as much as possible of current electronics architecture**
  - no manpower capacity to develop new FPGA board this year
  - no manpower capacity di develop new firmware this year
  - use ALCORv2 (32 channels)
- **design new electronics boards to fit the new layout configuration**
  - possibly with the same features, if all needed

dRICH SiPM optical readout unit (prototype)



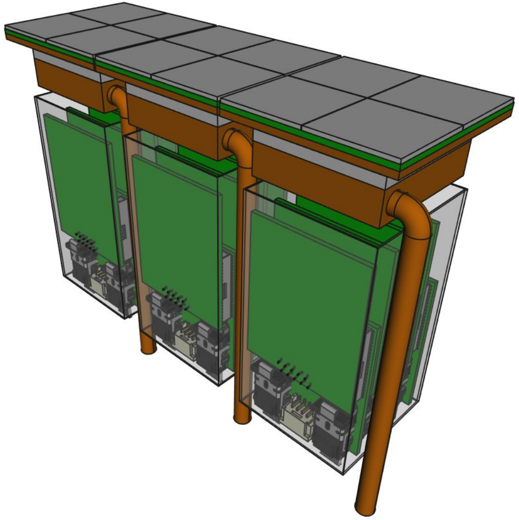
initial design concept

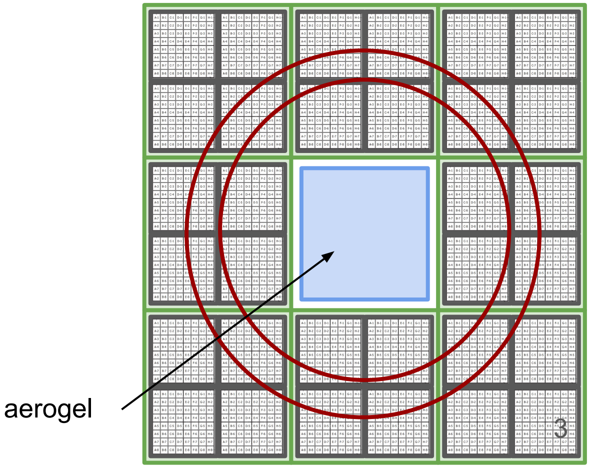
concept developed for the dRICH prototype

electronics engineers working on implementation of the electronics

mechanical design will progress with the help of mechanical engineers

arrangement in beam test 2023





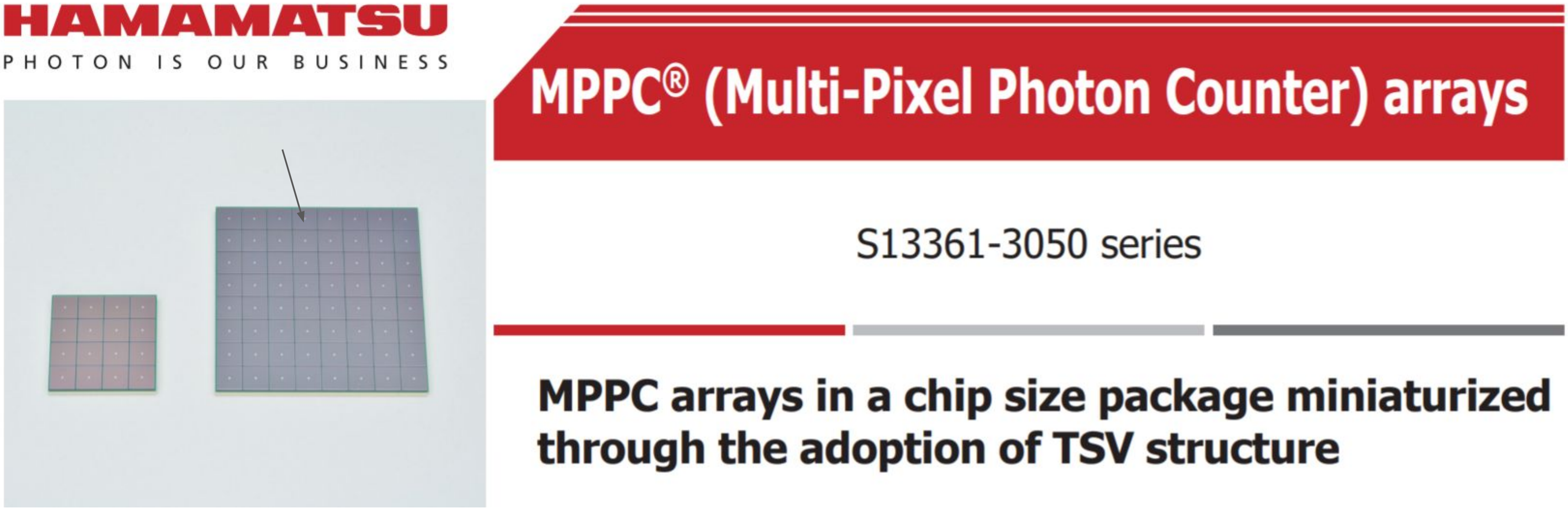
SiPM sensors

SiPM sensors for large area dRICH prototype

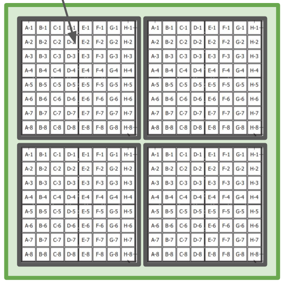
Roberto Preghenella (INFN Sezione di Bologna)
November 20, 2022

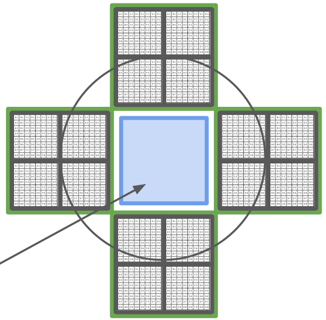
A large-area optical readout surface for the dRICH prototype will be developed as a milestone for the eRD102 project. The readout will be based on modern SiPM photosensors coupled with the ALCOR ASIC [1,2] front-end chip. Hamamatsu S13361-3050 8x8 MPPC arrays [3] with $3 mm^2$ sensors have been chosen as the reference sensor to instrument the readout surface. In this document we summarise the details of the selection.

https://docs.google.com/document/d/1ld6ECmUsicYPZtr-JJJ5YB7spOVG8kJMT2iWek2L0xw https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s13361-3050_series_kapd1054e.pdf



readout unit:
4 8x8 matrices





readout area:
4+ readout units
(and spares)

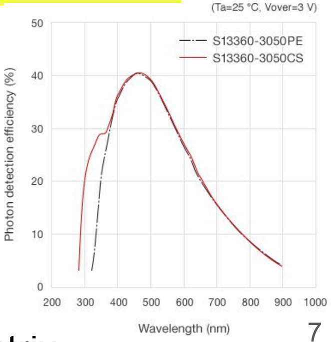
aerogel

Structure

Parameter	Symbol	S13361-3050NE-04	S13361-3050AE-04	S13361-3050NE-08	S13361-3050AE-08	Unit
Number of channels	-	16 (4 × 4)		64 (8 × 8)		-
Effective photosensitive area/channel	-	3 × 3				mm
Pixel pitch	-	50				μm
Number of pixels/channel	-	3584				-
Fill factor	-	74				%
Package type	-	Surface mount	With connector*1	Surface mount	With connector*1	-
Window	-	Silicone ~~Epoxy~~ resin				-
Refractive index of window material	-	1.55				-

*1: A connector made by SAMTEC is mounted on the back side of the board.
ST4-20-1.00-L-D-P-TR (S13361-3050AE-04)
ST4-40-1.00-L-D-P-TR (S13361-3050AE-08)
These connectors mate with a SAMTEC receptacle (SS4-20-3.00-L-D-K-TR or SS4-40-3.00-L-D-K-TR).
See the following URL for detailed information.
http://www.samtec.com/ftppub/pdf/ss4.pdf

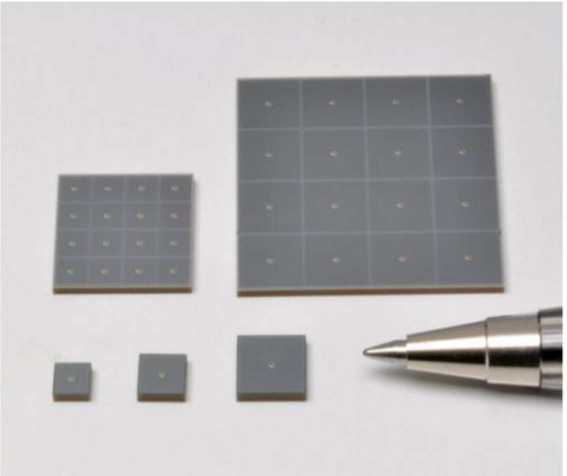
requested silicone resin



we want to have the full surface in contact for optimise the cooling of the matrix https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s14160_s14161_series_kapd1064e.pdf

HAMAMATSU

PHOTON IS OUR BUSINESS



MPPC® (Multi-Pixel Photon Counter)

S14160/S14161 series

Low breakdown voltage type MPPC for scintillation detector

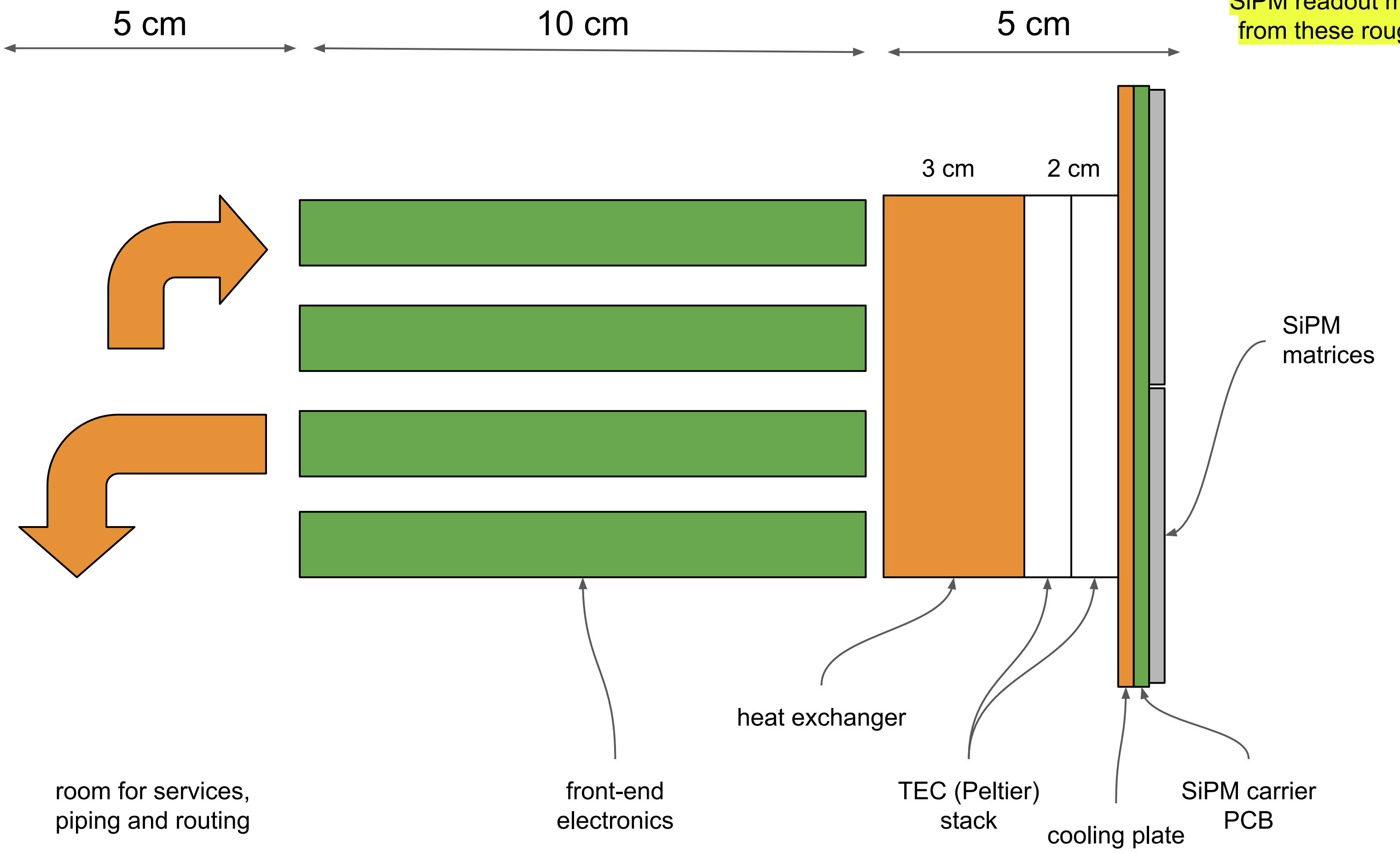
Structure

Typ. no.	Number of channels (ch)	Effective photosensitive area/channel (mm^2)	Pixel pitch (μm)	Number of pixels/channel	Package	Window	Window refractive index	Geometrical fill factor (%)
S14160-3050HS		3.0 × 3.0		3531				
S14160-4050HS	1	4.0 × 4.0		6331				
S14160-6050HS		6.0 × 6.0		14331				
S14161-3050HS-04	16 (4 × 4)	3.0 × 3.0	50	3531	Surface mount type	Silicone	1.57	74
→ S14161-3050HS-08	64 (8 × 8)	3.0 × 3.0		3531				
S14161-4050HS-06	36 (6 × 6)	4.0 × 4.0		6331				
S14161-6050HS-04	16 (4 × 4)	6.0 × 6.0		14331				

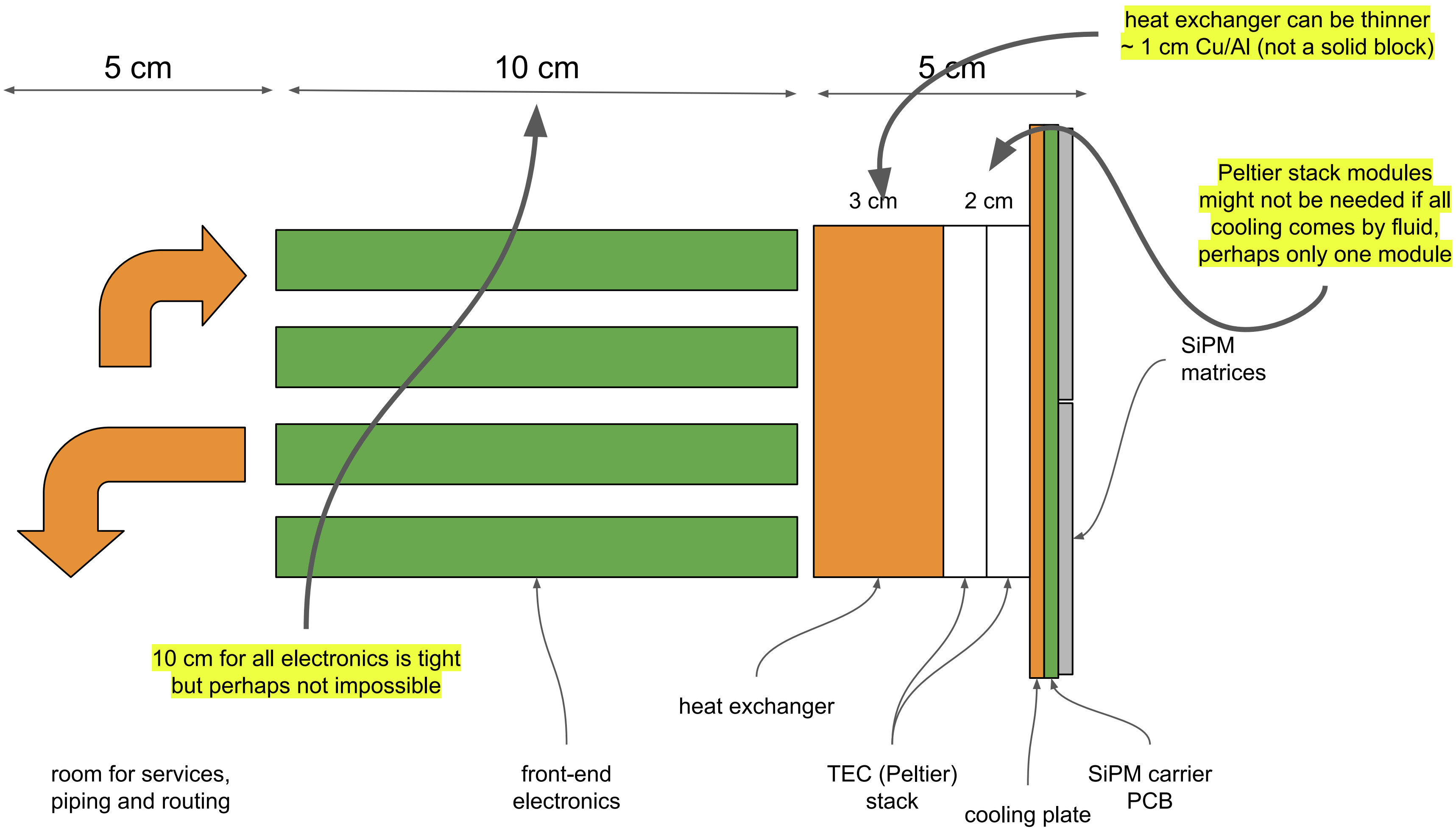
series 14 is also available in 8x8 matrices, same form factor and landing pattern: cheaper sensors with higher PDE (but higher DCR)
make few readout units based on this technology for comparison

preliminary design concepts

20 cm longitudinal space for SiPM readout module comes from these rough estimates



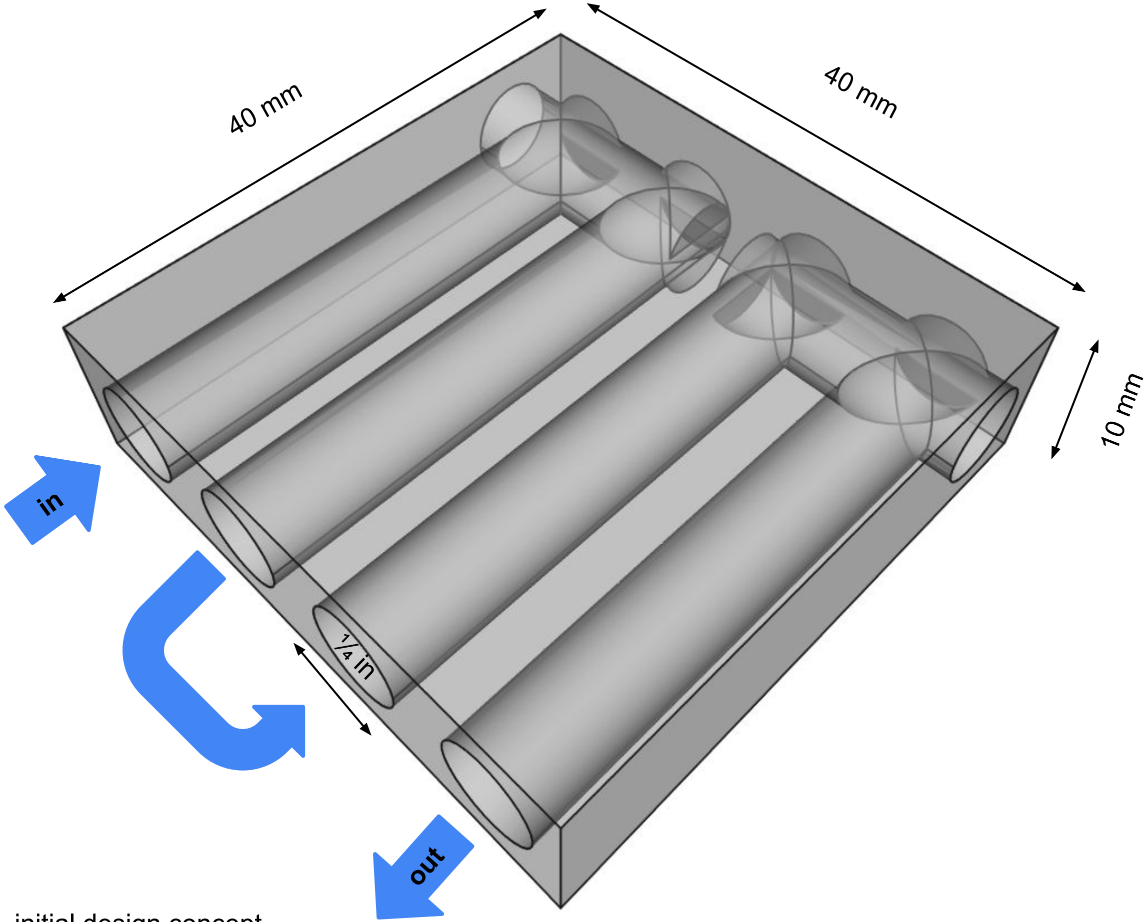
From GDI presentation on 24 October 2022: [“Status of SiPM photosensor technology”]



From GDI presentation on 24 October 2022: “Status of SiPM photosensor technology”

SiPM cooling block

conceptual design



initial design concept

$4 \times 4 \times 1$ cm = 16 cm³
remove 5 ¼ inch holes = 6.3 cm³
V = 9.7 cm³

Aluminium: 250 W/mK thermal cond.
ρ = 2.7 g/cm³
M = 26.2 g
X = 1.64 g/cm²

A = 16 cm²
X_0 = 24.1 g/cm²
X/X_0 = 6.8% we can do slightly better

plus 1% of water = 7.8%

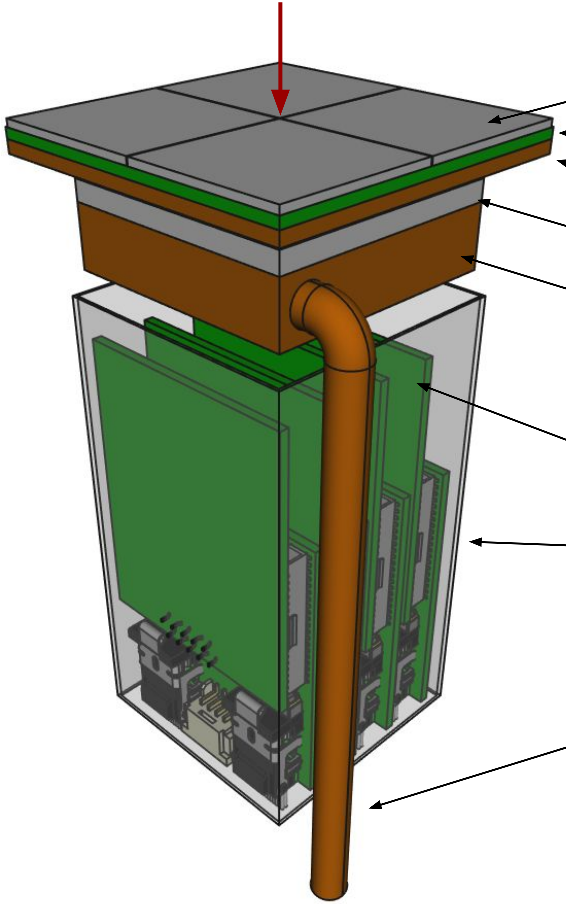
Copper: 400 W/mK thermal cond.

ρ = 8.96 g/cm³
M = 86.9 g
X = 5.43 g/cm²

X_0 = 12.86 g/cm²
X/X_0 = 42.2% Copper, no way

Material budget estimates

average for a particle hitting normally (electron-side RICH)



SiPM array: Si, 0.5 mm + 1 mm FR4 = 0.5% + 0.3% X/X_0

support PCB: FR4, 1.6 mm = 1% X/X_0

cooling plate: Al, 1-2 mm = 1-2% X/X_0

Peltier modules: likely not in final design

heat exchanger: Al, 10 mm (hollow) + water = 8% X/X_0

SiPM with cooling
~ 12% X/X_0 center
~ 4% X/X_0 periphery
~ 9% X/X_0 average

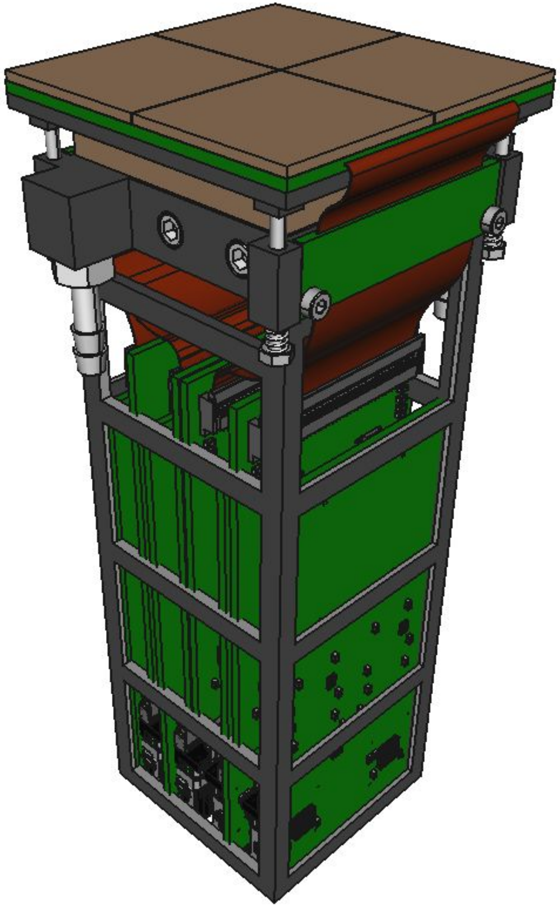
front end electronics: FR4, < 150 mm (8 boards) **< 28% X/X_0**

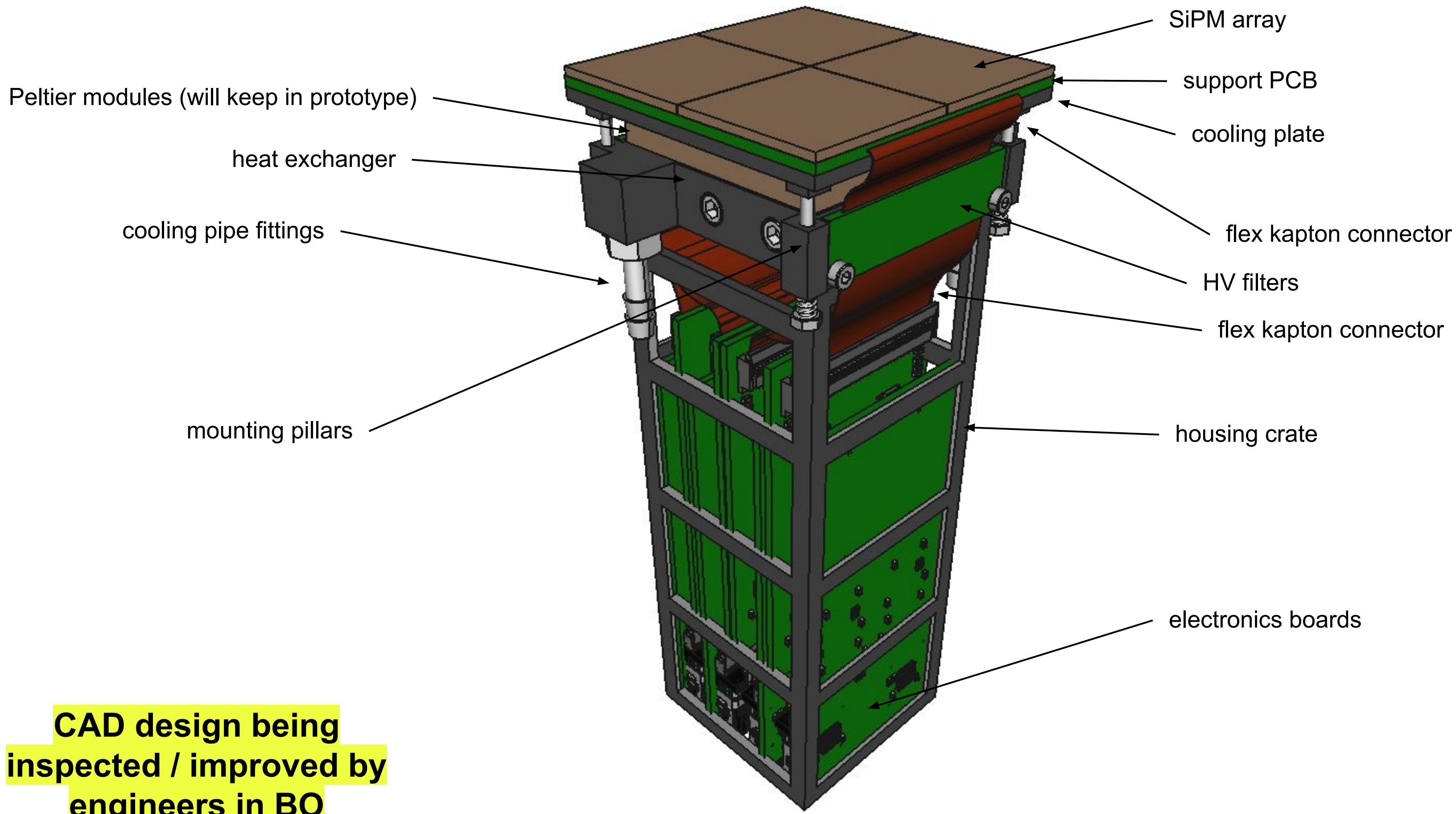
mini-crate: not defined yet (Al, plexiglass, … ?)

cooling pipes: not defined yet (nylon, rilsan, … ?)

initial design concept

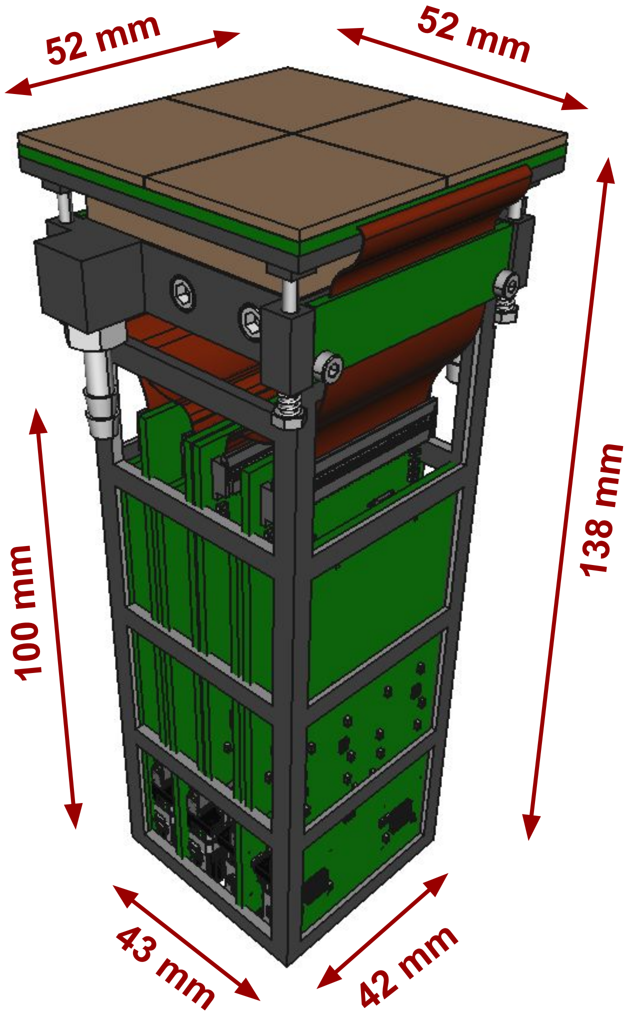
current status





CAD design being inspected / improved by engineers in BO

advanced design concept

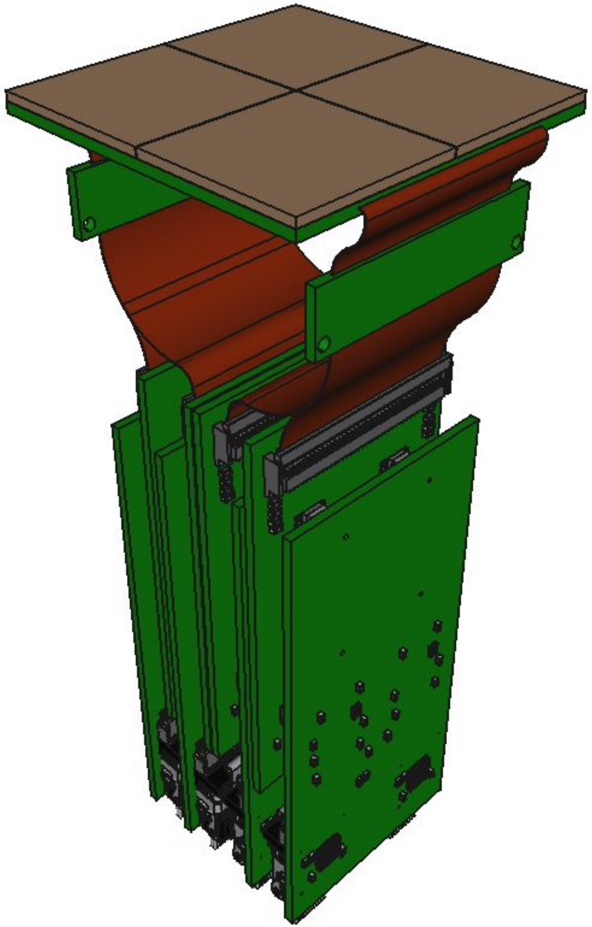


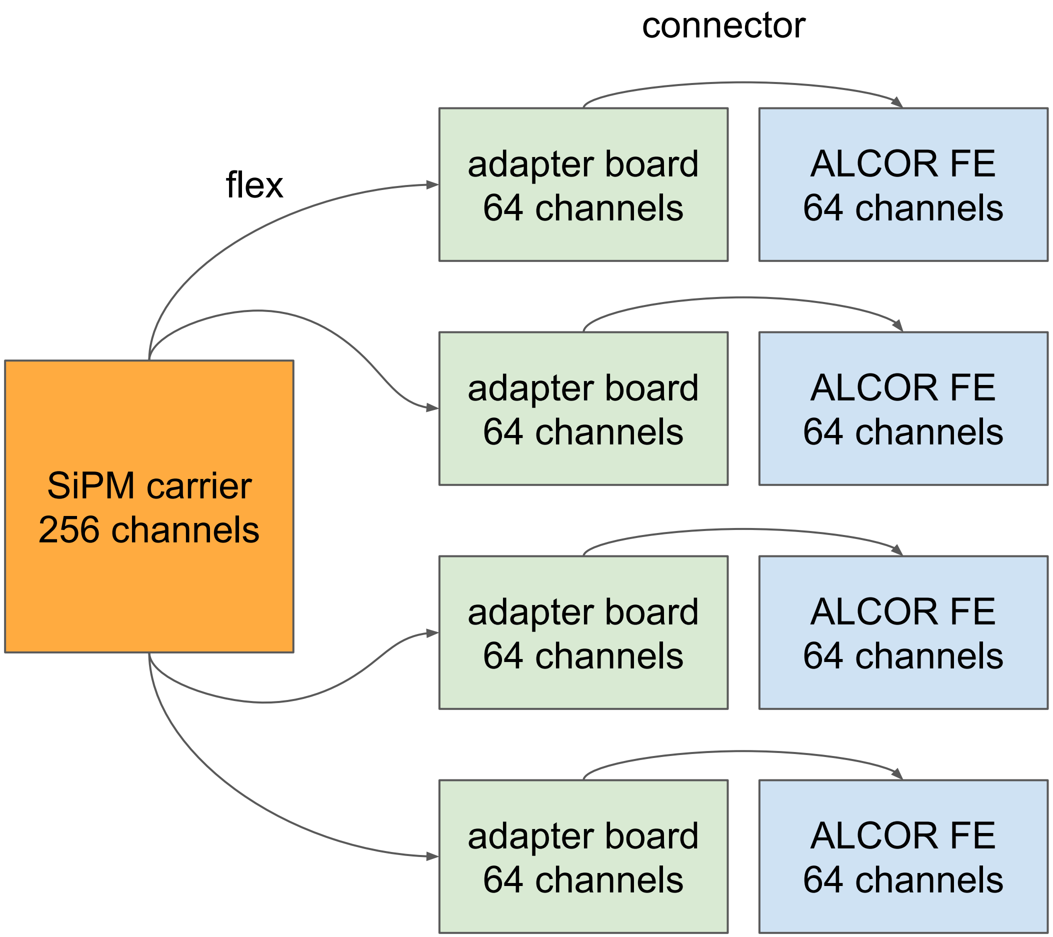
dimensions might slightly change

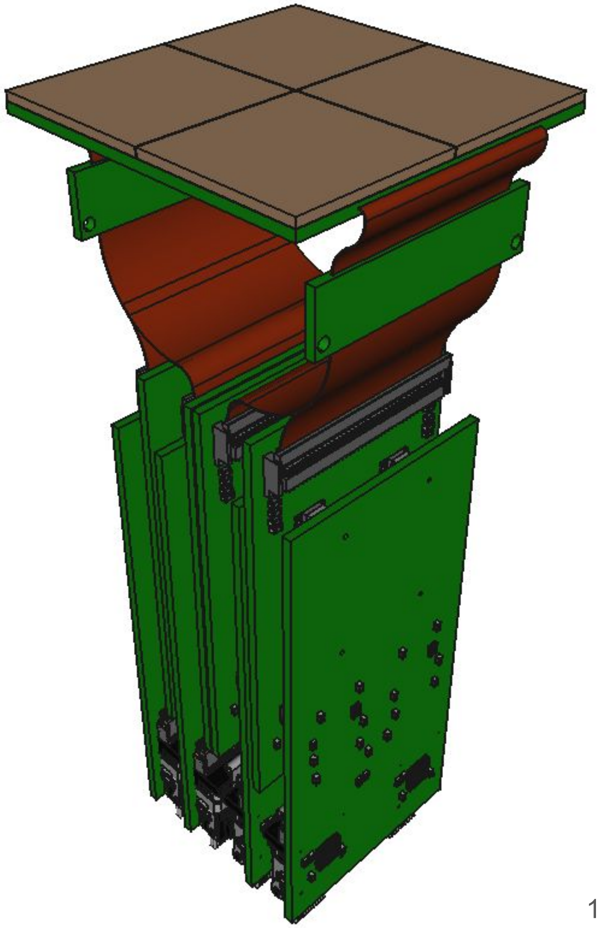
outstanding job to keep electronics within very small envelope

advanced design concept

electronics




connector
flex
SiPM carrier
256 channels
adapter board
64 channels
ALCOR FE
64 channels
adapter board
64 channels
ALCOR FE
64 channels
adapter board
64 channels
ALCOR FE
64 channels
adapter board
64 channels
ALCOR FE
64 channels

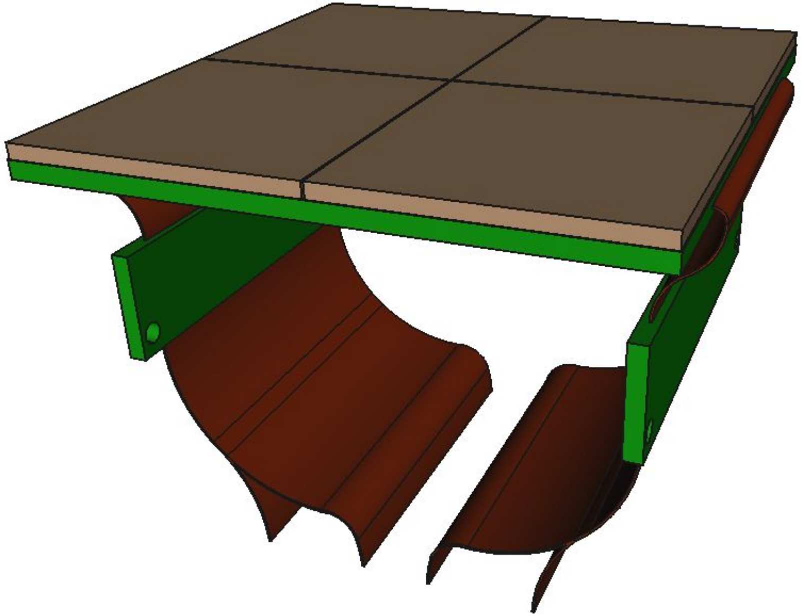


Carrier board V2

under development

mounts 4x SiPM sensor matrices (256 total channels)
receives HV and sends signals via flex connectors (1 mm bending radius)
PCB-flex-PCB-flex design to host HV RC-filters
back-side temperature sensors for monitor / feedback

designed in Bologna
Casimiro Baldanza



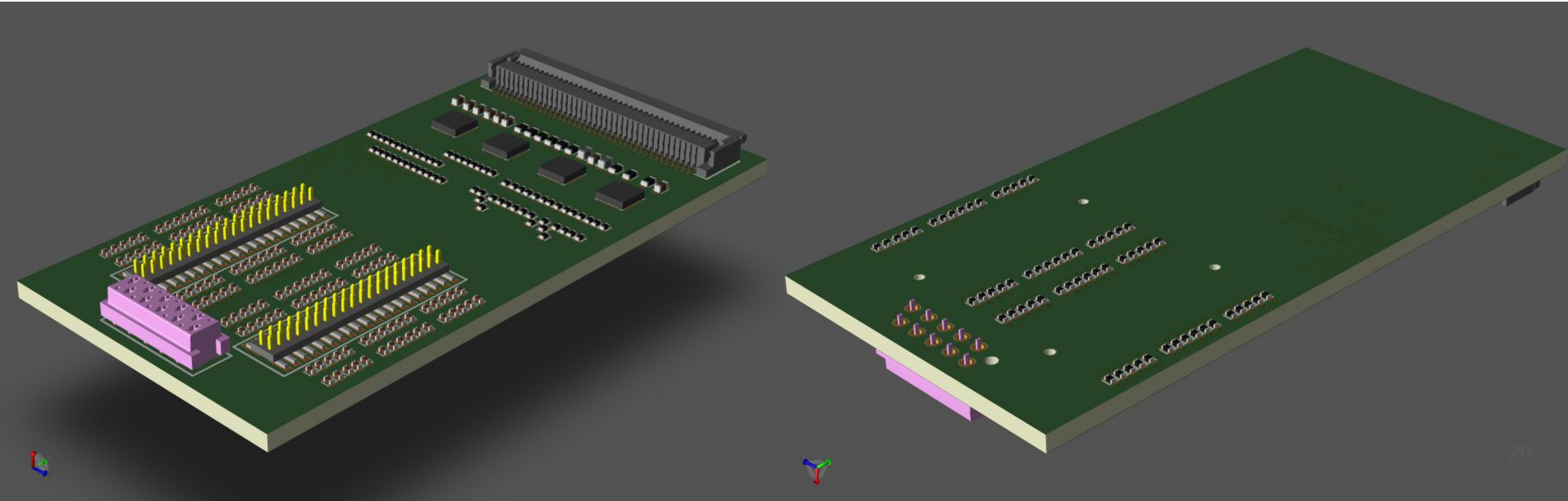
Adapter board V2

very advanced stage

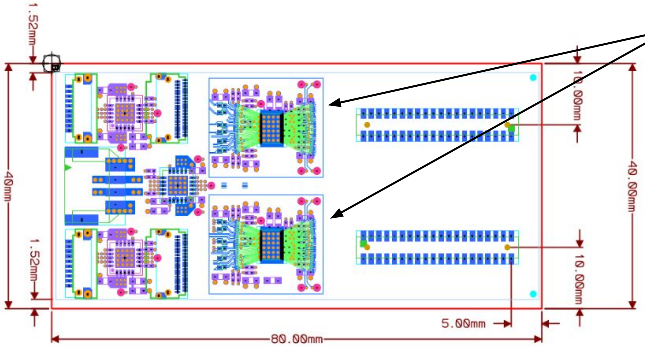
receives signals from SiPM, ships them to ALCOR
includes **complex circuitry** to

- allow HV regulation (0-5 V) for each channel
- derivate signals before ALCOR
- switch from “regular mode” to “annealing mode”

designed in Ferrara
Roberto Malaguti



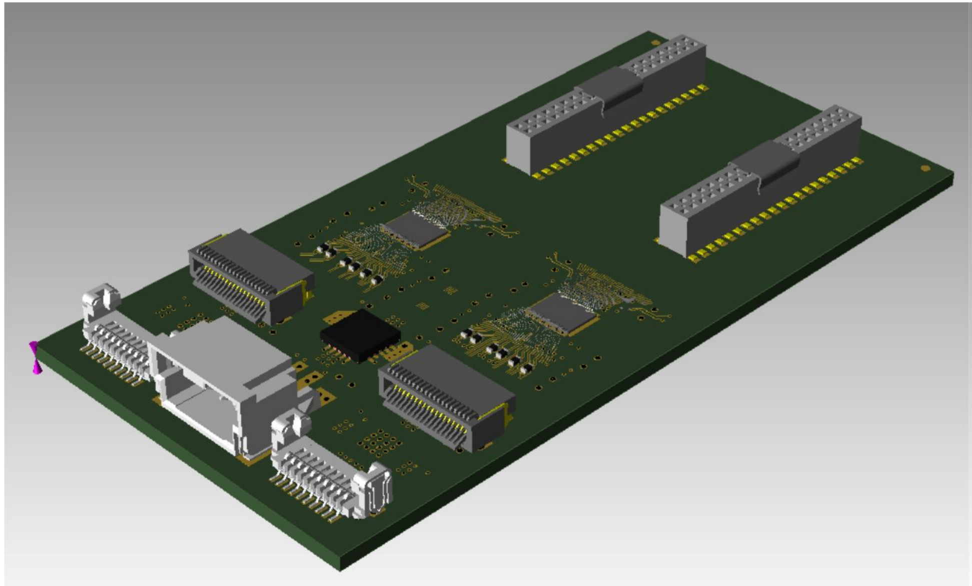
ALCOR board V2

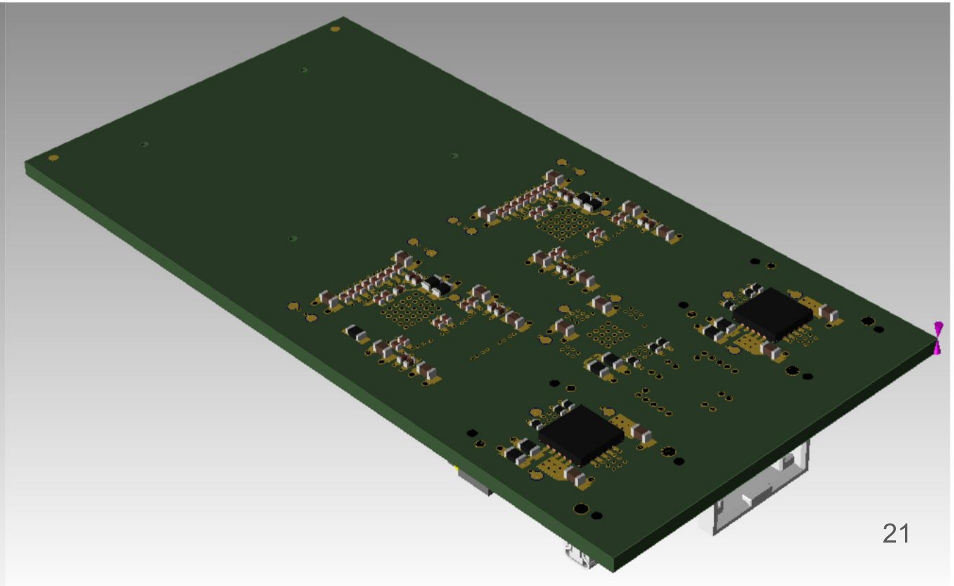


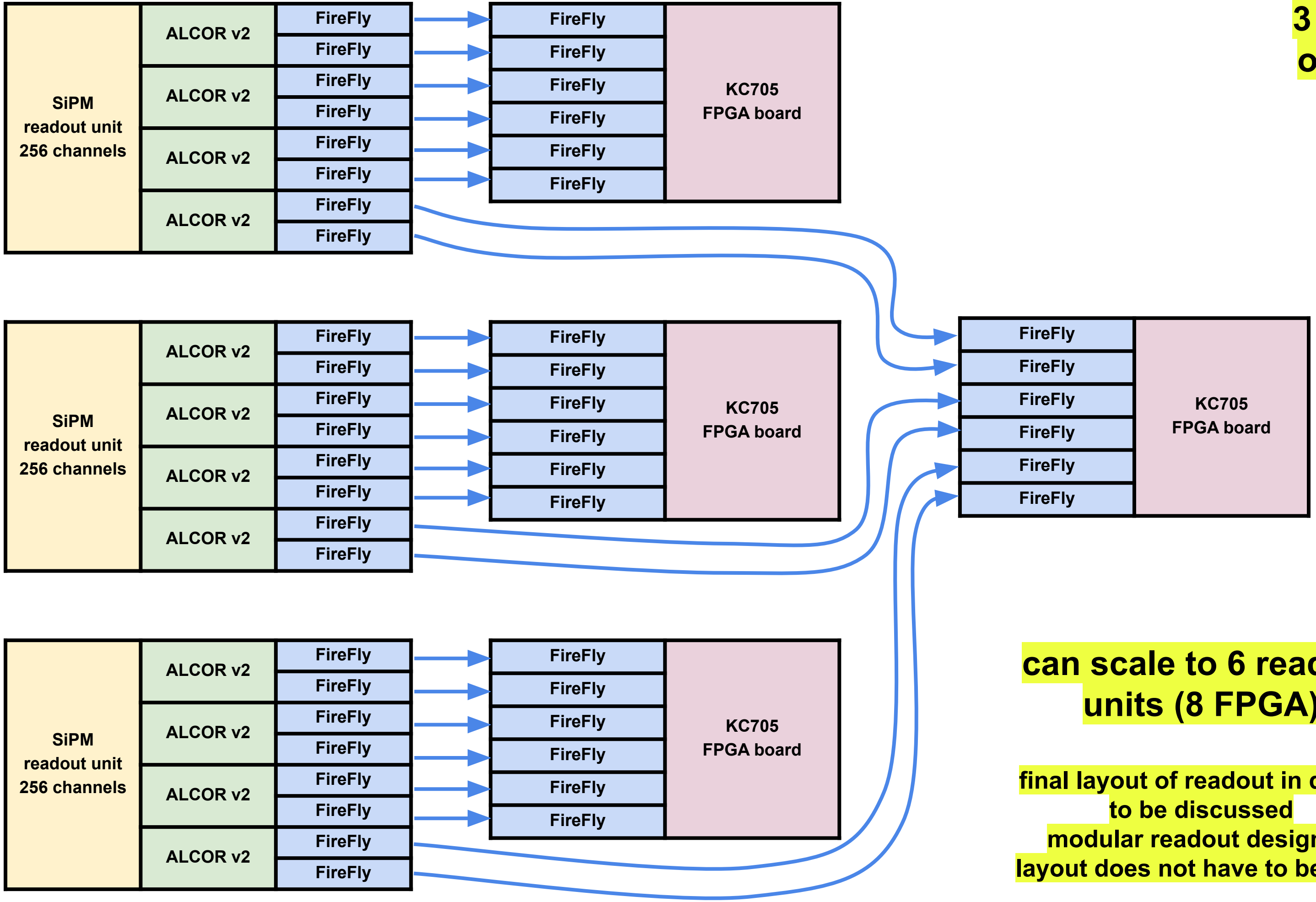
2x ALCOR-v2 ASICs (2x 32 channels)
future ALCOR-v3 will be 64 channels

very advanced stage

designed in Torino
Marco Mignone





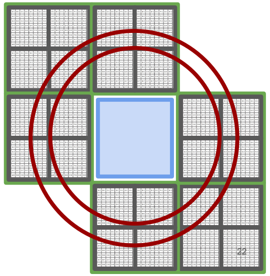


3 readout units readout out by 4 KC705 boards

Xilinx Kintex 5 FPGA evaluation boards

can scale to 6 readout units (8 FPGA)

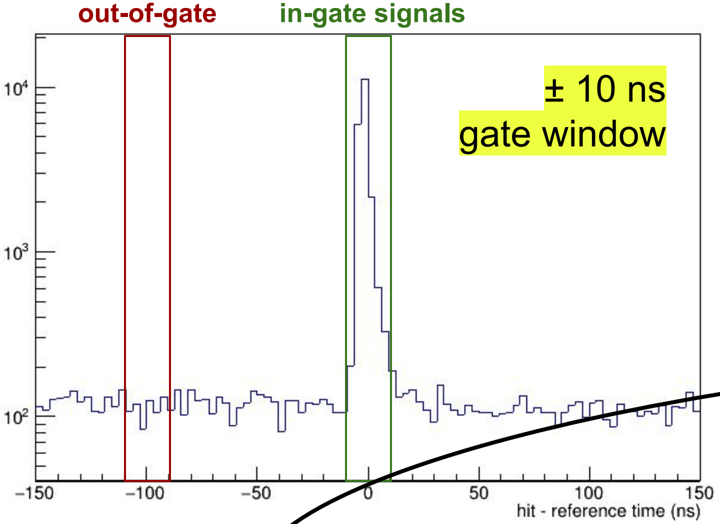
final layout of readout in dRICH to be discussed
modular readout design ⇒ layout does not have to be fixed



Summary

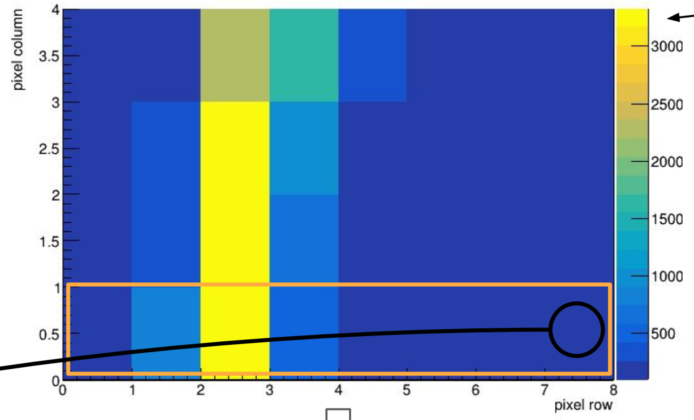
- **design of dRICH prototype SiPM readout**
  - SiPM sensors selected
  - concept idea is advancing
  - INFN engineers working on realisation
- **SiPM cooling system based on Al heat exchanger**
  - not that “bulky”, less than 10% of a radiation length
  - will ask engineers to run simulations to optimise it
  - Peltier modules will be used for prototype, likely not for EPIC
- **put all this stuff into EPIC simulation**
  - at least as first step towards a realistic readout system
  - with space allocation
  - and material allocation

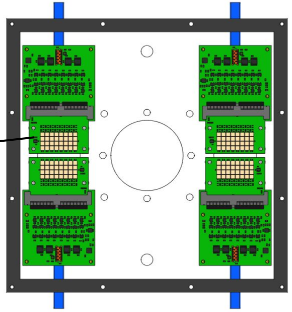
reference time is the particle time measured by the timing scintillators
an time offset of ~10 ns is removed to correct for distance of ~ 2 m between Cherenkov radiator and timing scintillators

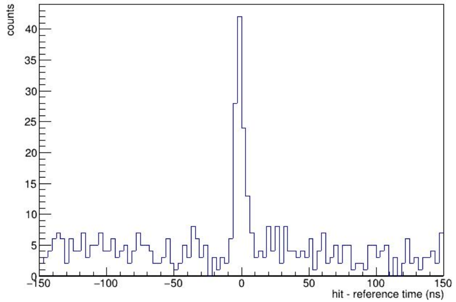


out of topic from test beam
but nice and important to share

HAMA1 - 8 GeV negative beam

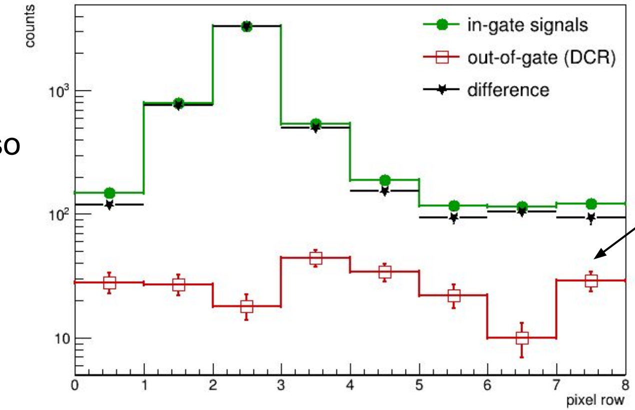






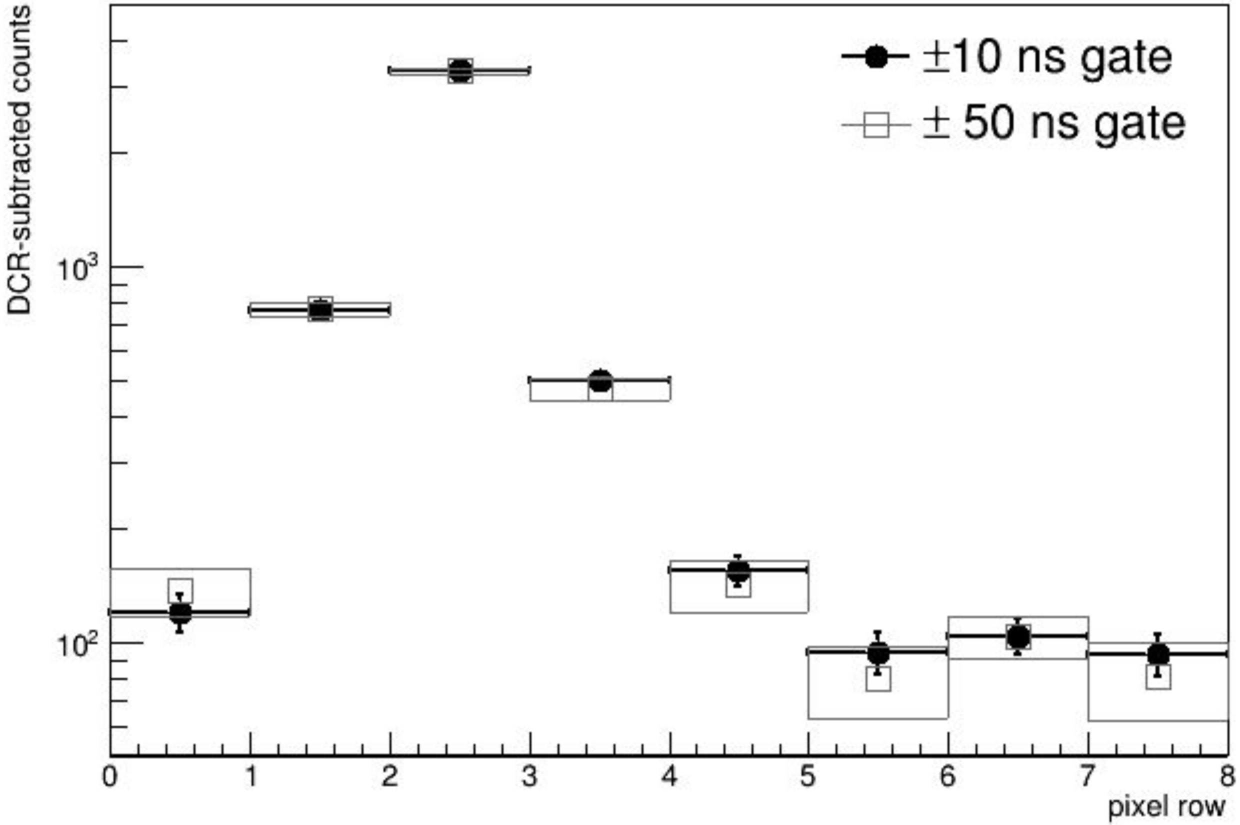
this SiPM sensor also sees signals correlated with passage of particle

Rayleigh scattered photons in aerogel?



amount of signals outside of coincidence gate (due to SiPM DCR) is negligible wrt. physical background coincidences (likely due to Rayleigh scattering of Cherenkov light in aerogel)

try with larger coincidence gate
smaller gate needs timing calibration
(not yet ready)

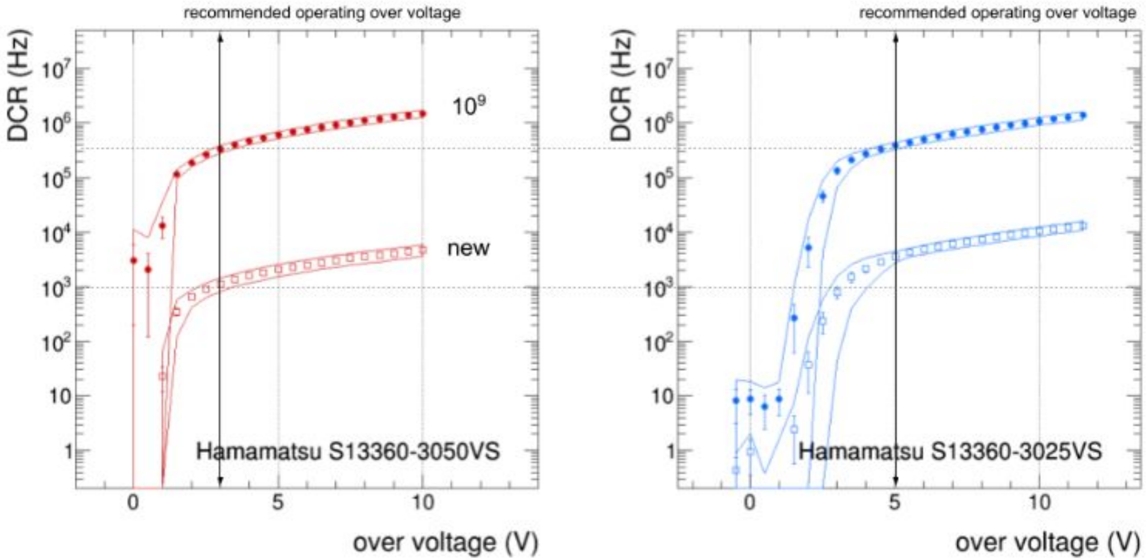


DCR-background subtracted signal unaffected by width of coincidence gate

END

small vs. large SPAD sensors

sensors with small SPADs have lower SNR



A comparison of the measured DCR shows that at the recommended operation voltages of 3 volts and 5 volts for the S13360-3050VS and S13360-3025VS sensors the DCR of S13360-3050VS is the lowest when the sensors are new. S13360-3050VS and S13360-3025VS sensors show the same DCR after irradiation of a fluence of 10^9 1-MeV n_{eq} cm^{-2}. In all cases, the performance of S13360-3050VS sensors is better than S13360-3025VS because

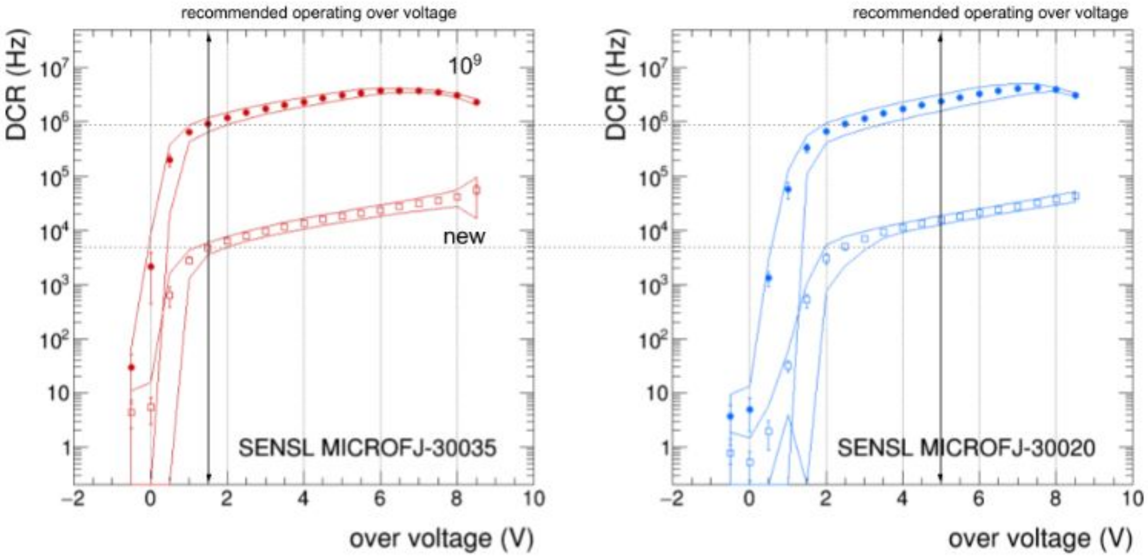
- the PDE is higher
- the DCR is lower or the same

which means that at all stages the signal-to-noise ratio (SNR) figure of merit of S13360-3050VS sensors is higher than S13360-3025VS. For new sensors the SNR of S13360-3050VS is a factor ~ 5 higher than S13360-3025VS.

small vs. large SPAD sensors

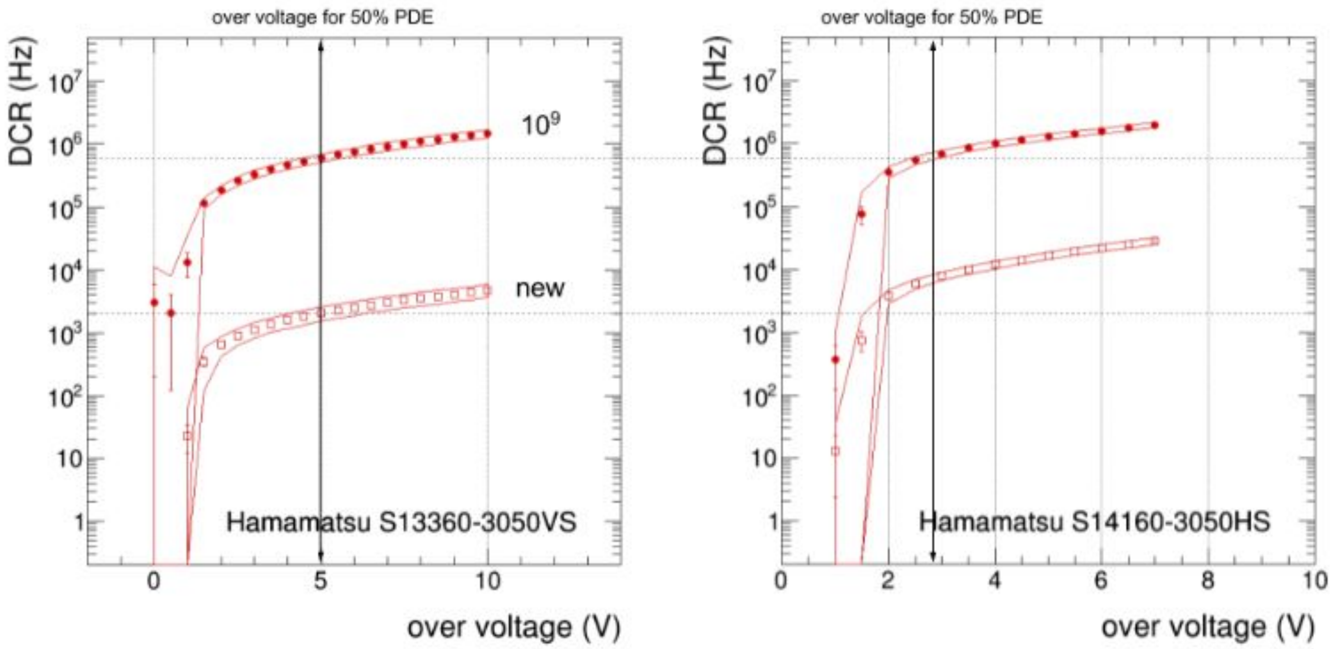
Similar results are obtained from measurements of SensL MicroFJ-30035-TSV (35 µm SPAD size) and MicroFJ-30020-TSV (20 µm SPAD size) sensors. The datasheet shows that MicroFJ-30035-TSV sensors and MicroFJ-30020-TSV sensors have the same PDE of 38% when operated at 2.5 V and 5 V of overvoltage, respectively. Comparison of the DCR of the sensors at these two recommended operational voltages shows that the DCR of MicroFJ-30035-TSV is lower than the DCR of MicroFJ-30020-TSV sensors both when new and after irradiation with fluences of 10^9 1-MeV n_{eq} cm^{-2}. Similarly as for the Hamamatsu sensors, we can conclude that the SNR figure of merit indicates a better performance for the EIC dRICH purposes of the larger SPAD MicroFJ-30035-TSV sensor, with a SNR larger than MicroFJ-30020-TSV sensors by about a factor 2. We do not have performed measurements on the light response for these two sensors.

sensors with small SPADs have lower SNR



two different Hamamatsu technologies

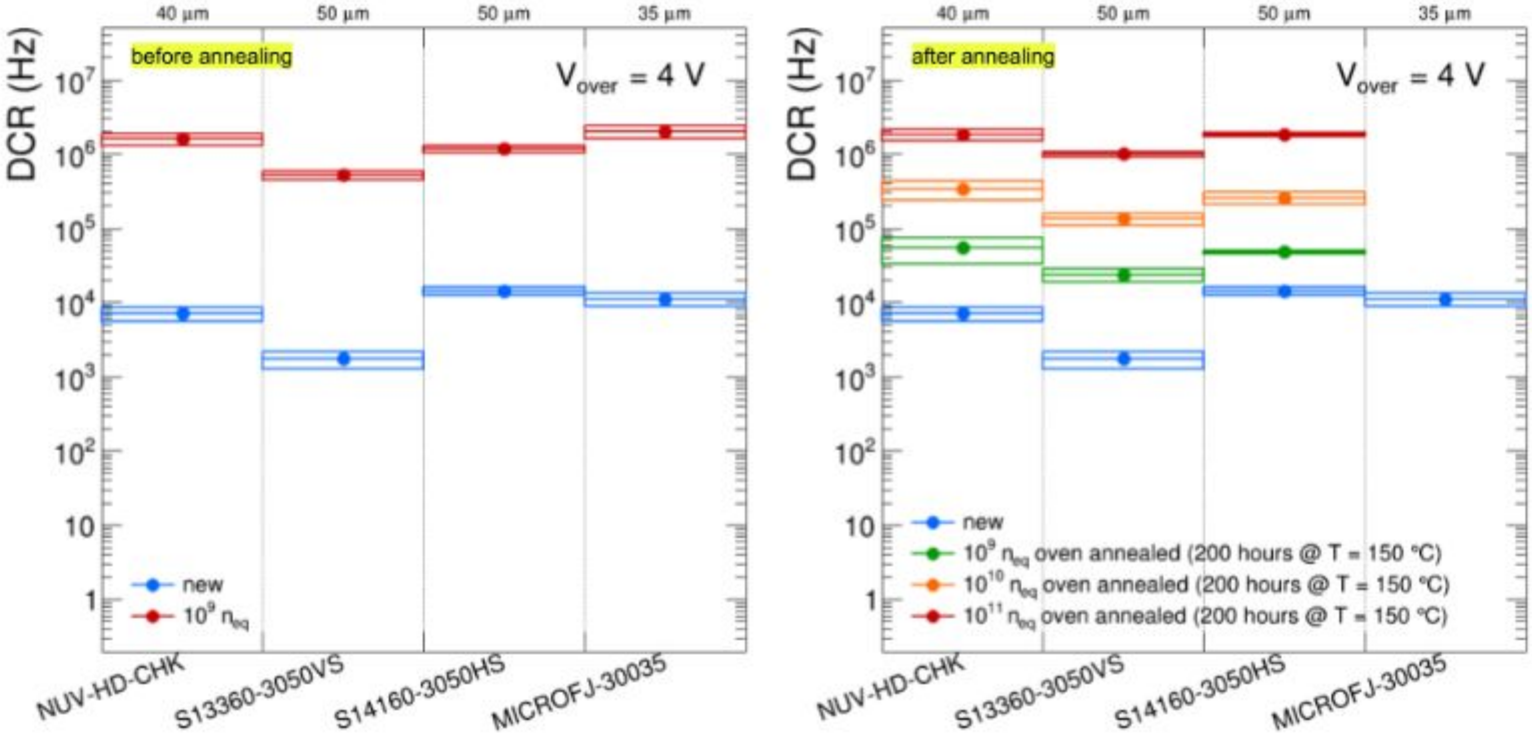
We therefore compare the DCR of the two sensors at the same PDE of 50%, which is reached for the S13360-3050VS sensors when the over voltage is 5 volts, whereas for S14160-3050HS it is reached with a lower overvoltage of 2.7 volts.



DCR in 13360 is lower at same PDE

Despite the significantly larger overvoltage in S13360-3050VS sensors to achieve the same PDE as S14160-3050HS, the DCR in S13360-3050VS sensors is significantly lower than in S14160-3050HS sensors by a factor of about 3.5. Therefore the SNR figure of merit of S13360-3050VS sensors is about a factor of 3.5 larger than S14160-3050HS sensors.

best commercial SiPM for the prototpe



Hamamatsu S13360-3050VS is at all stages the sensor with the lowest DCR.