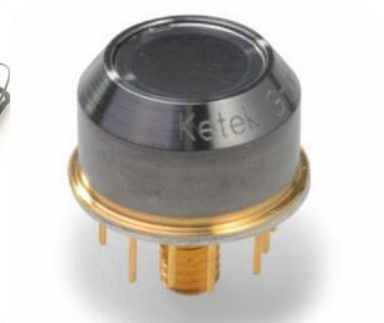
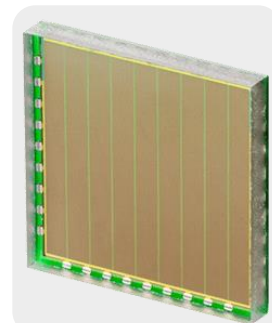


# **KETEK**

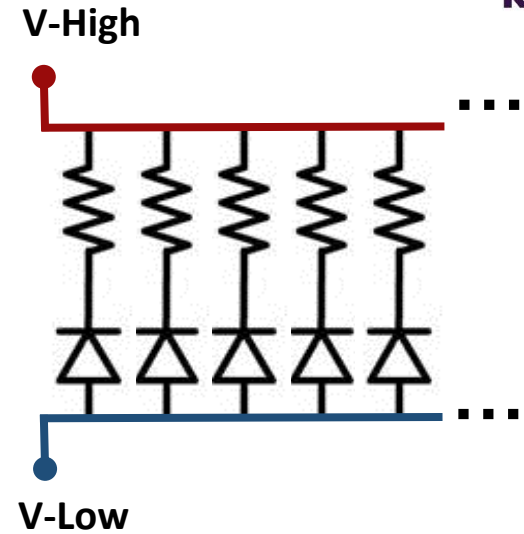
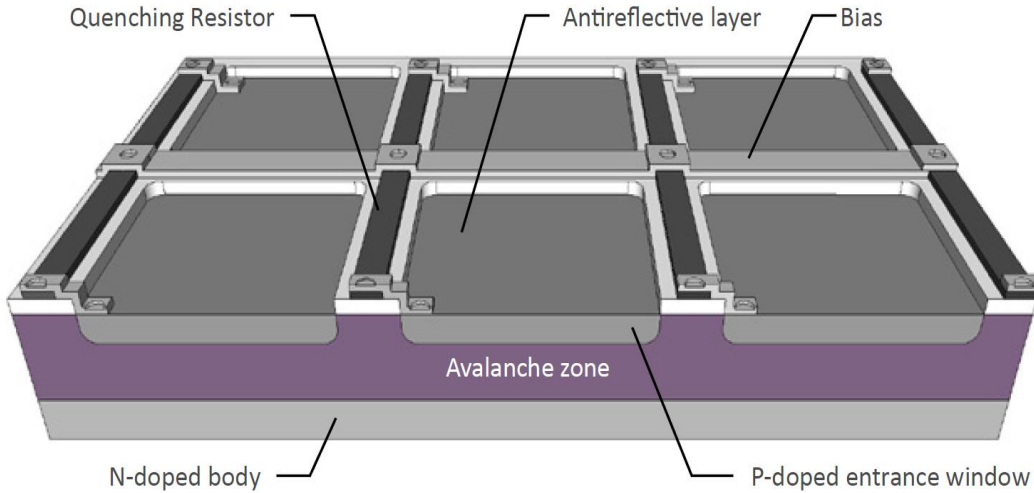
## **Latest Developments in KETEK's Silicon Photomultiplier Solutions**

Tobias Eggert, Wolfgang Gebauer, Florian Wiest

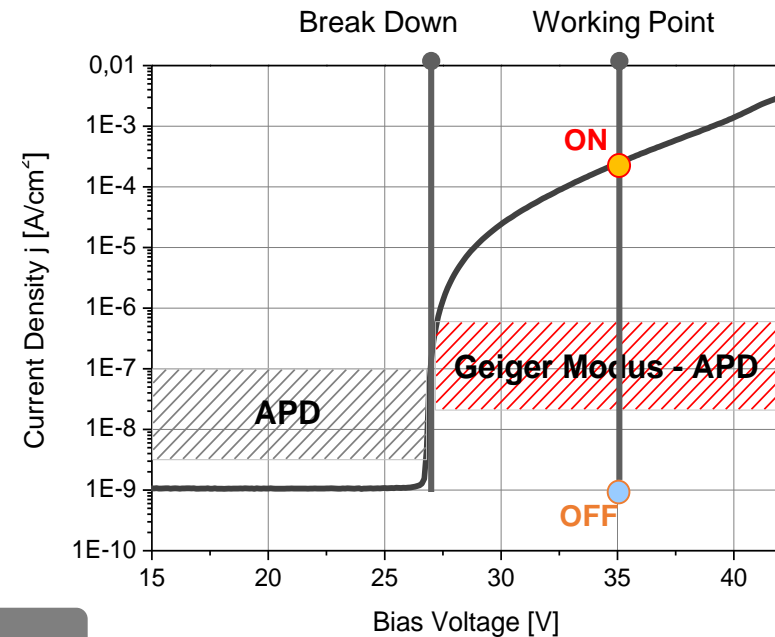
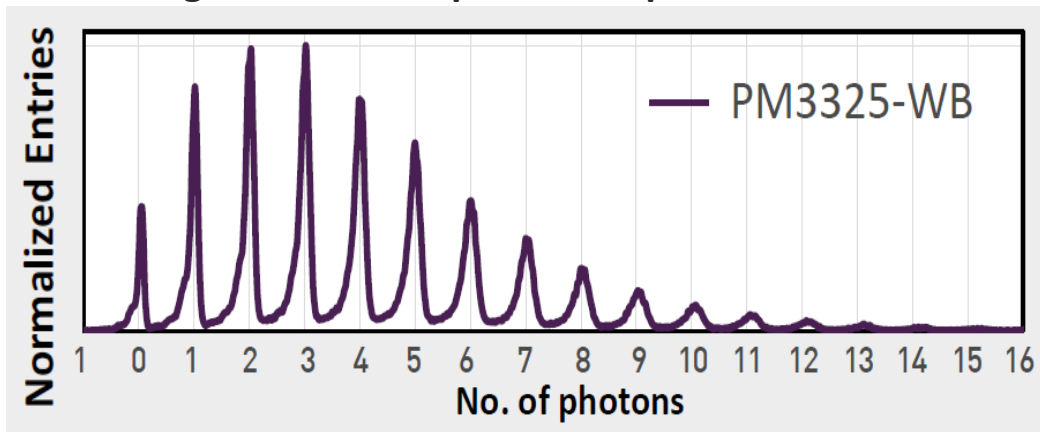


- Family-owned enterprise, founded in 1989 by Dr. Josef Kemmer
- 100 employees. Headquarter: Munich, Germany
- Major product lines:
  - SDD modules, detector electronics and complete systems
  - **Silicon Photomultipliers (SiPM)**
- Quality Management certified according to ISO 9001:2015

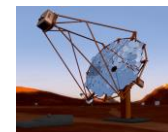
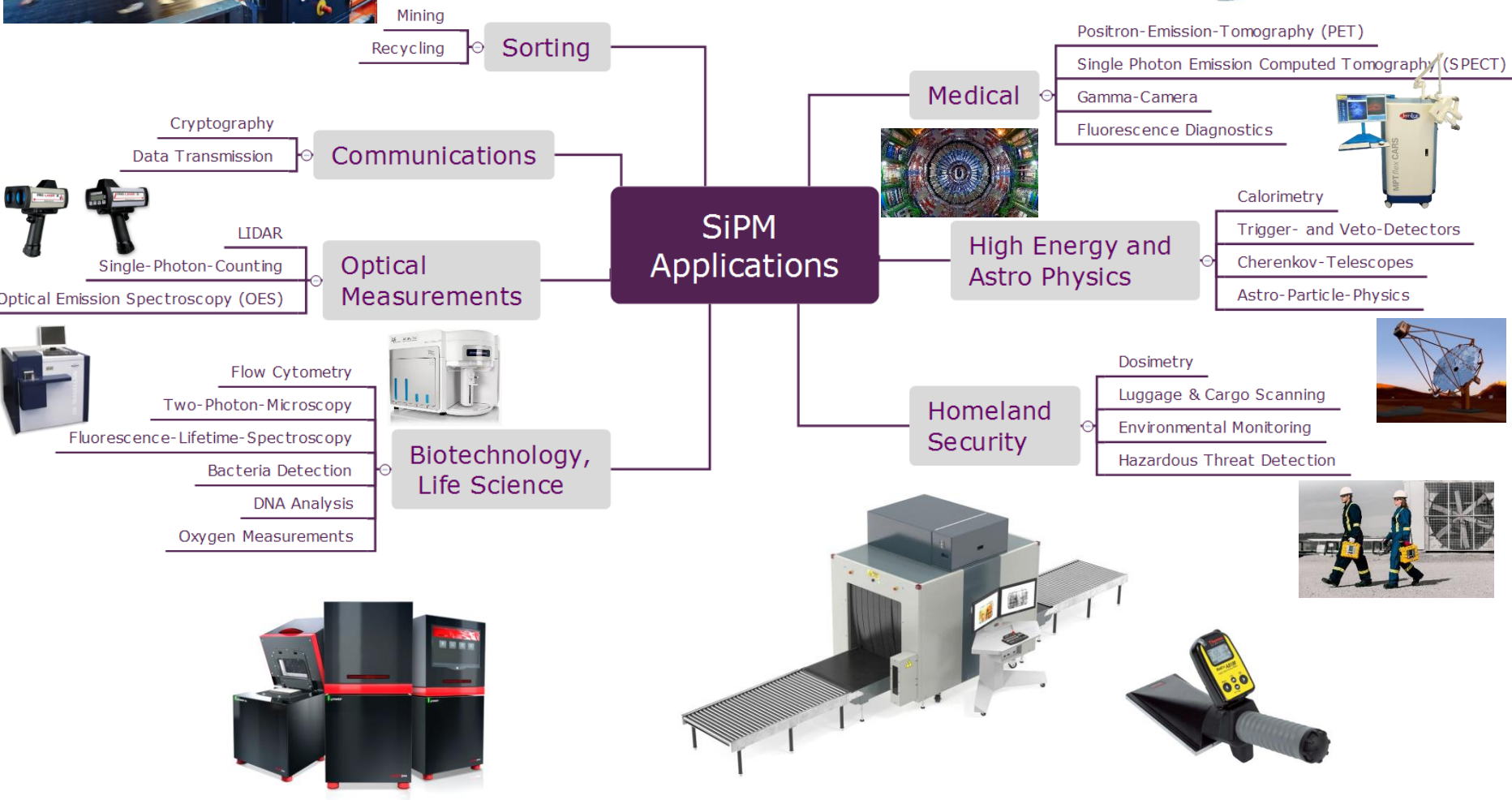
# SiPM Working Principle

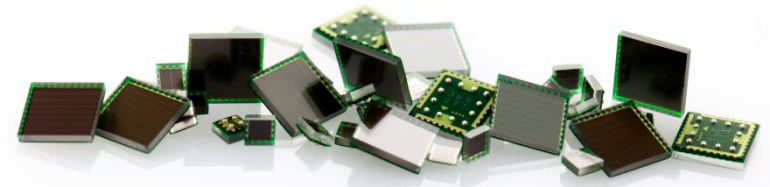
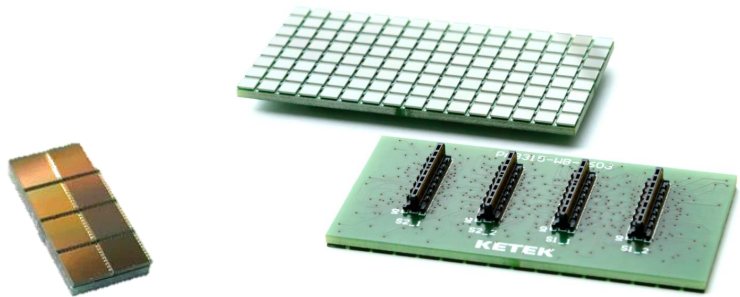


## Histogram of the response to a pulsed laser source



# SiPM Applications





SiPM Arrays  
Module

Customized  
Products

SiPM  
Products

Single Channel  
SiPM

PM1125-WB  
PM3315/25-WB

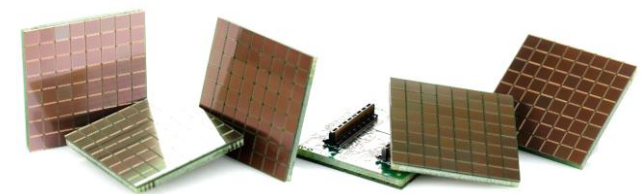


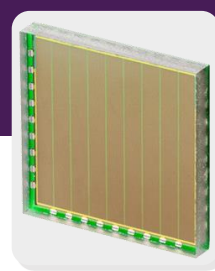
SiPM with cooling in TO8  
TIA-Modul

Integrated  
Modules

Multi Channel  
SiPM Arrays

PA3325-WB-0808  
PA3325-WB-0404  
PA1125-WB-0808



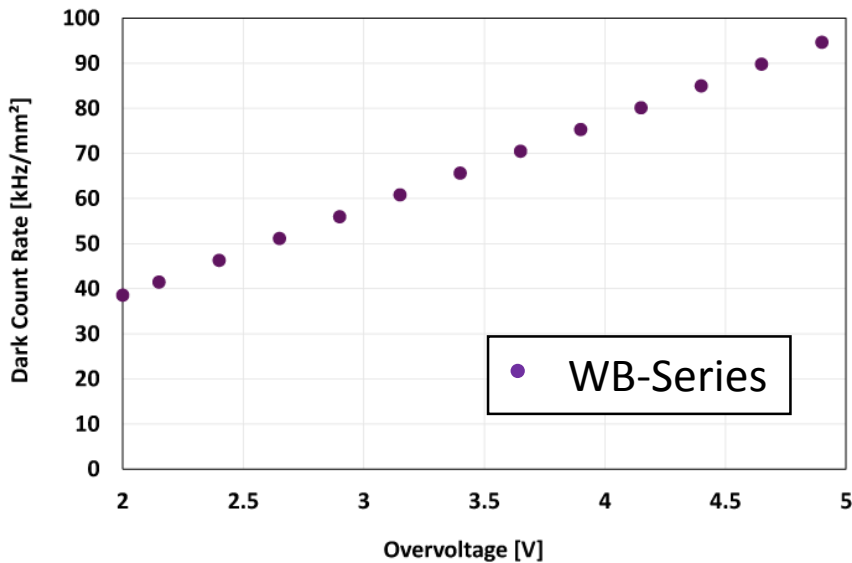
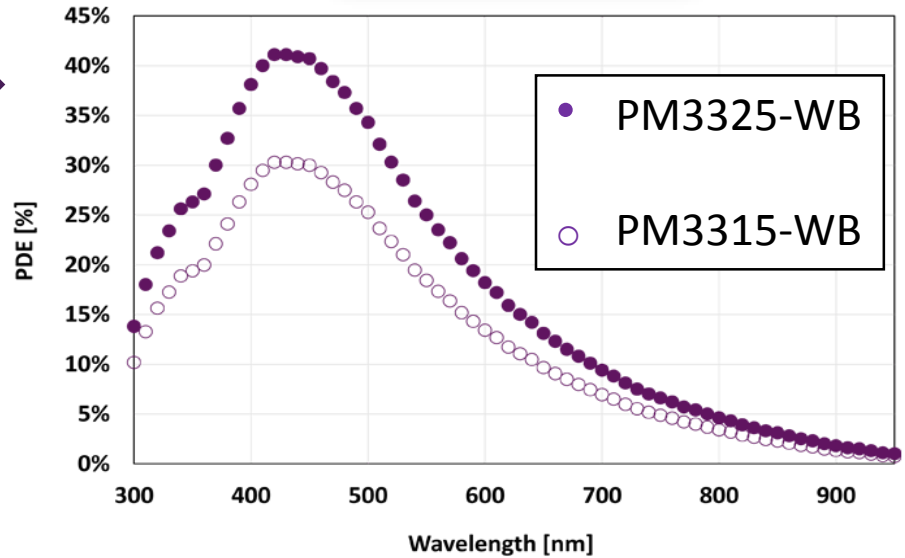


PM3325:  
43 % @ 430 nm

Photo detection efficiency of the WB Series SiPMs versus photon wavelength. The peak PDE is at ca. 430 nm. **Excellent PDE to cell size ratio.**

$$PDE(\lambda, V) = QE(\lambda) \cdot \varepsilon(V) \cdot GE$$

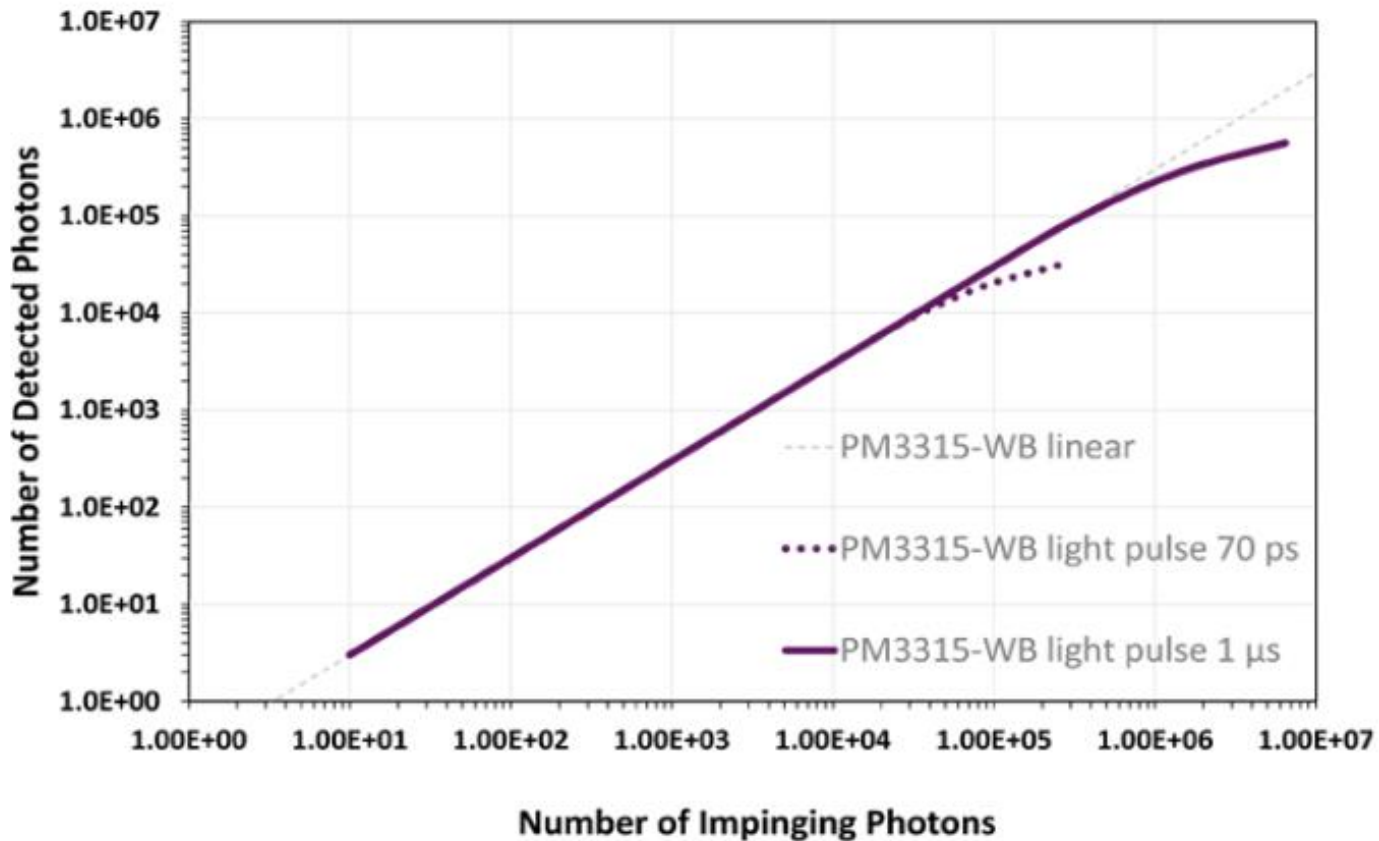
<i>QE</i>	<i>Quantum Efficiency</i>
$\varepsilon$	<i>Geiger/Breakdown Efficiency</i>
<i>GE</i>	<i>Geometrical Efficiency (active area)</i>
$\lambda$	<i>Wavelength</i>
<i>V</i>	<i>Bias</i>



Typical Dark Count Rate (DCR) of the WB Series versus overvoltage.

**DCR greatly improved**

- Dark pulses = pulses not being excited by incoming light
- Dark pulses are triggered by thermally generated electrons

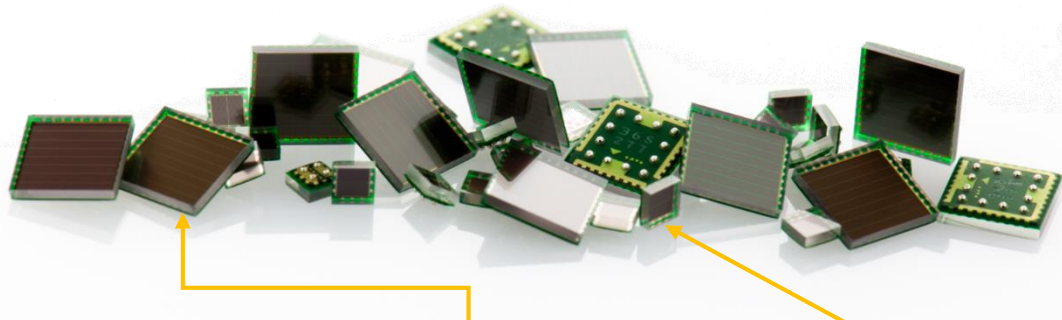


- The dynamic range is limited by the recovery time and the number of micropixels

- PM3315-WB Recovery Time: 13ns  
Number of pixels: 39k

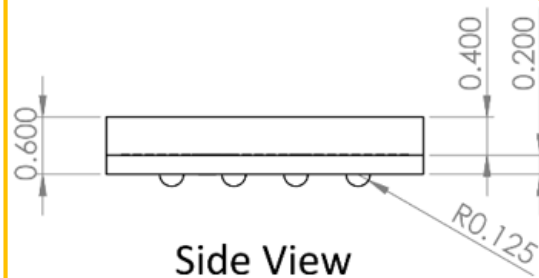
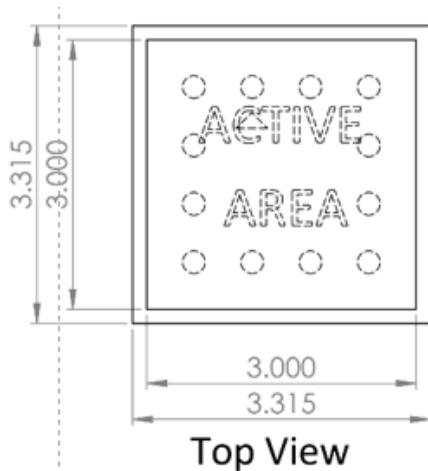
$$N_{Pixel-fired} = N_{Cell} \cdot \left(1 - e^{-\frac{PDE \cdot N_{ph}}{N_{Cell}}}\right)$$

$N_{Pixel-fired}$	Number of fired Cells
$N_{Cell}$	Total Number of Cells
$PDE$	Photon Detection Area
$N_{ph}$	Number of incident Photons



## Wafer Level Package

- Cost efficient
- High volume production
- Robust and reliable
- Insensitive to high magnetic fields



## PM11

- 1x1 mm<sup>2</sup> active area
- 1.315 x 1.315mm<sup>2</sup> lateral size
- Ideal for high resolution arrays

## PM33

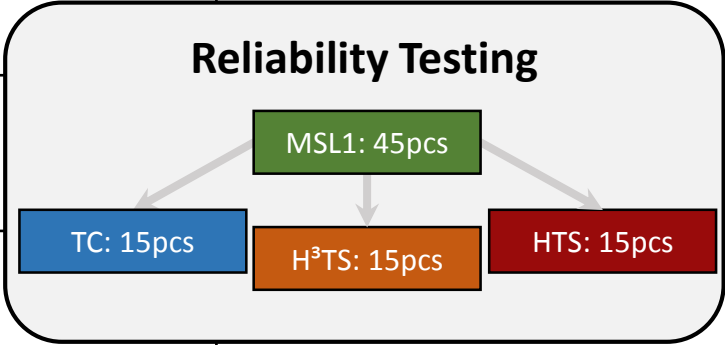
- High shearing forces (~30N/device)
- Excellent package fill factor



Tape and Reel Delivery



Test	JEDEC Test Method	Test Conditions
PC	Pre-conditioning / MSL classification according to J-STD-020	<b>MSL1:</b> Moisture Sensitivity Level 1 <ul style="list-style-type: none"> <li>Temp.-Cycle: 5 x -40°C / +60°C</li> <li>Bake: 24h at 125°C</li> <li>Soak: 168h at 85°C / 85% R.H.</li> <li>Reflow: 3 x Peak 255°C – 260°C</li> </ul>
TC	Temperature Cycling according to JESD22-A104	1000 cycles @ -55°C/125°C without bias
H <sup>3</sup> TS	High Humidity High Temperature Storage according to JESD22-A101	1000h @ 85°C/85% RH without bias
HTS	High Temperature Storage according to JESD22-A103	1000h @ 125°C without bias



- 45 devices of each batch are picked for reliability testing
- 10 devices for ESD test (3kV HBM)
- Additional reliability tests with applied bias voltage have been successfully completed (HTRB + H<sup>3</sup>TRB)

**Moisture sensitivity level**  
 J-STD-020: Components must be mounted and reflowed within

- MSL 3 – 168 hours
- MSL 2 – 1 year
- MSL 1 – Unlimited

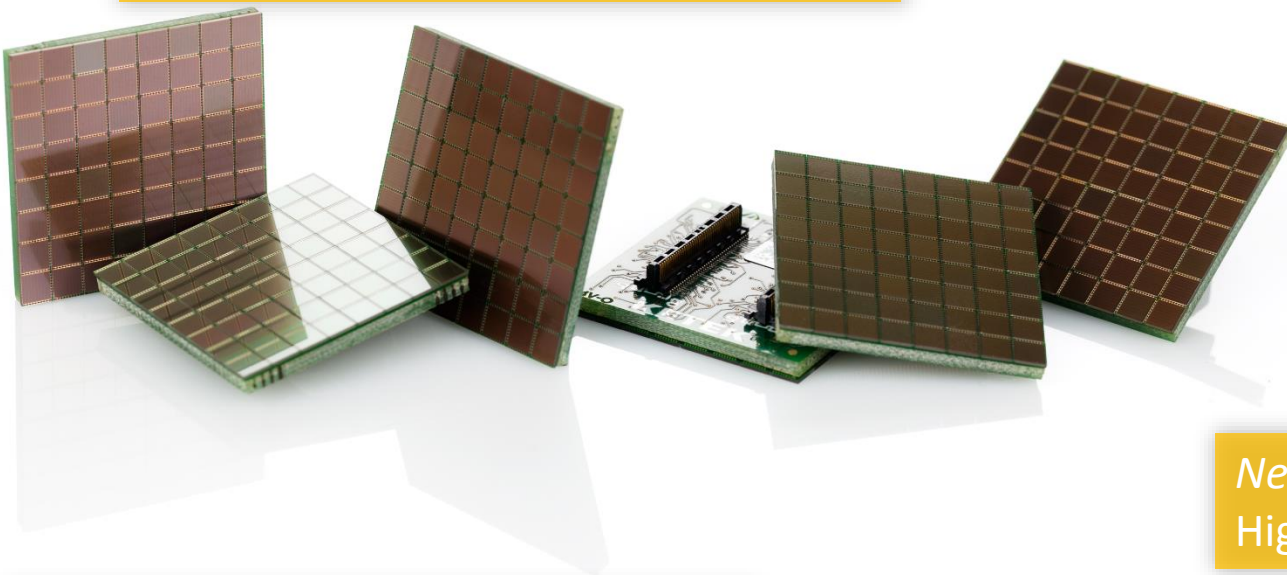
“floor life out of the bag”

# SiPM Arrays off the shelf



PA33xx-WB-0808

64 channel array with 80% fill factor

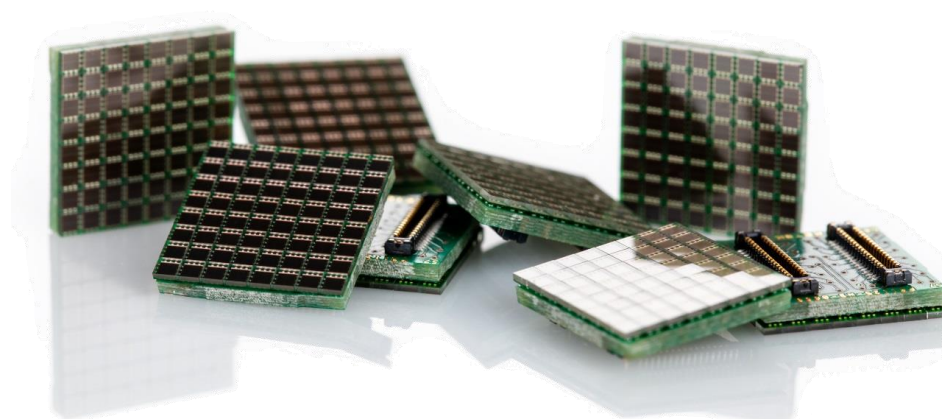
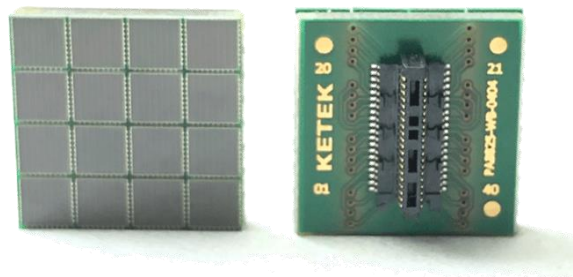


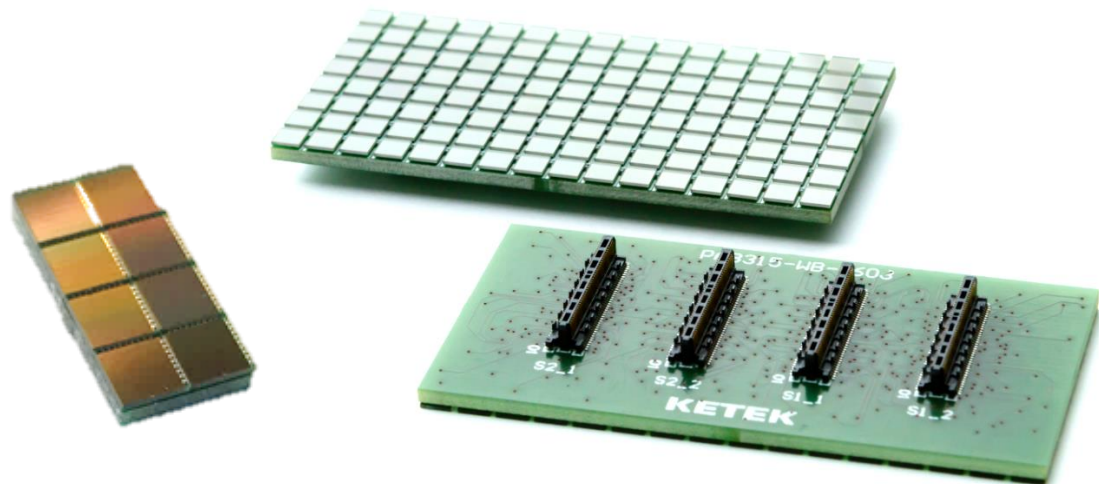
New PA1125-WB-0808

High resolution SiPM array

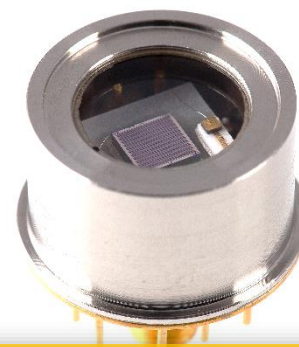
PA3325-WB-0404

16 channel array with 80% fill factor

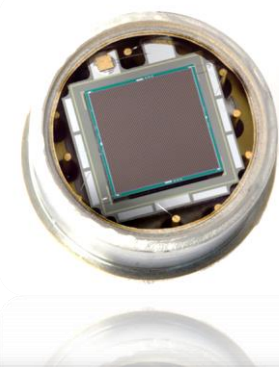




Custom arrays based on SiPM WB series

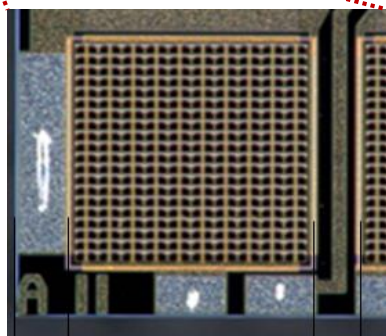
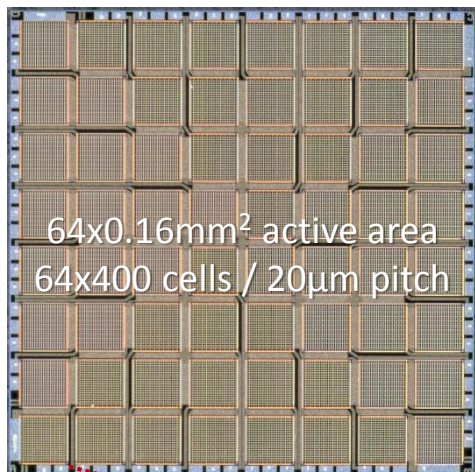


SiPM module with integrated cooling in TO8 housing

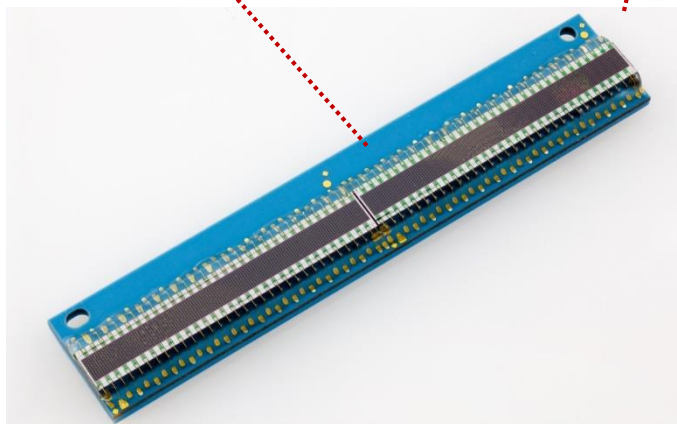
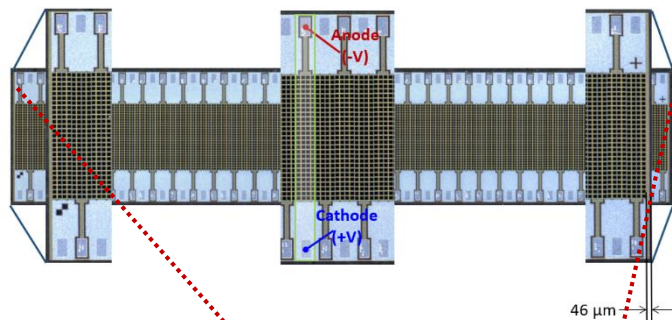


4x PM3325-WB on evaluation PCB for optical bench applications

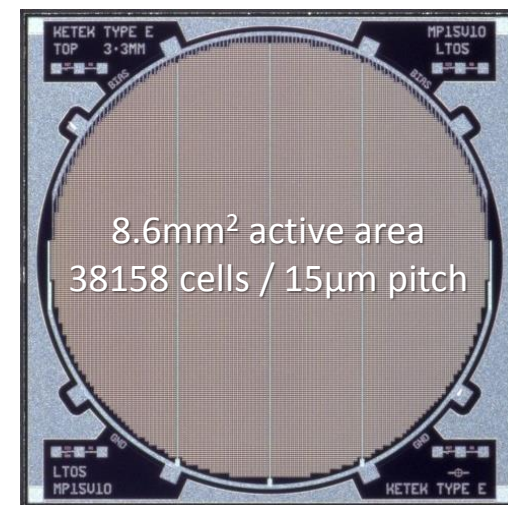
## Monolithic 64-channel-array for the University of Tokyo



## Linear 64-channel SiPM chip for CERN LHCb experiment



## Round-shaped high dynamic range SiPM for CERN CMS

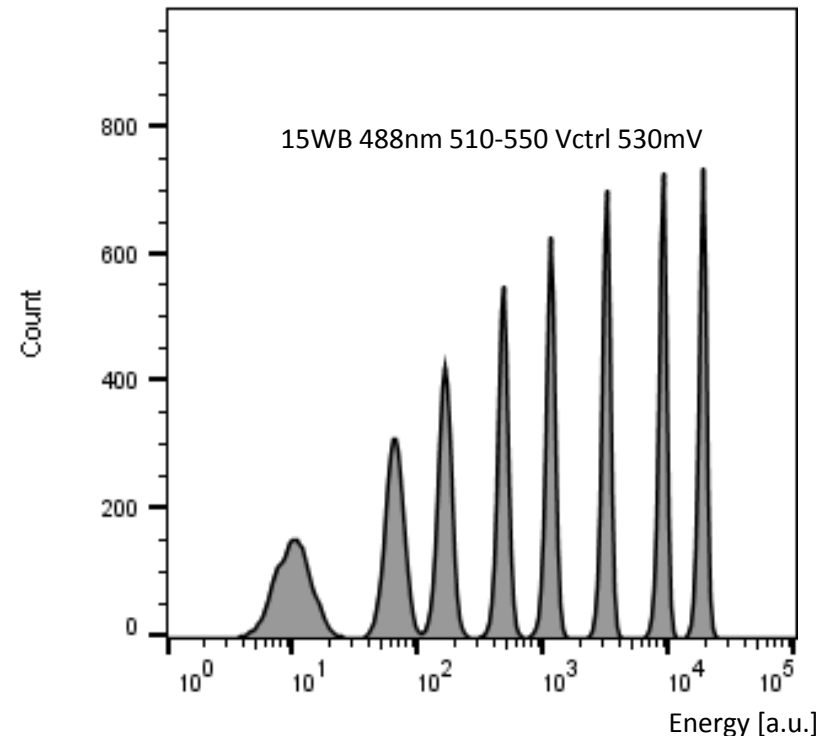


## SiPM Module successfully tested and evaluated at MoFlo (Beckman Coulter cell sorter)



- PM3315-WB SiPM based
- Integrated Transimpedance Amplifier (TIA)
- Plug and Play Solution for Cytometry
- Control Input for SiPM Bias Voltage

- Compatible with Thorlabs® SM05 Optics and Hamamatsu® PMT mounts
- TIA Module output signal directly can be fed into DAQ without further preprocessing
- Highly cost effective solution compared to PMT

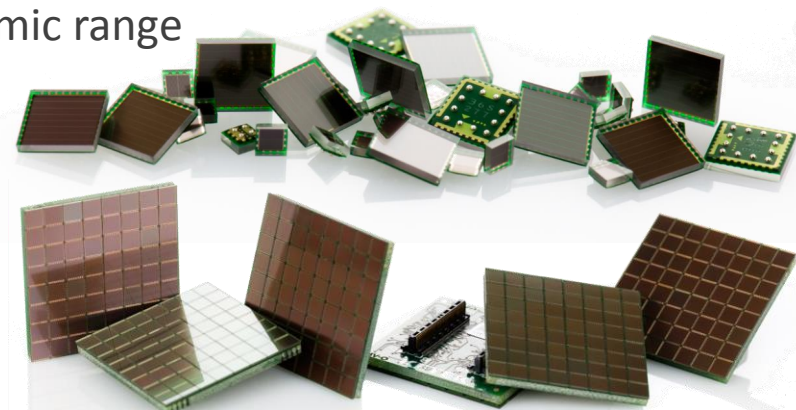


Data courtesy of Dr. Malte Paulsen (EMBL, Heidelberg)

# Conclusion



- KETEK SiPM combine high fill factor with large dynamic range
- Highly reliable and robust chip-size package
- Customized as well as off-the-shelf array solutions
- Customized electronics and cooled SiPM modules
- Flexible partner for industrial and scientific projects



## MEDICAL IMAGING

Looking inside the body for early detection and treatment of disease.

- POSITRON EMISSION TOMOGRAPHY (PET)
- GAMMA CAMERA
- COMPTON CAMERA
- INTRAOPERATIVE PROBES
- SINGLE PHOTON EMISSION TOMOGRAPHY (SPECT)
- OPTICAL TOMOGRAPHY



## LIDAR & 3D-RANGING

Ultra-fast light detection down to single photon level.

- DRONES
- AUTONOMOUS VEHICLES
- CARTOGRAPHY
- ROBOTICS



## HAZARD & THREAT DETECTION

Excellent energy resolution for rapid isotope identification.

- X-RAY SCANNING
- AREA MONITORS
- ISOTOPE IDENTIFIERS
- RADIATION SPECTROSCOPY
- DOSE METERS
- SPECTROSCOPIC PERSONAL RADIATION DETECTORS (SPRD)
- NEUTRON DETECTION



## BIO-PHOTONICS

Excellent properties for highest measurement accuracy in the laboratory or at the point-of-care.

- CYTOMETRY
- TWO-PHOTON EXCITATION MICROSCOPY
- FLUORESCENCE ANALYSIS
- FLUORESCENCE LIFETIME MICROSCOPY
- SPECTROSCOPY



## SORTING & RECYCLING

Fast and energy resoluvent detectors for high throughput sorting facilities.

- CARGO SCANNING
- SORTING & RECYCLING
- MINING
- BORDER CONTROL



## HIGH ENERGY PHYSICS

Understanding how our universe works at its most fundamental level.

- CALORIMETERS
- TRIGGER DETECTORS
- CHERENKOV TELESCOPES
- NEUTRON DETECTION

# CREATIVE DETECTOR SOLUTIONS



**30**  
**YEARS**  
1989 - 2019  
**THANK**  
**YOU**

## **SDD**

**THE GOLD STANDARD IN  
SILICON DRIFT DETECTORS**

## **SiPM**

**SILICON PHOTOMULTIPLIERS  
NEXT GENERATION VERSATILITY**

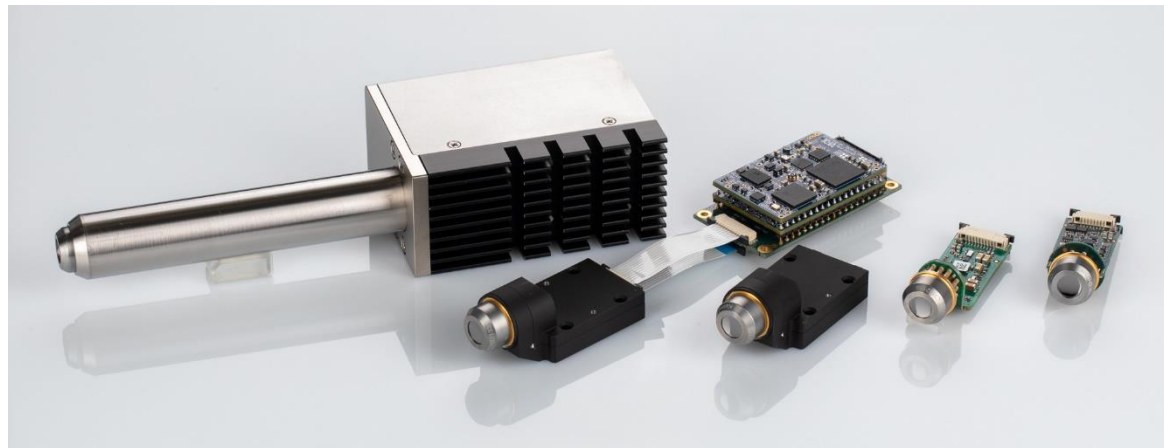
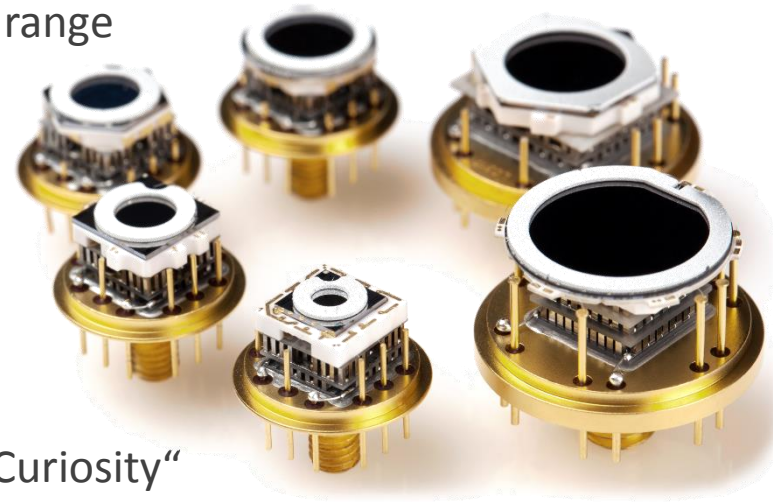
# Backup



# Silicon drift detectors for X-Rays



- KETEK's VITUS Silicon Drift Detectors (SDD) are the state-of-the-art X-ray detectors for 0.05 keV - 50 keV energy range
- Applications such as EDS, XRF,  $\mu$ XRF and TXRF
- Patented graphene window
- Tailored electronics solutions for unprecedented performance
- Modern production facilities in Munich
- VITUS SDD on Mars rovers „Spirit“, „Opportunity“, „Curiosity“ and on NASA/JPL PIXL experiment for „Mars 2020“ rover



- Quality in focus: First Certification of ISO 9001:2000 in March 2008
- First Certification according ISO 9001:2015 in April 2017
- Successful Re-Certification according ISO 9001:2015 in March 2018
- Quality Policy



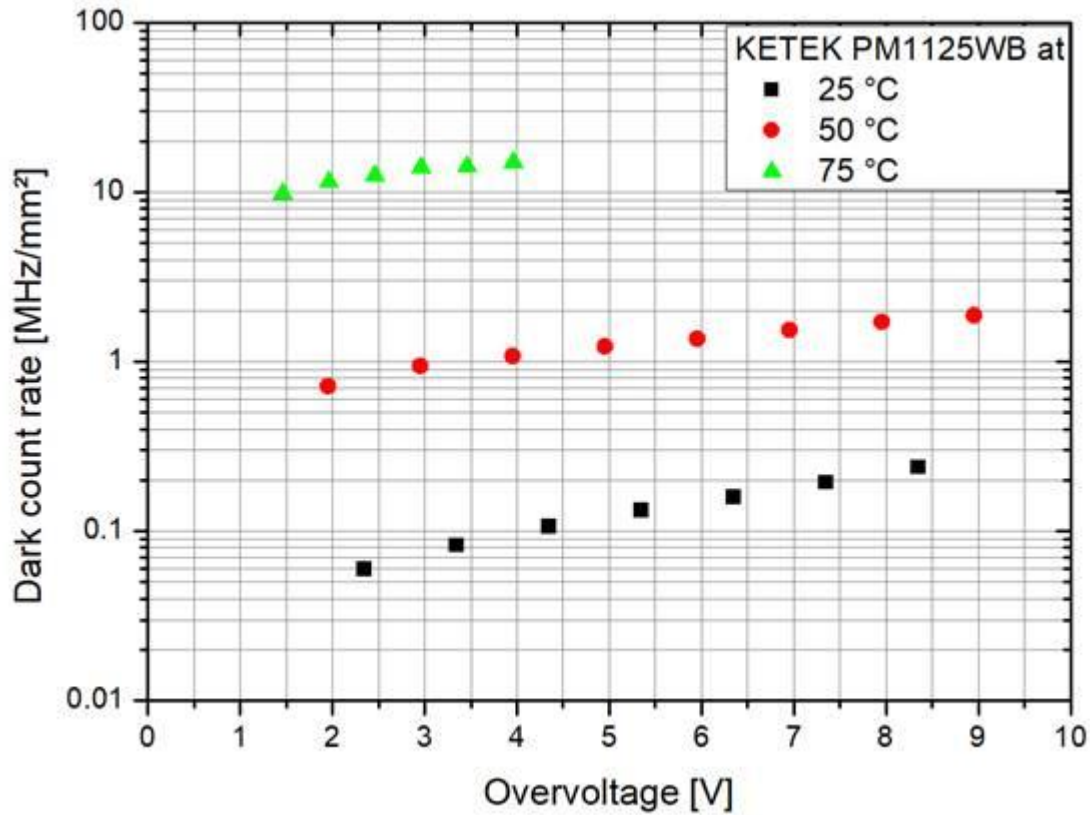
Quality is the basis of all activities at KETEK, and every employee contributes significantly to quality.

It is our ultimate goal to gain and maintain satisfied and convinced customers. This is achieved through in-time and precise products and services and by competent and friendly cooperation with our customer's staff. These goals require commitment, expertise, and **personal responsibility of all employees**.

The production of the detector and electronics systems is monitored by methods of statistical process control and optimized for quality and cost. Highest yield, on-time delivery, and a zero-defect quality are the objectives of all processes, products, and services. Moreover, they are essential to ensure the company's future.

Close **cooperation with key customers** allows KETEK an on-time development and production of customized detector solutions with a high value creation. This leads to close customer loyalty and ensures the quality characteristics of KETEK's products and systems in the market.

**Full commitment to quality** during their work and active contribution to the continuous improvement to the quality of KETEK's products, processes, and services are expected from every employee in order to improve the quality continually.

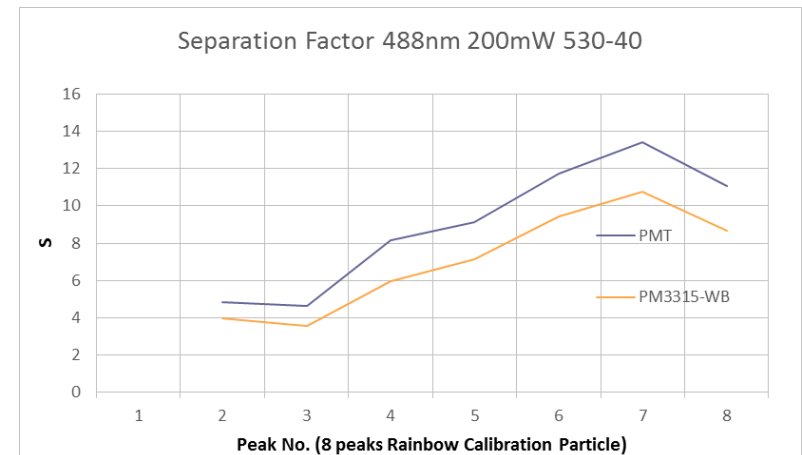
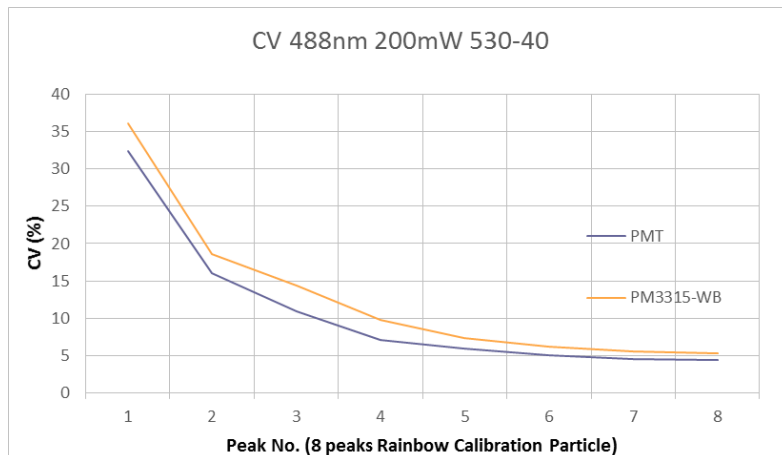
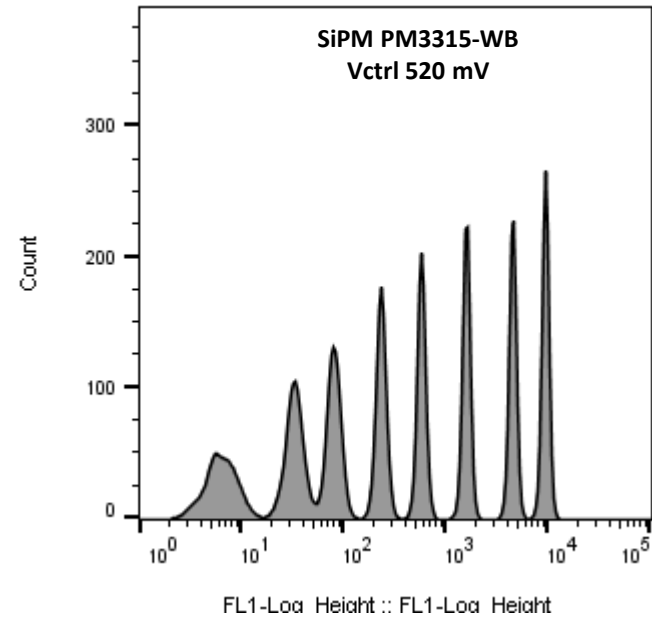
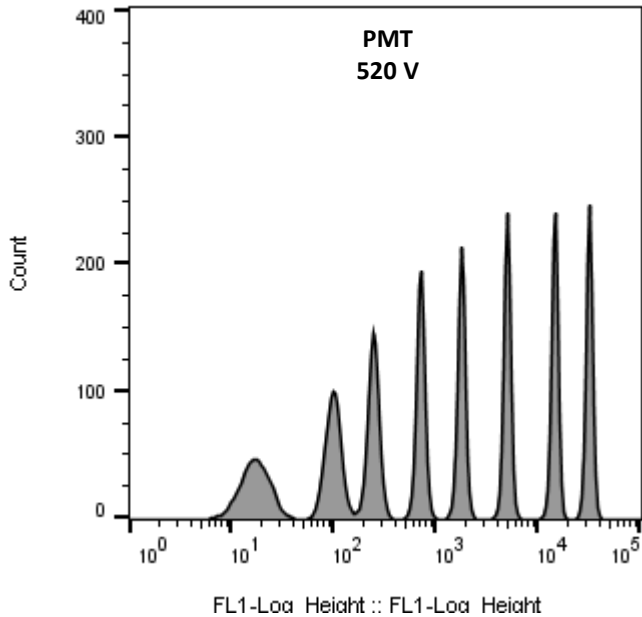


Typical Dark Count Rate (DCR)  
over Temperature  
**DCR greatly improved**

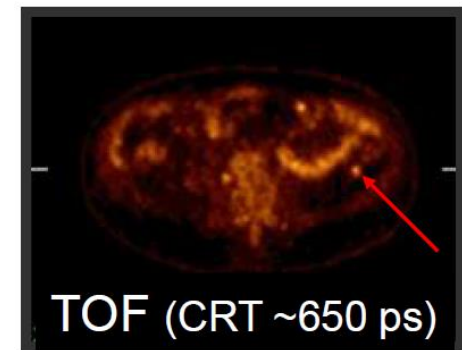
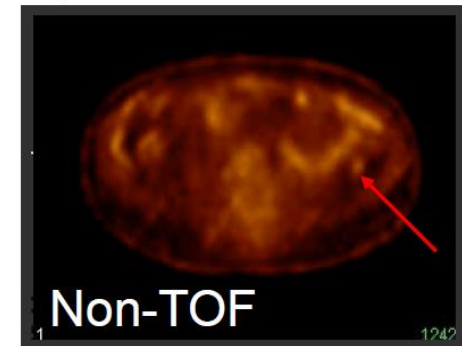
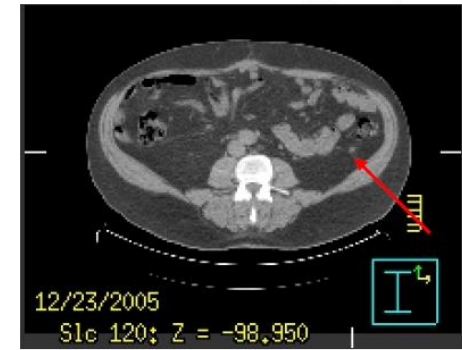
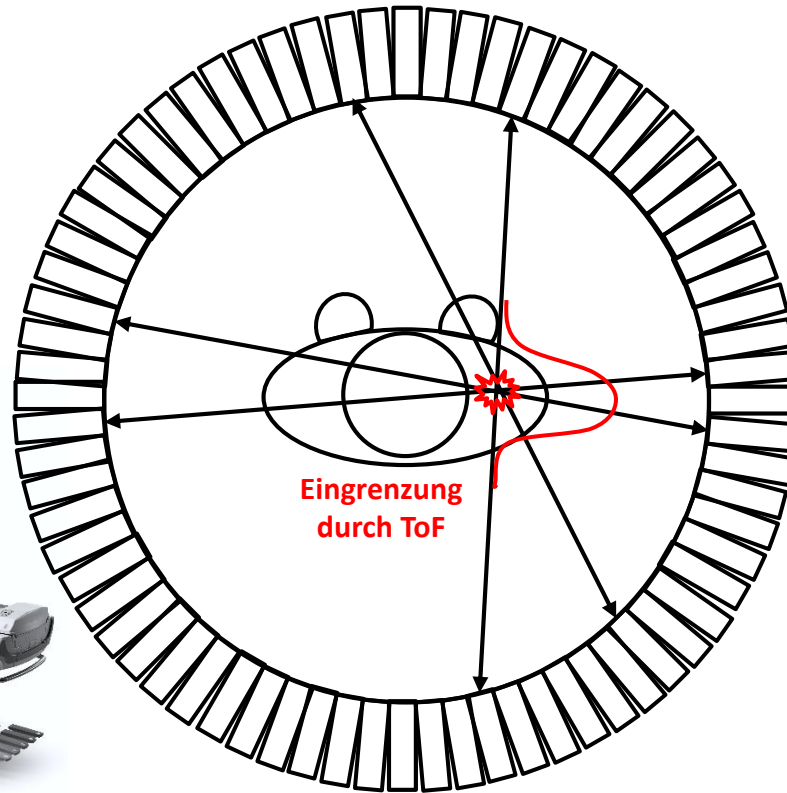


- Comparison of PMT vs. SiPM TIA Module – 8 peaks Rainbow Calibration Particle**

setup parameters: 488nm 200mW laser power 530-40

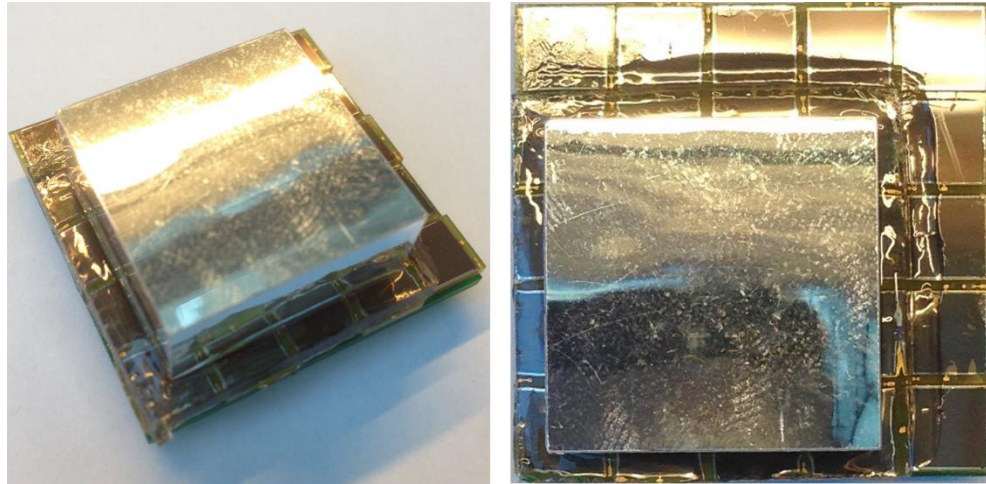


- **PET:** Medical Imaging for Cancer Diagnostics
- SiPM is the ideal detector
- Demand for high SiPM volumes

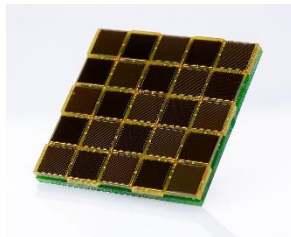


[1] J. Karp, University of Pennsylvania  
[2] gehealthcare.com

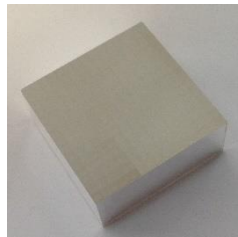
- 5 x 5 SiPM array with 25 pcs PM6660 (6 x 6 mm<sup>2</sup> active area, 60 μm cell size)
  - 15 x 15 LYSO crystal array, each crystal 1.5 x 1.5 x 10 mm<sup>3</sup>, pitch 1.55 mm, 3M ESR reflector, Saint Gobain BC 630 optical grease, light guide 2.7 mm



- Read out by Multichannel Readout System



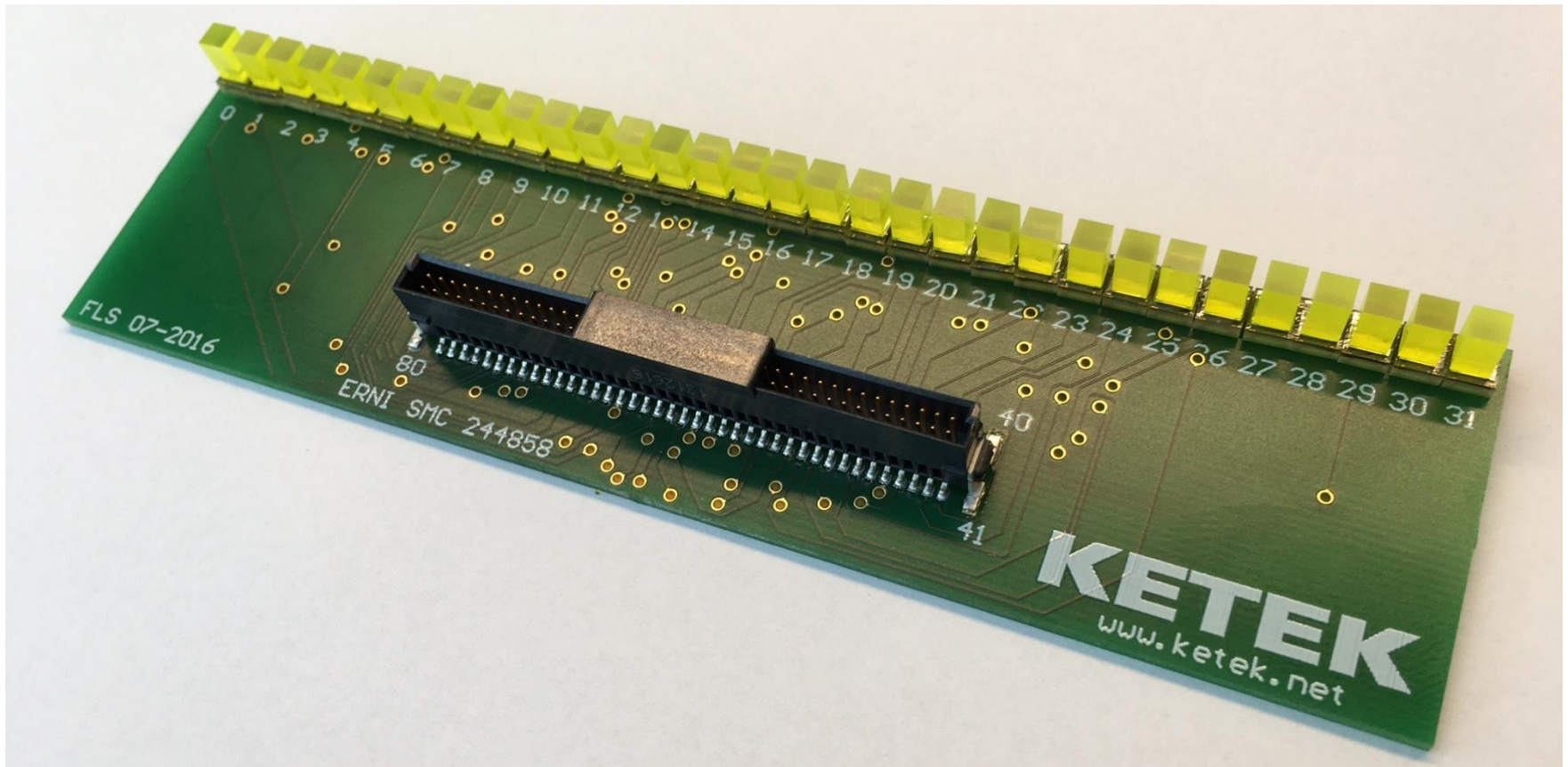
+



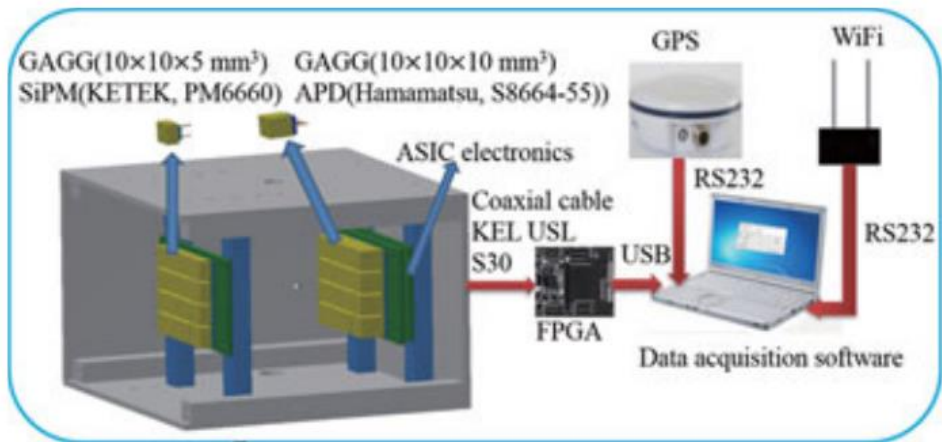
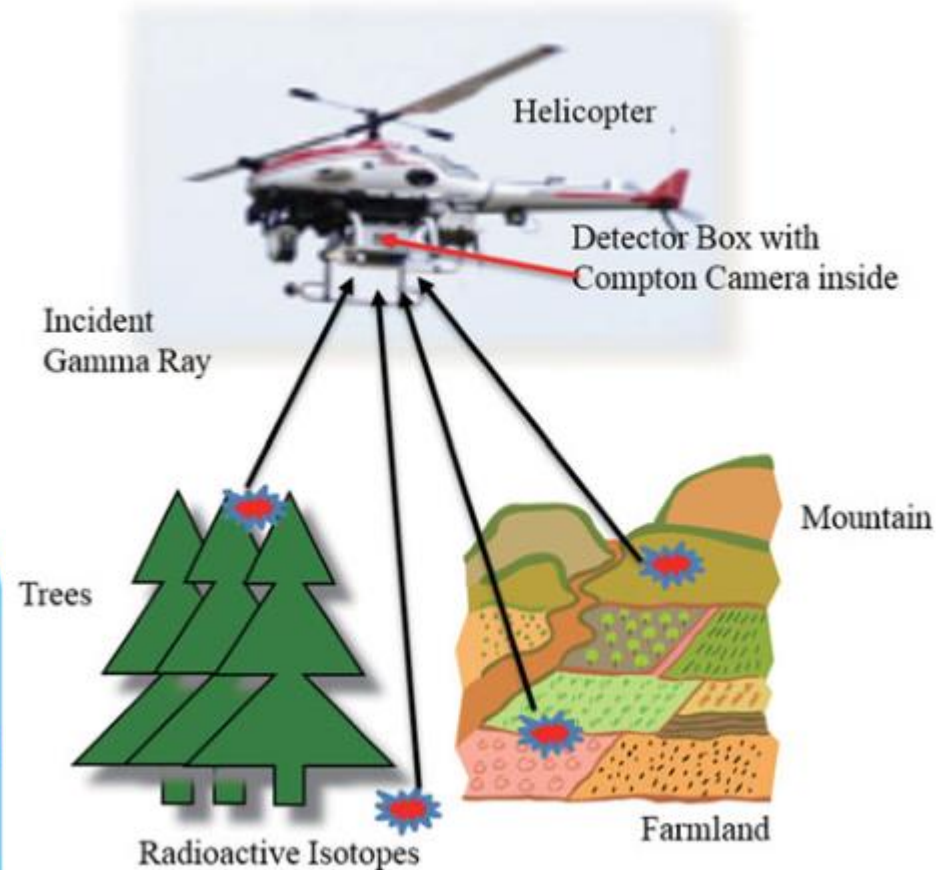
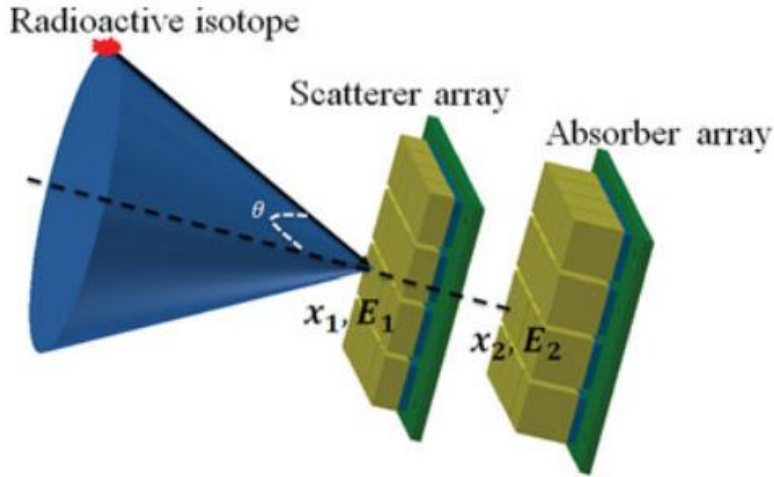
+



- Line Array Prototype with 32 PM3350 and GAGG scintillators
  - Read out by PETsys Electronics



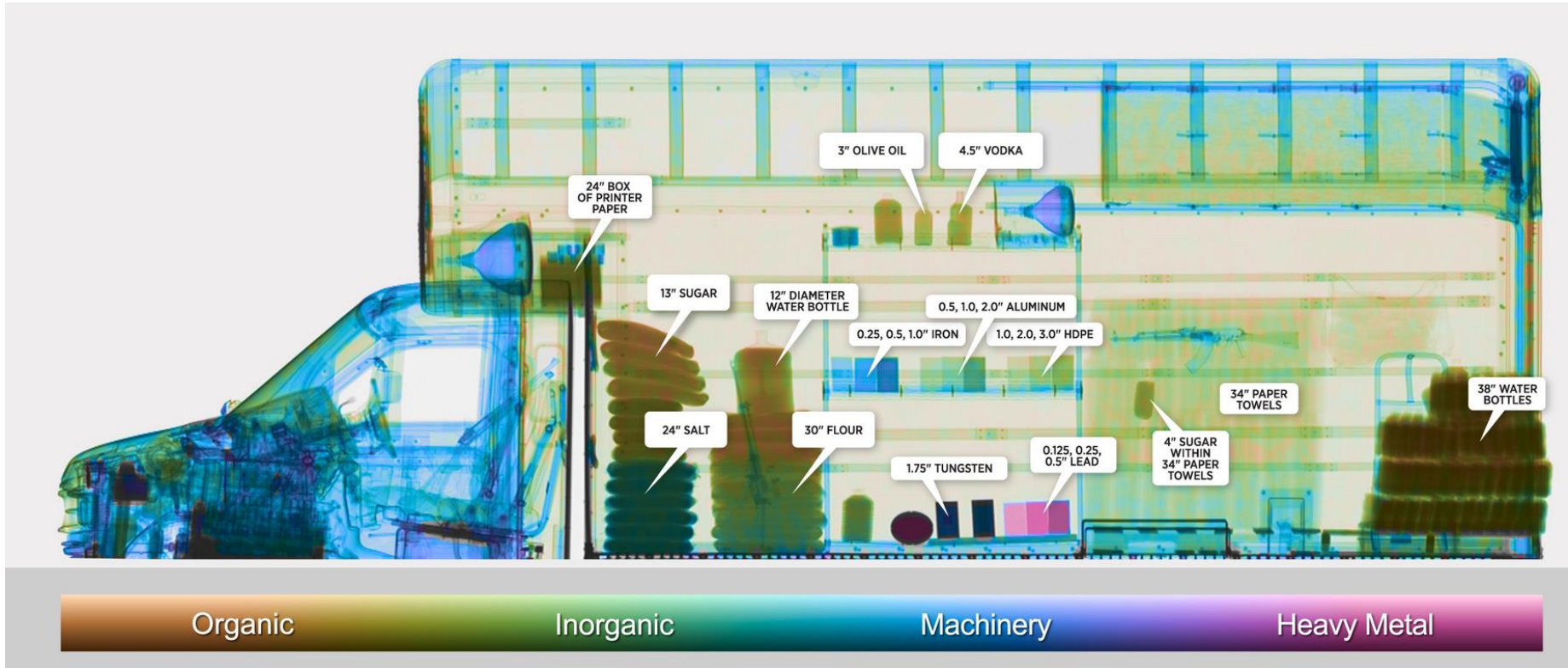
- Compton Camera with our SiPMs (PM66)
  - Radiation Monitoring and Surveillance



Kenji Shimazoe

<http://dx.doi.org/10.1080/00223131.2015.1089796>

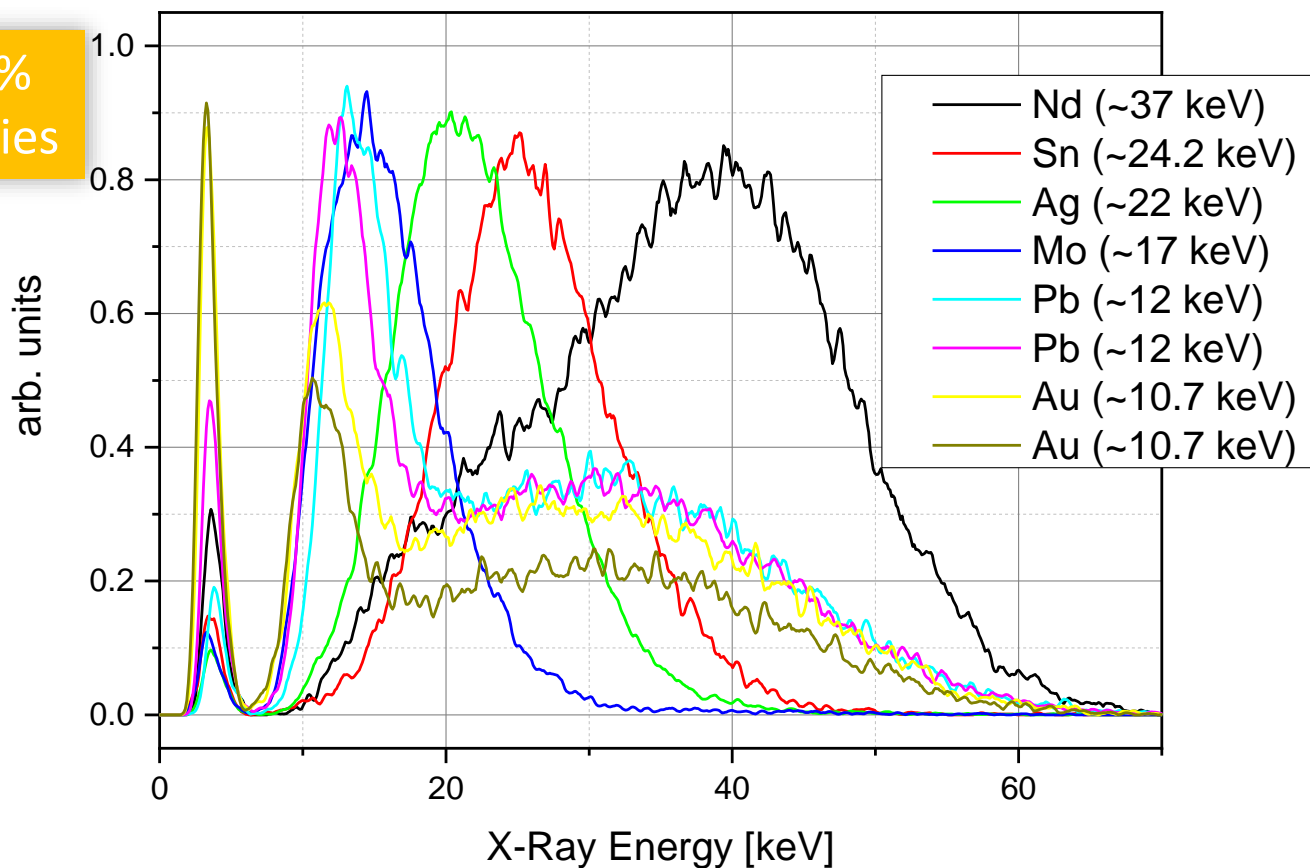




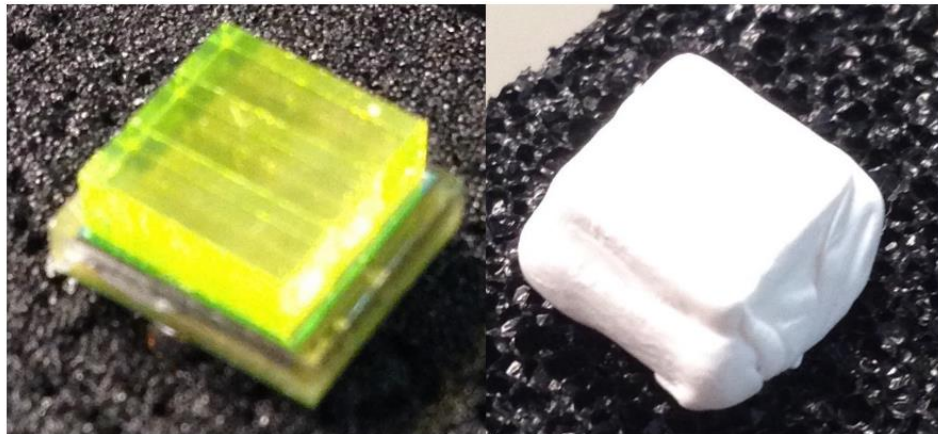
- PM1150-EB with 1.2x1.2x4 mm<sup>3</sup> LYSO
- 50 keV X-Ray Source
- No Pre-amplification
- Charge Integration at 50 Ohm with Oscilloscope

$\Delta E/E \sim 50-60\%$   
for all energies

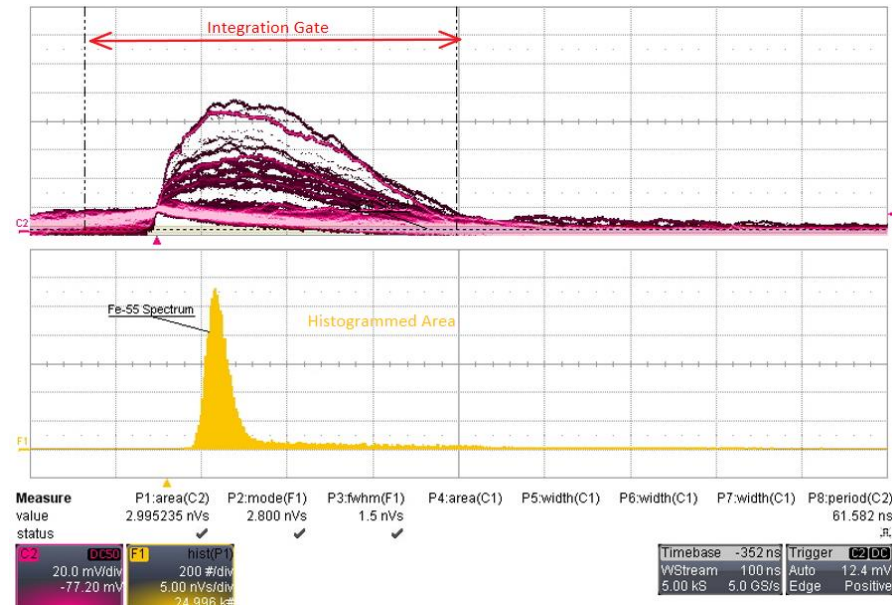
### X-Ray Spectroscopy with SiPM + LYSO



- **SiPM** in combination with a **scintillator** can be used for X-Ray counting
  - Limited energy resolution
  - Lower limit currently reached: 5.9 keV,  $dE/E = 50\%$  FWHM (3keV)
  - Energy range of detection complimentary to SDD

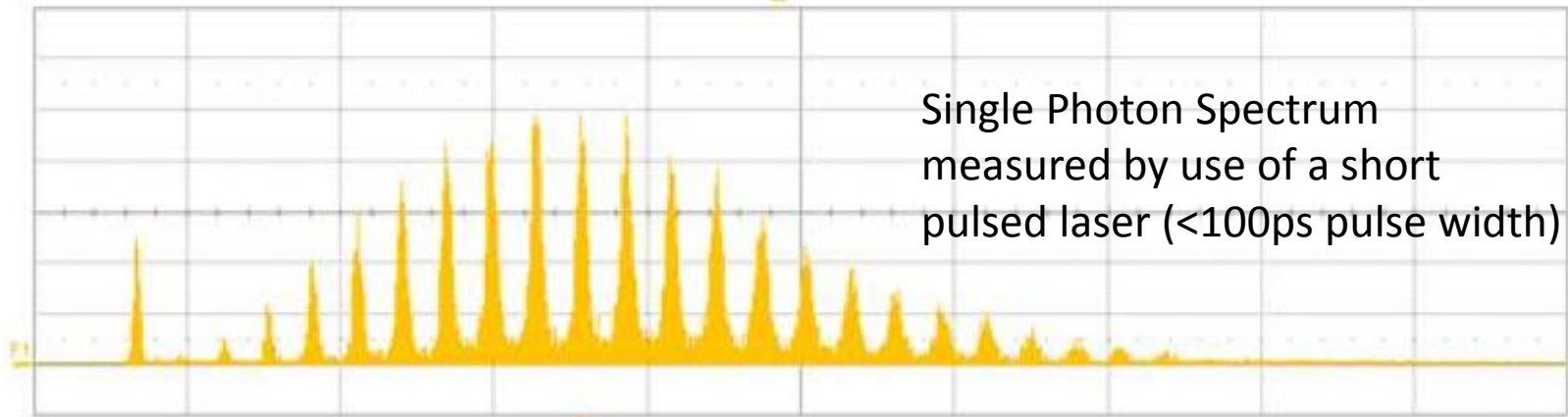
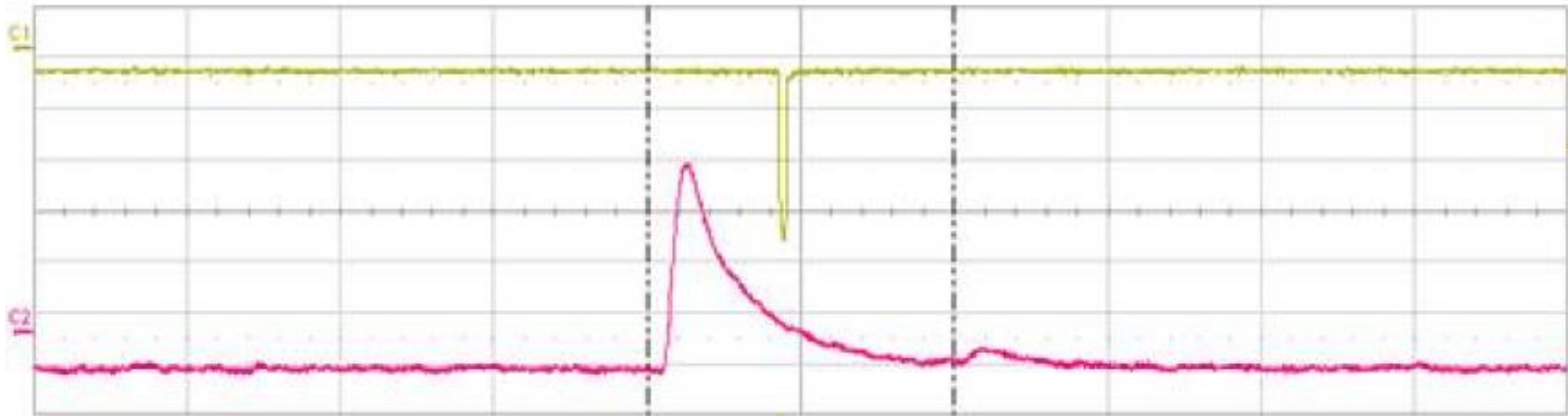


KETEK PM6660 coupled to GAGG scintillator



Counting the interactions of Fe-55 (5.9 keV)  
50% FWHM energy resolution

# Single Photon Spectrum with PM3325-WB (1 kV/A Module)



Single Photon Spectrum  
measured by use of a short  
pulsed laser (<100ps pulse width)

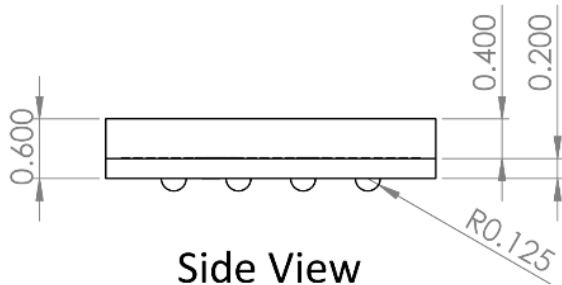
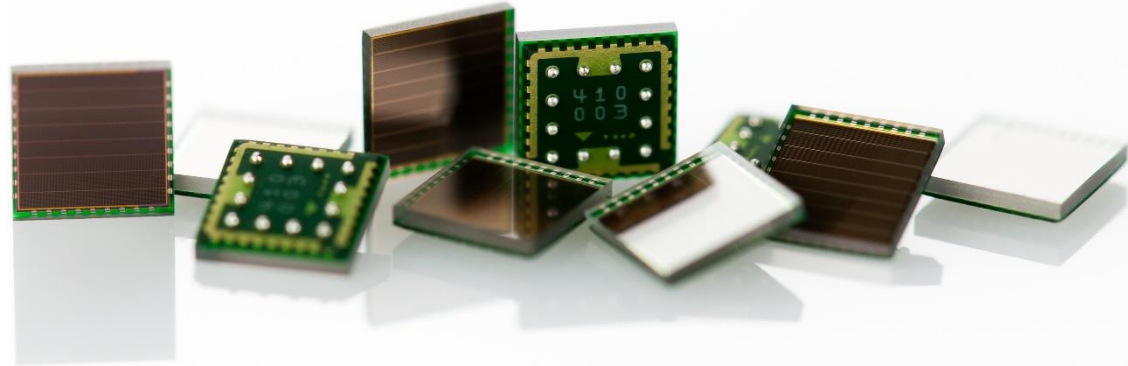
Measure	P1:area(C2)	P2:mode(F1)	P3:area(C2)	P4:mode(F2)	P5:area(C3)	P6:pkpk(C4)	P7:area(C3)	P8:rms(C4)
value	1.112259 nVs	-290.0 pVs						
status	✓	✓						

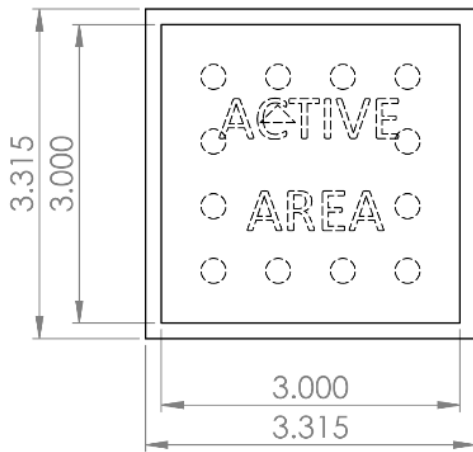
<b>C1</b> DC50 200 mV/div 630.0 mV	<b>C2</b> Int (DC50) 20.0 mV/div -47.60 mV	<b>F1</b> hist(P1) 50.0 #/div 1.00 nVs/div 29.353 kHz
--	--	--

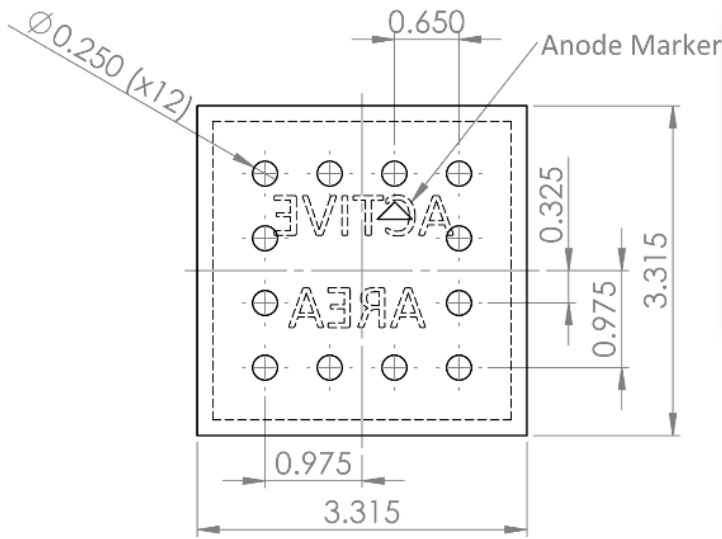
Timebase -14 ns	Trigger C1 DC
100 ns/div	Auto -394 mV
5.00 kS	Edge Negative



Side View



Top View



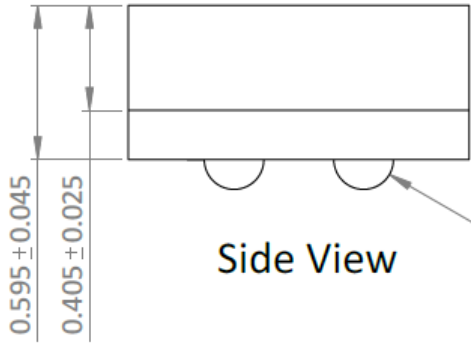
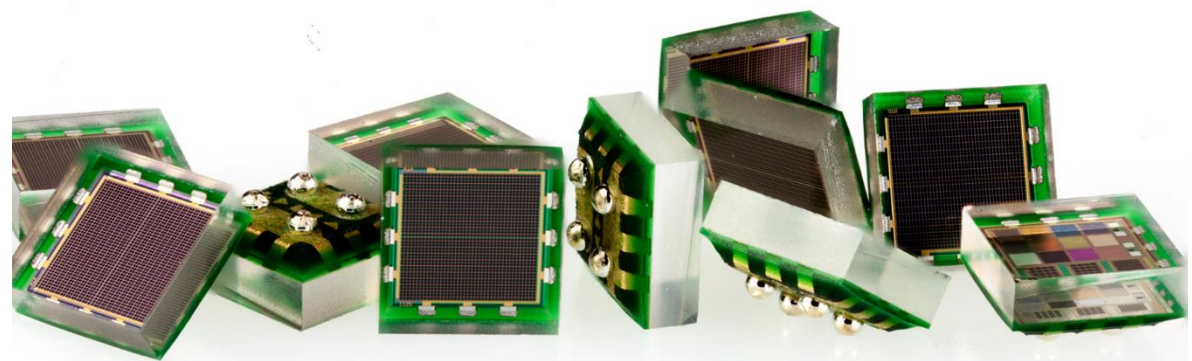
Bottom View

## Wafer Level Package

- cost efficient
- high volume production
- robust & reliable
- MR compatible

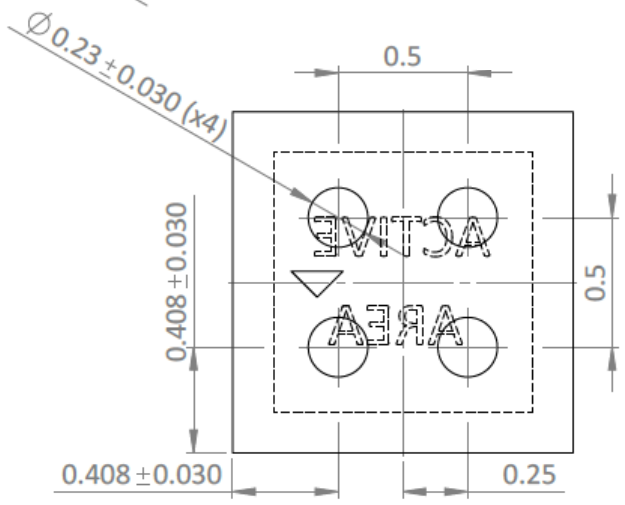
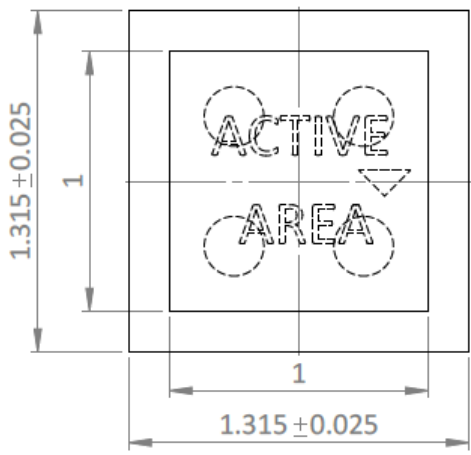


## Tape and Reel Delivery



Side View

$R0.115 \pm 0.015$



- Smallest 1x1 mm<sup>2</sup> device  
- Ideal for high resolution arrays



Tape and Reel Delivery