AMPD tests at Charles University of Prague (Progress)

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Avalanche Micro-Pixel Photo-Diodes for Frontier Detector Systems
G-APD Workshop at Charles University, Prague, February 22-23, 2010

Introduction

A setup for testing silicon position sensitive detectors using a focused pulsed laser beam was used to test a **Micro-pixel Avalanche Photodiode detector** (MAPD). **Laser focuser** is positioned at **stages allowing 3D motion and rotation around 2 axes**. The MAPD was read out by an **NI PCI-5124 scope board** in a PC.

Testing method was presented at the Darmstadt meeting. We present tests of three samples produced by Zecotek Company

Tests with a focused pulsed laser beam were performed in April and May 2009.

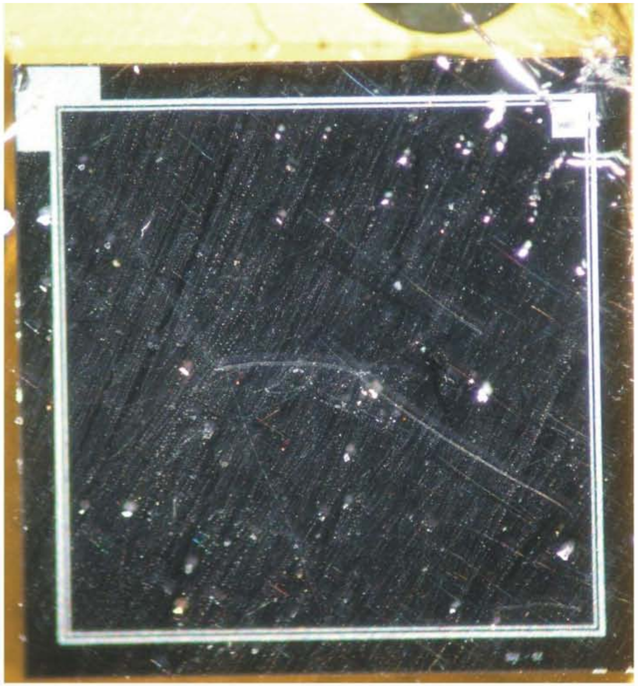
Three samples 3A, 3N and 3N1P were tested using small laser power in level of several hundred photons in pulse in avalanching and proportional acquisition mode.

Two type of scans were used: Rough Scan and High Resolution Scans

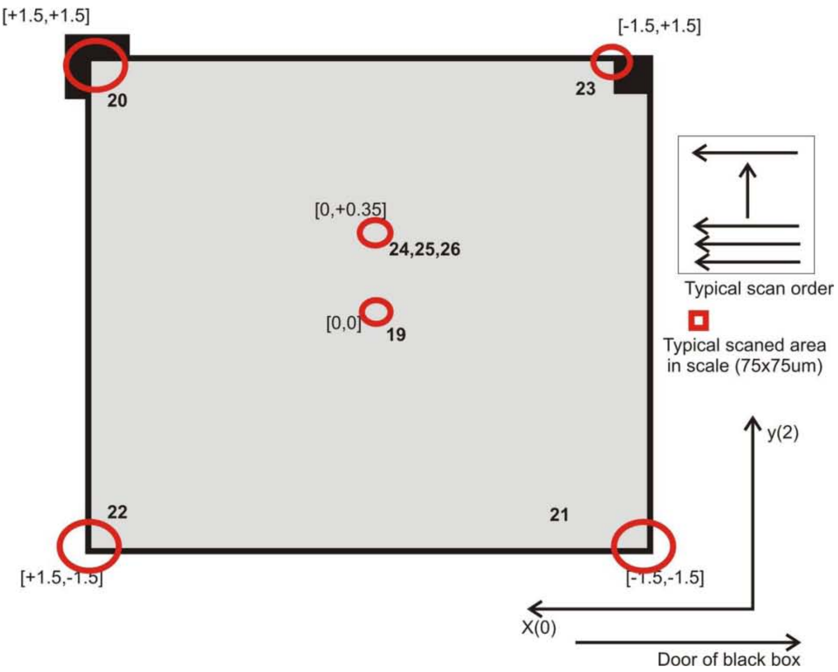
Measurement And Analysis

- Conditions of measurement:
  - Focused / defocused laser beam (spot $\sigma \approx 3\ \mu m$/ $30\ \mu m$) scan
  - Laser pulse: width 5ns, frequency 1kHz. Opt. Attenuator, 1000/5000 pulses/point
  - Avalanche (66.5V/68nA) or proportional (64.0V/5nA) mode
  - Middle or corners of area
- Analysis is done by (method without fine tuning)
  - simple determination of peak
  - excluding pedestals (read from signal before pulse)
  - integration of signal in peak
  - fitted by Gauss and mean value was found
  - averaging of statistics
  - collect results on 2D signal plots

MAPD 3A



sensor of an older type, size 3x3 mm^2 with pitch between sensing cells 8 μm in both directions, collecting sense area in cell is 3x5 μm^2, expected gain is 2 - 3 $x10^4$. Noise is ≈10 MHz / 9 mm2 and PDE 10 - 12 % in blue- green region.



Number of small bubbles on epoxy cover is a source of the dissipation of focused light in laser beam and final response is smeared. Also attempt of cleaning of surface created number of scratches and grease layer on a surface.

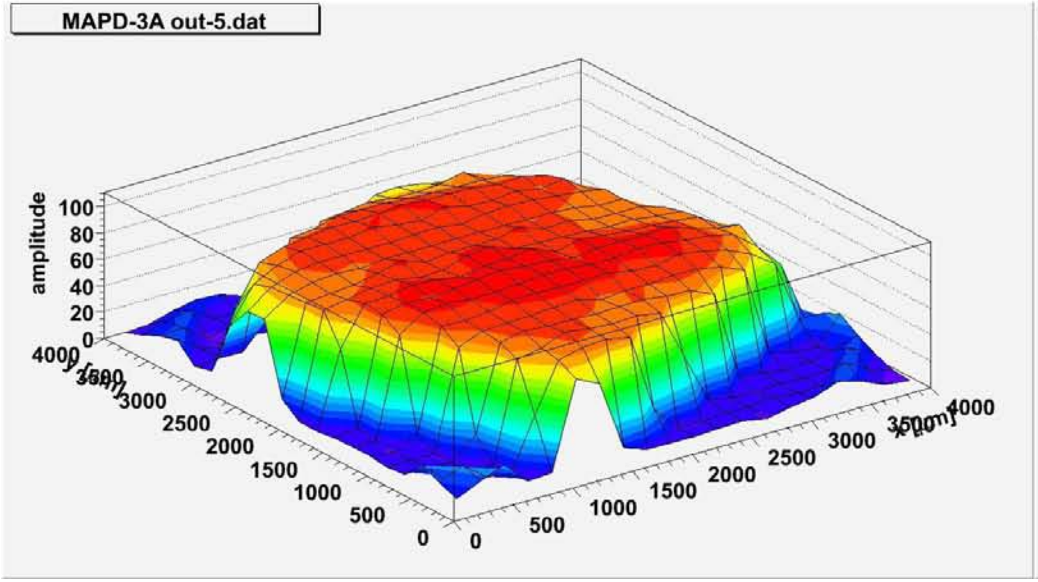
MAPD 3A

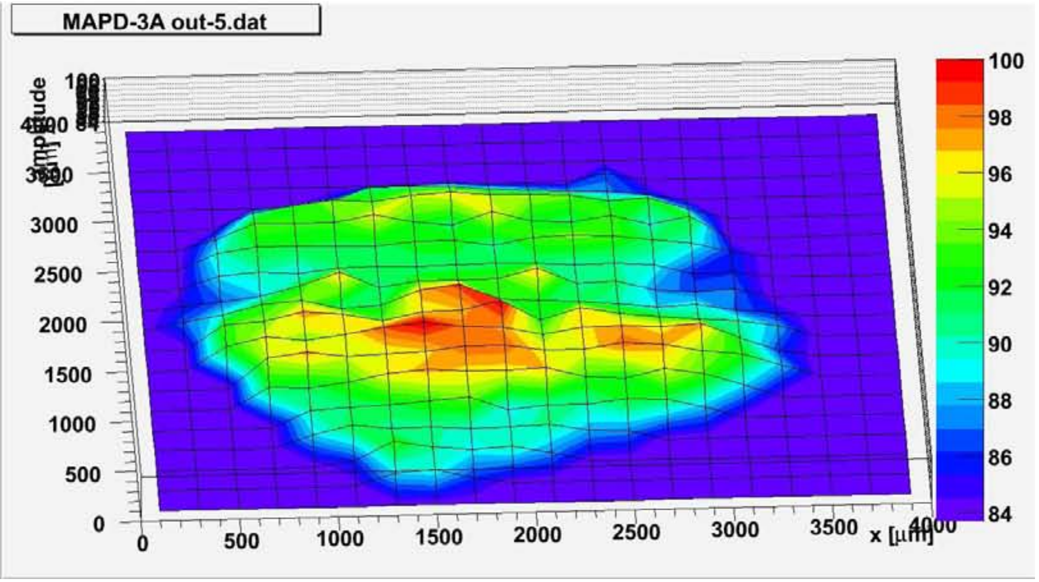
Scan Number	Scan Matrix	Step Size [μm]	Comment / Conditions
-5	20 × 20	200 × 200	rough scan, Def+0.3mm Avl 66.5V/68nA 3.39V/20ns 1kHz OptA7000 1000Ev/p bad par
19	20 ×20 middle	2.5 × 2.5	focused scan, Avl 66.5V/68nA 3.8V/20ns 1kHz OptA7000 1000Ev/p
20	30 × 30 corner + +	2.5 × 2.5	focused scan, Avl 66.5V/68nA 3.8V/20ns 1kHz OptA7000 1000Ev/p
21	30 × 30 corner - -	2.5 × 2.5	focused scan, Avl 66.5V/68nA 3.8V/20ns 1kHz OptA7000 1000Ev/p
22	30 × 30 corner + -	2.5 × 2.5	focused scan, Avl 66.5V/68nA 3.8V/20ns 1kHz OptA7000 1000Ev/p
23	50 × 50 corner - +	2.5 × 2.5	focused scan, Avl 66.5V/68nA 3.8V/20ns 1kHz OptA7000 1000Ev/p
24	20 × 20 close middle	1.25 × 1.25	focused scan, Avl 66.5V/68nA 3.8V/20ns 1kHz OptA7000 1000Ev/p
25	20 × 20 close middle	1.25 × 1.25	focused scan, Prop 64V/4nA 3.97V/20ns 1kHz OptA5000 1000Ev/p
26	20 × 20 close middle	1.25 × 1.25	focused scan, Prop 64V/4nA 3.97V/20ns 1kHz OptA5000 5000Ev/p

Table 2.1: List of 3A MAPD scans, Def+0.3mm = defocused beam with spot diameter ≈ 30 μm far from sensor, Avl = avalanche mode, Prop = proportional mode, bad par = paralelism between position stages and MAPD was not very good and there some changes of a spot size are possible, OptA = setting of an optical attenuator

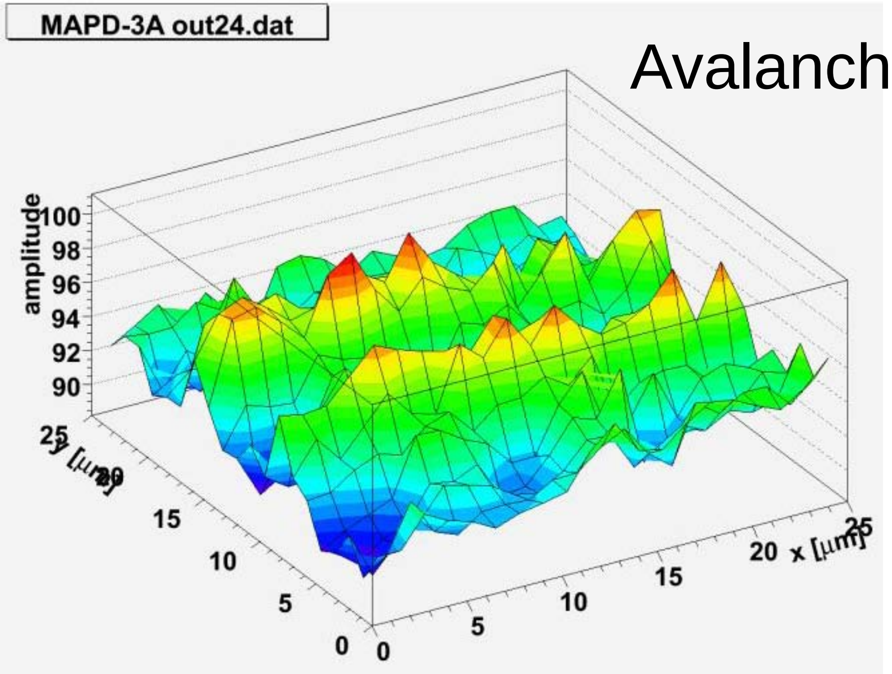
MAPD 3A – rough scan

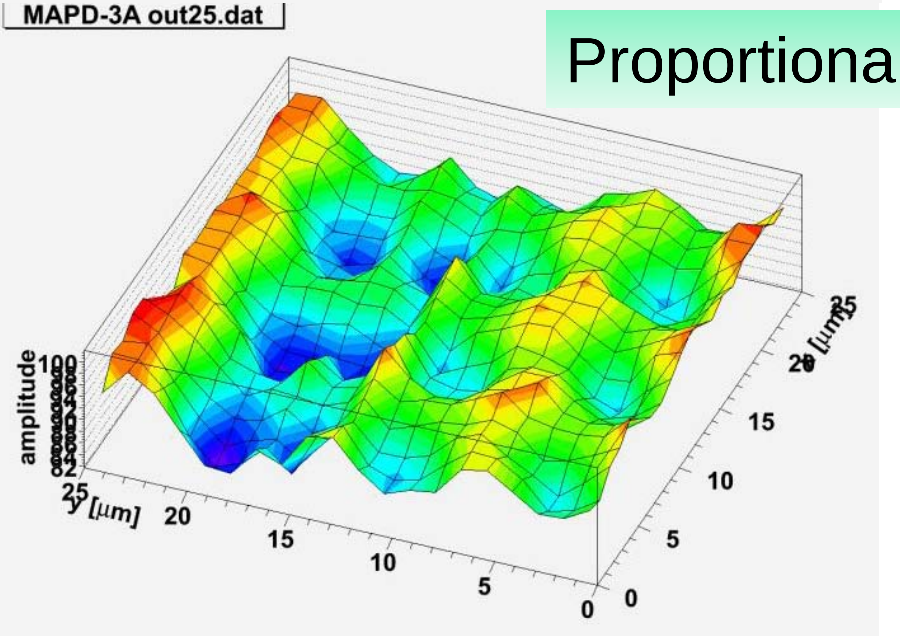
There is no special trend of response distribution. Sensor was not perpendicular with xy position stages plane.

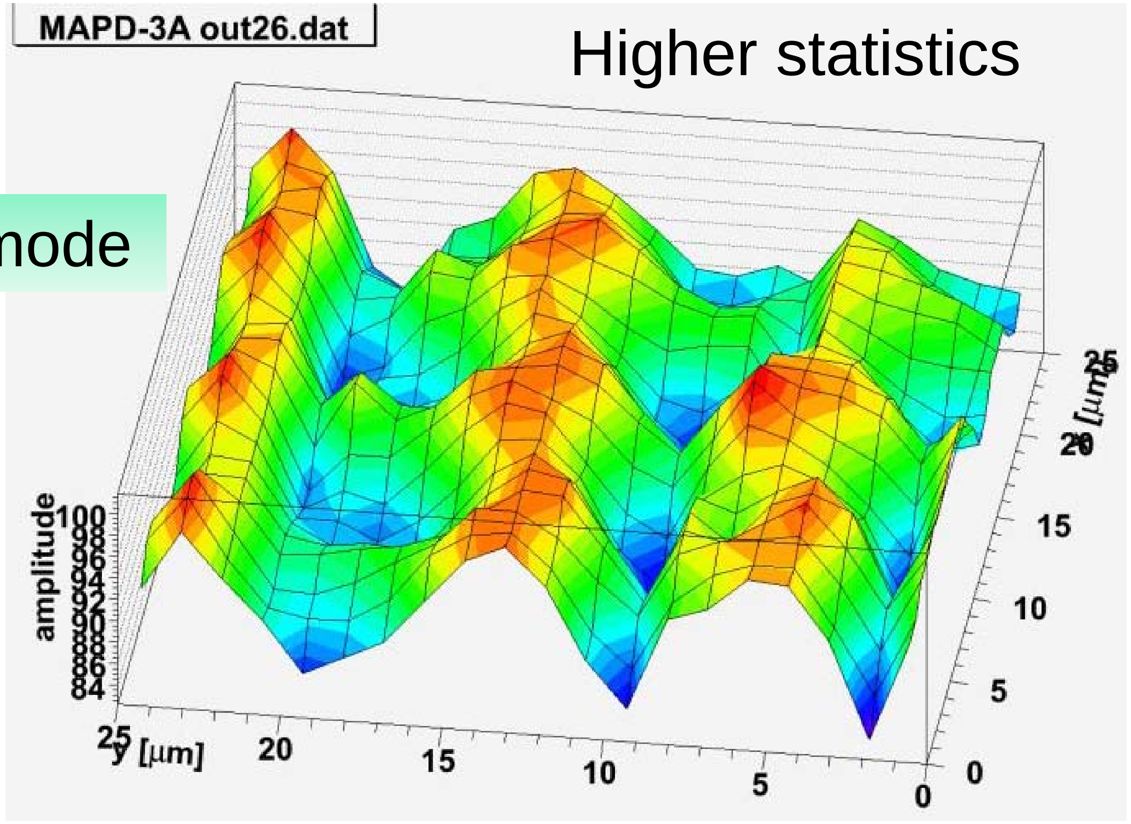




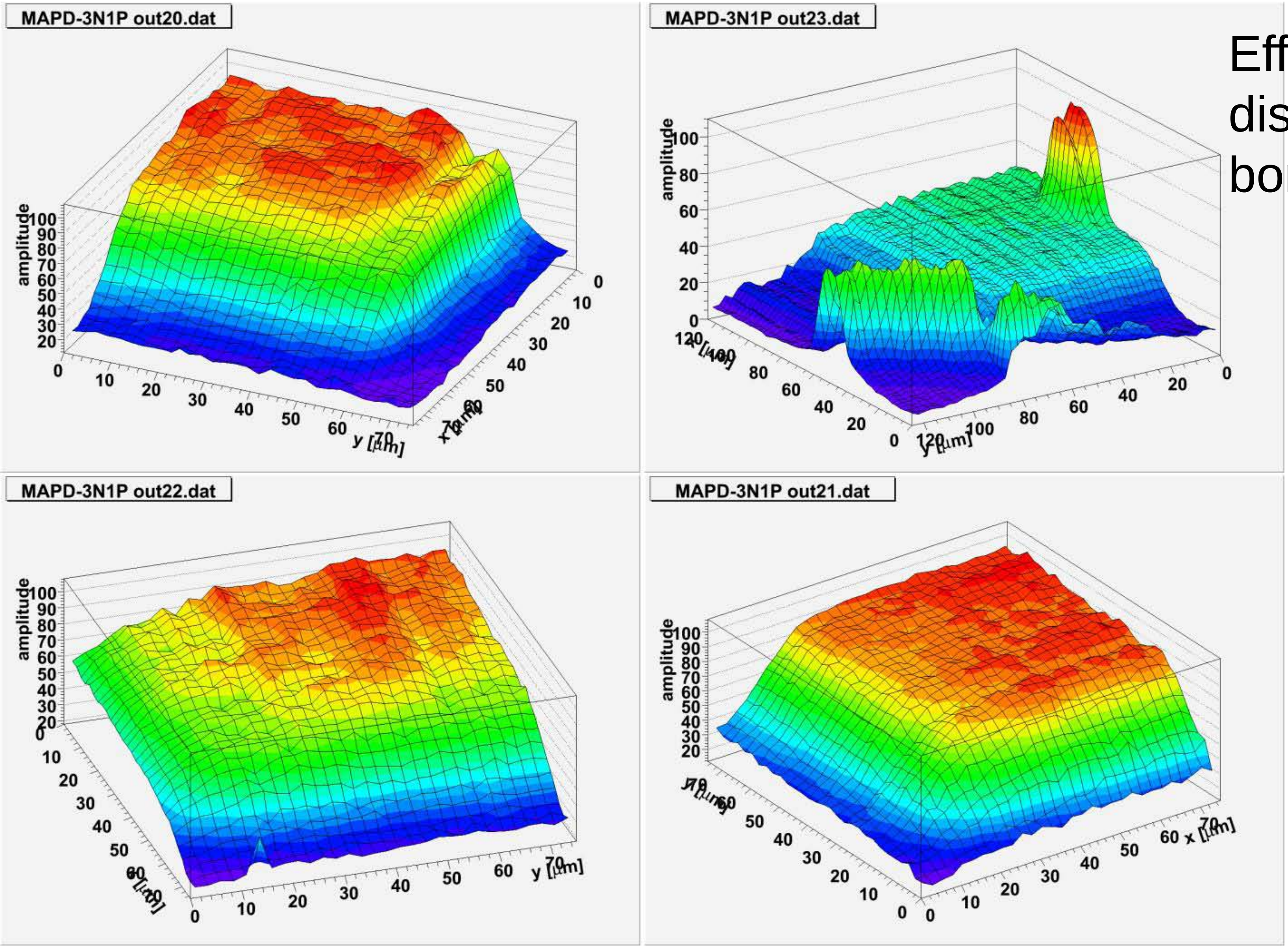
MAPD 3A – middle







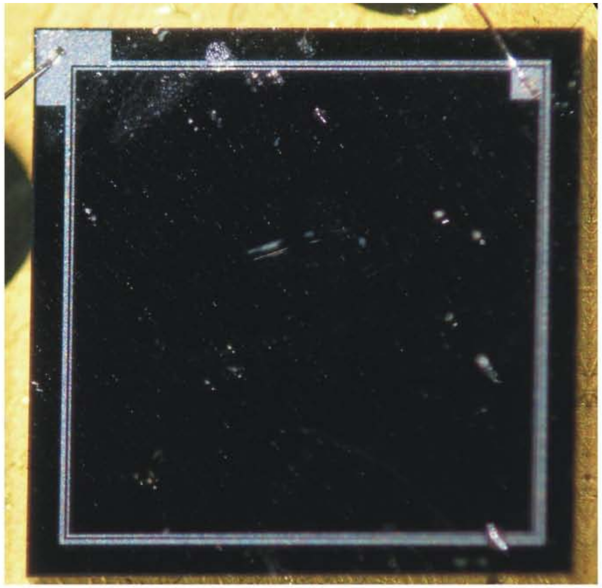
MAPD 3A – corners

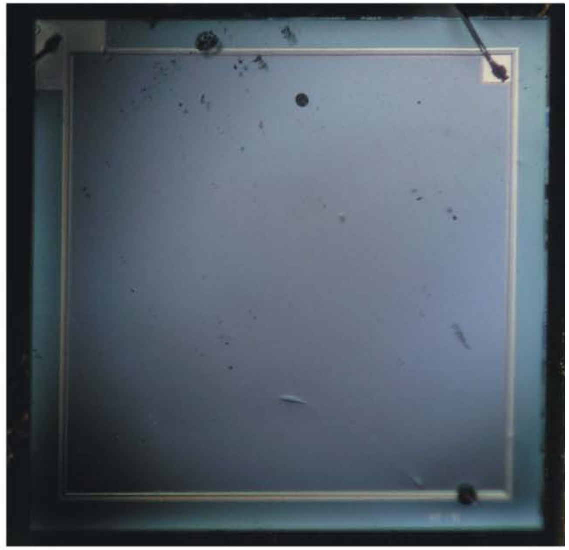


Effect of light dissipation on wire bond

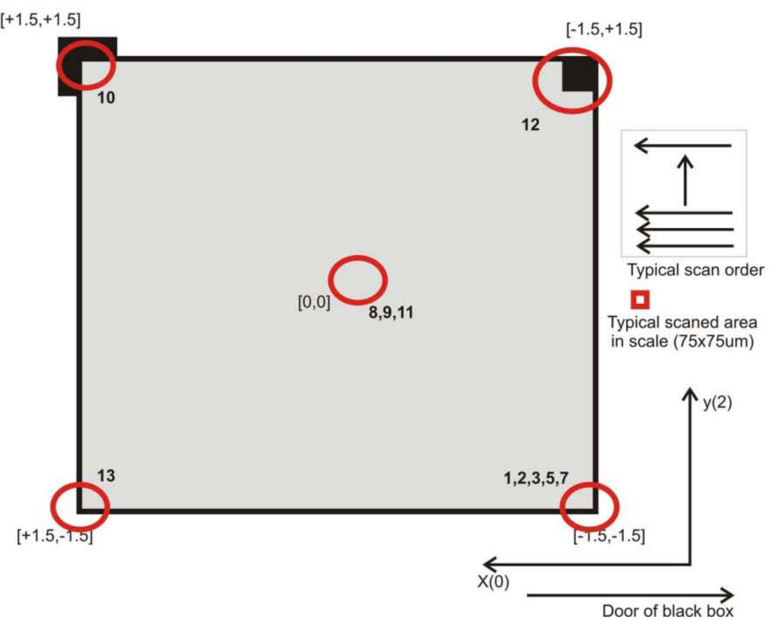
Note that plots are related to photos with mirroring transformation.

MAPD 3N





sensor of an newer type, size 3x3 mm^2 with pitch between sensing cells 8 μm in both directions, collecting sense area in cell is 5x5 μm^2, expected gain is 6 - 7 $x10^4$. Noise is 5 MHz / 9 mm2 and PDE 28 % for blue(470nm), 25 % for green(530 nm) and 10 % for red(650nm) light.



Number of small bubbles on epoxy cover is a source of dissipation of focused light in laser beam and final response is smeared. There are also few bigger bubbles. On right photo a few surface defects are visible

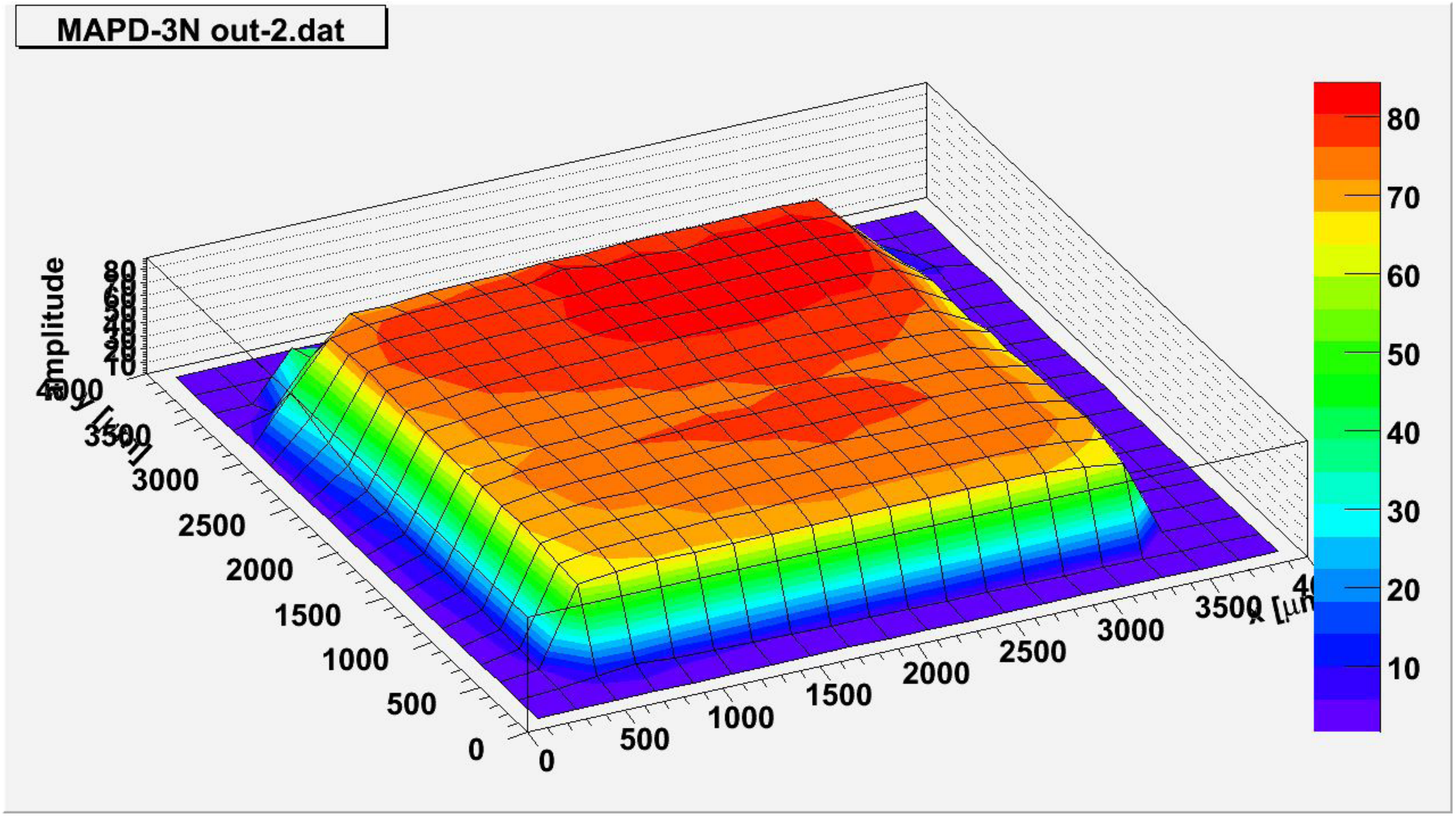
MAPD 3N

Scan Number	Scan Matrix	Step Size [μm]	Comment / Conditions
-2	20 $\times$ 20	200 $\times$ 200	rough scan, Def+0.5mm Avl 90.1V/97nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
-1	20 $\times$ 20	200 $\times$ 200	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
1	20 $\times$ 20 corner - -	10 $\times$ 10	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
2	20 $\times$ 20 corner - -	10 $\times$ 10	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
3	5 $\times$ 5 corner - -	20 $\times$ 20	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
5	5 $\times$ 5 corner - -	20 $\times$ 20	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
7	40 $\times$ 40 corner - -	2.5 $\times$ 2.5	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
8	10 $\times$ 10 middle	1.25 $\times$ 1.25	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
9	10 $\times$ 10 middle	2.5 $\times$ 2.5	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
10	10 $\times$ 10 corner + +	5 $\times$ 5	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
11	20 $\times$ 20 middle	1.25 $\times$ 1.25	focused scan, Avl 89.8V/70nA HighStat 3.6V/20ns 1kHz OptA7000 10000Ev/p
12	40 $\times$ 40 corner - +	7.5 $\times$ 7.5	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
13	50 $\times$ 50 corner + -	2.5 $\times$ 2.5	focused scan, Avl 89.8V/70nA 3.6V/20ns 1kHz OptA7000 1000Ev/p

Table 3.1: List of 3N MAPD scans, Def+0.5mm = defocused beam with spot diameter $\approx$ 50 μm far from sensor, Avl = avalange mode, OptA = setting of optical attenuator

MAPD 3N – rough scan

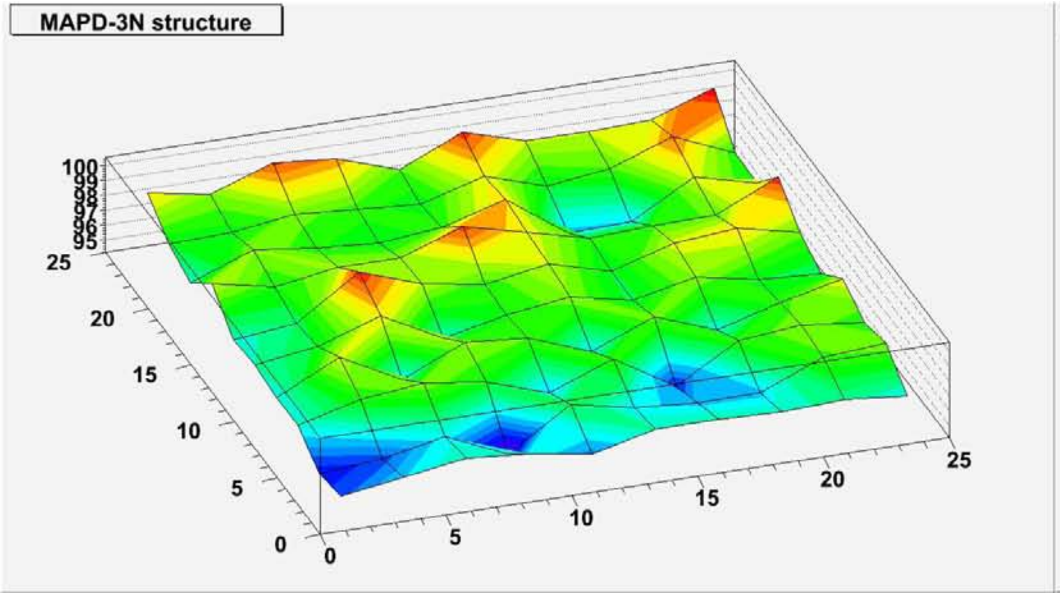
Maximum response (gain) is on corner ++ side close outer electrode bond pad and than second highest response is on corner -+ with the second inner electrode bond pad. Sensor was perpendicular with xy position stages plane, changes (≈20 %) seem to be an issue of gain.

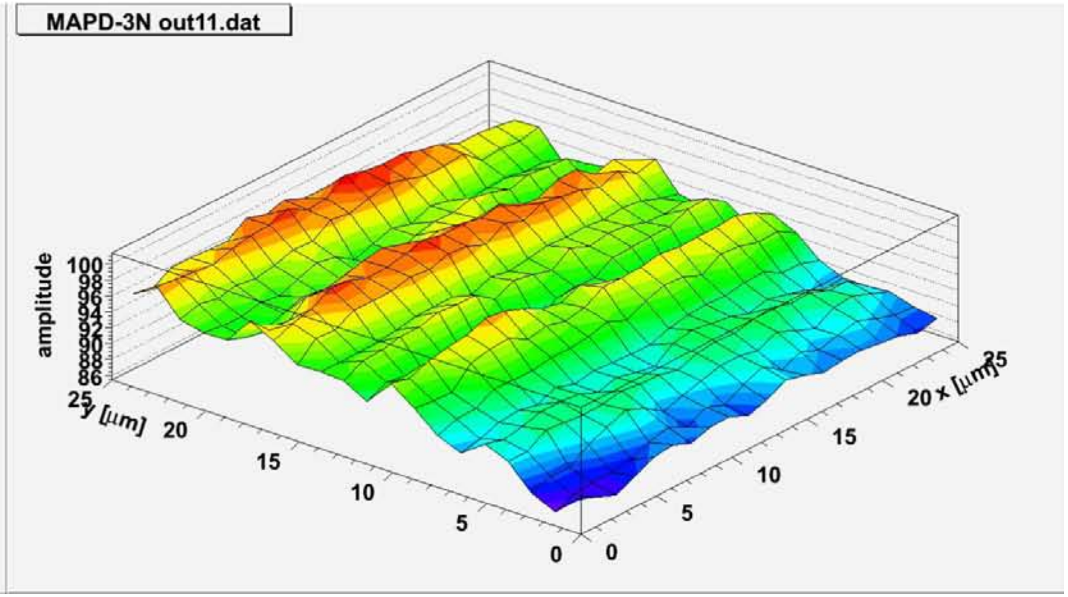


MAPD 3N – middle

response on the middle of sensor in smaller 1000 events per point (left) and higher 10 000 events per point (right) statistics.

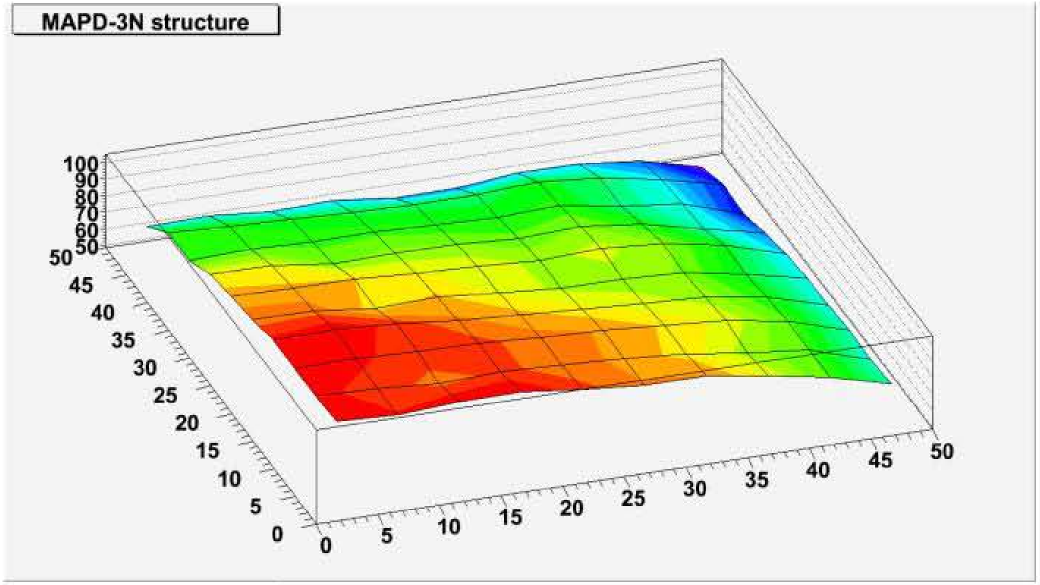
Scans are on different places in the middle.

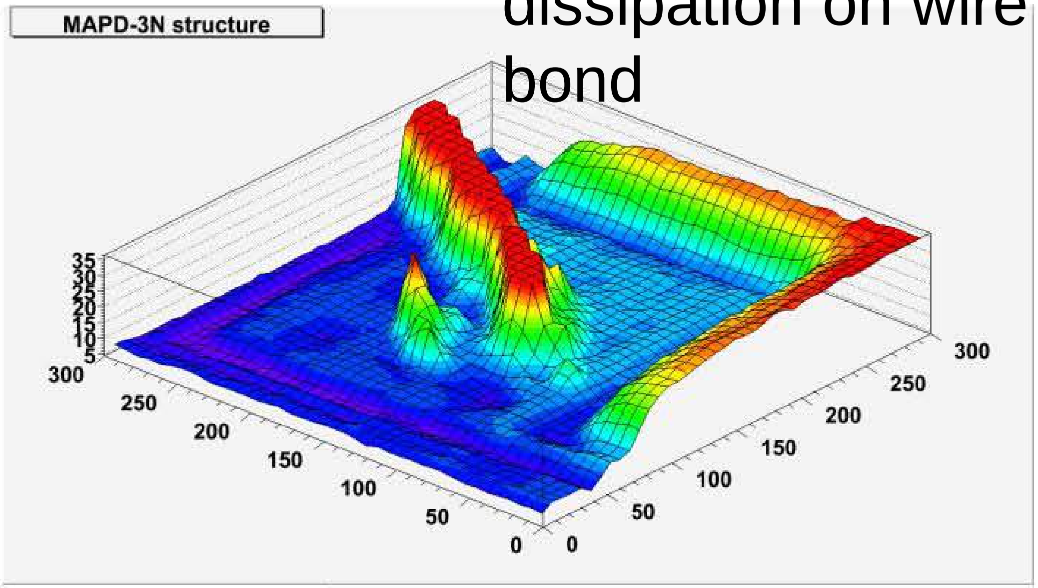


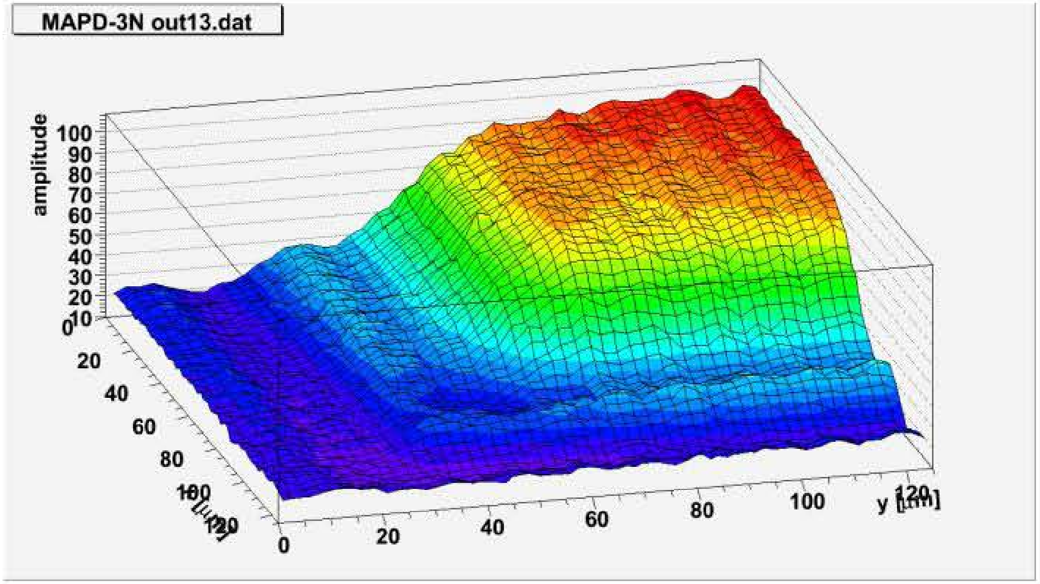


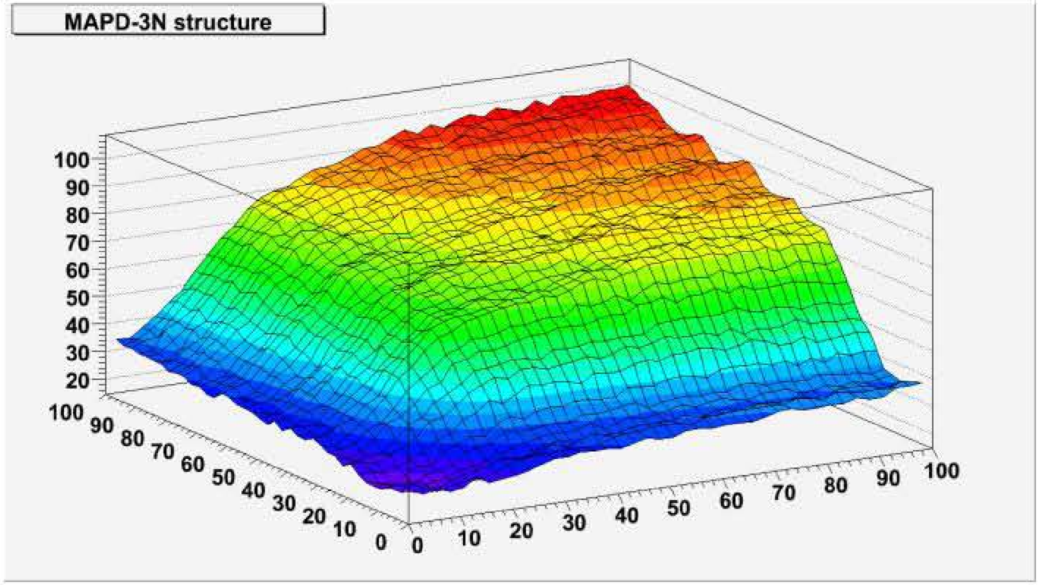
MAPD 3N – corners

Effect of light dissipation on wire bond



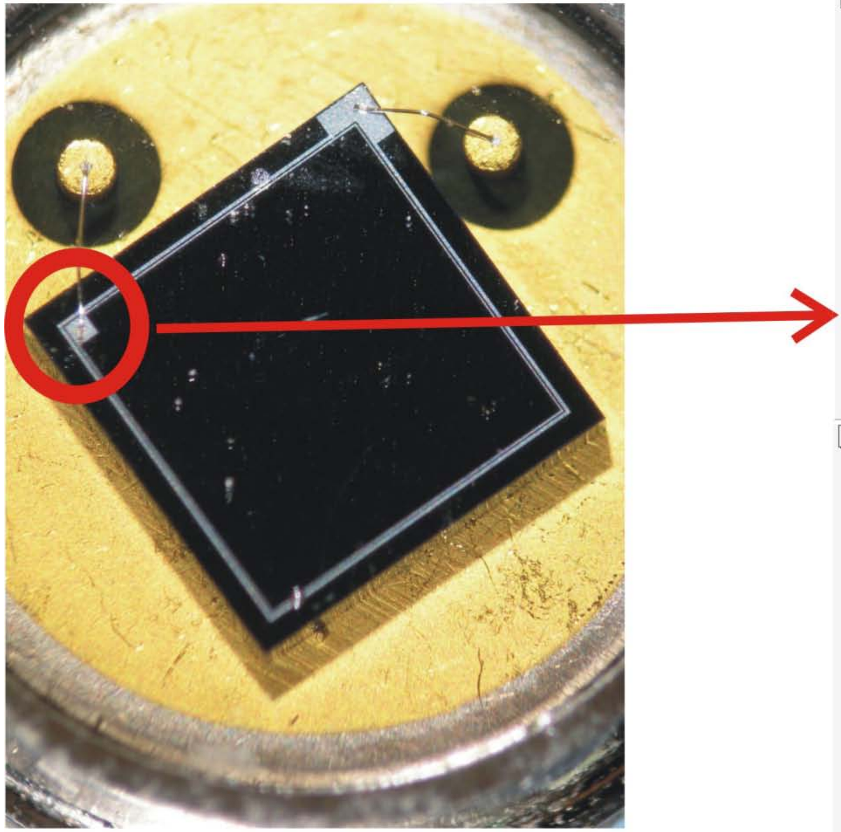


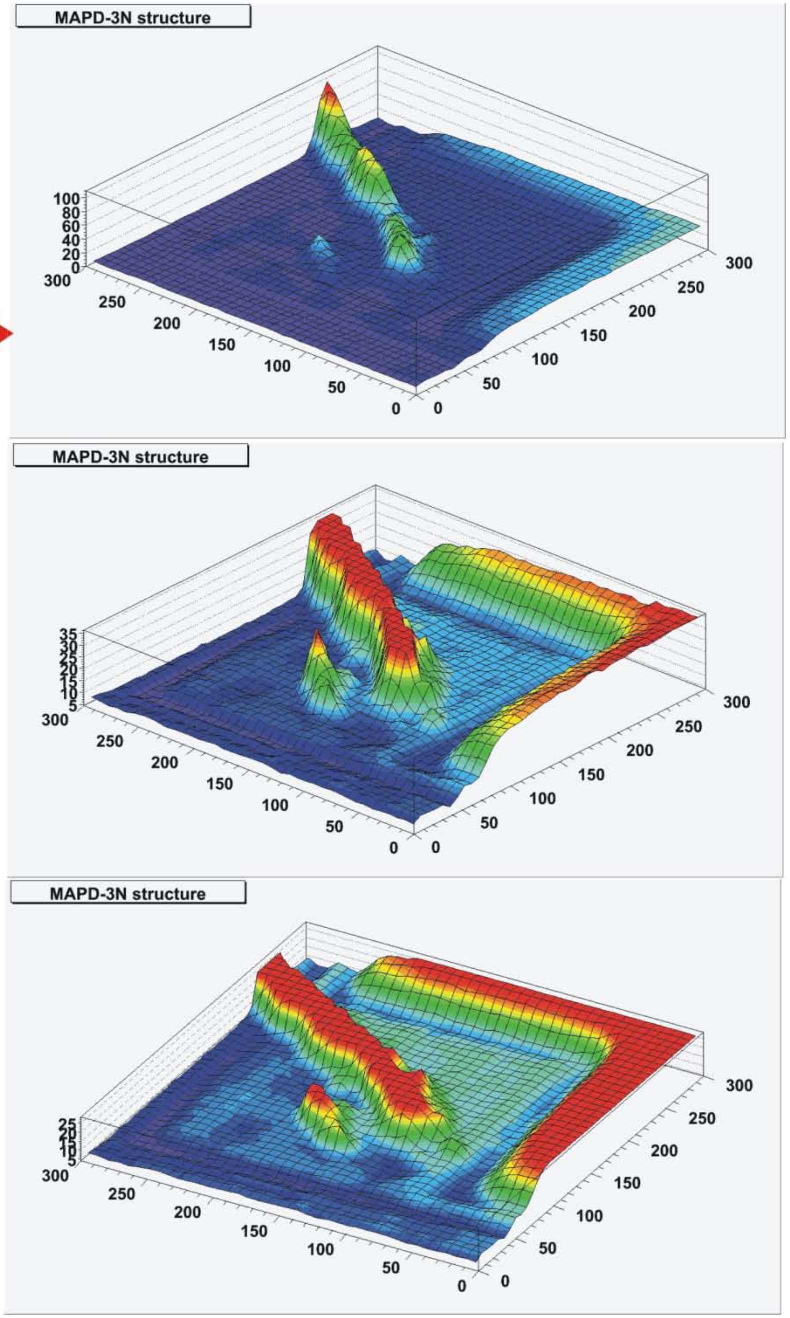




Note that plots are related to photos with mirroring transformation.

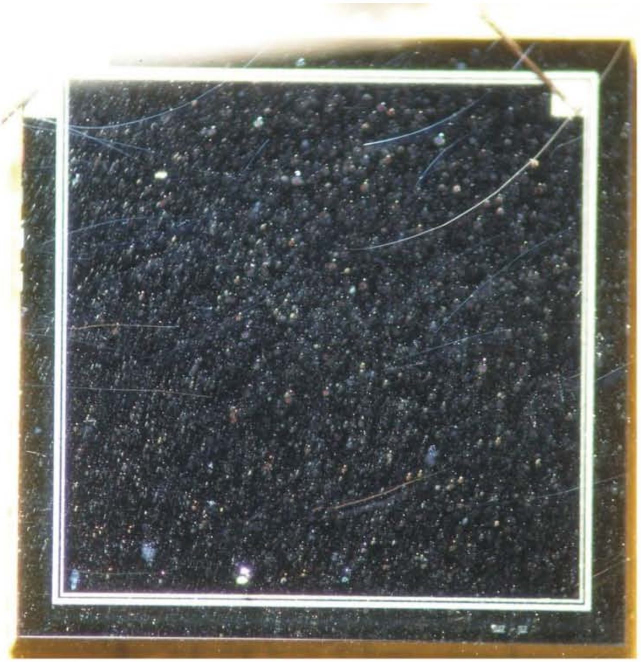
MAPD 3N – corners





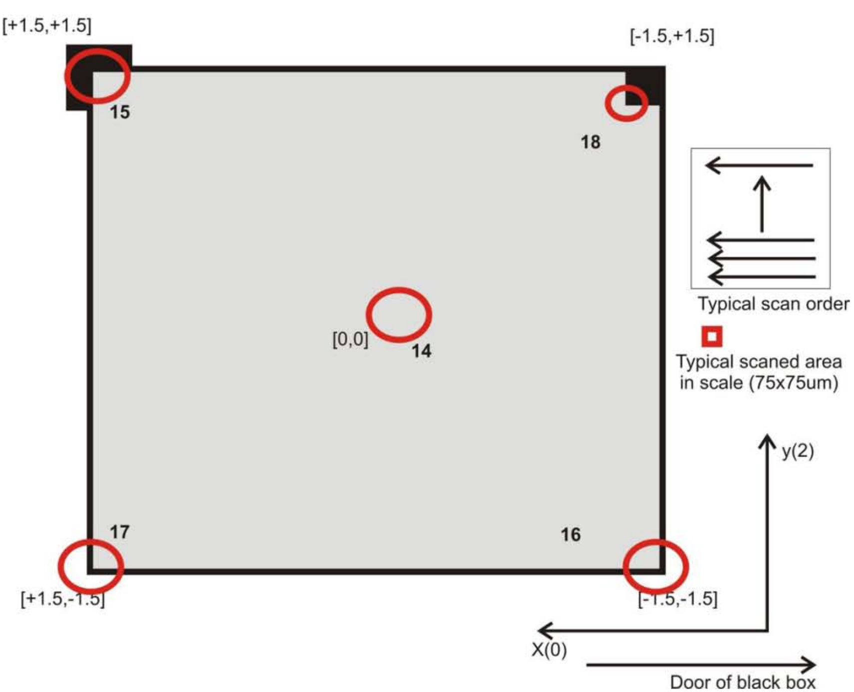
Study of effect of light dissipation on wire bond

Is it potential problem?



MAPD 3N1P

sensor of an newer type, size 3x3 mm^2 with pitch between sensing cells 8 μm in both directions, collecting sense area in cell is 5x5 μm^2, expected gain is 6 - 7 x10^4. Noise is 5 MHz / 9 mm2 and PDE 28 % for blue(470nm), 25 % for green(530 nm) and 10 % for red(650nm) light



Number of small bubbles on epoxy cover is a source of a dissipation of focused light in laser beam and final response is smeared. Also attempt of cleaning of surface created number of scratches and grease layer on surface.

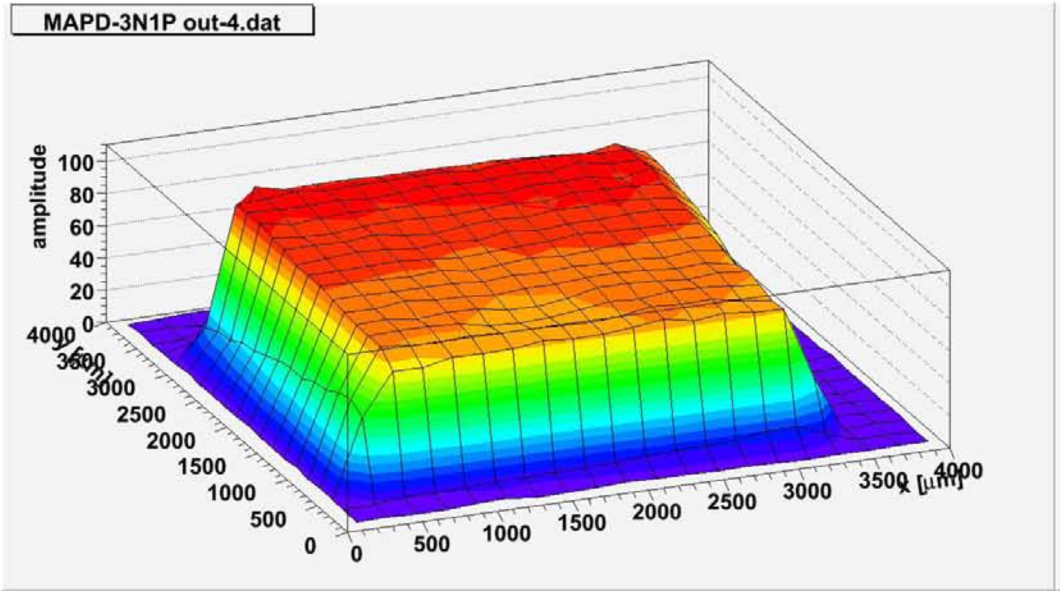
MAPD 3N1P

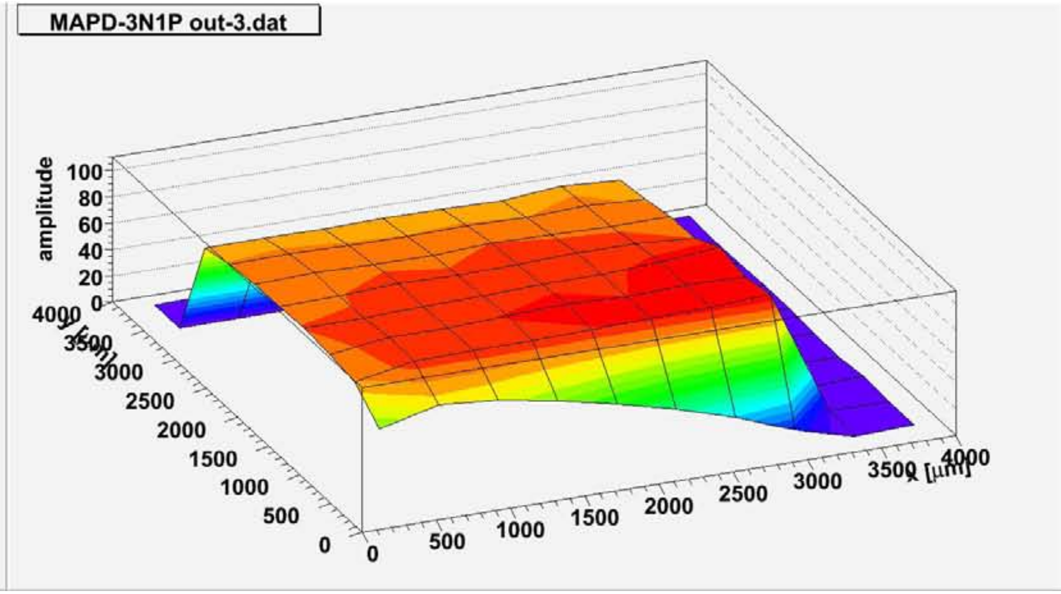
Scan Number	Scan Matrix	Step Size [μm]	Comment / Conditions
-4	20 × 20	200 × 200	rough scan, Def+0.4mm Avl 93.9V/60nA 3.36V/20ns 1kHz OptA7000 1000Ev/p
-3	20 × 20	400 × 400	rough scan, Def+0.4mm Avl 94V/67nA SwpAx 3.6V/20ns 1kHz OptA7000 1000Ev/p
14	20 × 20 middle	2.5 × 2.5	focused scan, Avl 94V/68nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
15	30 × 30 corner + +	2.5 × 2.5	focused scan, Avl 94V/68nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
16	30 × 30 corner - -	2.5 × 2.5	focused scan, Avl 94V/68nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
17	30 × 30 corner + -	2.5 × 2.5	focused scan, Avl 94V/68nA 3.6V/20ns 1kHz OptA7000 1000Ev/p
18	50 × 50 corner - +	2.5 × 2.5	focused scan, Avl 94V/68nA 3.6V/20ns 1kHz OptA7000 1000Ev/p

Table 4.1: List of 3N1P MAPD performed scans, Def+0.4mm = defocused beam with spot diameter $\approx$ 40 μm far from sensor, Avl = avalange mode, OptA = setting of optical attenuator, SwpAx = swap axes

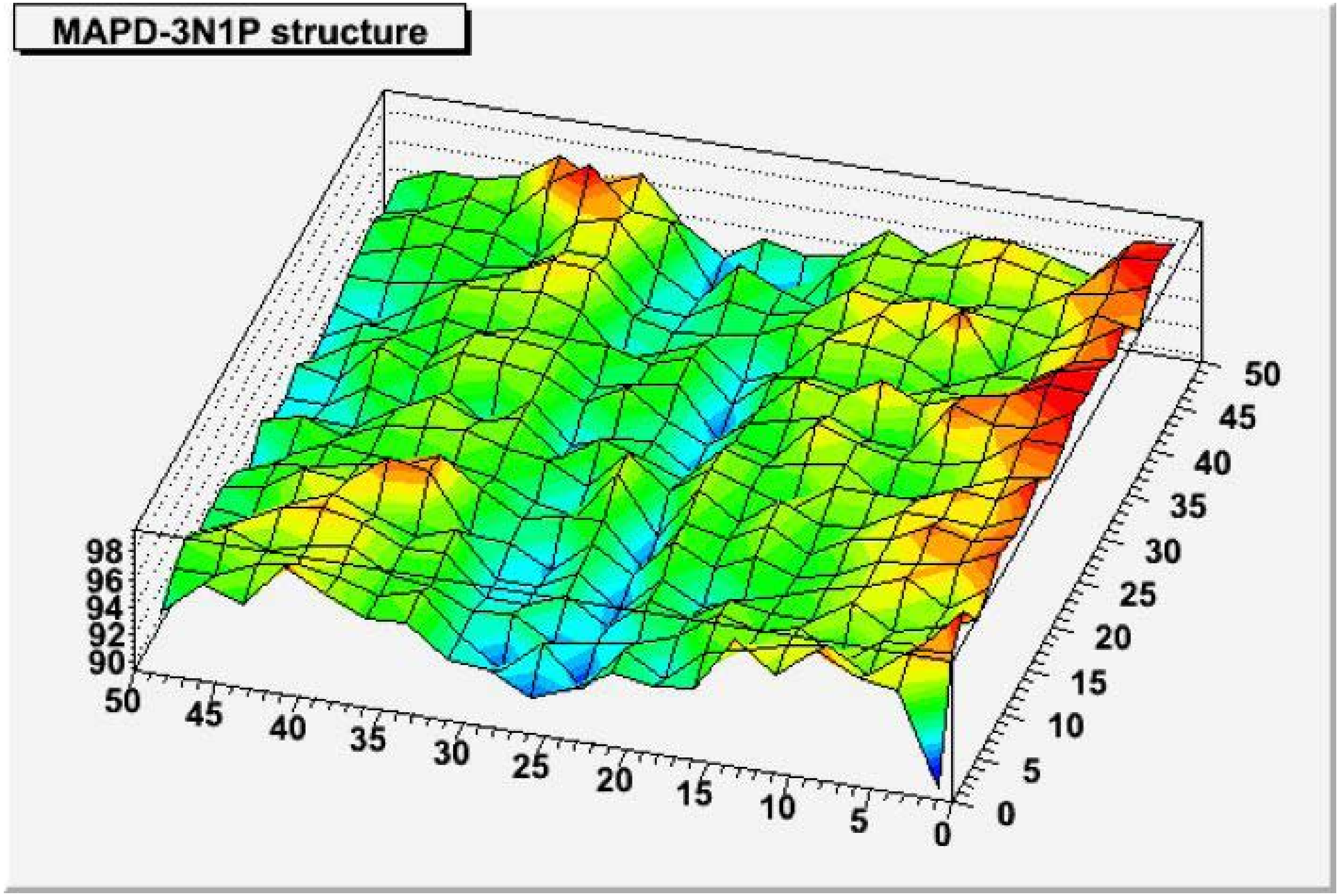
MAPD 3N1P – rough scan

Maximum response (right) (gain) is on corner ++ side close outer electrode bond pad and than second highest response is on corner -+ with second inner electrode bond pad. Sensor was not good perpendicular with xy position stages plane, checking of response in very good focus explain half (≈ 10 %) of difference in response, so half of changes (≈10 %) seems is issue of gain. Left plot was turned 180 deg

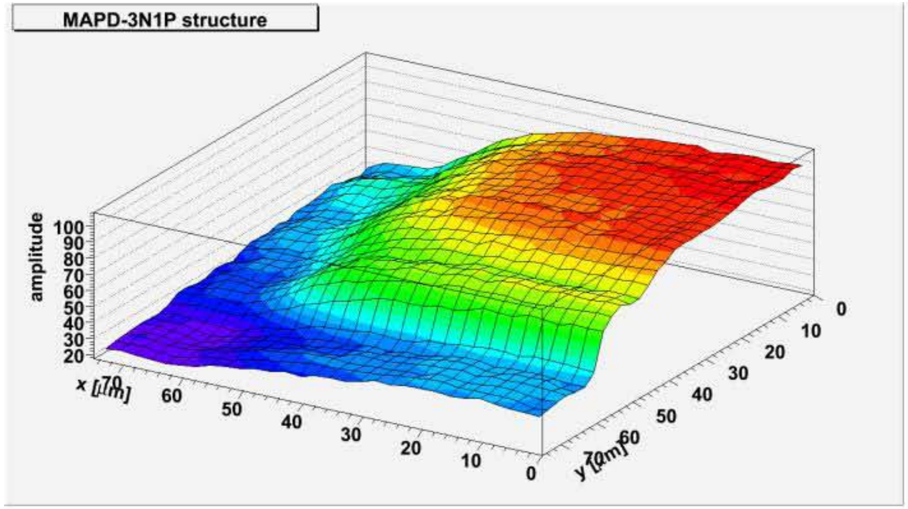


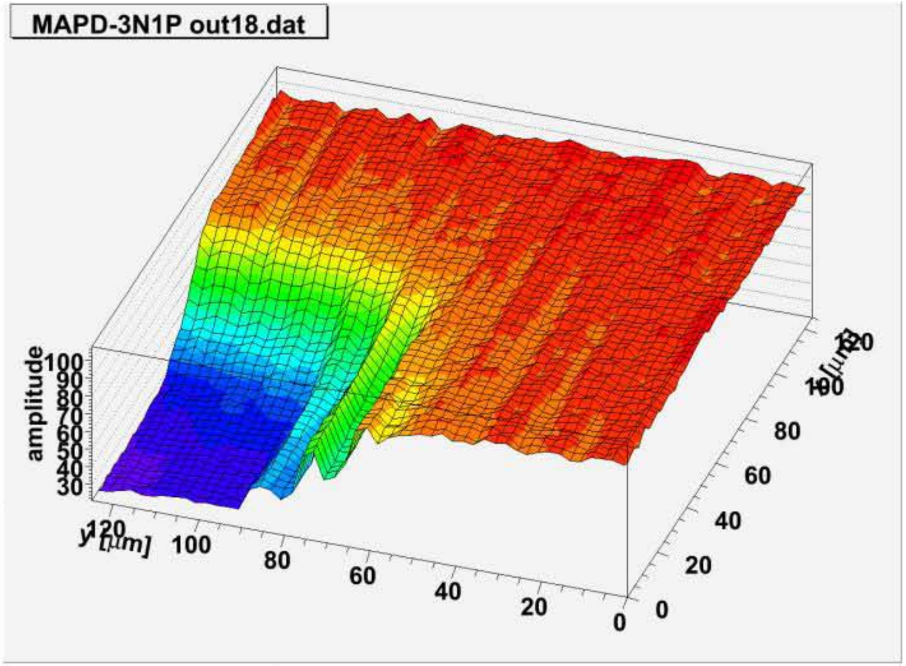


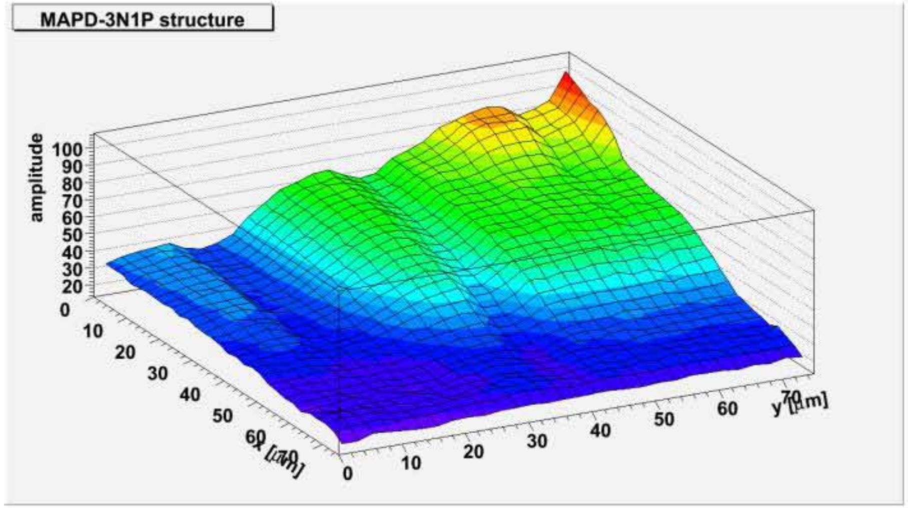
MAPD 3N1P – middle

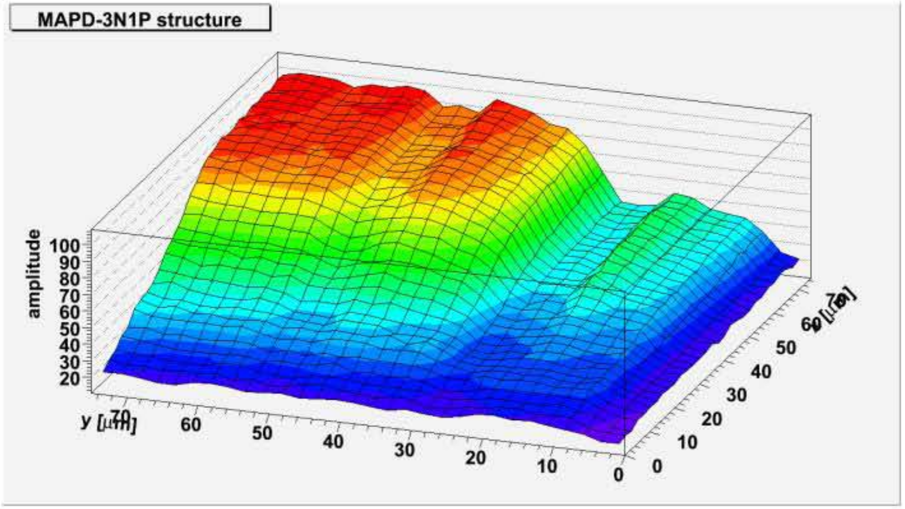


MAPD 3N1P – corners









Note that plots are related to photos with mirroring transformation.

Summary And Conclusion

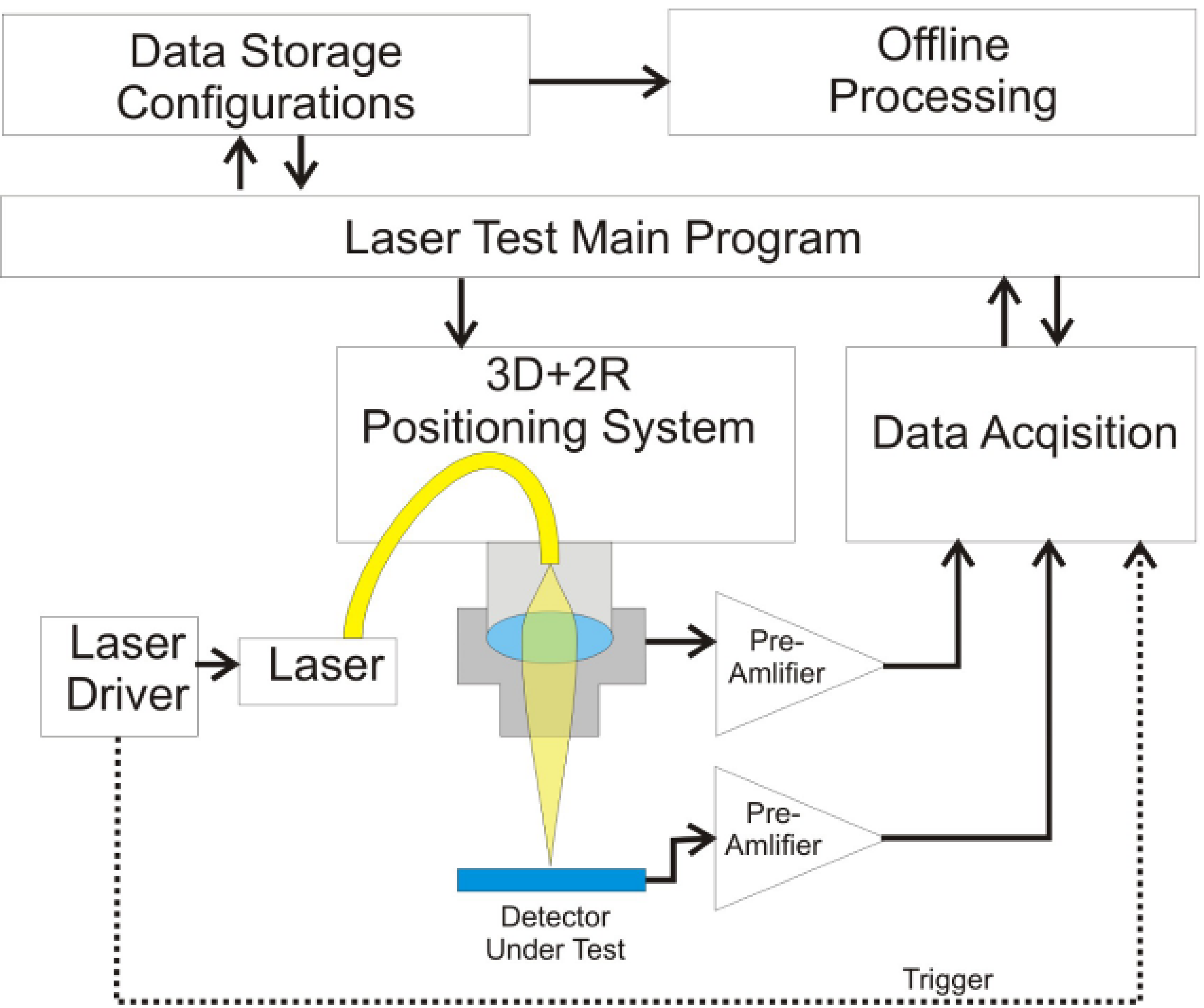
- Further tuning of laser setup was performed.
- Method of focusing was successfully applied and efficiently used.
- Basic set of scans takes approximately 1 day.
- Plots show in one dimension clear visible structure on response – some changes on large area response (gain seems to change on range 10 % and its maximum is close to pads for bonding)
- Change of response in cell area at a level of 10 - 20 % (which can be an effect of response from few more cells at the same places)
- Nice response in high statistics measurement in proportional mode.
- Measurement method is well under control, it is easy and quickly applicable for samples and should give good feedback to MAPD designers.

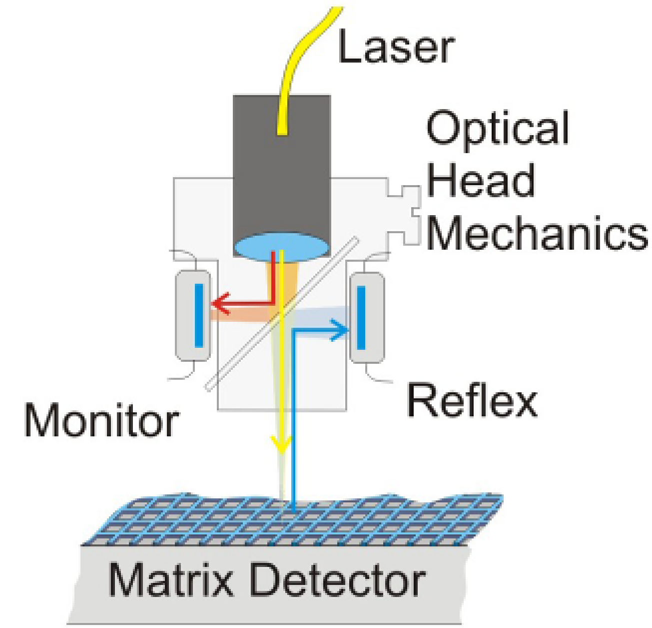
This project was supported by CSF Nr. 114-55/7720 (local ID), project IN-TAS Ref. Nr 05-1000008-8114, grant of cooperation of Czech Republic with JINR and grant of Ministry of Education, Youth and Sports: MSM0021620859.

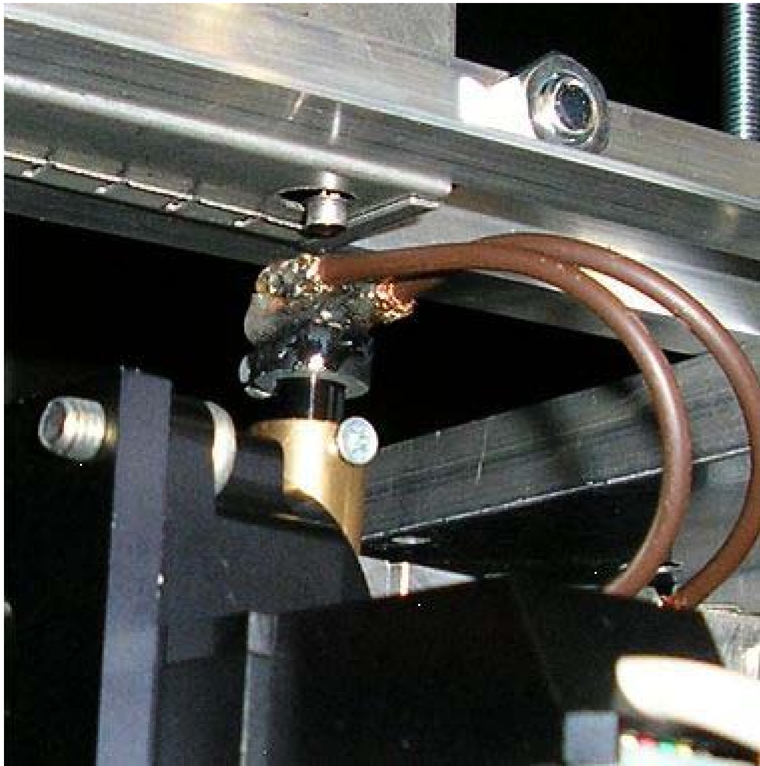
Backup slides (more in Darmstadt talk)

Test Arrangement

Schematic of measurement electronics, optics and photograph of optical head in the test setup

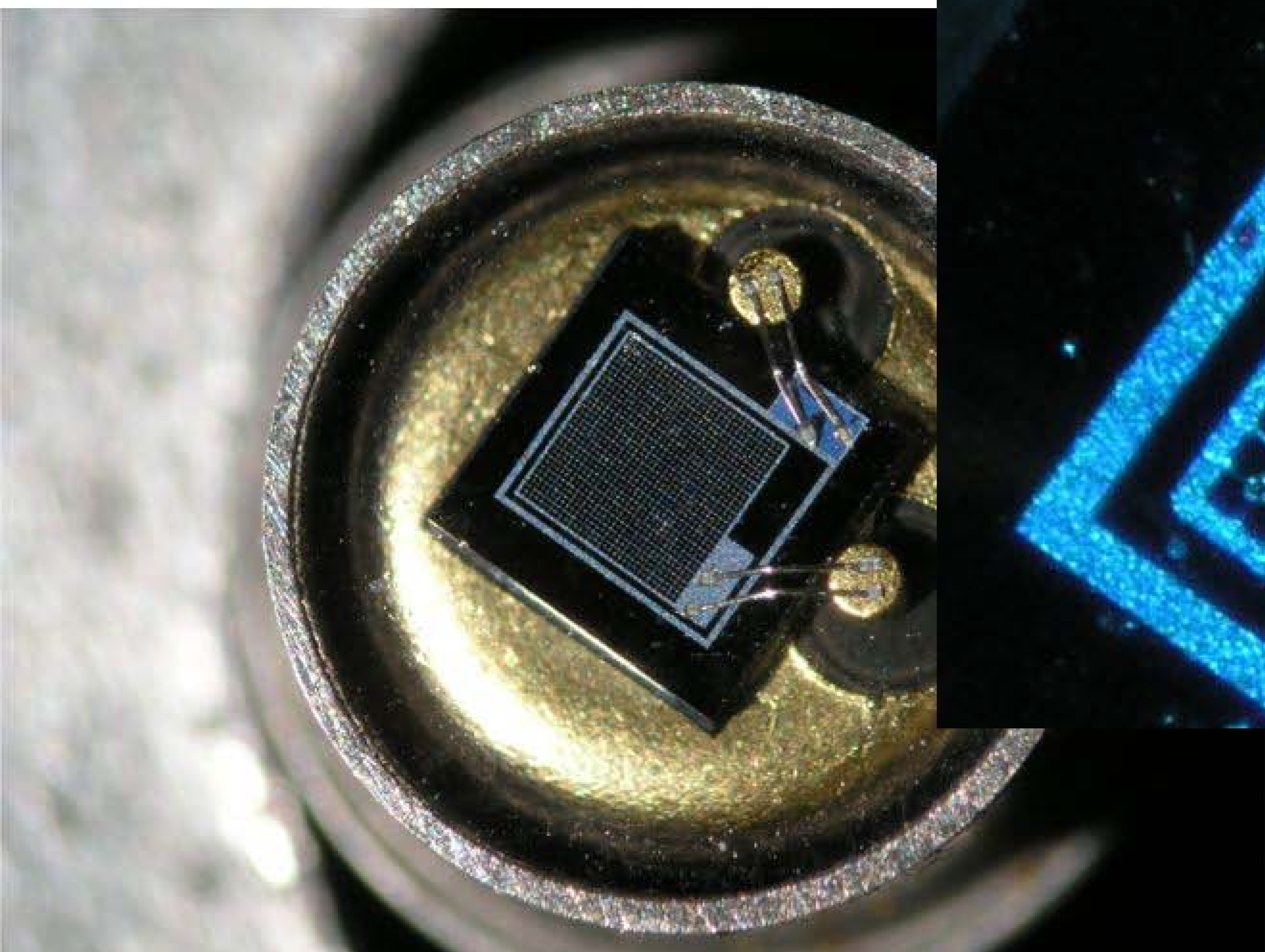


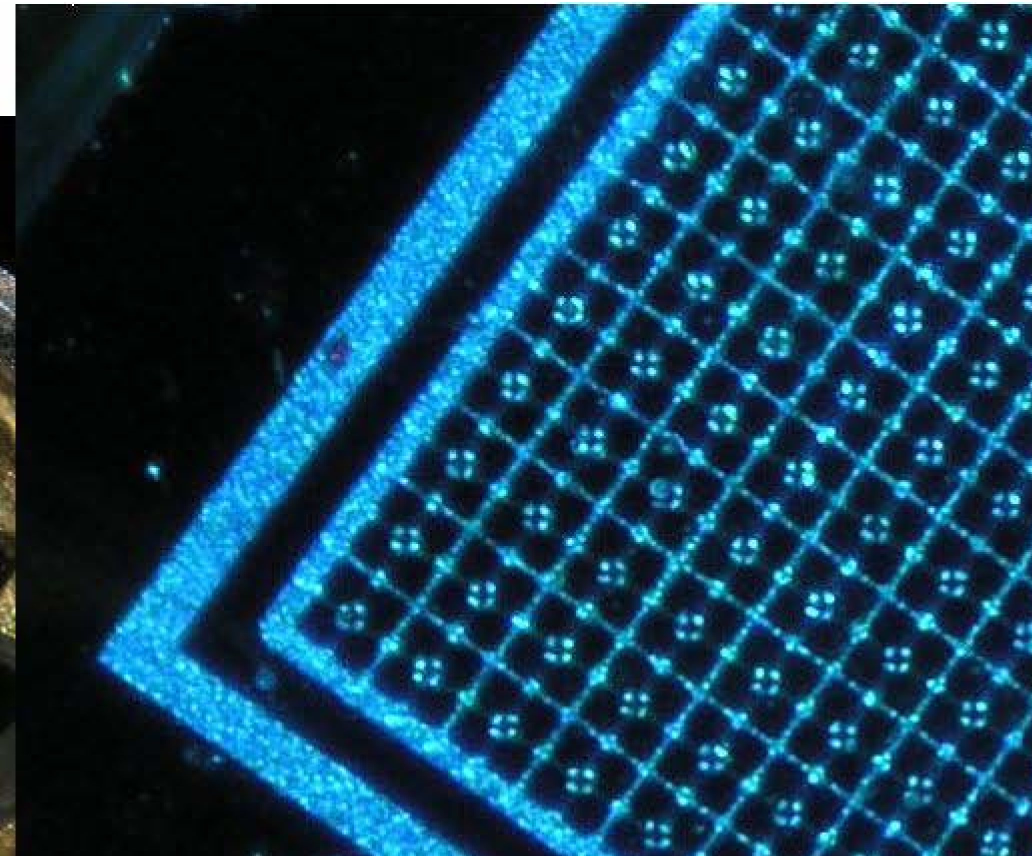




Samples Arrangement

MAPD samples are mounted to standard 2-pin covers and join to preamplifier electronic via ~2cm wires

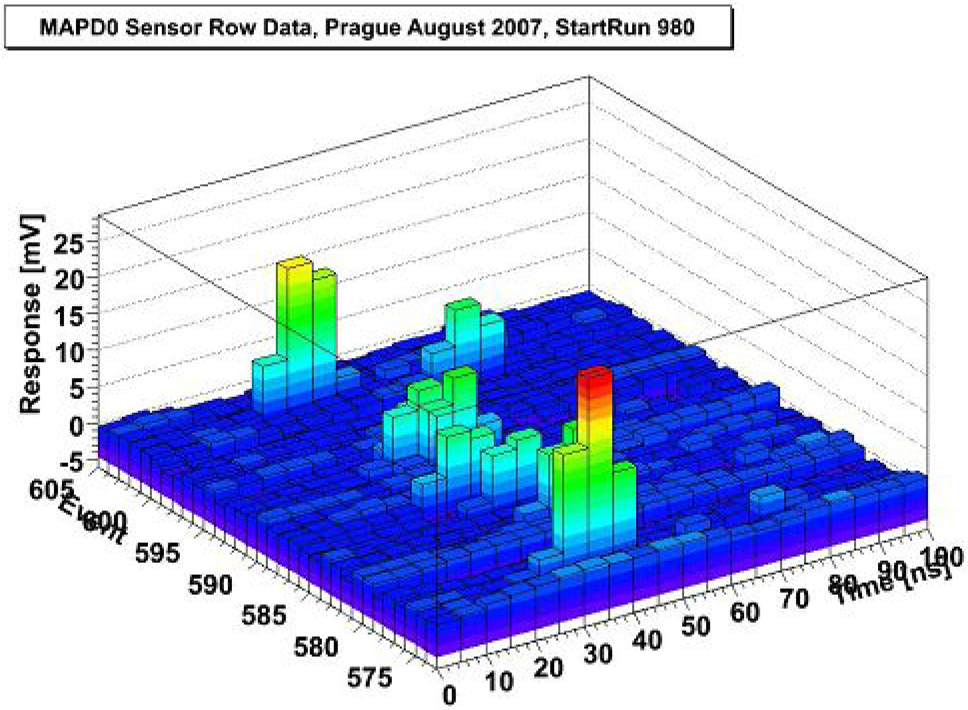


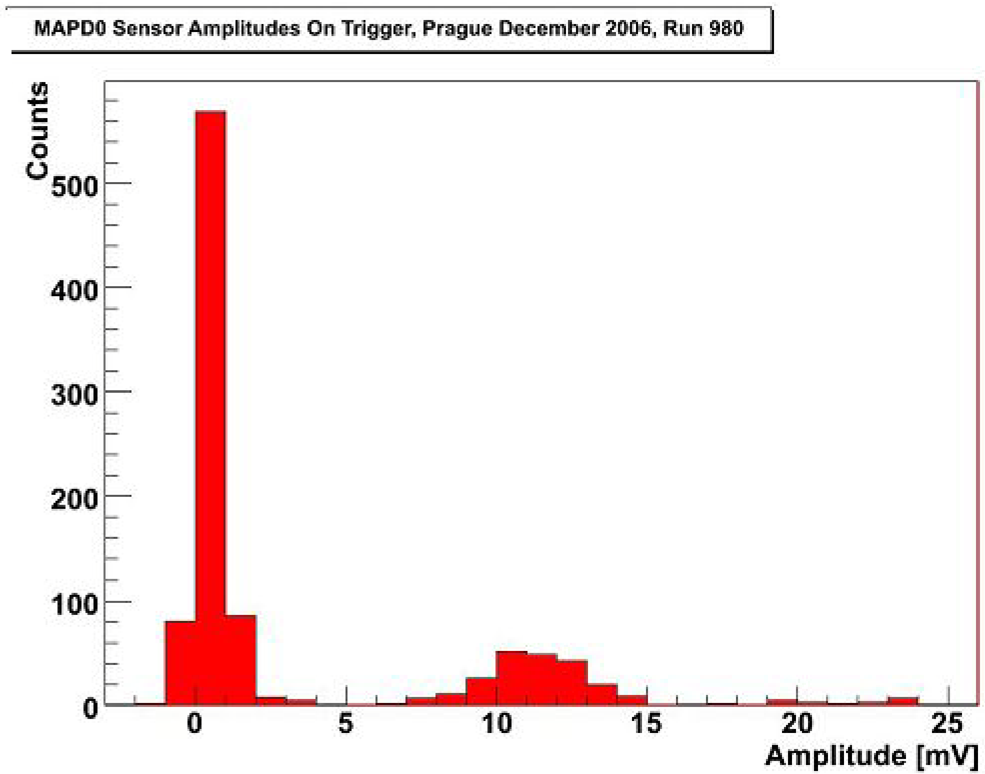


Measurement procedure

- MAPD response was observed on an common trigger for laser pulse and readout scope, home made preamplifier electronics
- Laser power was adjusted by optical attenuator from OC Optics
- Two laser energies are available for deep and surface charge creation: 1055 nm (infrared) and 680 nm (red) wavelength
- Each measurement contains 1000 (10 000) acquired events
- Every millisecond 20 values of amplitude with time distance 5ns have been collected
- We observe a response from the MAPD in 3-5 converted points
- The maximum response after pedestal subtraction (evaluated as the average of 5 points before MAPD signal) of the 5 points is used in further processing to collect and cut in response amplitudes histogram
- Tuning of focus distance is crucial, precision was about 100 μm
- Special method for finding an amplitude of maxima was applied

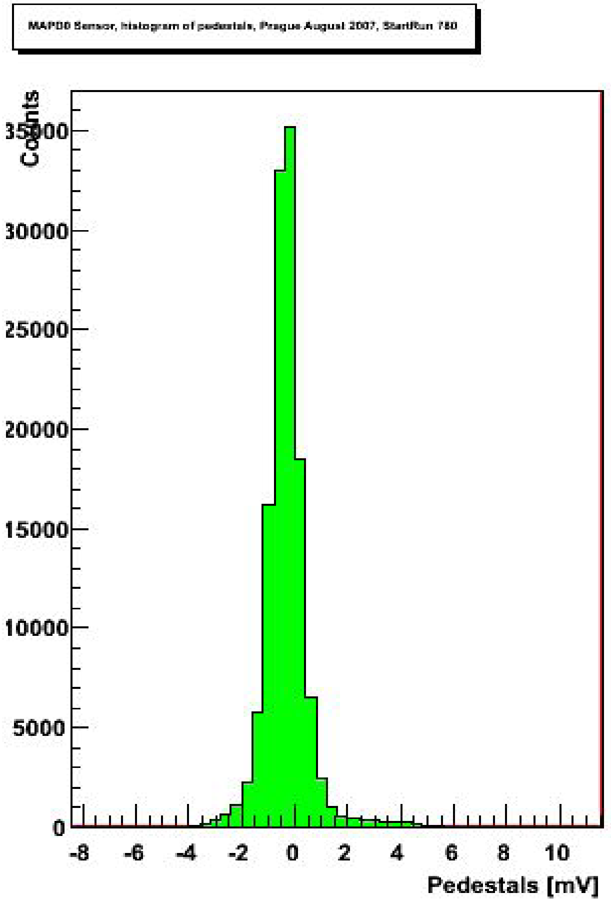
Measurement procedure

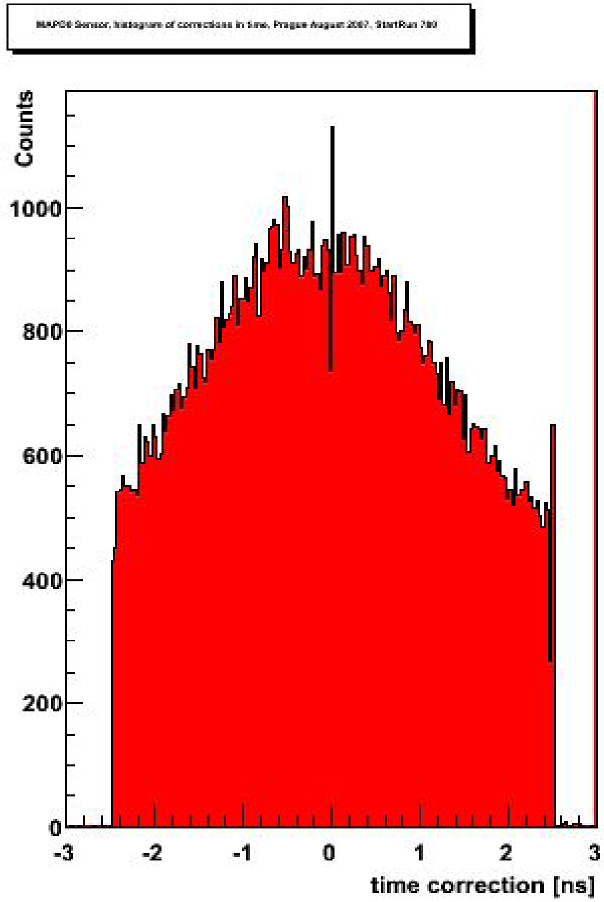


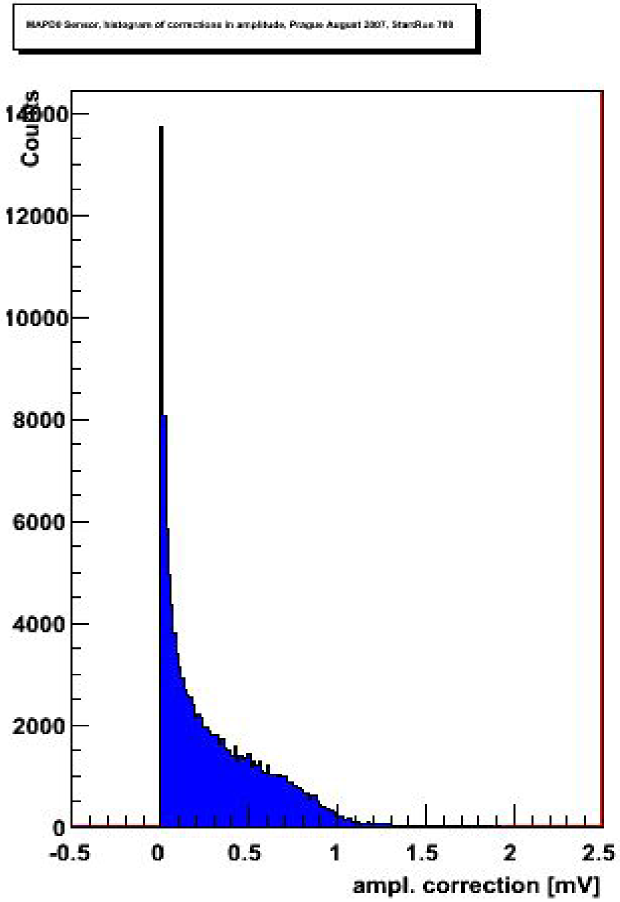


Acquired raw data from scope (left - polarity is inverted) a used for finding maximum (include corrections) which is collected for all 1000 events in histogram for further processing: select empty events, 1, 2 or more pixels response.

Measurement procedure

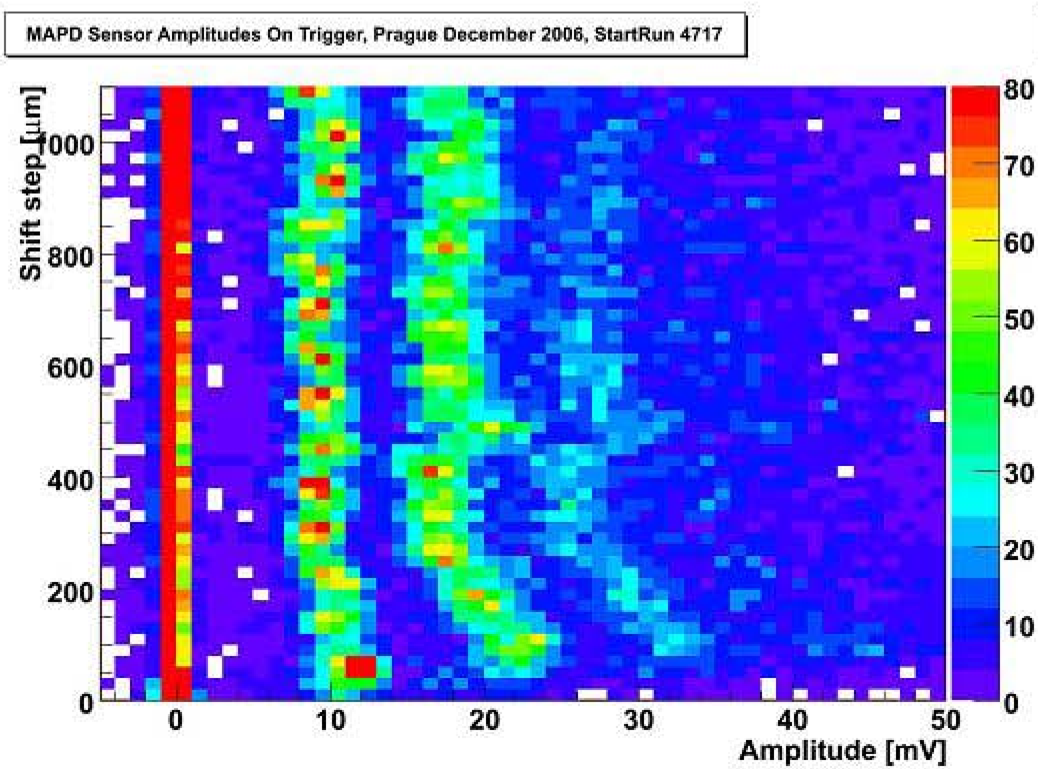


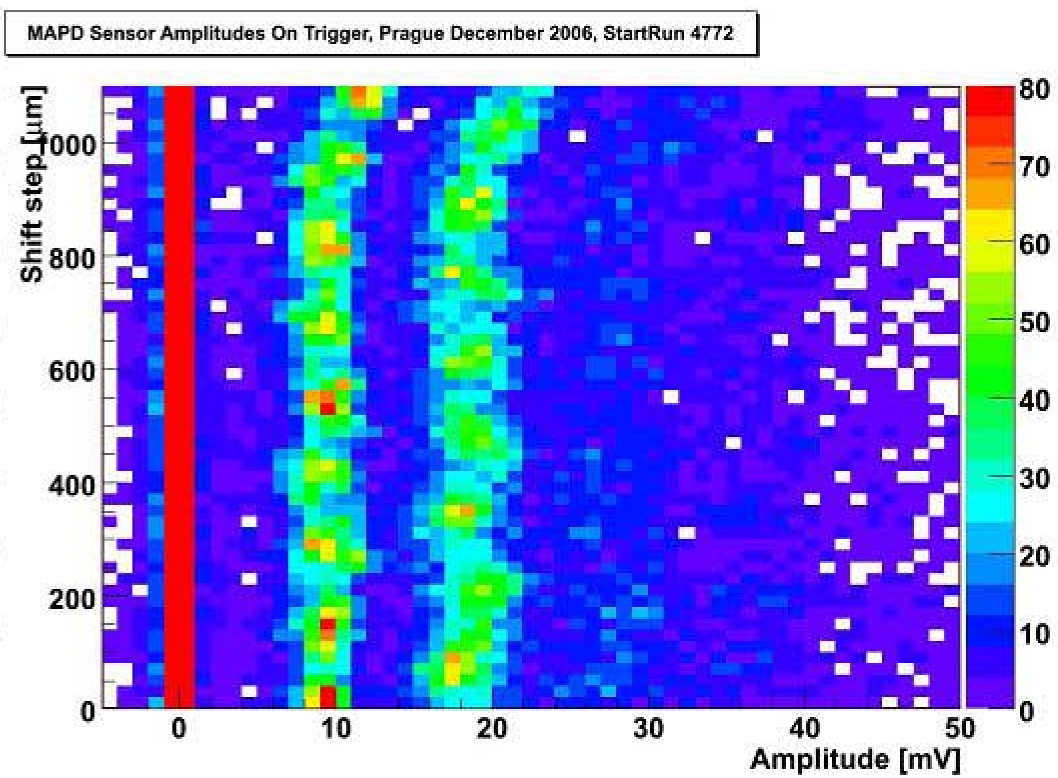




Corrections for fine tuning of response: pedestal subtraction for every pulse (left), time correction for position of maxima (middle) (this is also because laser pulse have width ≈ 2 ns) and finally amplitude correction (right) as extrapolation from 3 highest points on raw data

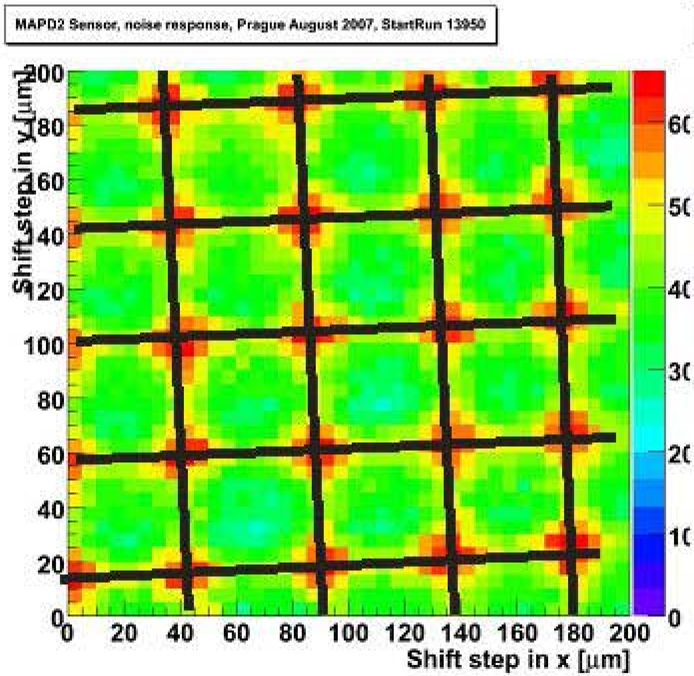
Measurement example

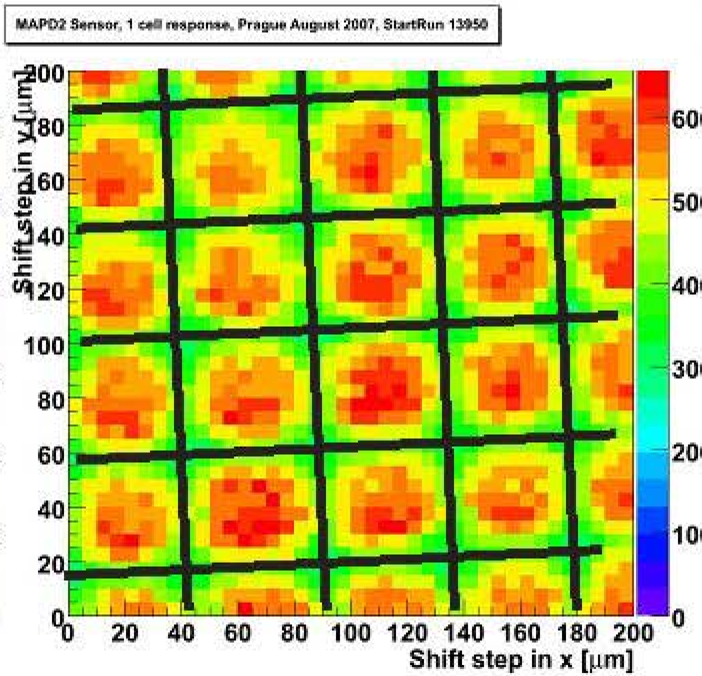


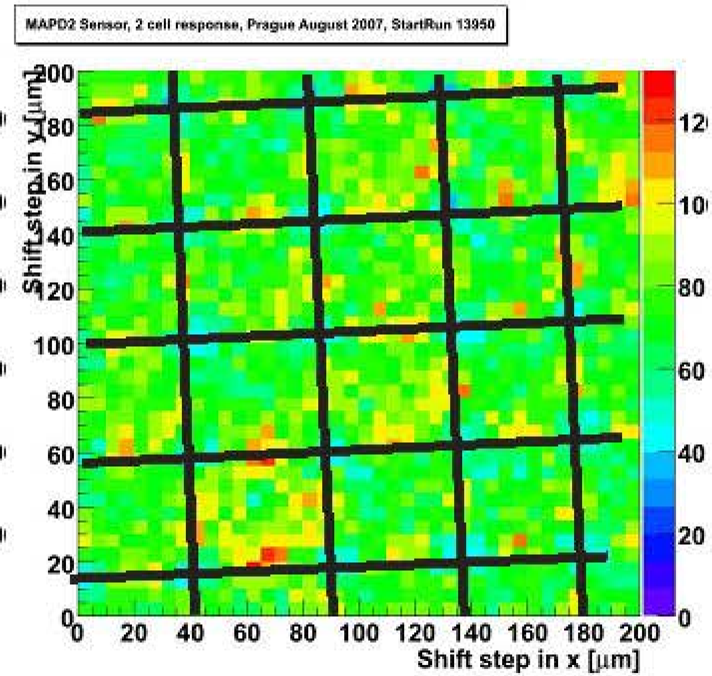


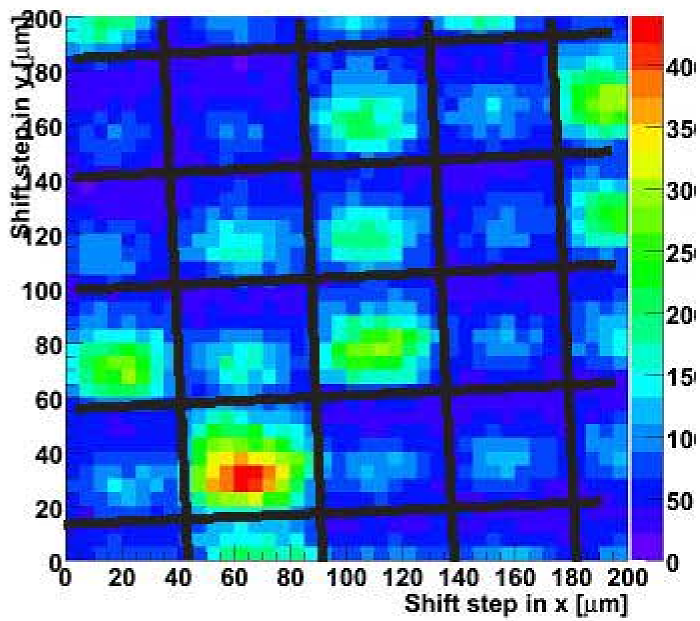
Scan over 1 mm range with 20 μm step in x (left) and y (right) directions. **Variations** in cell responses, such as **different gains near detector edge**, are visible on both plots.

Measurement example









MAPD#3: Scan 40 x 40 with step 5 x 5μm. Final matrices of empty (left upper), 1 (middle upper), 2 (right upper) pixels response. Bottom is selected 1 pixel response with only higher voltage response - it is **map of unhomogenities** of response between pixels and is subtracted from 1 pixel response matrix. There are some individual or groups of pixels with **higher voltage response** without clear reasons, and seems there are some of them very different.

Summary

All tools in place to evaluate **MAPD** performance:

- Detail response from single pixel
- Response homogeneity from set of pixels
- Edge effects close borders of sensitive area
- Quality of surface, cover epoxies,…
- Uniformity of gain from single pixels

Some **setup improving** are on progress:

- External focusing mechanism
- Blue/green 470 / 520 nm laser installation
- Analysis improvement and automation of data evaluation

Anyone interested in coming to Prague with other APDs?