FONDAZIONE
BRUNO KESSLER

SiPM technology at FBK

C. Piemonte

http://srs.fbk.eu

www.advansid.com

Outline

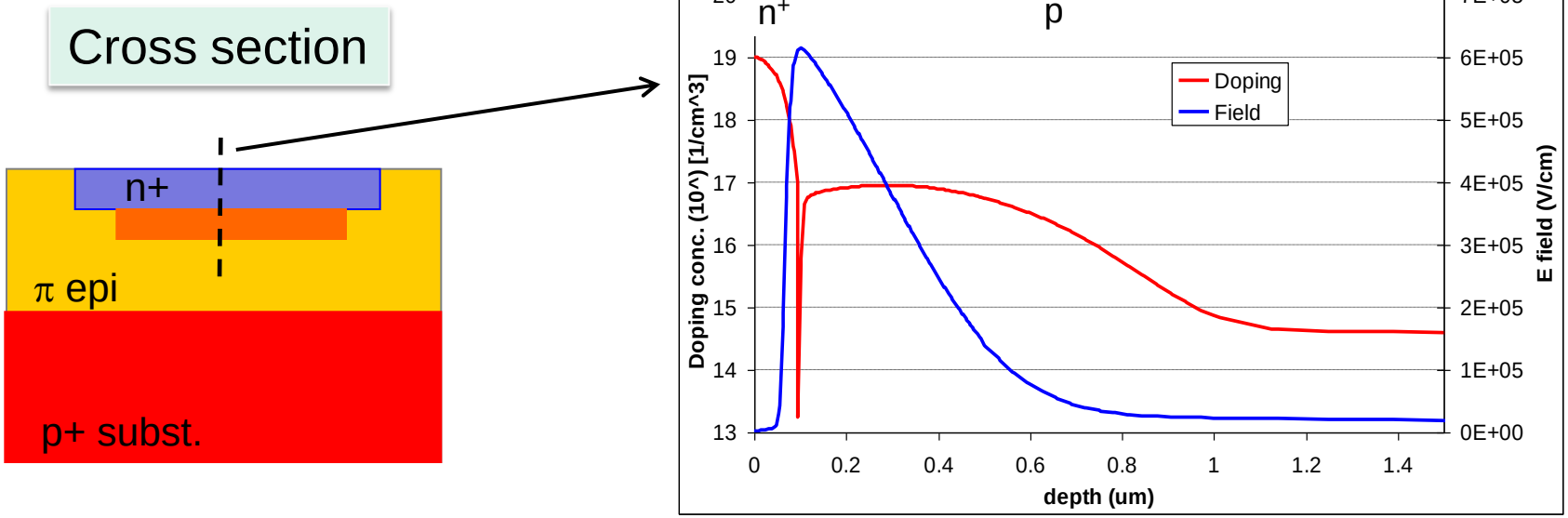
- **FBK SiPM technology overview**
- **Development of SiPMs for TOF-PET**
- **AdvanSiD**

FONDAZIONE
BRUNO KESSLER

SiPM technology overview

SJ-SiPM Technology

Development started in 2005 in collaboration with INFN

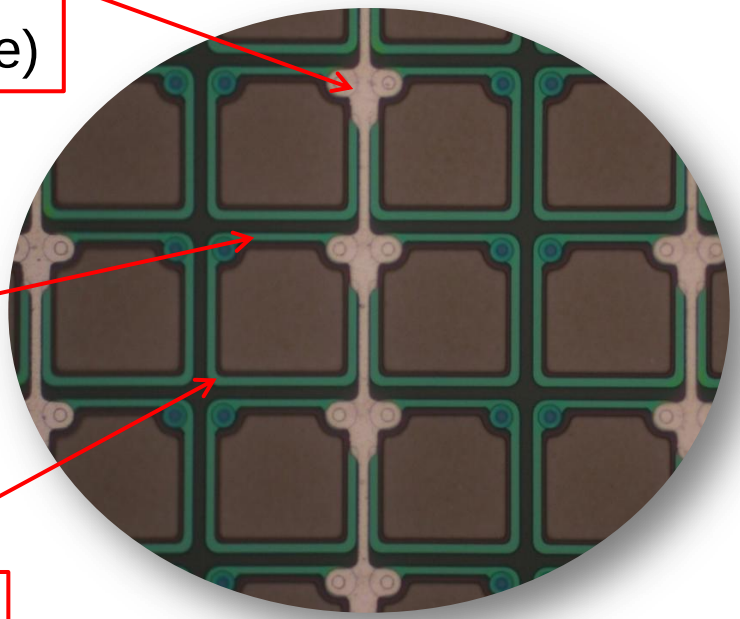


Technology characteristics:

1) Integrated polysilicon resistor
2) Very shallow junction to enhance QE at short wavelengths
2) possible ARC to optimize QE at certain wavelengths

Device Layout: example of internal structure

Metal line connecting all cells in parallel (one common anode)



Polysilicon resistor

Field-plate to reduce electric field around the junction

The cathode is contacted on the rear side.

Resistor is located around the active area => no fill factor loss

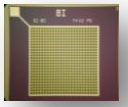
FF ~ 25% 25x25um2 cell
~ 45% 40x40um2 cell
~ 55% 50x50um2 “
~ 72% 100x100um2 “

Device Layout: examples of SiPM geometries

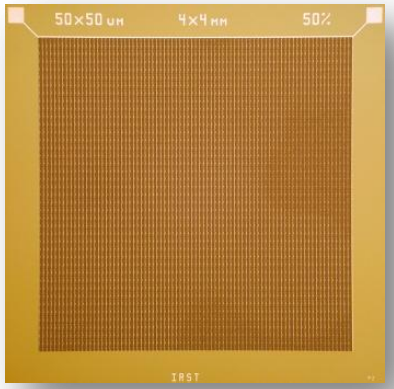
Scale of the pictures is the same

2006

1x1mm^2
40x40μm^2 cell



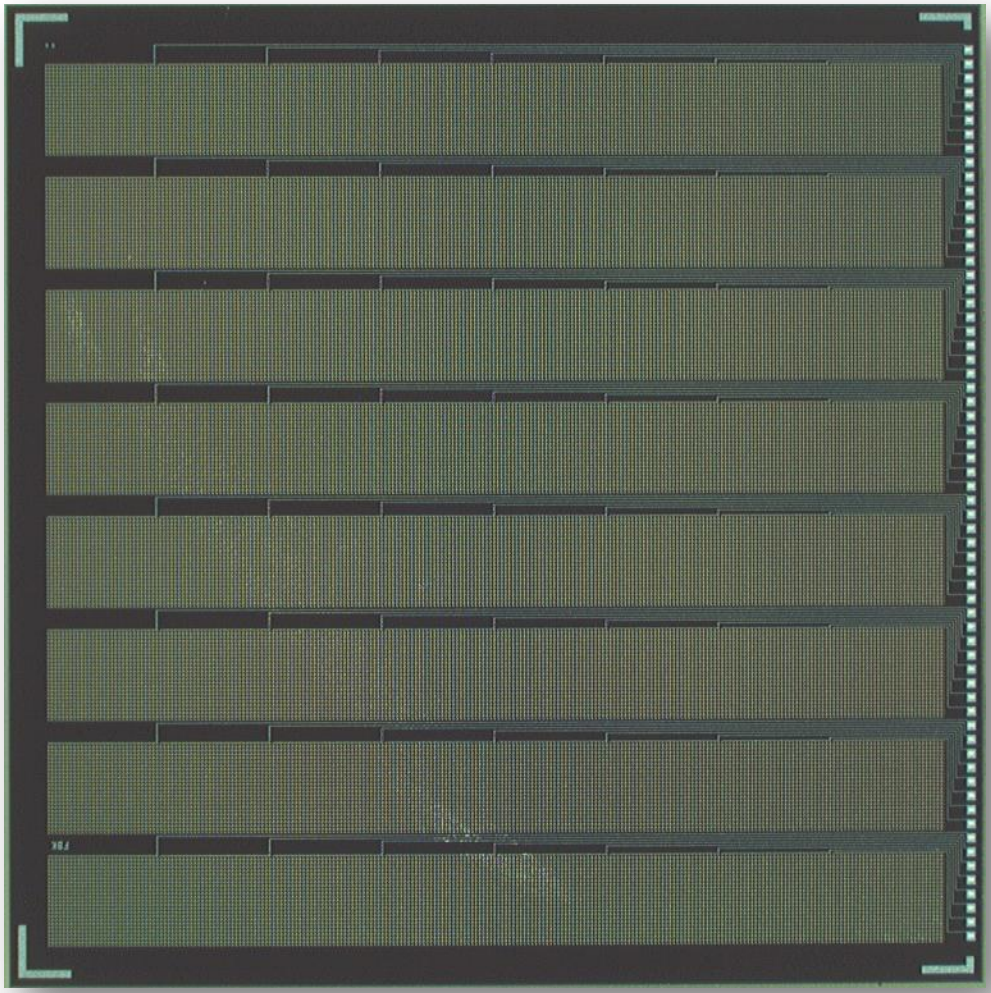
2007



4x4mm^2
50x50μm^2 cell

2009

8x8 array of SiPMs
1.5x1.5mm pitch
50x50μm^2 cell



Produced for DaSiPM (INFN project)

Process & Device characterization at FBK

Wafer level testing:

-Automatic IVs: forward and reverse on all devices

-Failure analysis in case of problems

Wafer dicing

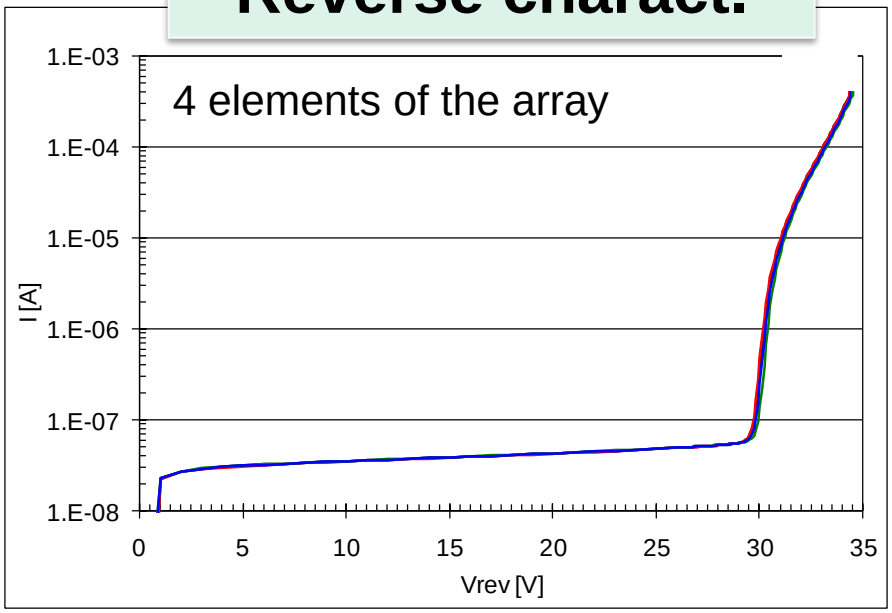
Packaging of some samples

Functional tests:

- Dark analysis in climatic chamber
- Laser response
- Photo-detection efficiency
- Energy & timing resolution with scintillators

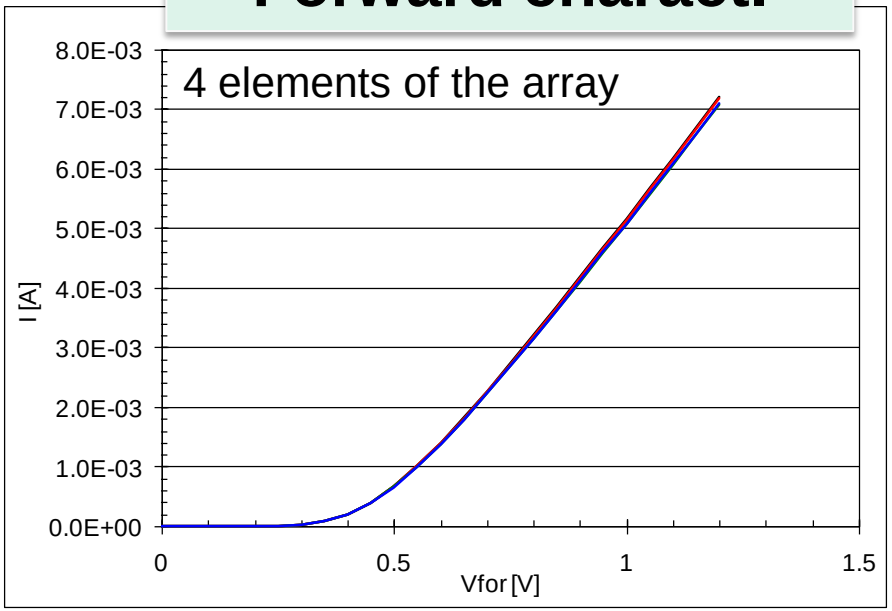
On-wafer automatic characterization

Reverse charact.



- Functionality of the device
- Breakdown voltage
- Dark count estimate

Forward charact.

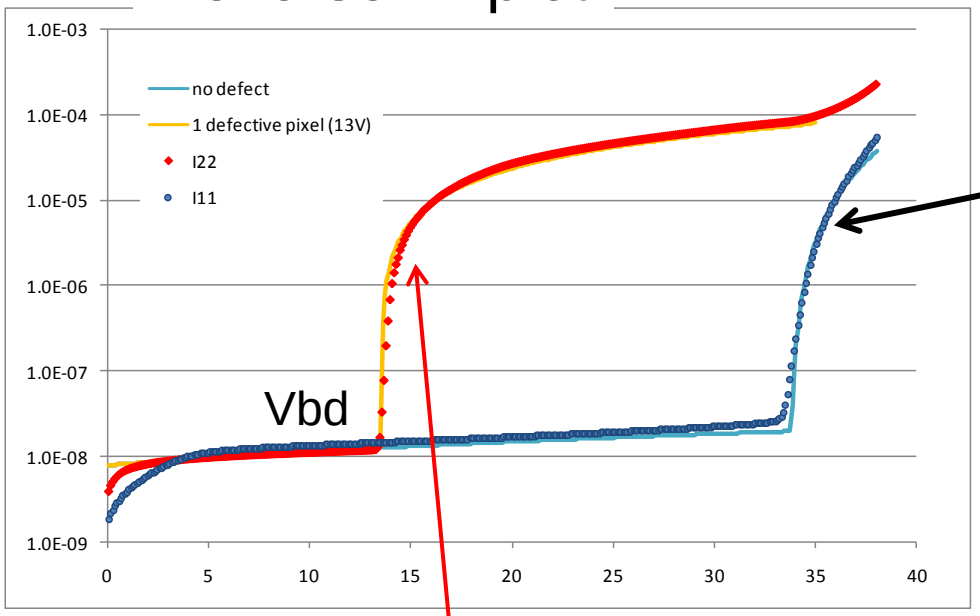


- Functionality of the device
- Resistor value estimate

Example of faulty device

Most common defect is premature breakdown

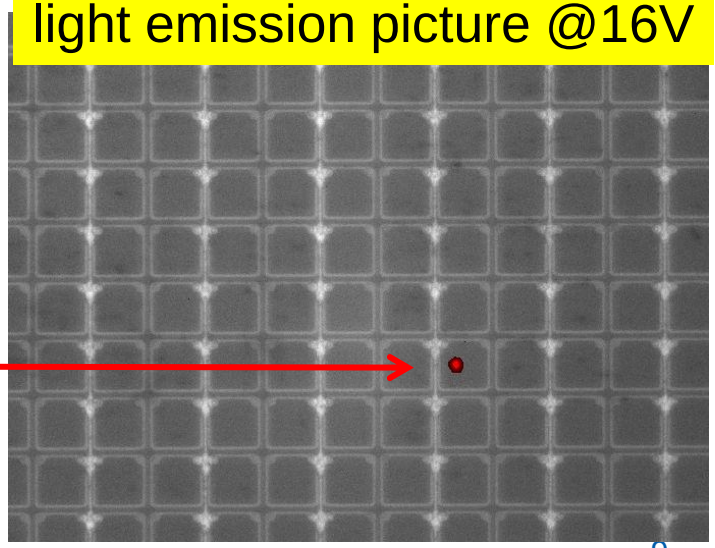
Reverse IV plot



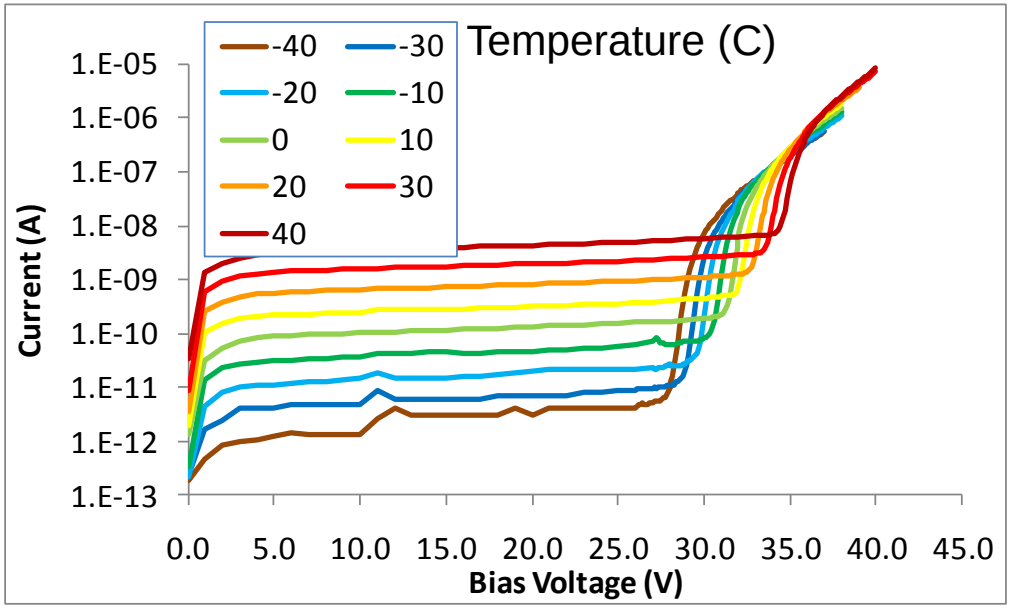
Working SiPM.
The current can be roughly modeled as $I=q*DC*G$

SiPM with 1 defective cell.
$I=(V-V_{bd})/Rq$

light emission picture @16V

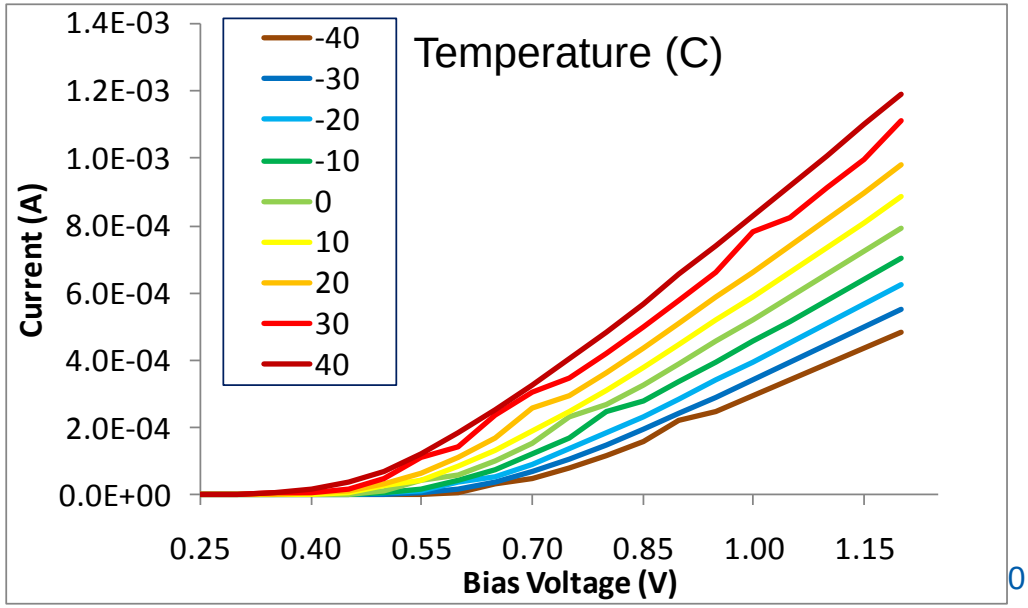


… after packaging…



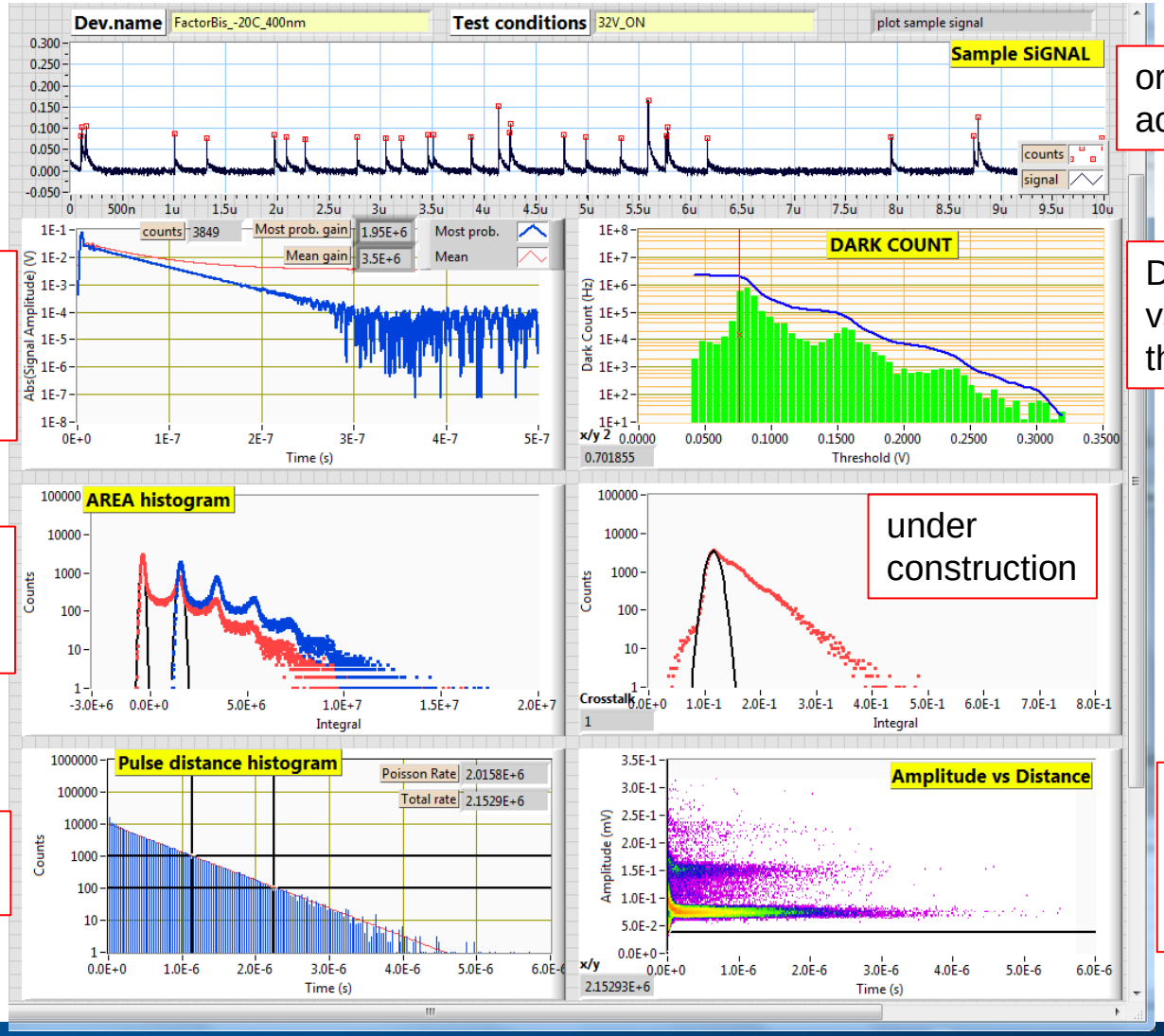
Reverse IV plot

Forward IV plot
(quenching resistor value
is temperature dependent)



Dark analysis in climatic chamber

For each bias voltage, Labview program performs following:



original data, acquired with scope

single-cell signal (blue), mean signal (red)

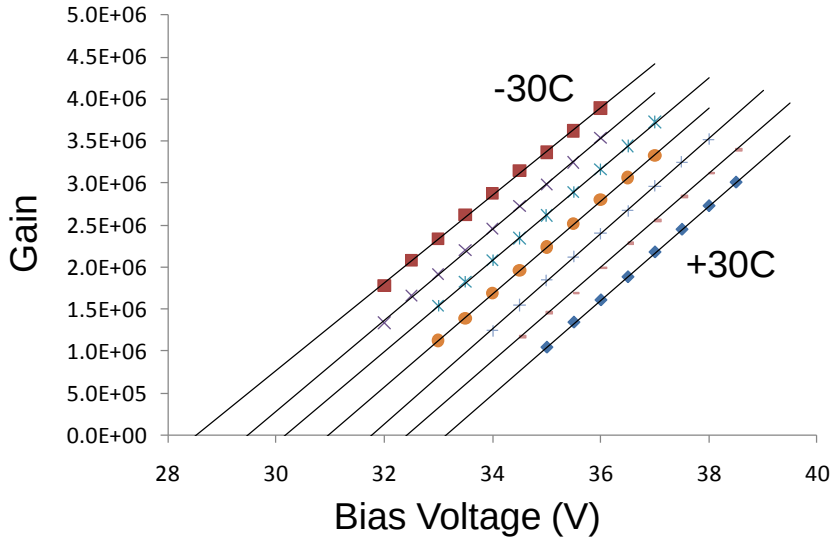
Dark count rate vs threshold (blue)

pulse area histogram (blue), baseline (red)

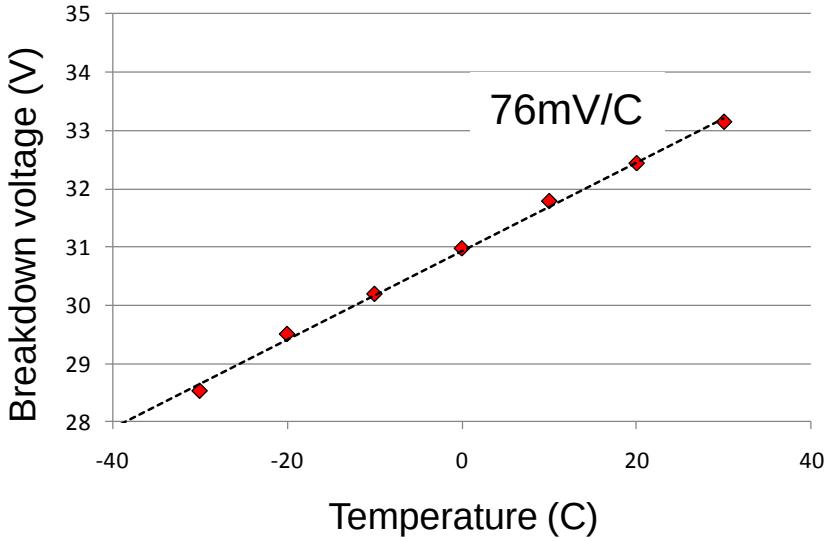
pulse distance histogram

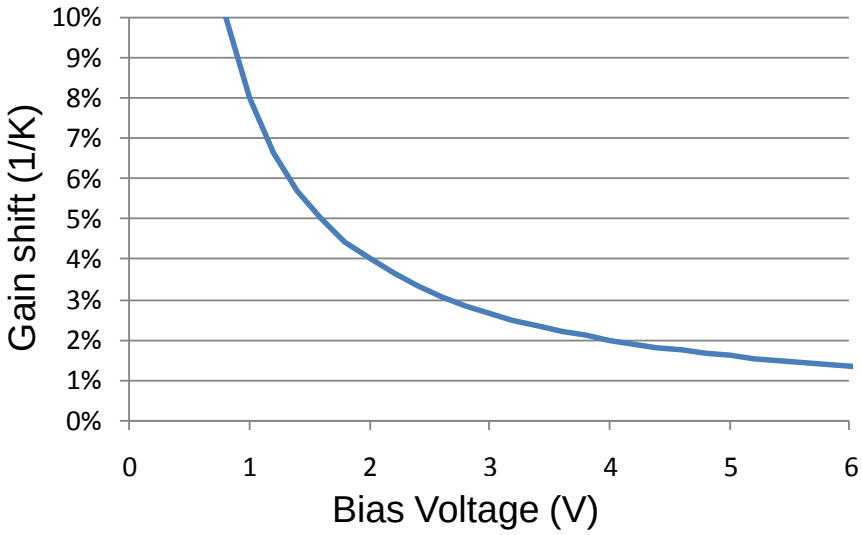
pulse amplitude distribution vs distance

Dark analysis in climatic chamber

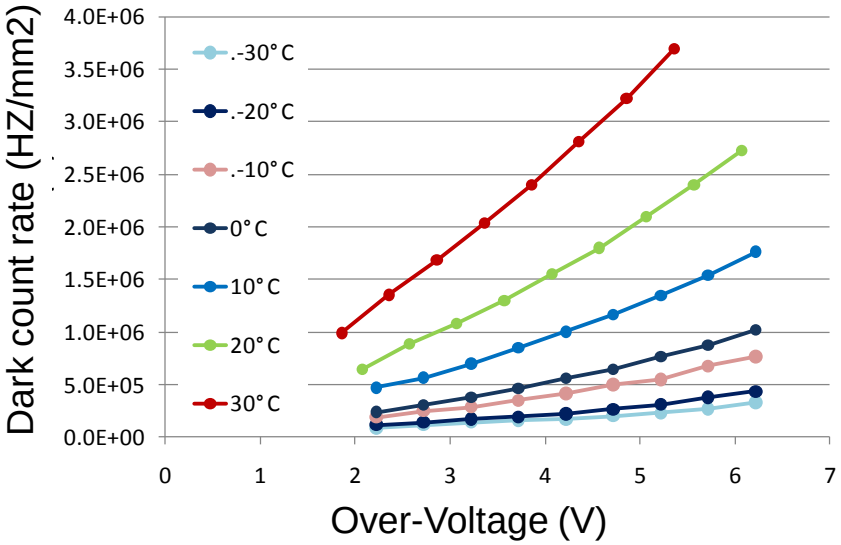


Breakdown
&
Gain





Dark analysis in climatic chamber



Dark count

doubles every 10C temperature increase

Quenching resistor

increasing with decreasing temperature

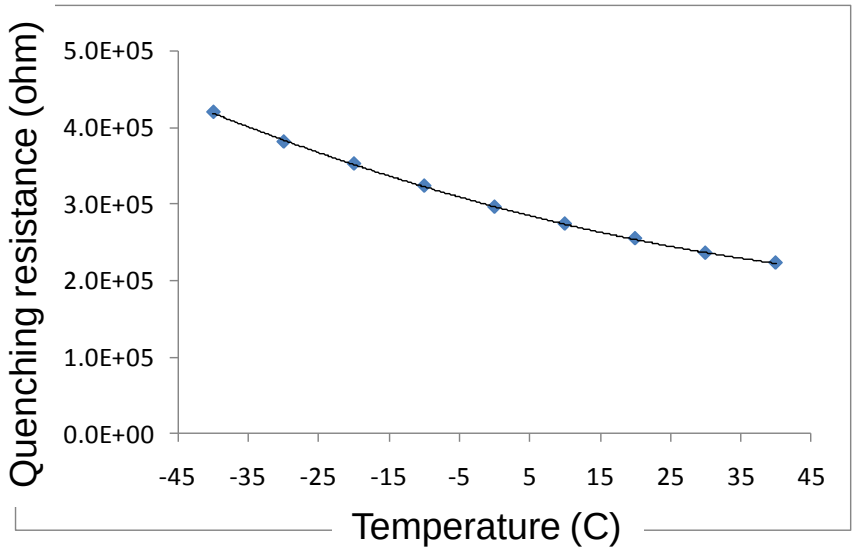
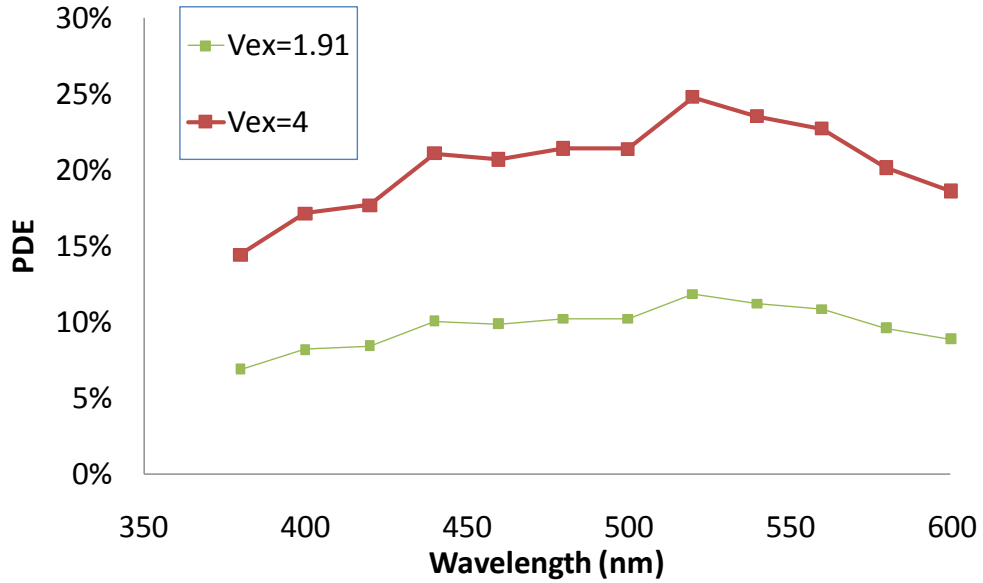


Photo-detection efficiency

Measured with low level constant light

$$PDE = \frac{PoissonLight - PoissonDark}{Number\ of\ incident\ photons}$$



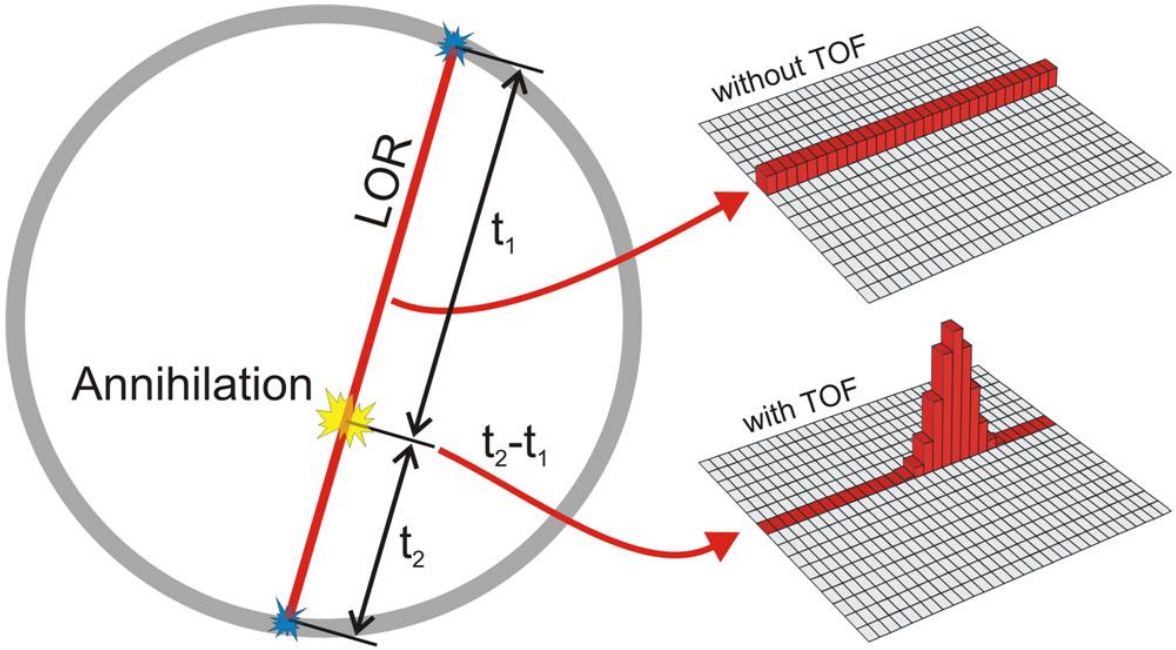
Using the Poisson rate we get rid of after-pulse and optical cross-talk

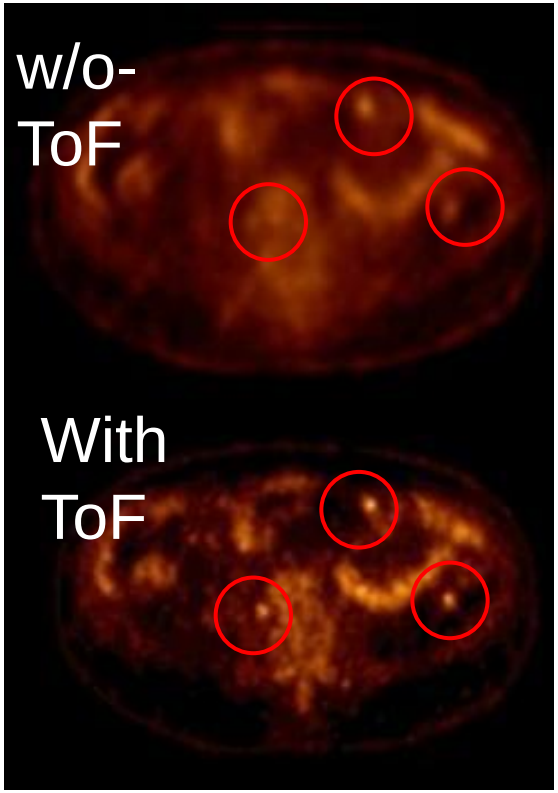
FONDAZIONE
BRUNO KESSLER

Application-oriented development: HYPERIMAGE TOF-PET

Example: TOF-PET

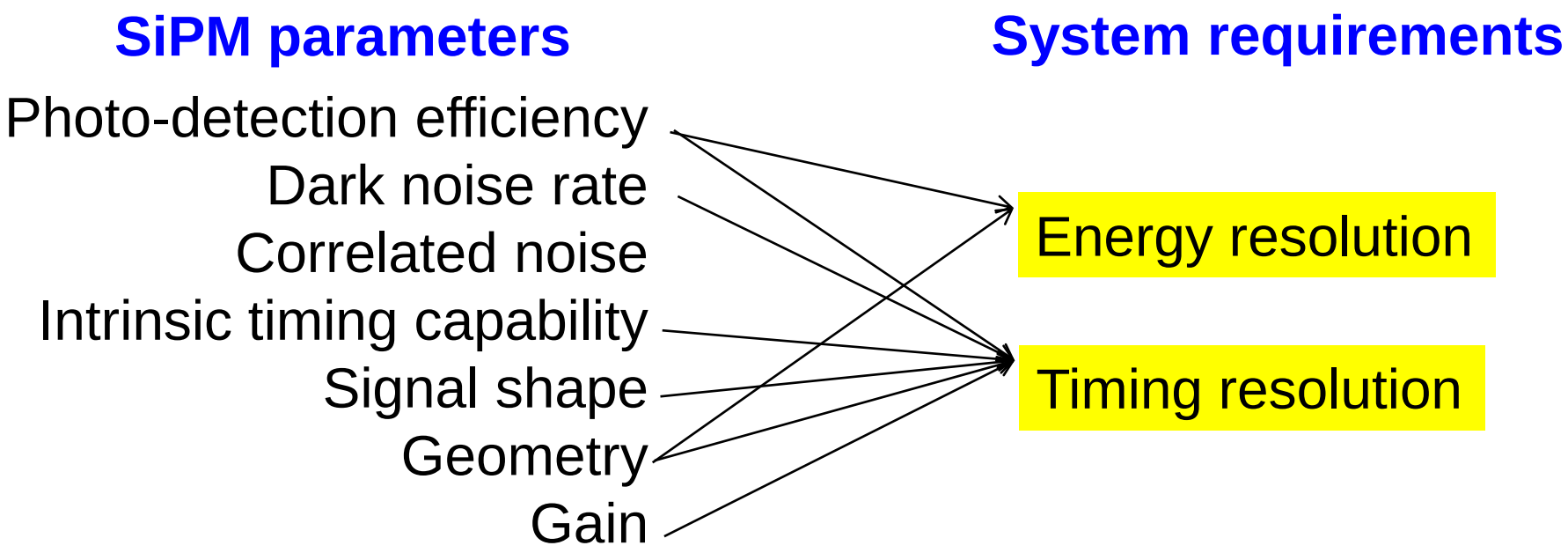
Time-Of-Flight Positron Emission Tomography





Info from the SiPM: **Energy** and **timing**

Critical SiPM parameters for TOF-PET



Other important SiPM features for such a large system are:

- temperature dependence
- breakdown voltage uniformity
- Voltage operability range
- …
- packaging/interconnectivity

Framework of the development

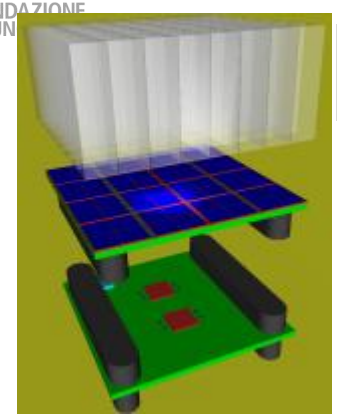
HYPERimage

http://www.hybrid-pet-mr.eu

Development of a **hybrid TOF-PET/MR** test system with improved effective sensitivity

First clinical whole body PET/MR investigations of breast cancer

HYPERimageToF-PET



The Stack

Pre-clinical system

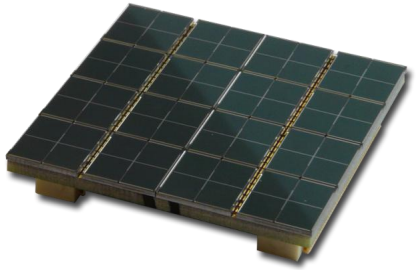
WB system

Why SiPMs?

	PMT		SiPM
MR compliant	no	yes	yes
ToF compliant	yes	no	yes

Photosensor activity

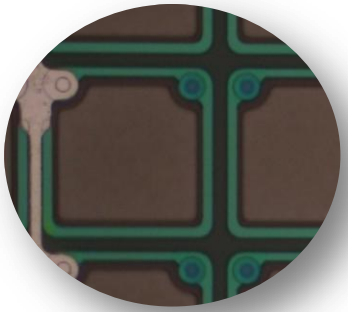
Sensor tiles production to equip a machine



- geometry definition
- integration scheme definition
- device production

some results presented @ IEEE NSS/MIC 2009

Development of improved SiPMs



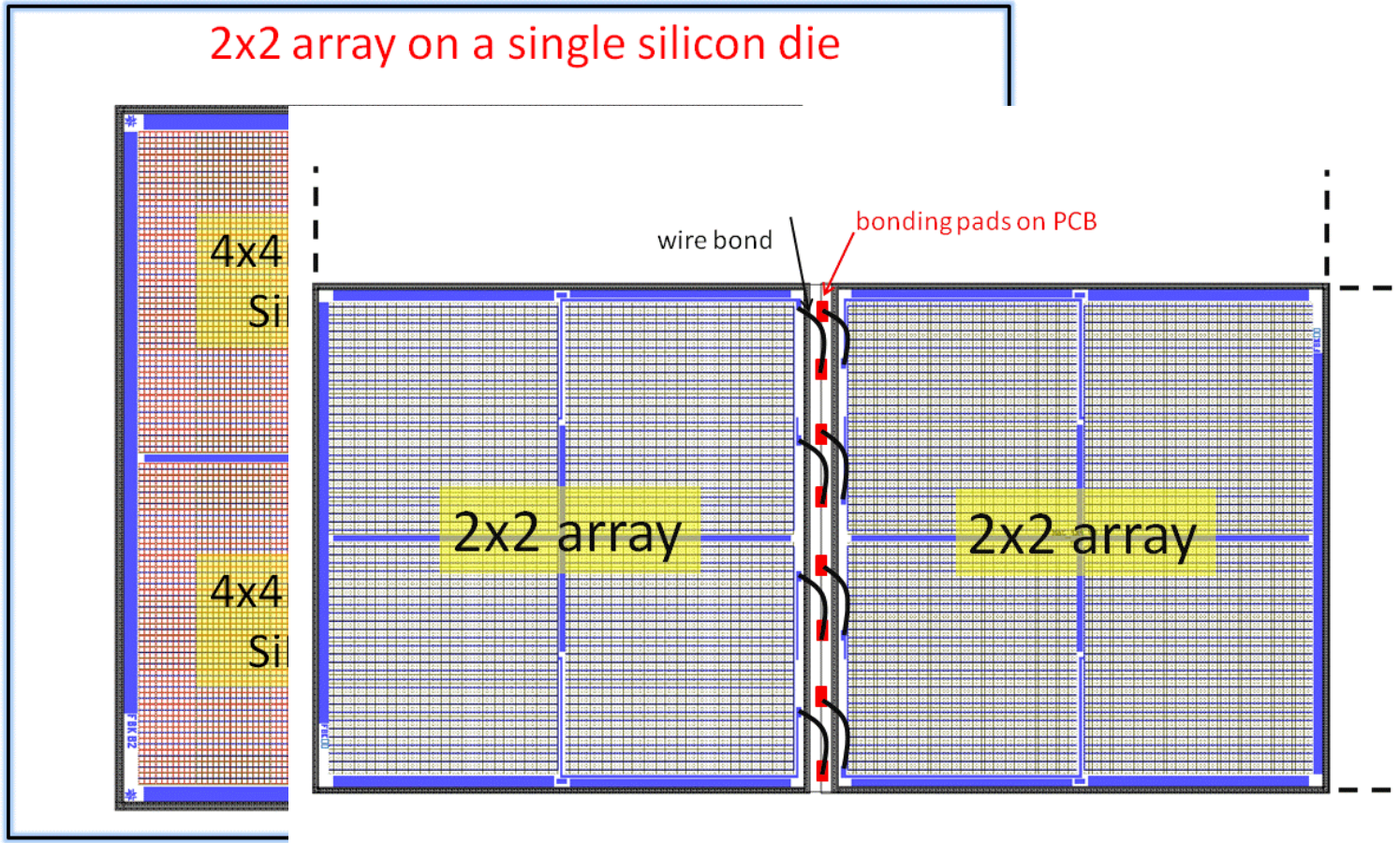
Tuning of both technology as well as design

- PDE
- Vbd uniformity
- Temperature dep.

- signal shape
- cells density

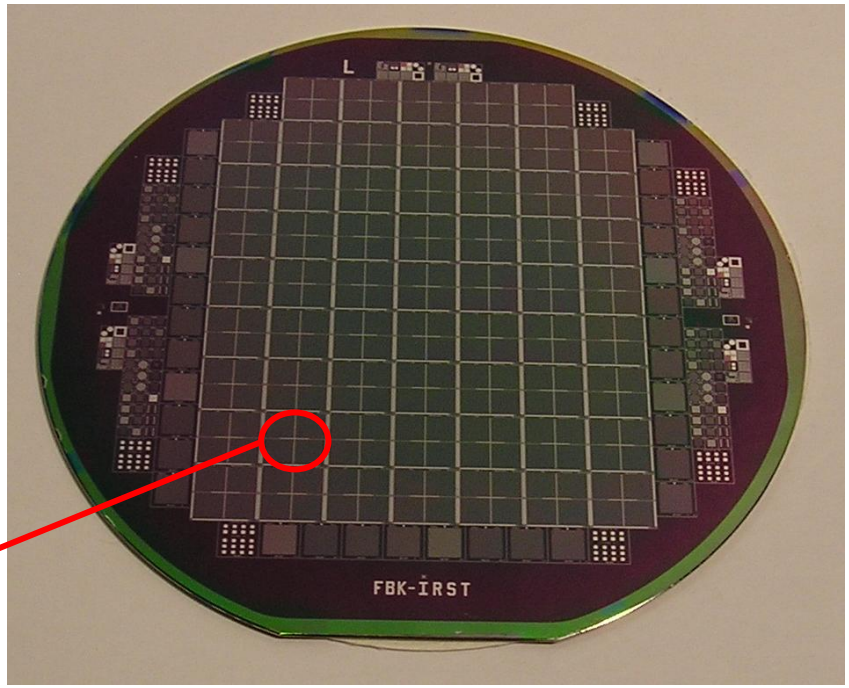
some results presented @ IEEE NSS/MIC 2010

SiPM production: geometry definition

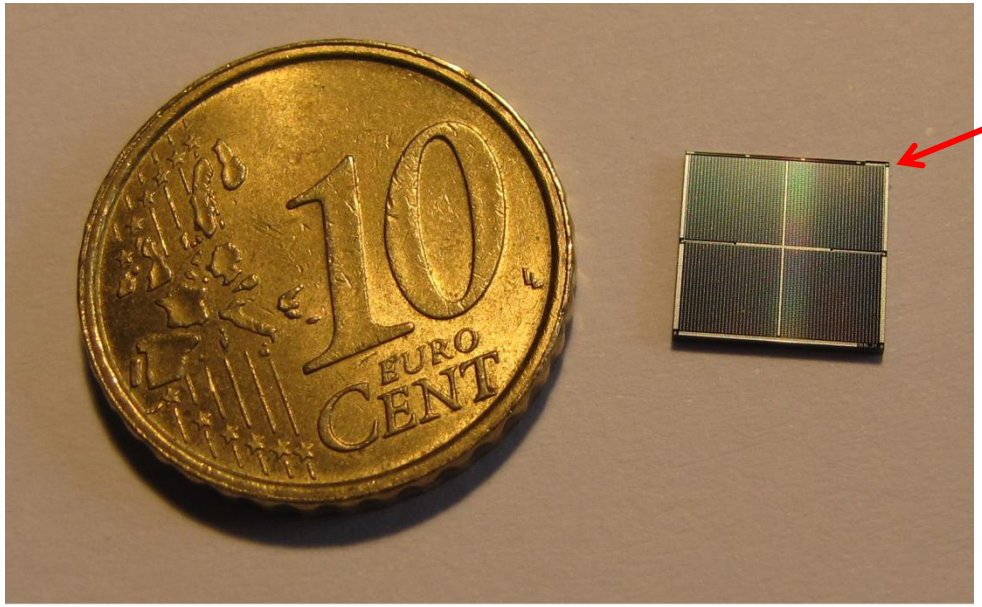


Production

Wafer view

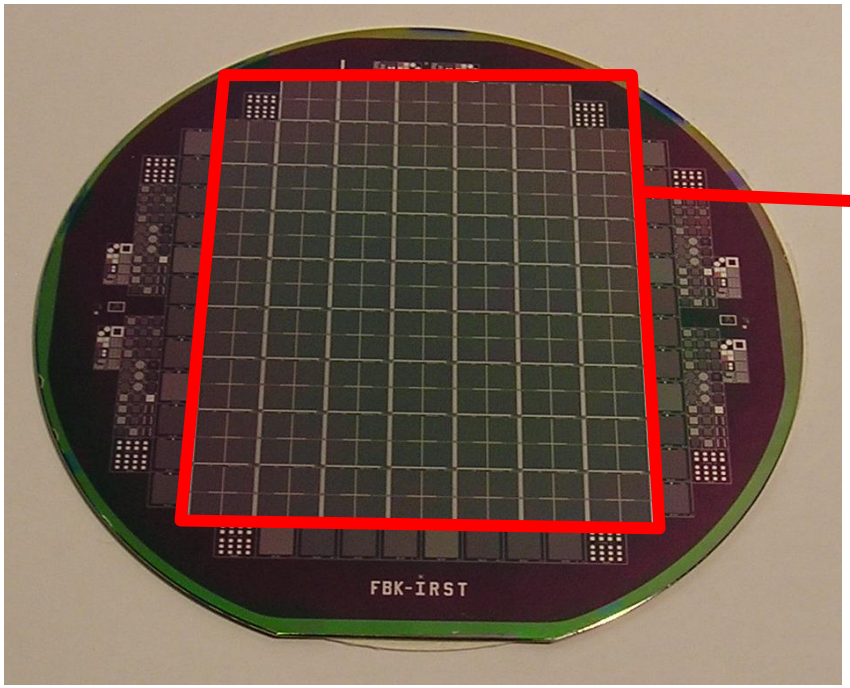


2x2 array of ~4x4mm² SiPMs
3600 cells per element



Lot production time: ~3-4 months

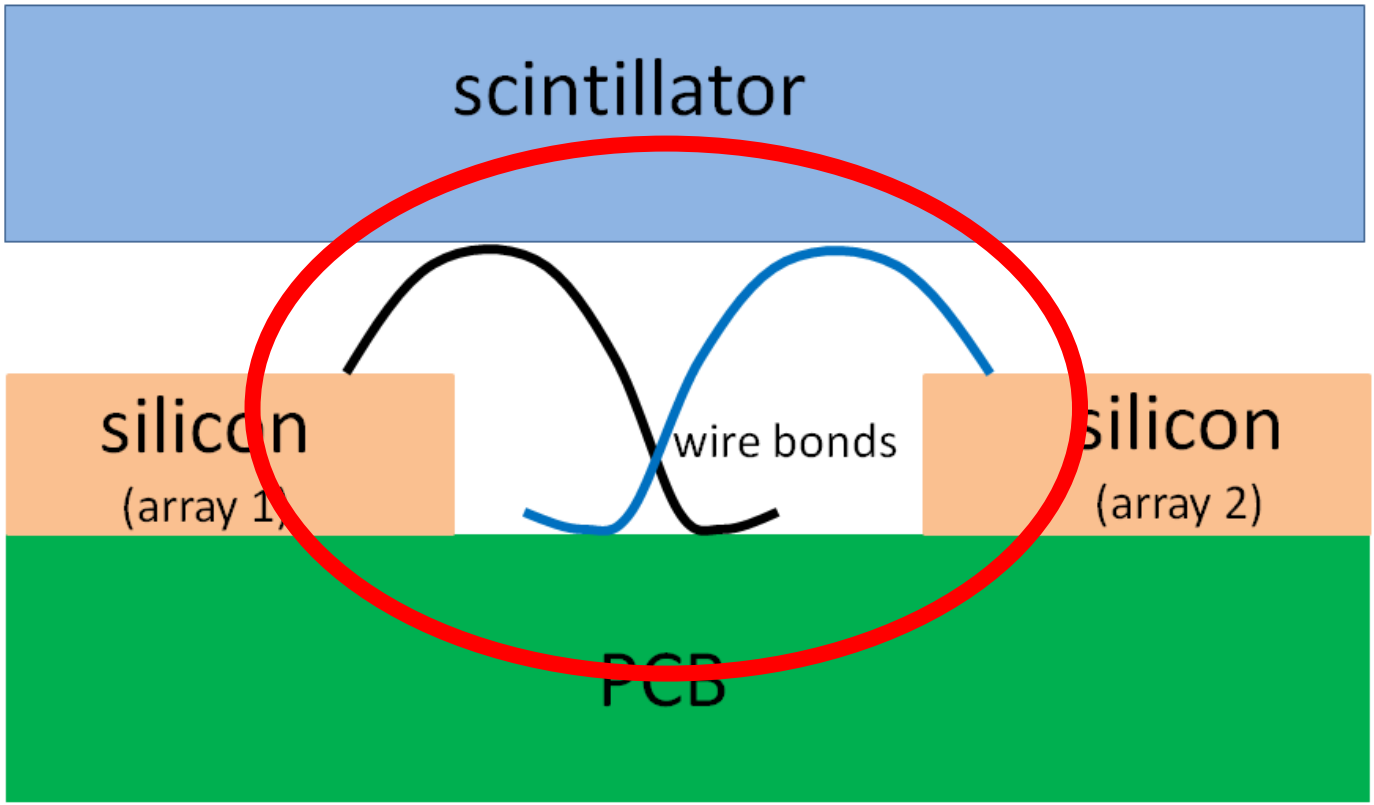
Data analysis (1) - yield



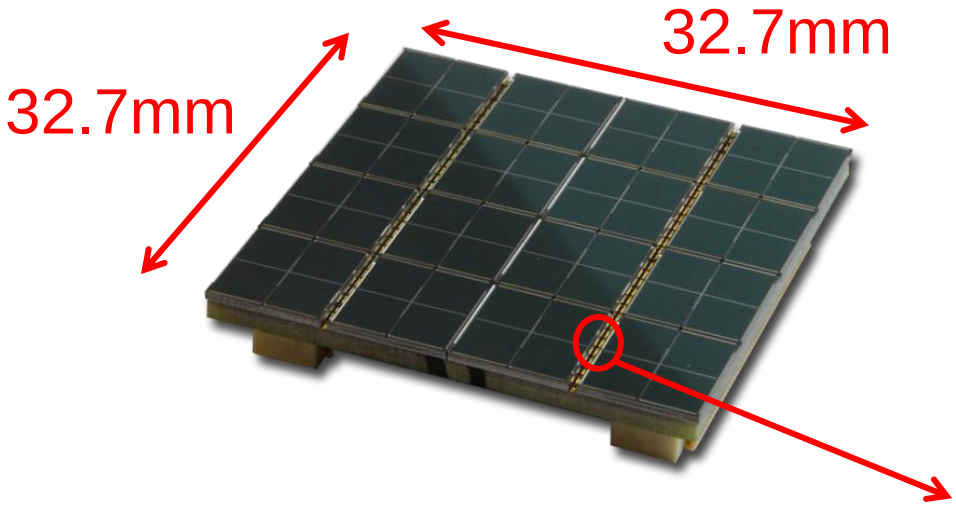
		29.0	6.0	28.8	28.9	28.8	28.7	28.6	28.8	26.0	29.4		
		28.8	28.5	28.4	28.6	28.9	28.9	28.7	28.7	28.8	29.0		
28.7	28.7	28.9	28.7	28.4	28.4	28.5	28.7	28.9	29.1	29.1	28.9	28.9	15.0
28.6	28.4	28.4	28.6	28.7	28.9	28.6	28.6	28.6	28.8	29.2	29.3	12.0	28.9
28.8	28.6	27.0	28.4	28.8	29.1	29.2	29.1	28.9	28.8	28.7	29.0	29.2	29.1
28.3	28.7	28.7	28.7	28.8	28.9	29.3	29.4	29.3	29.1	28.8	28.7	28.6	28.7
28.3	28.2	15.0	29.1	29.4	29.4	29.4	29.3	29.3	29.4	29.1	28.8	28.7	28.5
28.4	28.4	28.5	28.8	16.0	29.9	29.9	29.6	29.3	29.1	28.9	28.9	28.8	28.6
28.6	28.6	28.8	29.1	29.4	29.8	30.1	30.1	29.8	29.2	28.8	28.6	28.5	28.9
28.4	28.5	29.1	15.0	29.6	29.8	29.9	29.9	29.5	29.4	29.0	28.6	28.6	28.5
28.5	15.0	28.9	16.0	29.7	30.1	30.0	29.6	29.2	29.0	29.0	28.7	28.7	28.5
28.9	29.0	29.1	29.3	29.4	29.7	29.9	29.7	29.1	28.6	28.5	28.7	28.5	28.7
28.7	29.1	29.3	29.6	29.6	29.5	29.4	29.3	29.1	28.8	28.6	28.3	28.3	28.6
28.9	28.9	29.1	29.5	29.7	29.6	29.4	29.0	28.6	28.7	28.6	28.4	28.4	28.4
29.1	29.1	29.0	29.3	29.4	29.6	29.3	28.9	28.6	28.4	28.2	28.4	28.6	28.7
29.1	29.2	18.0	12.0	29.2	29.2	29.0	28.9	28.8	28.4	28.2	28.3	28.4	28.7
26.9	29.1	29.3	29.3	29.3	17.0	28.7	28.6	28.6	28.6	28.5	28.5	28.5	28.5
12.0	29.2	12.0	29.2	29.1	13.0	28.7	28.5	28.4	28.4	28.6	28.7	28.7	28.9

white = OK
red = premature breakdown
green/blue = problems after breakdown

Solution for Scintillator coupling

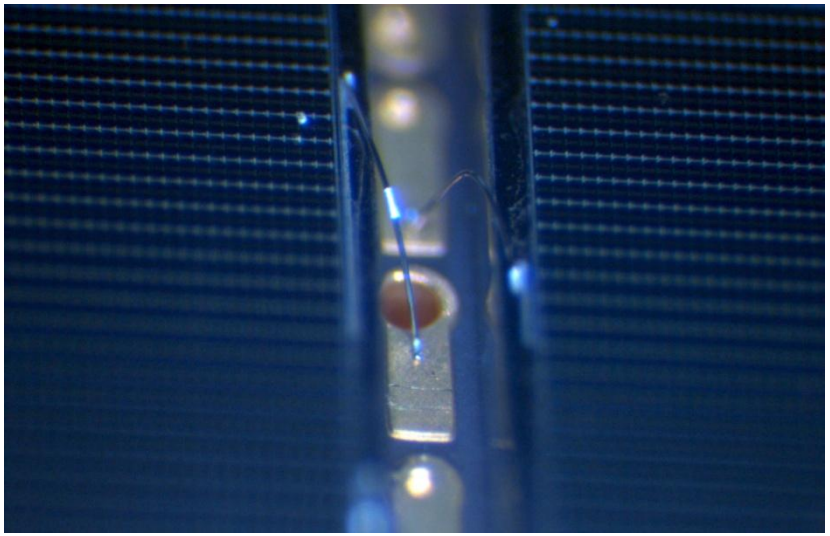


The SiPM tile



- **Fill factor ~ 84%** (not including SiPM FF)
- **Flat surface for crystal mounting**

500μm



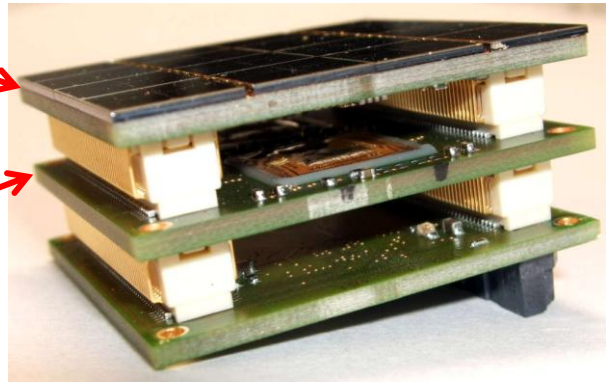
PCB design and mounting at Uni. Heidelberg and Philips

1300 working arrays delivered for the preclinical system

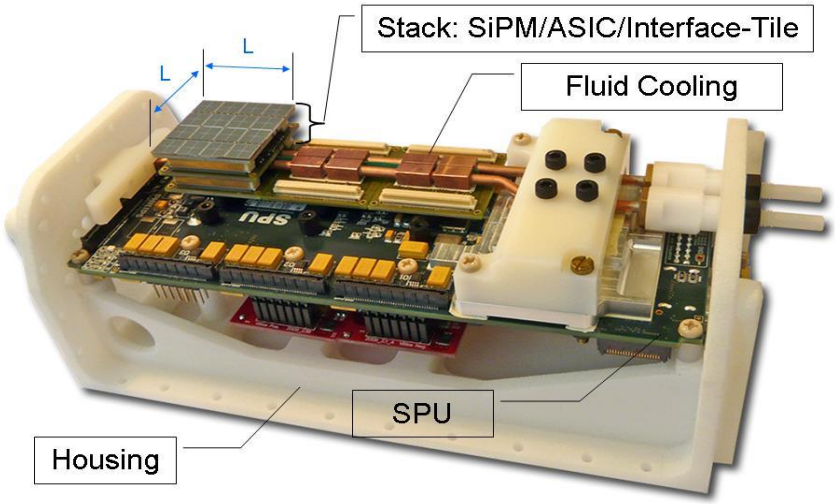
The stack

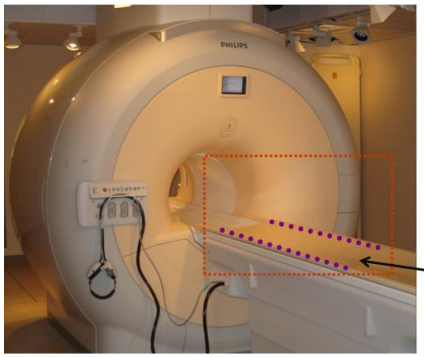
SiPM tile

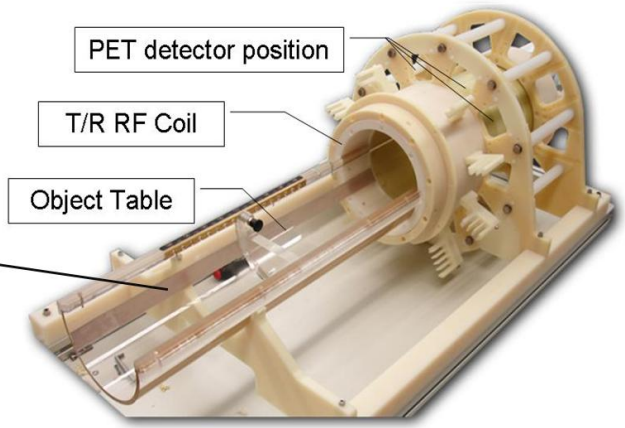
ASIC tile



The module



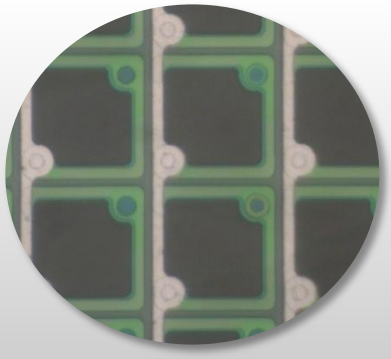




Mechanics

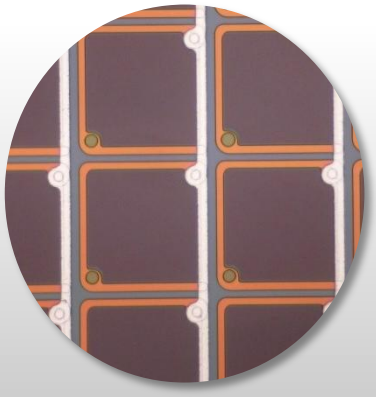
Device optimization: Cell design

50x50um2 cell size, 6400 cells
Fill factor = 48%



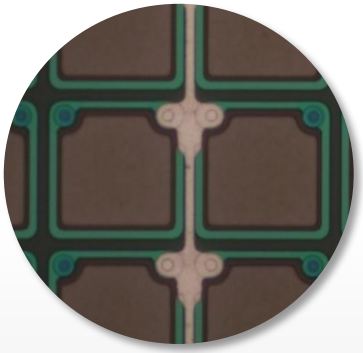
metal every column

80x80um2 cell size, 2500 cells
Fill factor = 65%



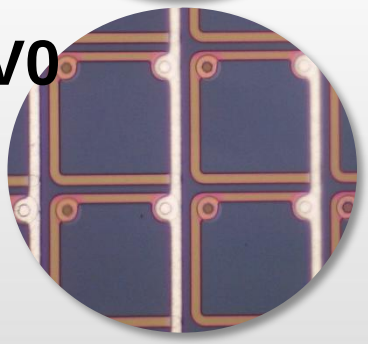
metal every column
relatively high R_Q

67x67um2 cell size, 3600 cells
Fill factor = 60%



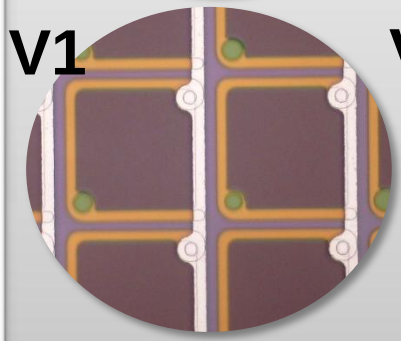
metal line every
second column

V0

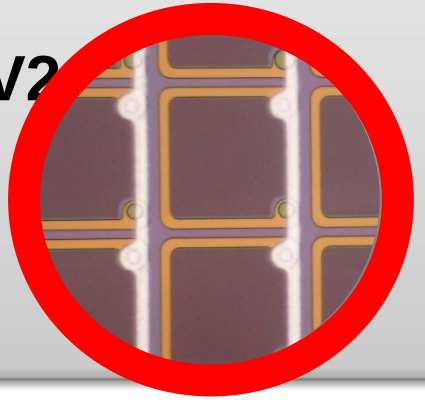


metal every column
different Rq and Cq

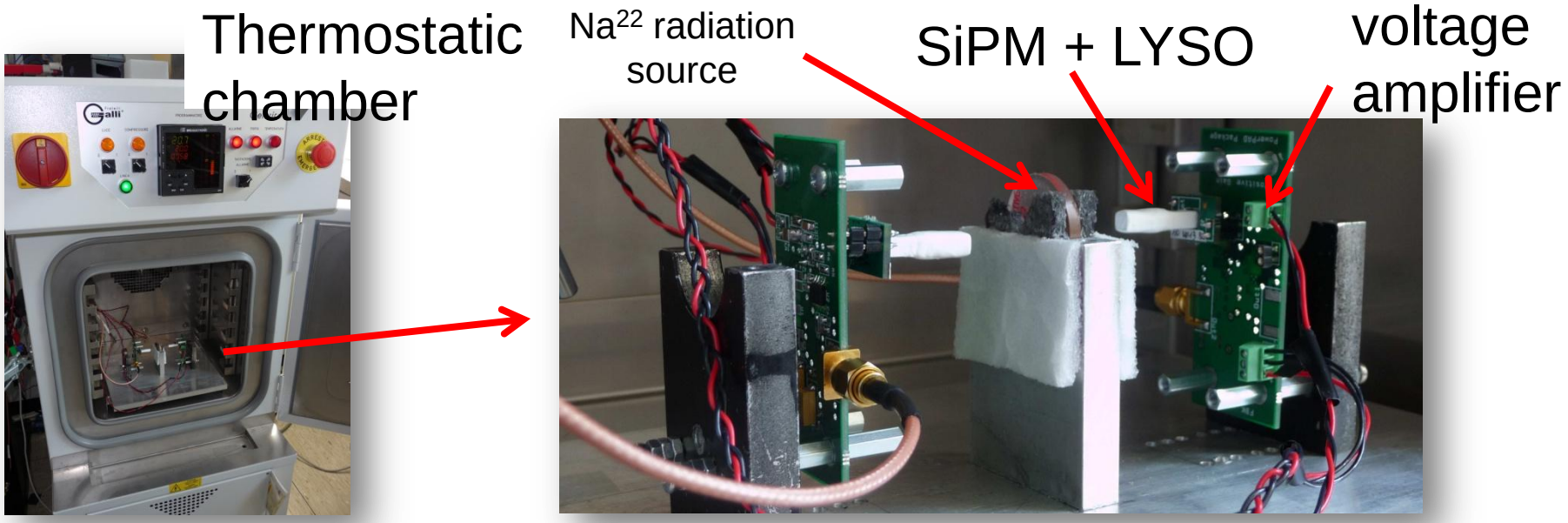
V1



V2

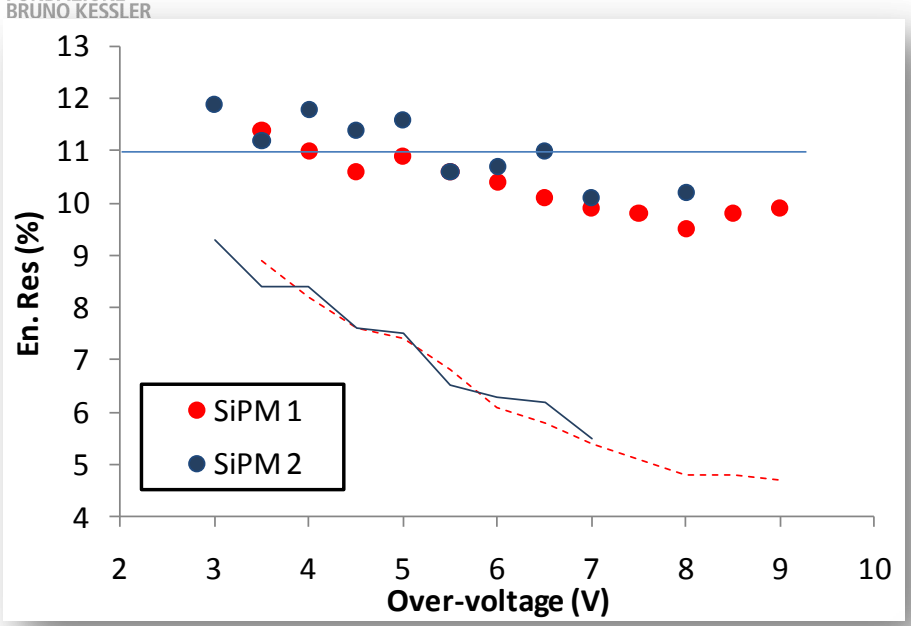


Experimental characterization



- **SiPMs**: 4x4mm^2, produced @ FBK, n-on-p technology
- **LYSO crystals**: 3.8x3.8x22mm^3, teflon-wrapped slightly smaller section than SiPM for easier alignment
- **voltage amplifiers**: R_{in}=20ohm; G=2.5

Best results:67x67v2

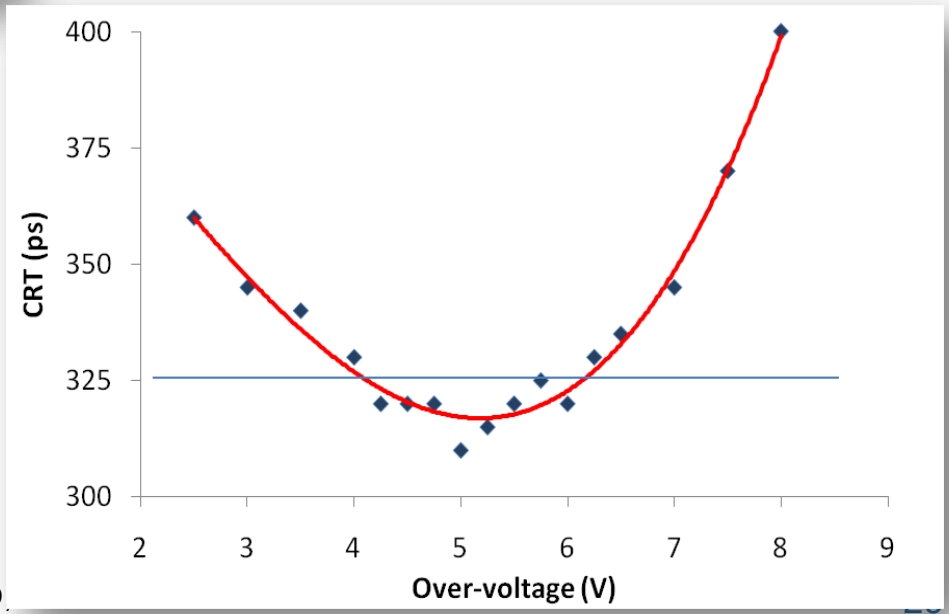


dE/E<11% @ 5-9V

compared to 14% of worse design

CRT<325ps @ 4-6V

compared to 460ps of worse design



Device optimization: technology

We are working on several aspects:

- **PDE improvement**: increasing the triggering probability

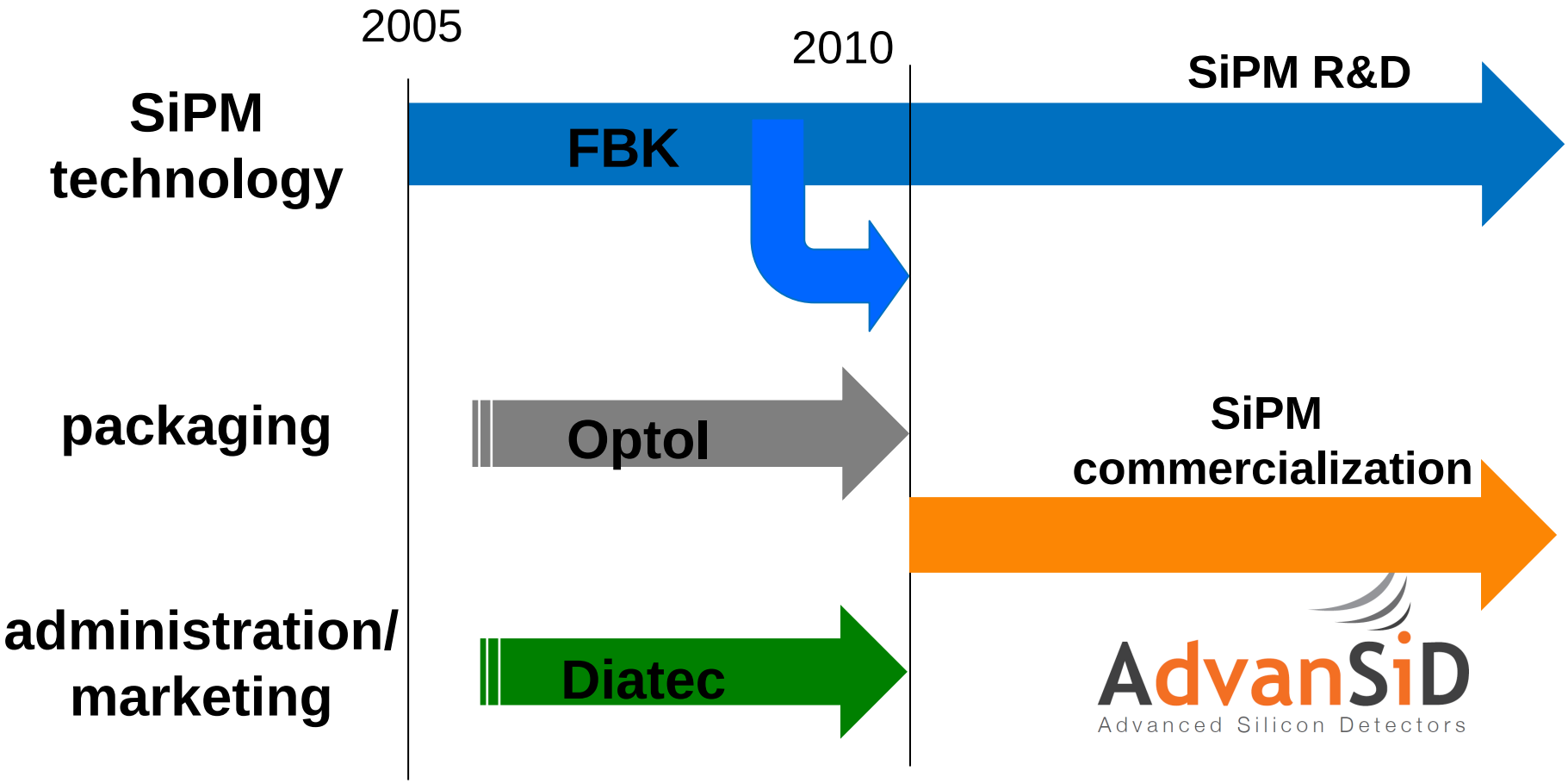
- **uniformity and stability** of operating conditions

- **new interconnection** with TSV

We have interesting preliminary results on all aspects which hopefully could be soon presented

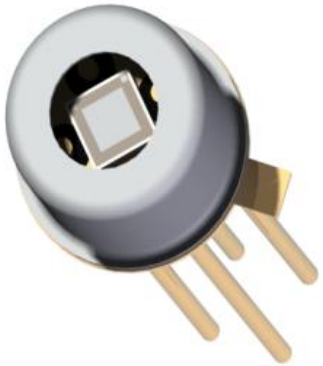

AdvanSiD
Advanced Silicon Detectors

AdvanSiD: genesis

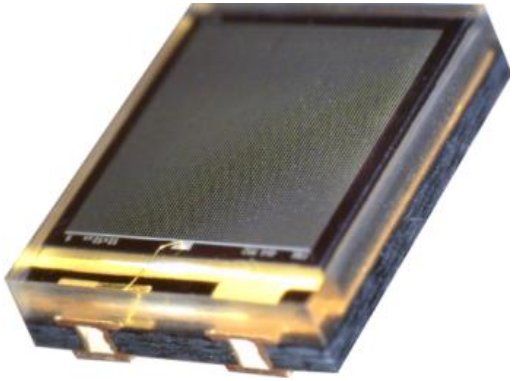


Standard products

1x1, 3x3, 4x4 mm² SiPM size



Metal Can Package

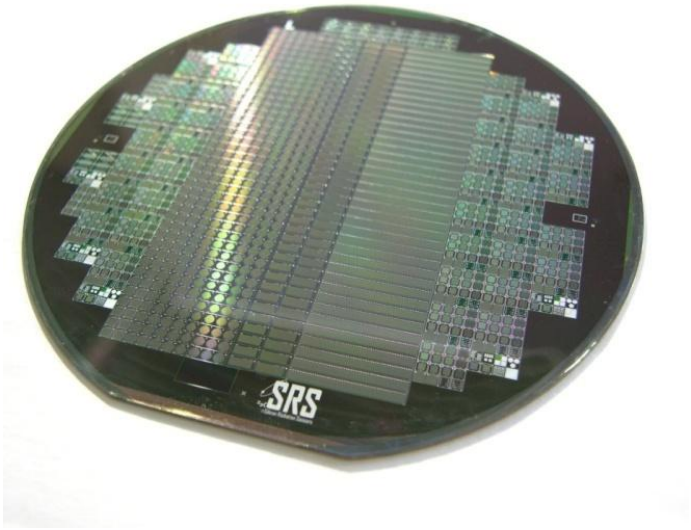


Chip Scale Package

More standard products will be soon available:
- circular 1.2mm diameter
- evaluation sipm tile: 4x4 elements of 4x4mm2 SiPMs

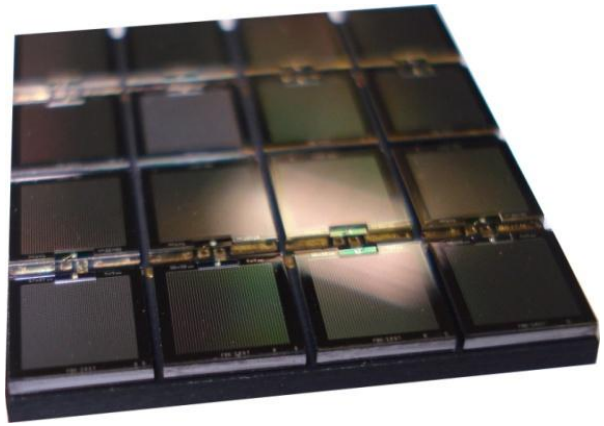
Custom products

Custom chip design



Capability of reducing development costs by organizing multi-project runs

Custom package design



Modular complex sensors in plastic or alumina packages

Acknowledgment

FBK SRS group:

Gabriele Giacomini
Alberto Gola
Elisabetta Mazzucca
Tiziana Pro
Alessandro Piazza
Nicola Serra
Alessandro Tarolli
Nicola Zorzi

AdvanSiD team!!

HyperImage

DaSiPM & MEMS projects