Laser scans of MAPD

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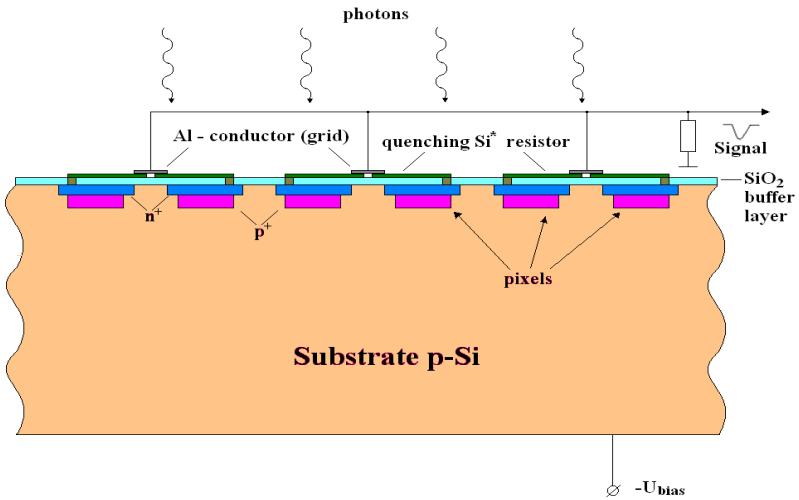
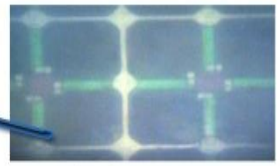
Micropixel Avalanche PhotoDiodes - MAPD.

Surface-pixellated structure



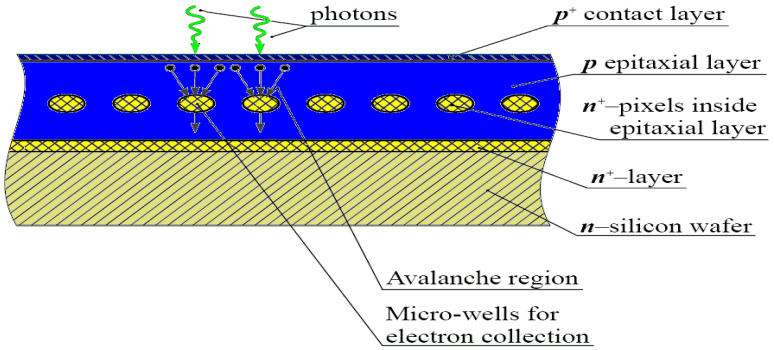
Общий вид МЛФД на корпусе КТ-1

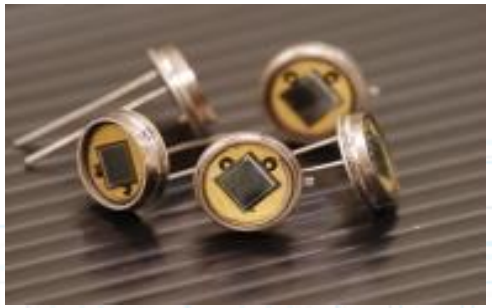


Микрофотография фрагмента матрицы МЛФД

- Pixels are on the surface
- Gain is of up to 10^6
- Has pixel density ~ 1000 mm^{-2}
- PDE is of up 40% (100 mm^{-2})
- PDE depends on pixel density (decrease with increasing density)
- Small dynamic range (depends on total number of pixels)
-Typical pixel size is (20-40)x(20-40) μm

Deep micro-well structure





- Pixels are deep inside epitaxial layer
- Gain is of up to 10^5
- Has pixel density ~ 10000 mm^{-2} (of up to 40 000 mm^{-2})
- PDE is of up 30% (15 000 mm^{-2})
- PDE slightly depends on pixel density (decrease with increasing density)
- Large dynamic range (depends on total number of pixels)
-Typical pixel size is (2-5)x(2-5) μm

Photon Detection Efficiency- PDE.

Photon Detection Efficiency – *PDE[1,2]*:

$$PDE = QE \cdot \varepsilon_g \cdot P_{tr}$$

where: *QE* – quantum efficiency of substance (silicon), ε_g – fill factor,
P_{tr} – triggering probability (depends on electrical field tension, that is PDE – depends on applied voltage).

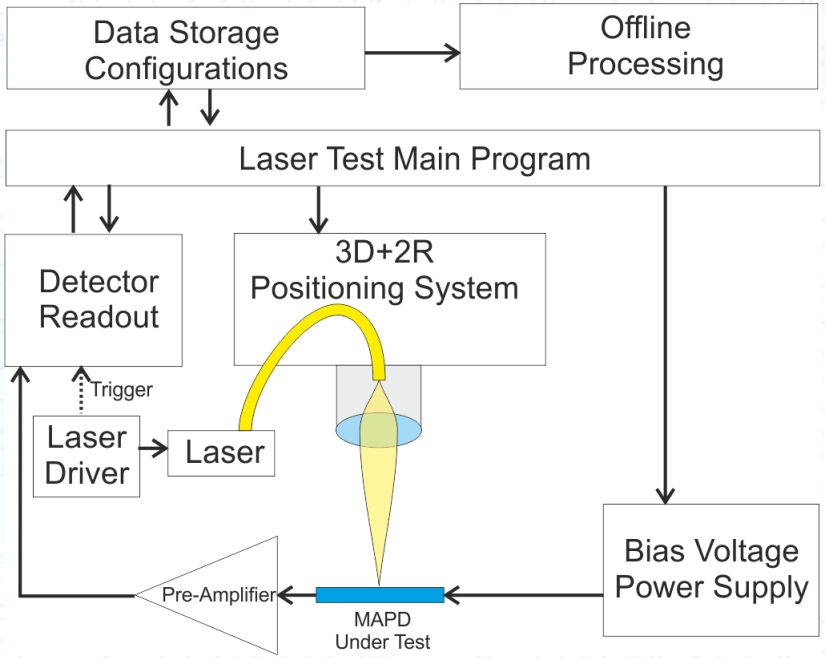
In surface-pixillated MAPD ε_g from (1600 pix/mm^2) up to 0.78 (100 pix/mm^2)[3].

Deep microwell MAPD – it is not actually known.
It is considered that $\varepsilon_g = 1$.
Triggering probability $P_{tr} < 1$.

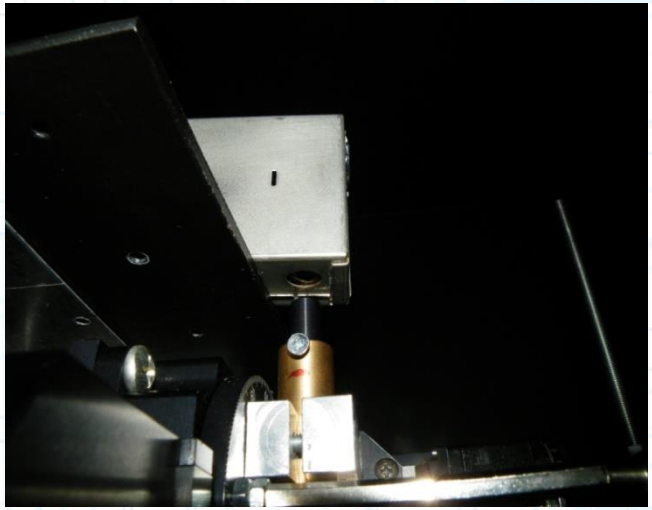
Typical PDE for MAPD (in maximum of spectral sensitivity) from 5% to 40%.

[1] D. Renker. Geiger-mode avalanche photodiodes, history, properties and problems. NIM A 567(2006) 48-56.
[2] N. Anfimov, et al. Test of micropixel avalanche photodiodes. 572(2007)413-415
[3] http://sales.hamamatsu.com/en/products/solid-state-division/si-photodiode-series/mppc.php

Experimental Setup (Charles University, Prague)



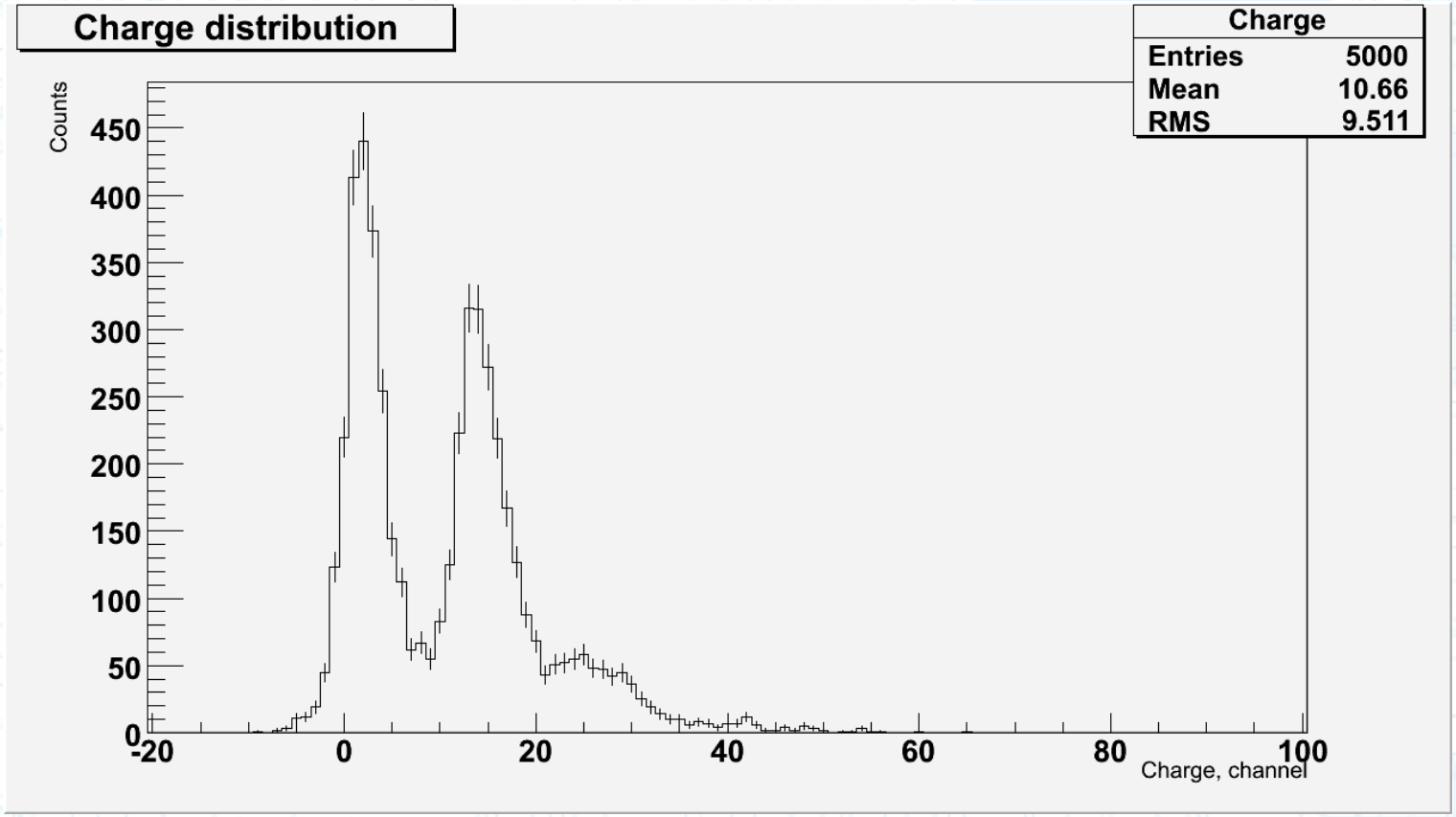
Main parameters:
- Pulsed laser (minimum pulse width 1.2 ns)
- Minimal spot size ~ 2.8 μm
- Minimal movement – 1.25 μm
- Wavelength of laser – 660 nm
- INR amplifier with gain K=260



SinglePixel spectrum of MAPD-2

(Charles University, Prague)

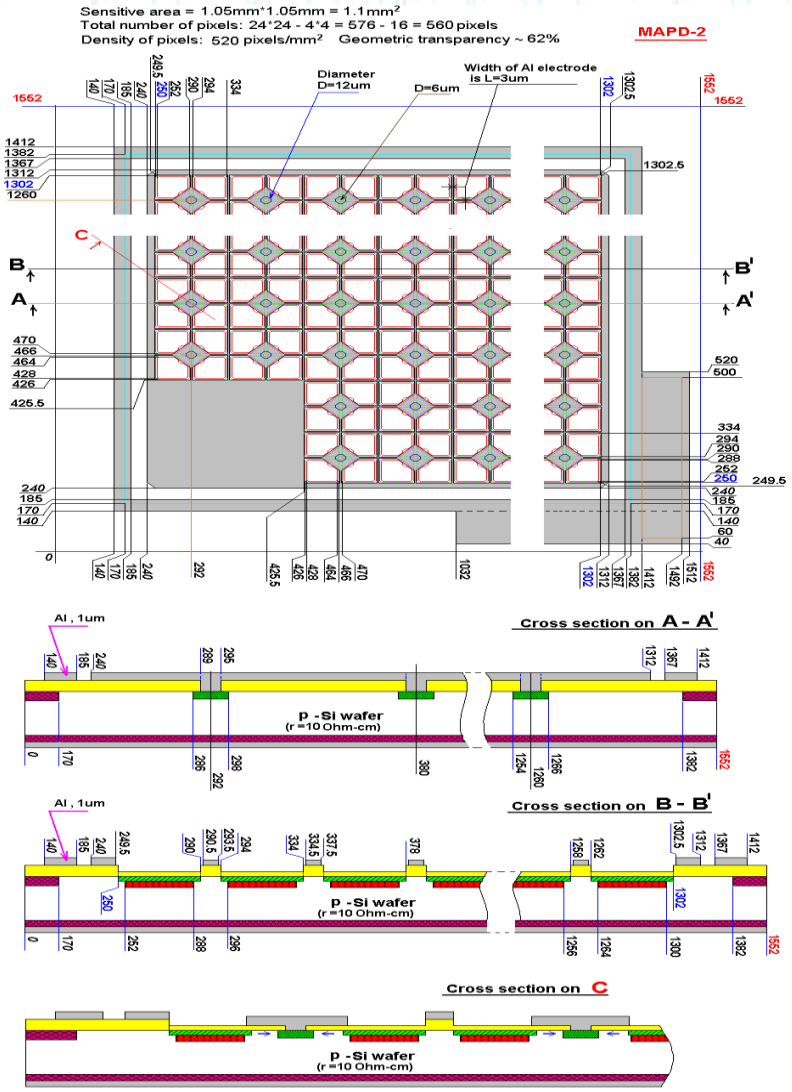
LASER spot size (sigma ≈ 2.8 μm). Pixel size = 41 μm.
Hitting center of pixels in ideal MAPD makes single pixel ampitudes,
but cross-talk effects produce lager amplitudes.



Distribution of relative PDE for MAPD-2

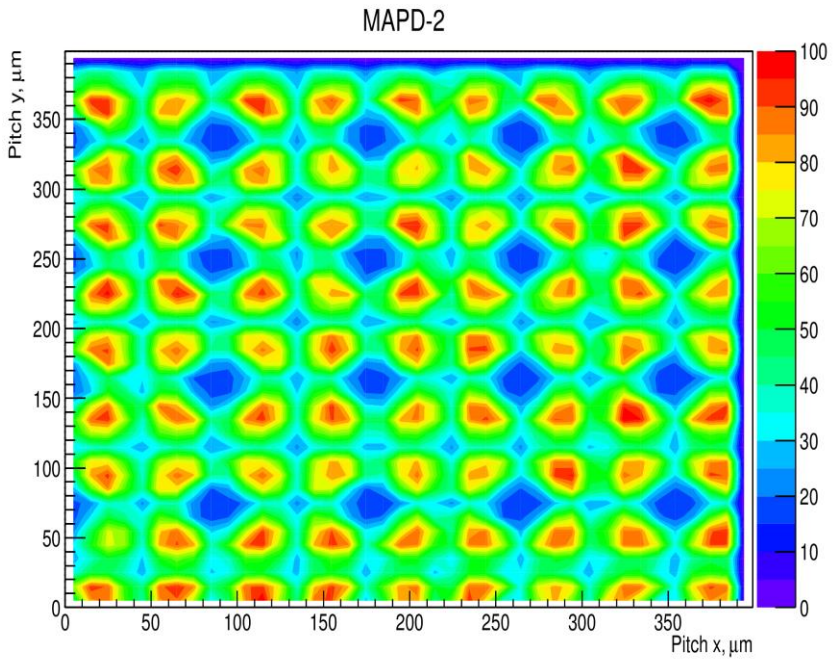
(Charles University, Prague)

MAPD-2 Design Draw



Theoretical fill factor = 0.62

Distribution of relative PDE of MAPD-2
PDE measured in photoelectrons and normalized to average maximum value



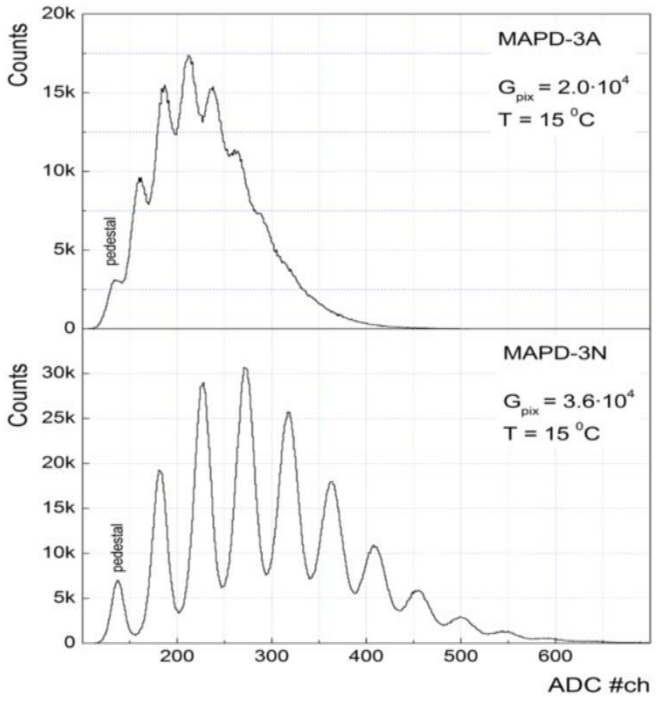
Experimental fill factor 0.58 +/- 0.07
(Calculated as an average PDE over all plot)

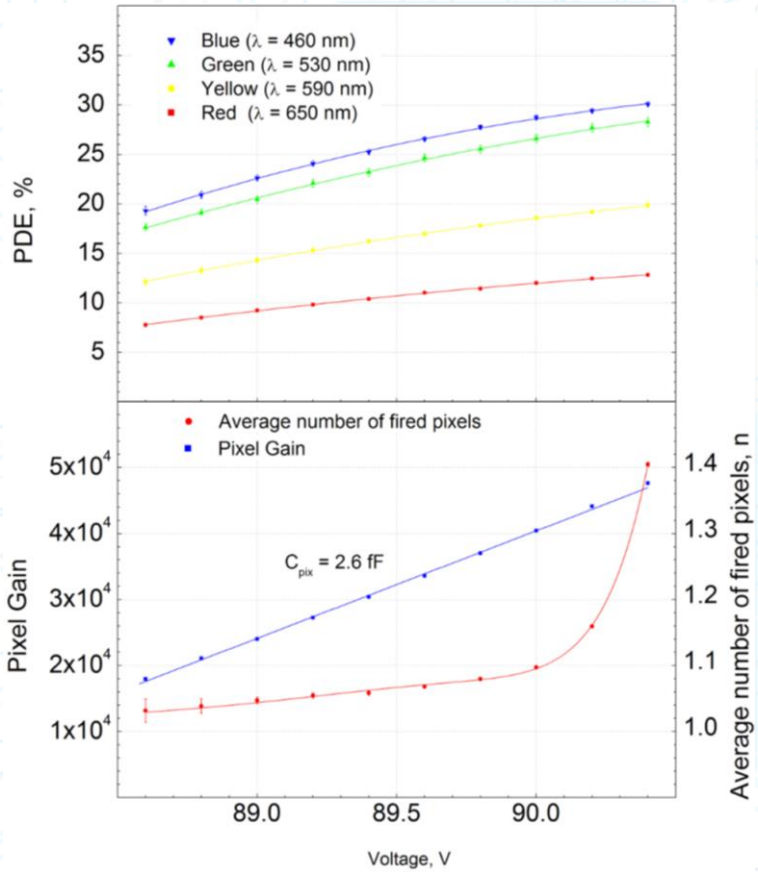
Pixels gain uniformity < 9%
(First peak position from single photoelectron spectra)

Pixels homogeneity < 5%
(Sigma of first peak from single photoelectron spectra)

Deep microwell MAPD-3N (Main characteristics)

Pixel size d = 5 um.
Pitch h = 8 um.
Pixels density 15 000 mm-2.
Operating voltage 89 – 95 V.

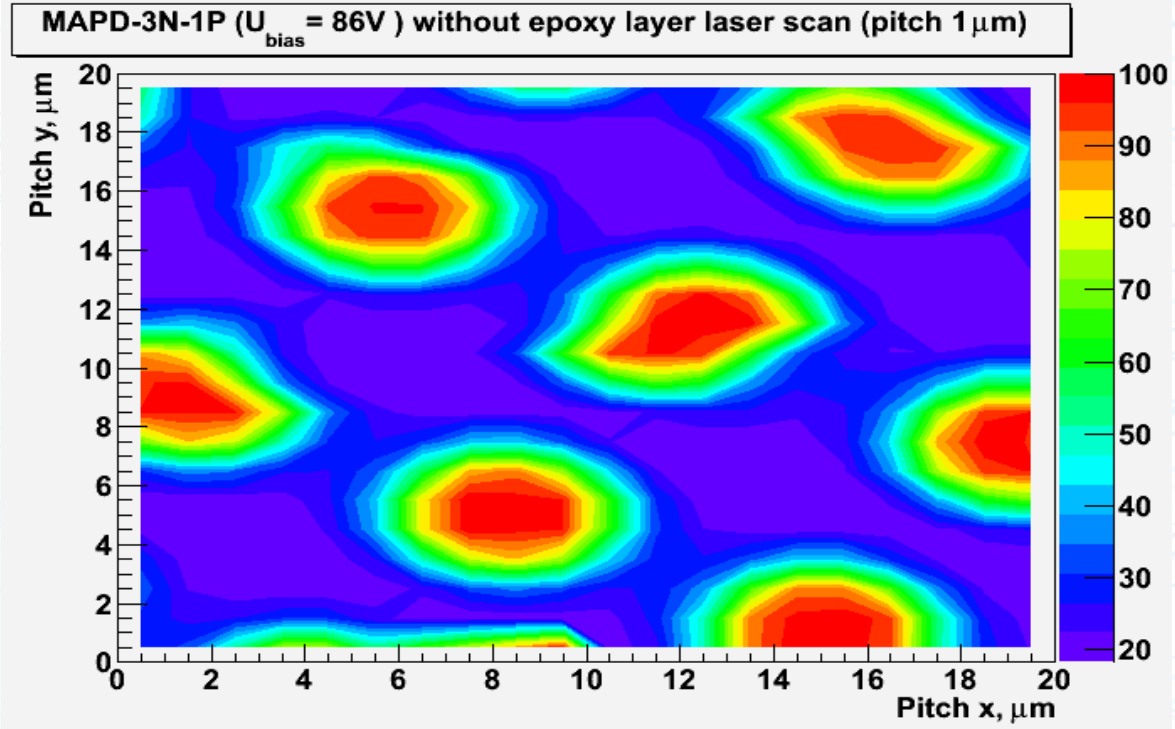




Single peaks are clear visible that allows to operate in single photoelectron mode

First measurement in current mode (Branch of MSU in Dubna, July 2011)

We used blue (λ=442 nm) ray laser (continuous) of confocal microscope.
Spot size (sigma) < 0.8 um
Movement (X-Y) of laser spot > 50 nm.
As a picoampermeter and voltage source Keithley 6487 was used.
MAPD-3N was without epoxy layer (defocused in epoxy layer)



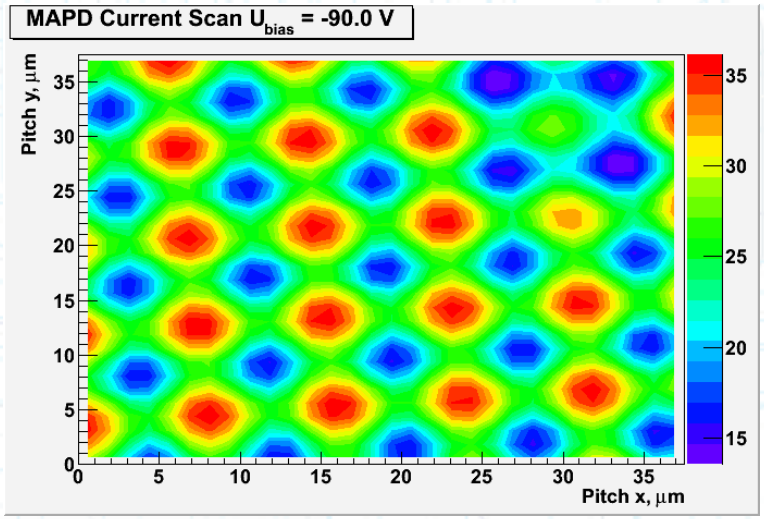
Pixel structure is clear visible ->
Might be not 100% geometrical factor!!!

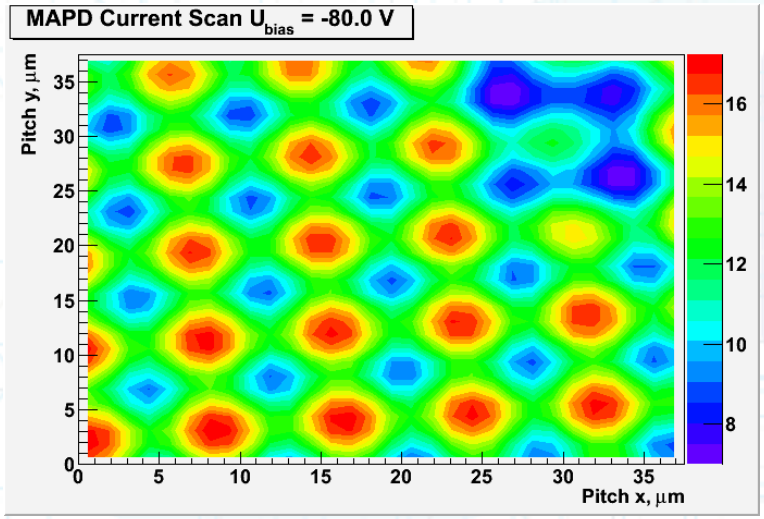
This fact have to be checked in operating (Geiger) mode!!!

But we used to use continuous laser -> Might be problem in Geiger mode!!!

Measurements in current mode (Prague, CU January 2012)

MAPD-3N without epoxy layer.
The same measurement scheme
Red (λ=660 nm) LASER. Spot size (sigma ≈ 2.8 μm).

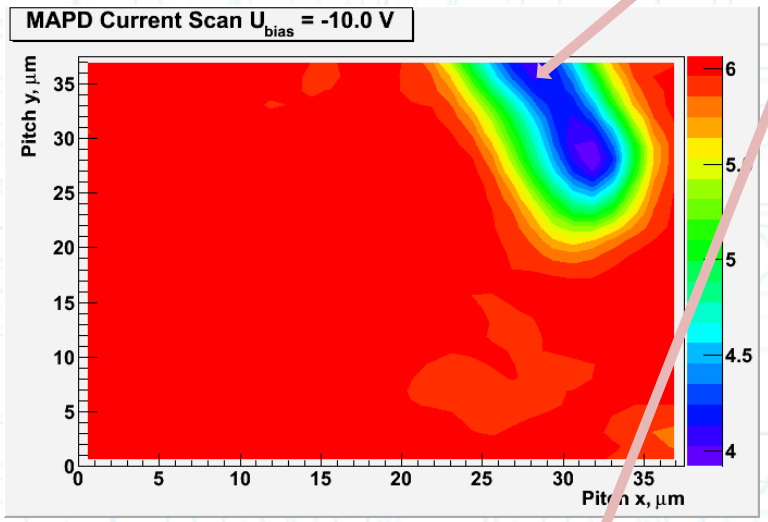


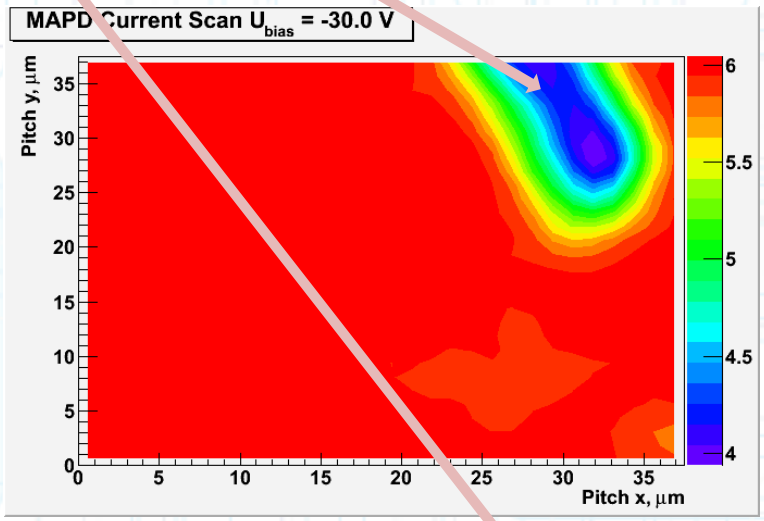


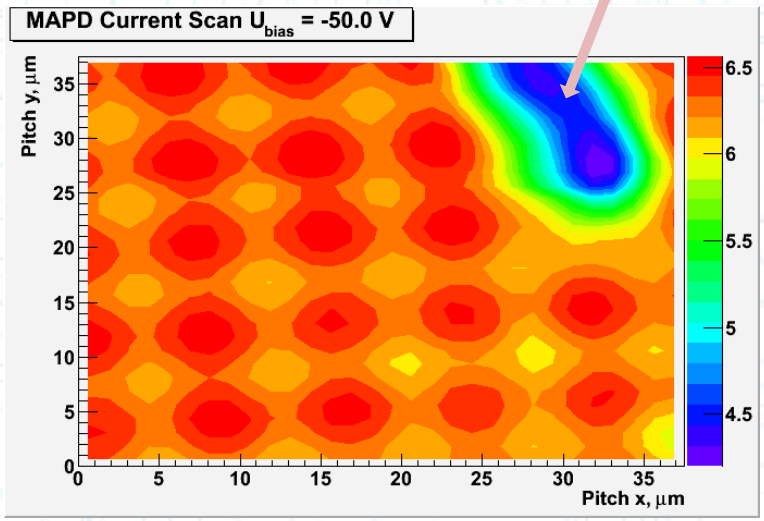
Pixel structure is clear visible also ->
Might be not 100% geometrical factor!!!

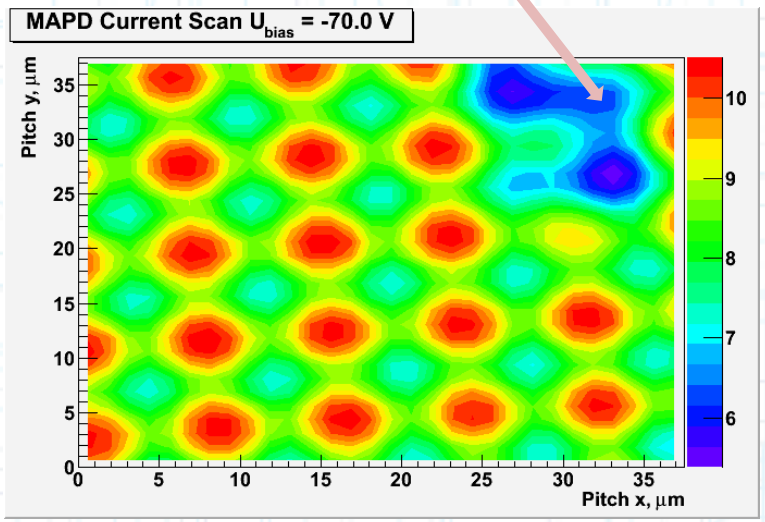
Measurements in current mode (Prague, CU winter 2012): Different voltages

Dust on sensor surface





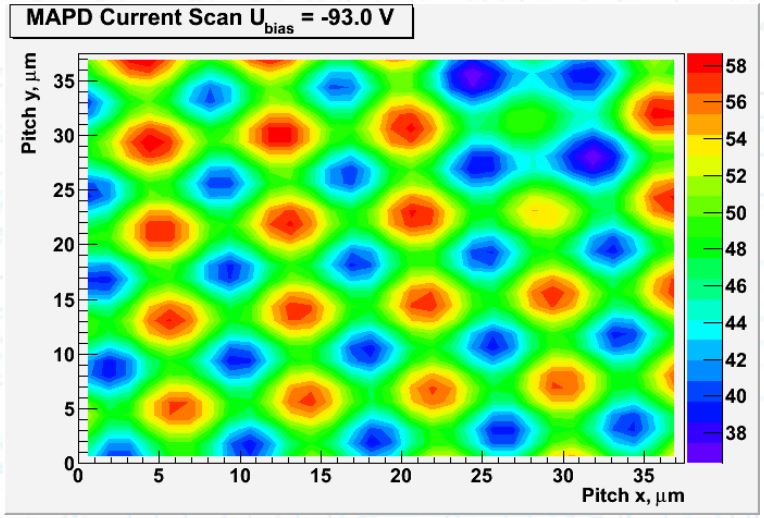


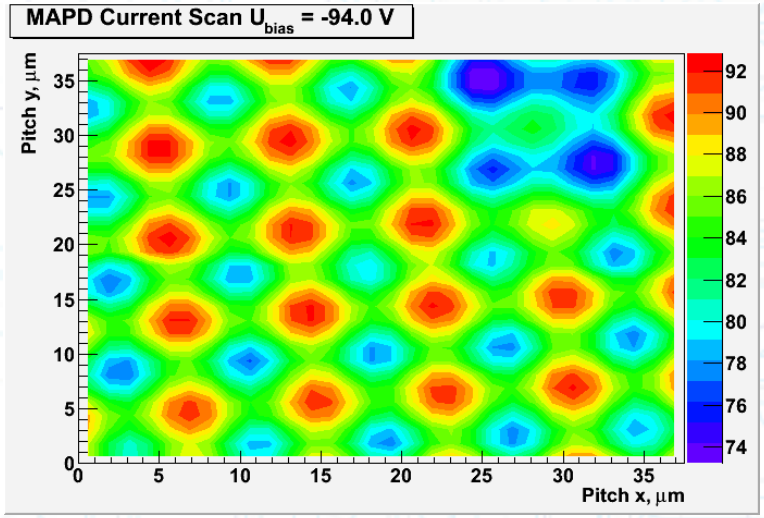


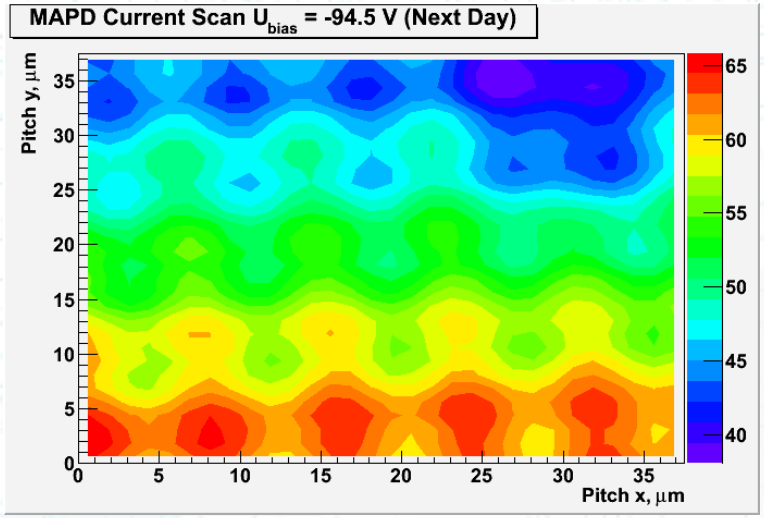
On low voltages MAPD works like PIN-photodiode

Pixels structure is driven by pixel gain (look at the current scale (z-axis, μA)

Measurements in current mode (Prague, CU January 2012): ”Geiger”-mode problem



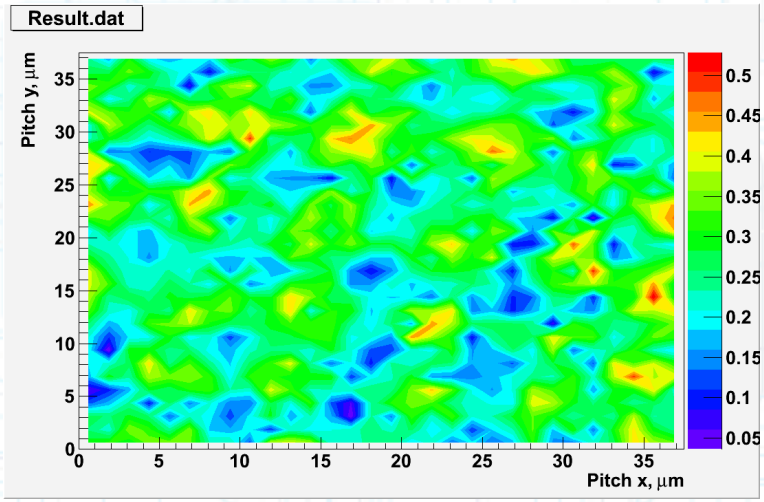


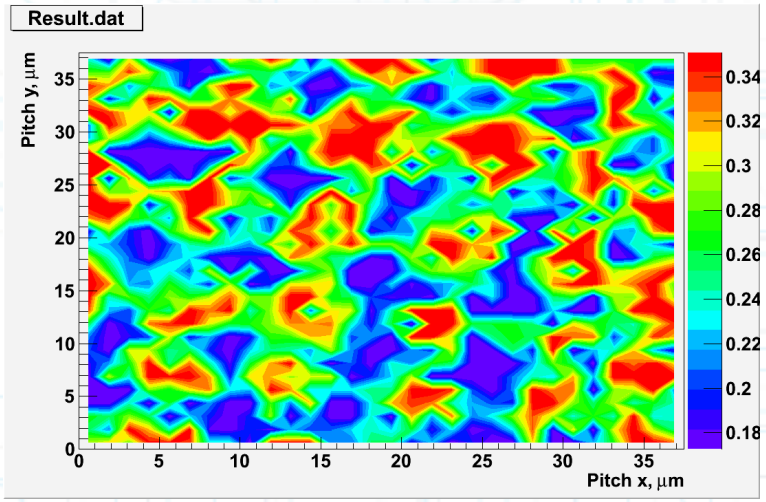


One can see that in Geiger mode PDE variation is less.
But in Geiger mode it might be due to pixel response saturation
-> we couldn’t investigate MAPD in current mode!!!

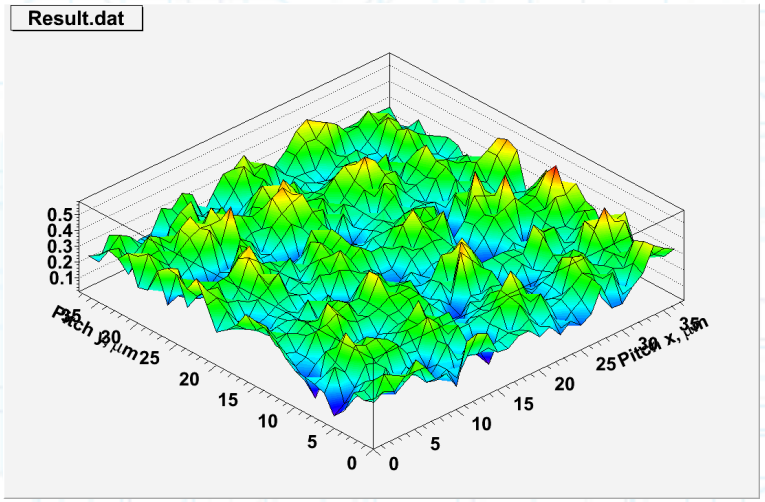
Measurements in single-photon mode

MAPD-3N (U = 93.5 V)



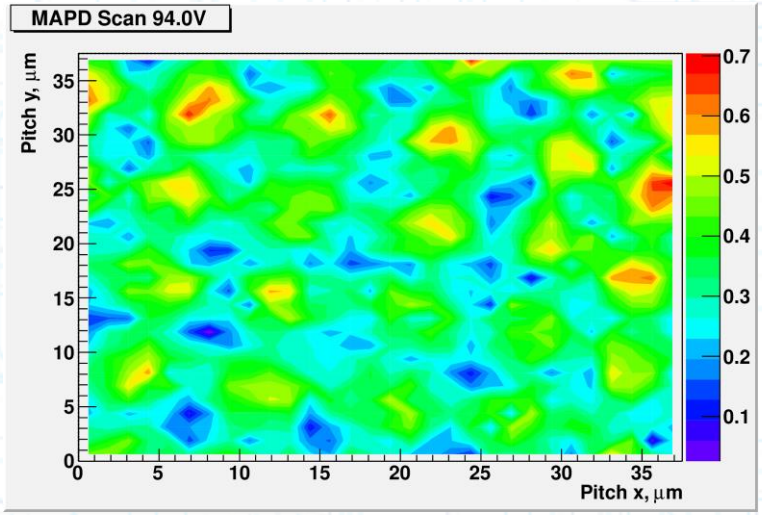


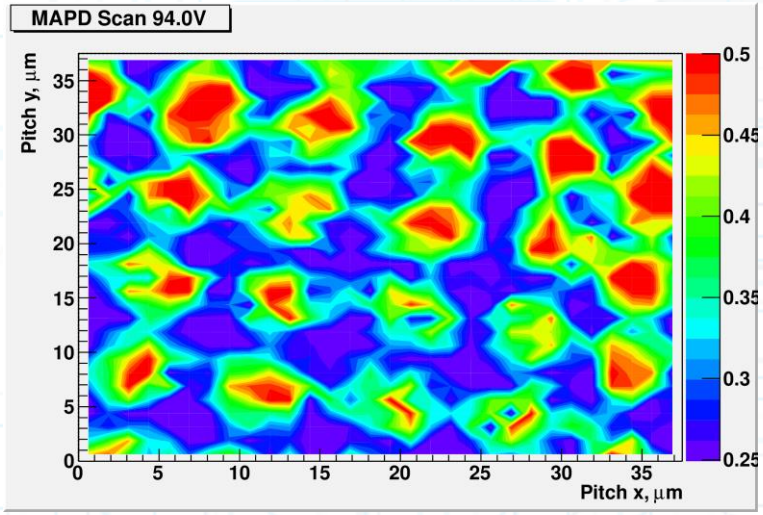
Pixel structure is clear visible ->
geometrical factor is not 100% for Red light

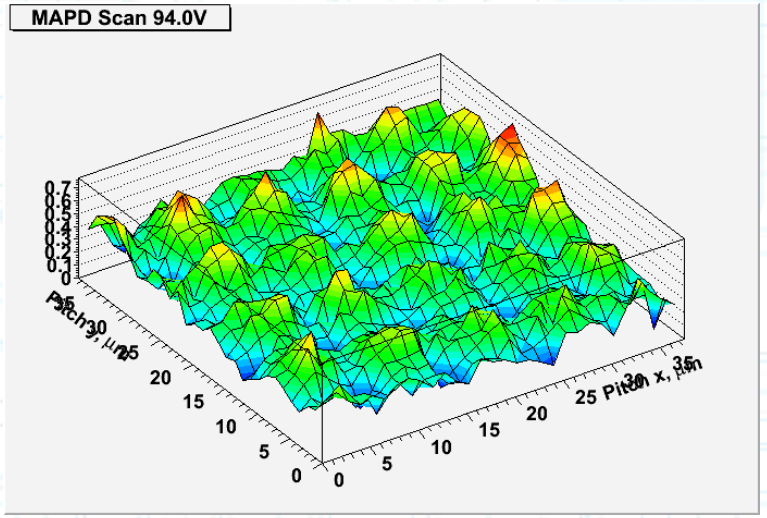


Measurements in single-photon mode

MAPD-3N (U = 94.0 V)



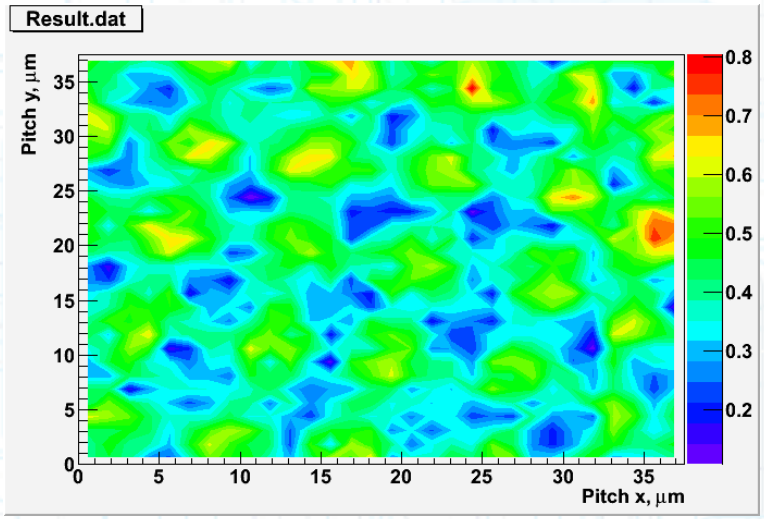


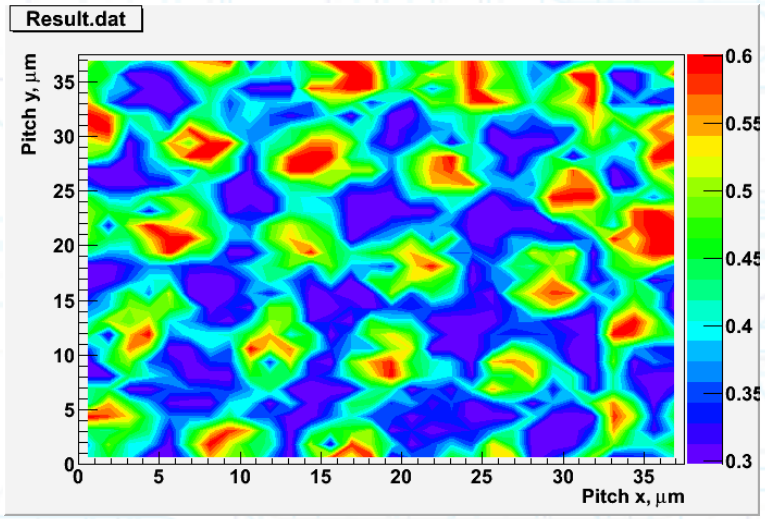


Pixel structure is clear visible ->
geometrical factor is not 100% for Red light

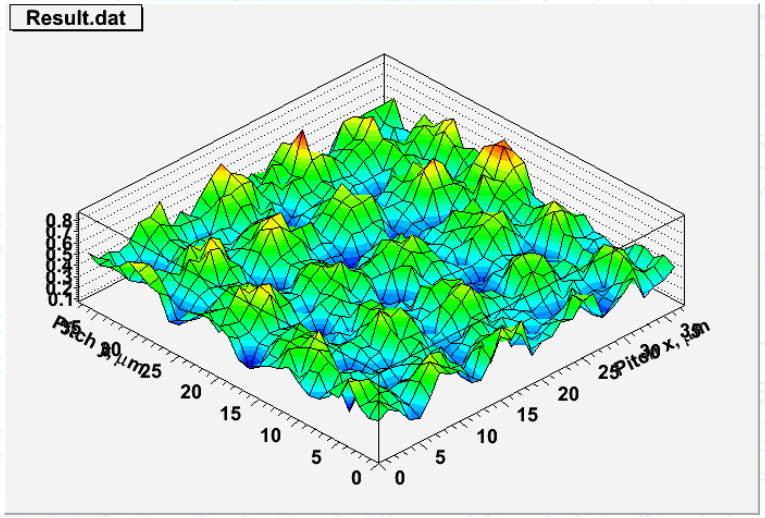
Measurements in single-photon mode

MAPD-3N (U = 94.5 V) – Maximum operating voltage for this sample





Pixel structure is clear visible ->
geometrical factor is not 100% for Red light



Conclusions:

- Method for MAPD scanning by laser spot in current and single photon mode was developed.
- Deep MAPD have amplitude variations with peak to valley ratio is in order for red light illumination.
- We have to scan Deep MAPD using blue light, so we started to adopt confocal Microscope in INP MSU. We've bought a picosecond laser to implement it into the microscope system.
- This measurements will stimulate development of new design of MAPD structure.