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WORKSHOP ON PICOSECOND PHOTON SENSORS
FOR PHYSICS AND MEDICAL APPLICATIONS

June 8-10, 2015, Prague (Czech Republic)

Detector testing with short laser pulses

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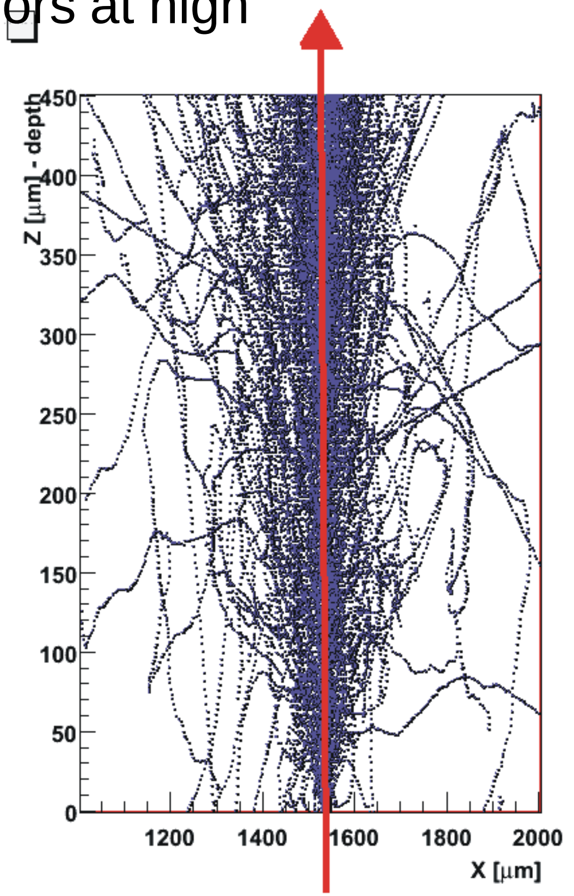
- Tests of silicon avalanche photodiodes
- Conclusions



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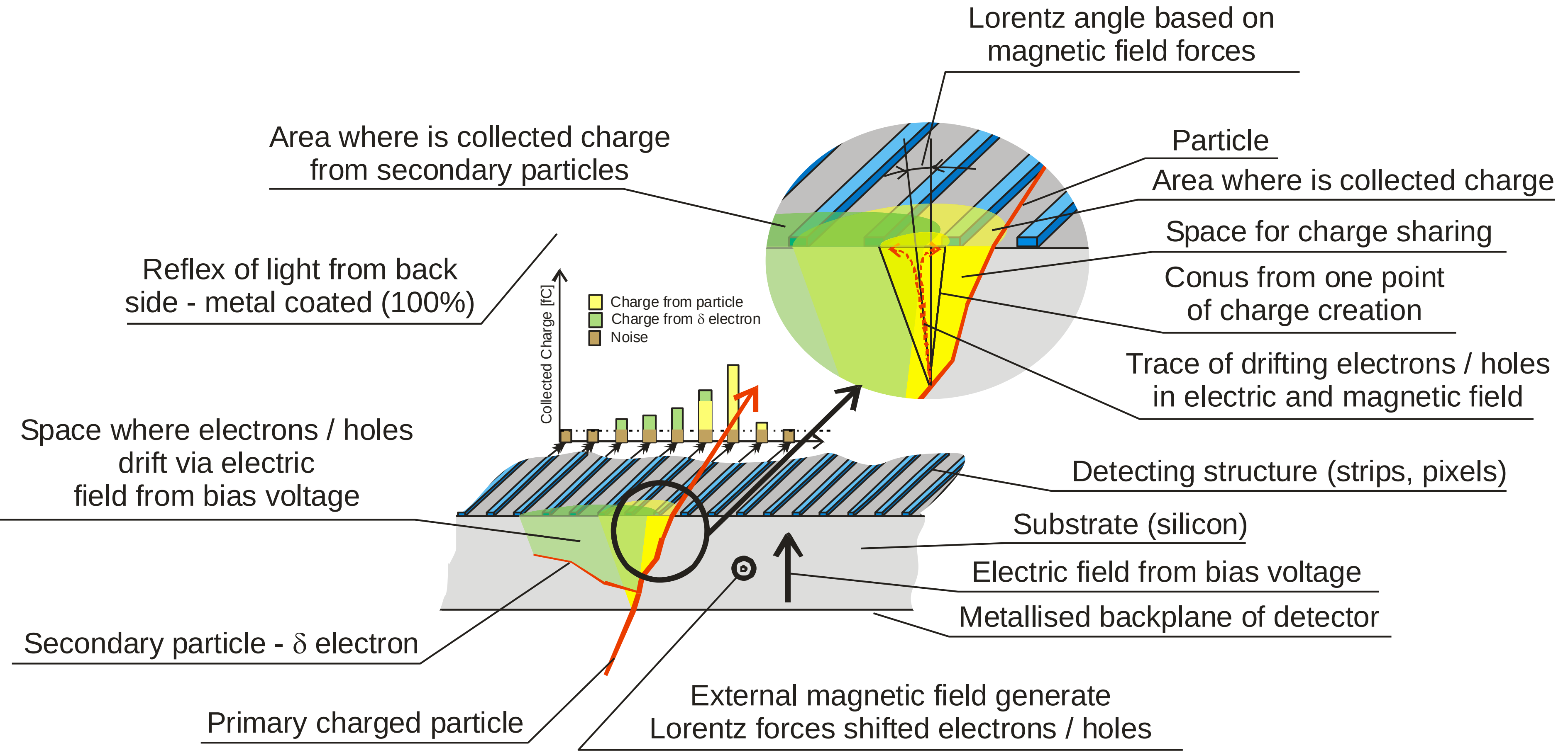
Properties of laser tests specific for silicon sensors at high energy physics

Differences from reality of HEP



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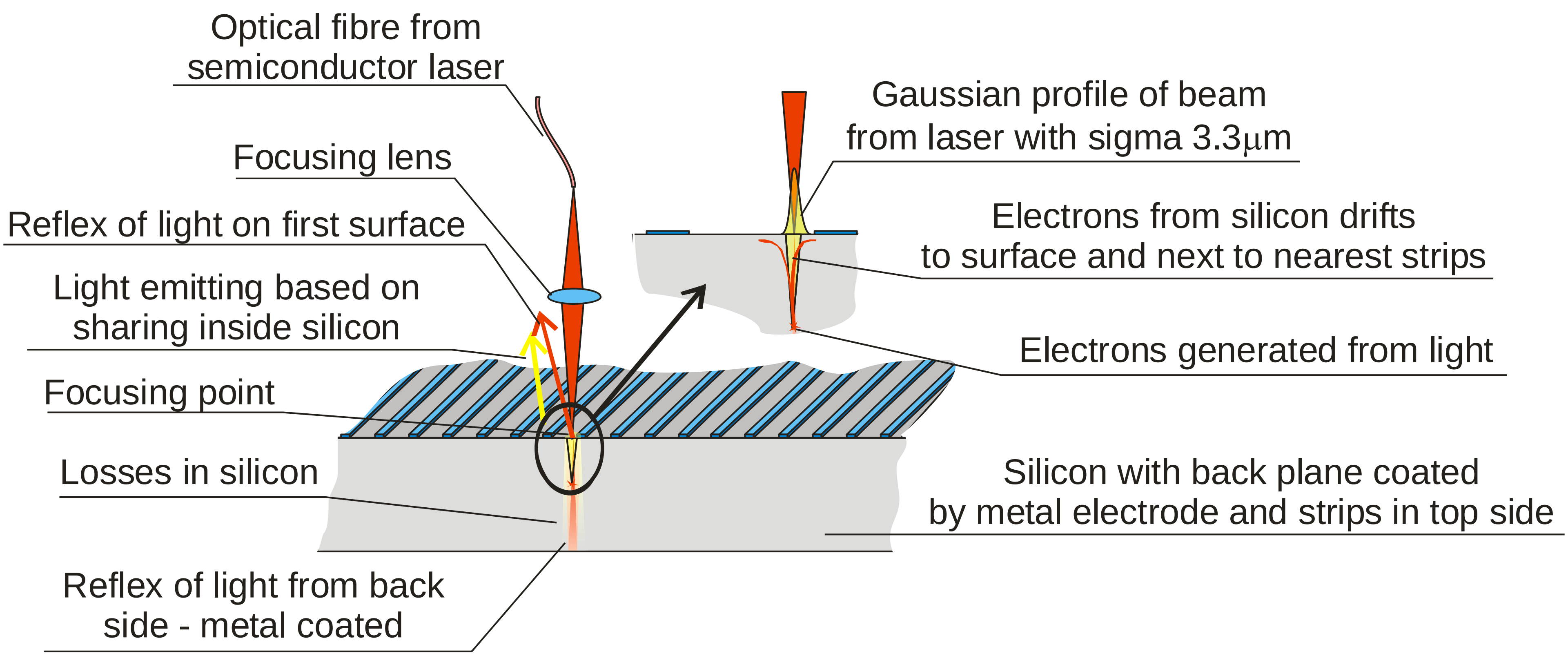
Differences from reality of HEP



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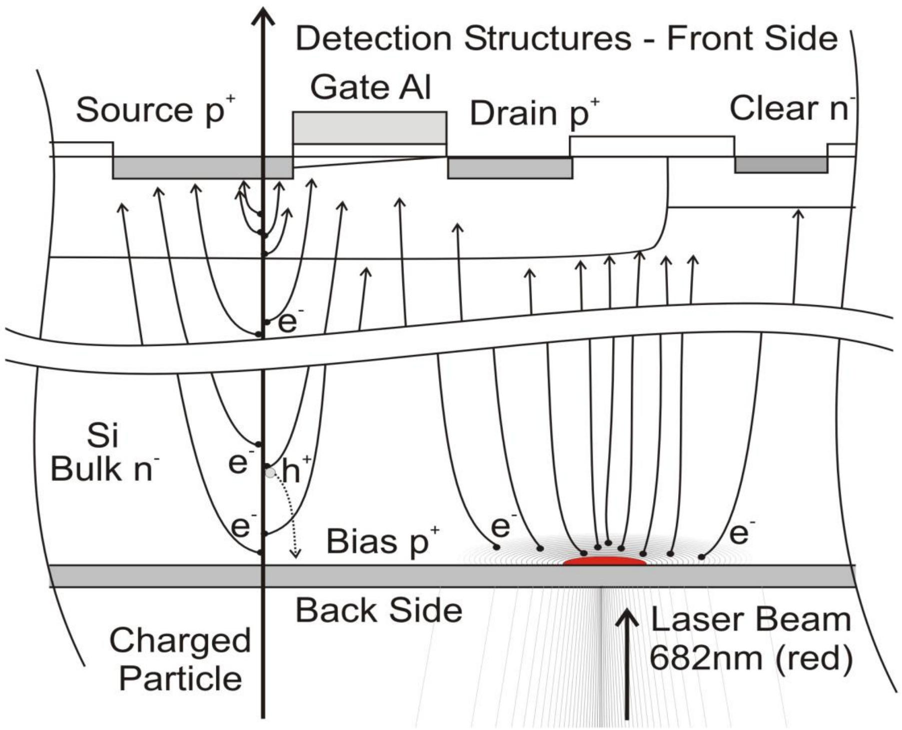
Properties of laser tests specific for silicon sensors at high energy physics

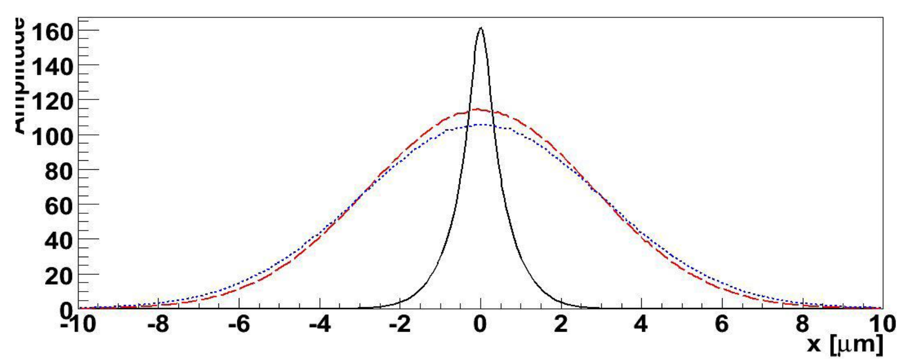
Differences from reality of HEP

Particle flight time ~ 1ps

Laser pulse generation ~ 1ns – shape well under control



Charge distribution on surface generated by particle passing perpendicularly the sensor (black), red (682 nm) laser (dash red), and infrared (1065 nm) laser (dot blue). Laser response scaled 4x for better visibility.



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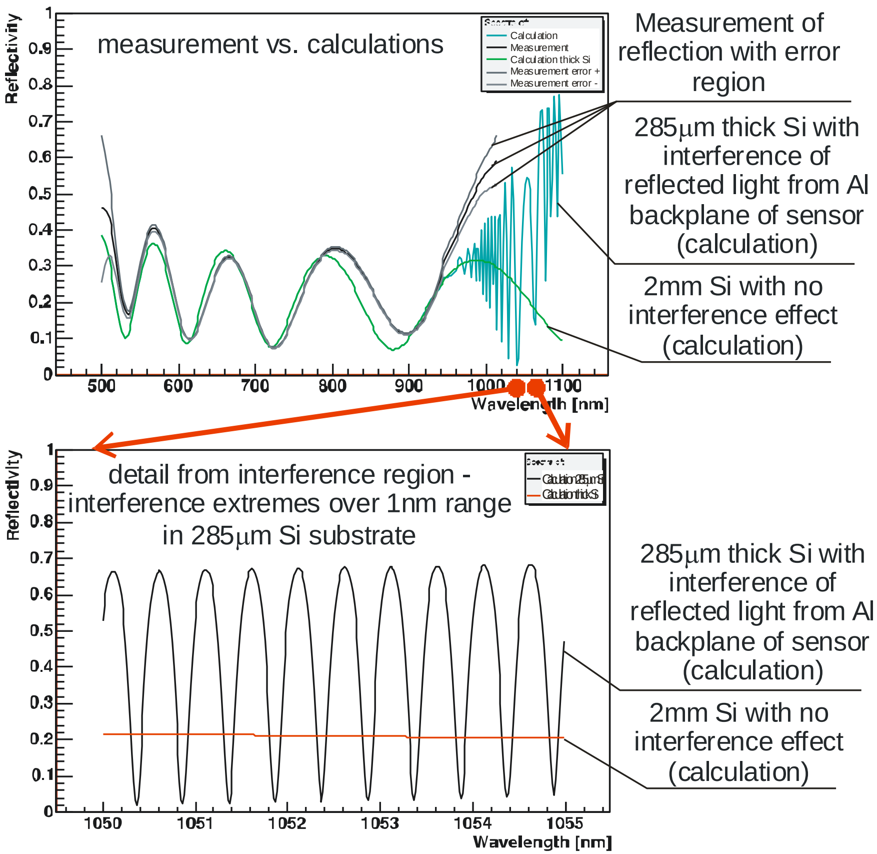
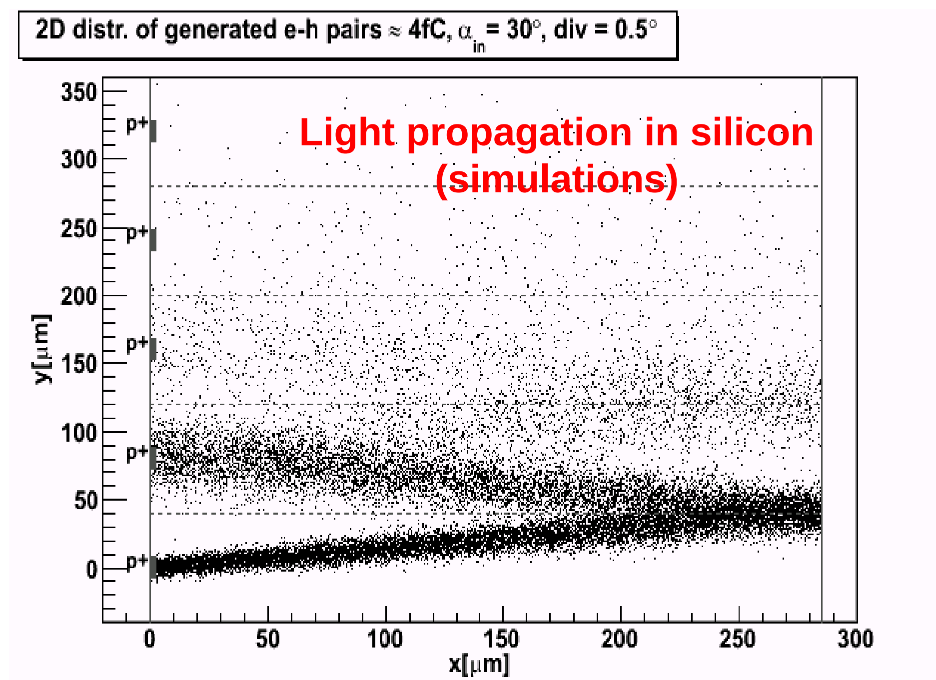
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Properties

Light: sensitivity to surface quality, layer thickness, refractive properties of silicon and layers, inhomogeneities, interferences, reflections, exponential attenuation in matter, penetration depth, speckle structure of spot





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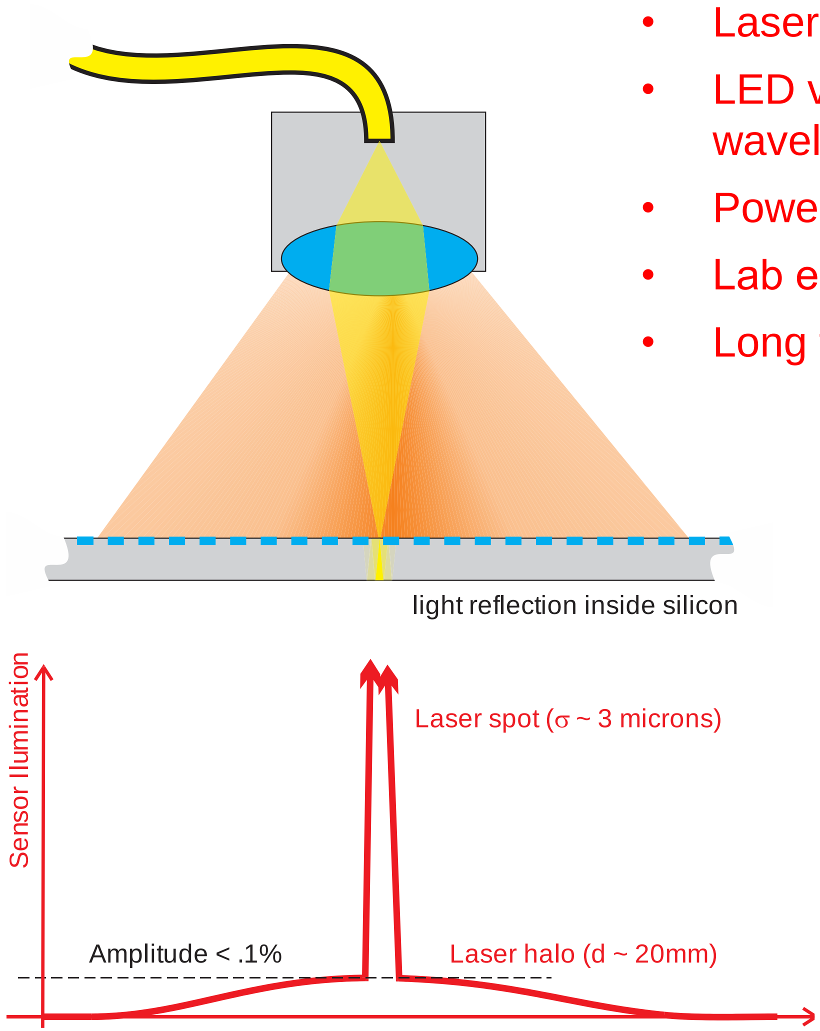
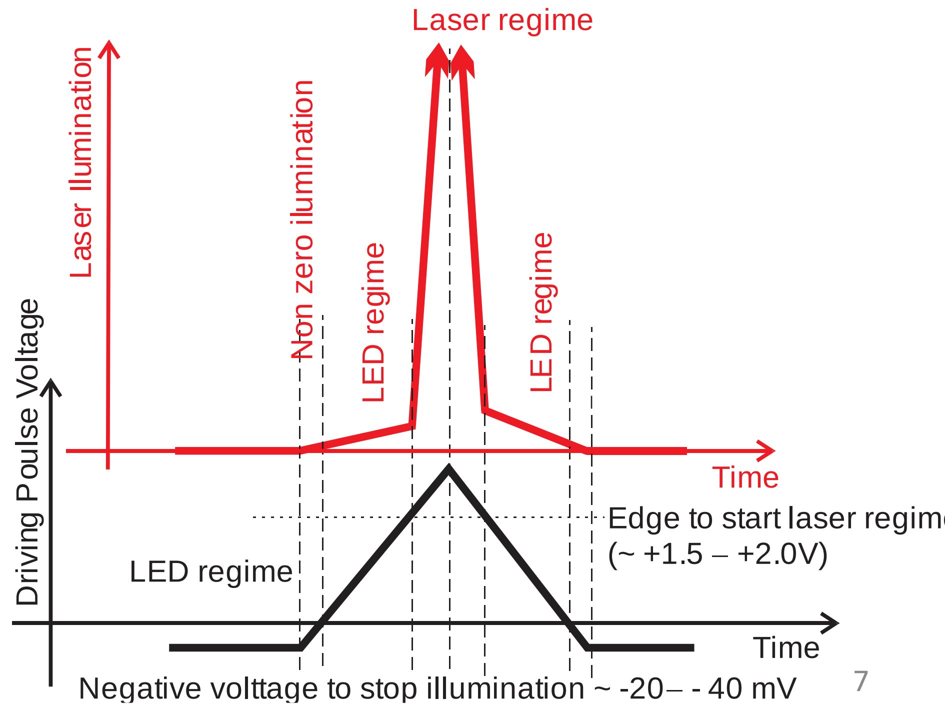
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Properties

- Light halo around the spot
- Laser light output even at zero input pulse or power off
- LED vs. laser regime of source: unstable power, multi-wavelength, wider spot
- Power setting by motorized optical attenuator
- Lab environment sensitivities (P, T, H,…)
- Long test duration (automation of measurements)





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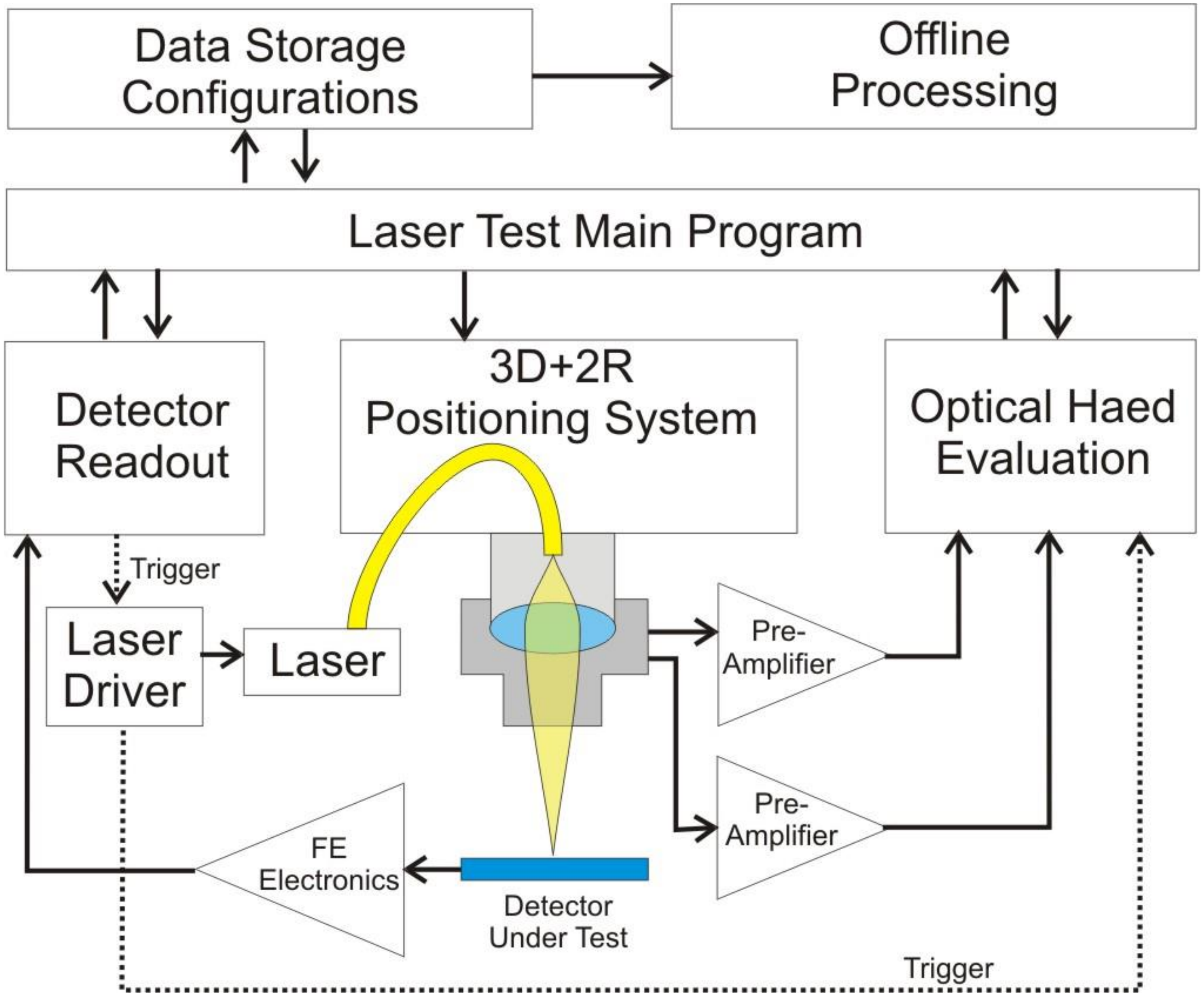
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Tricks and hints



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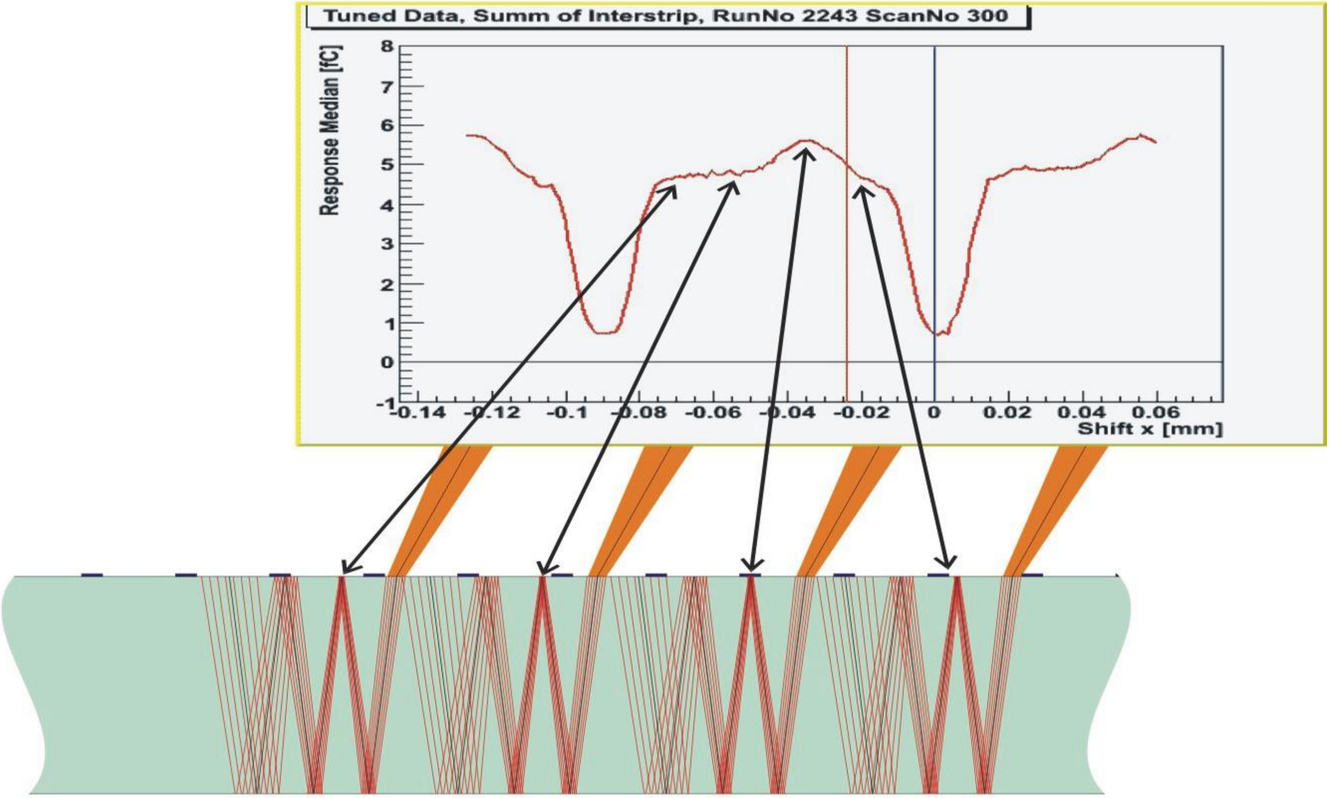
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Tricks and hints

Tilt laser beam

Focusing to top surface from inside (deep focusing)



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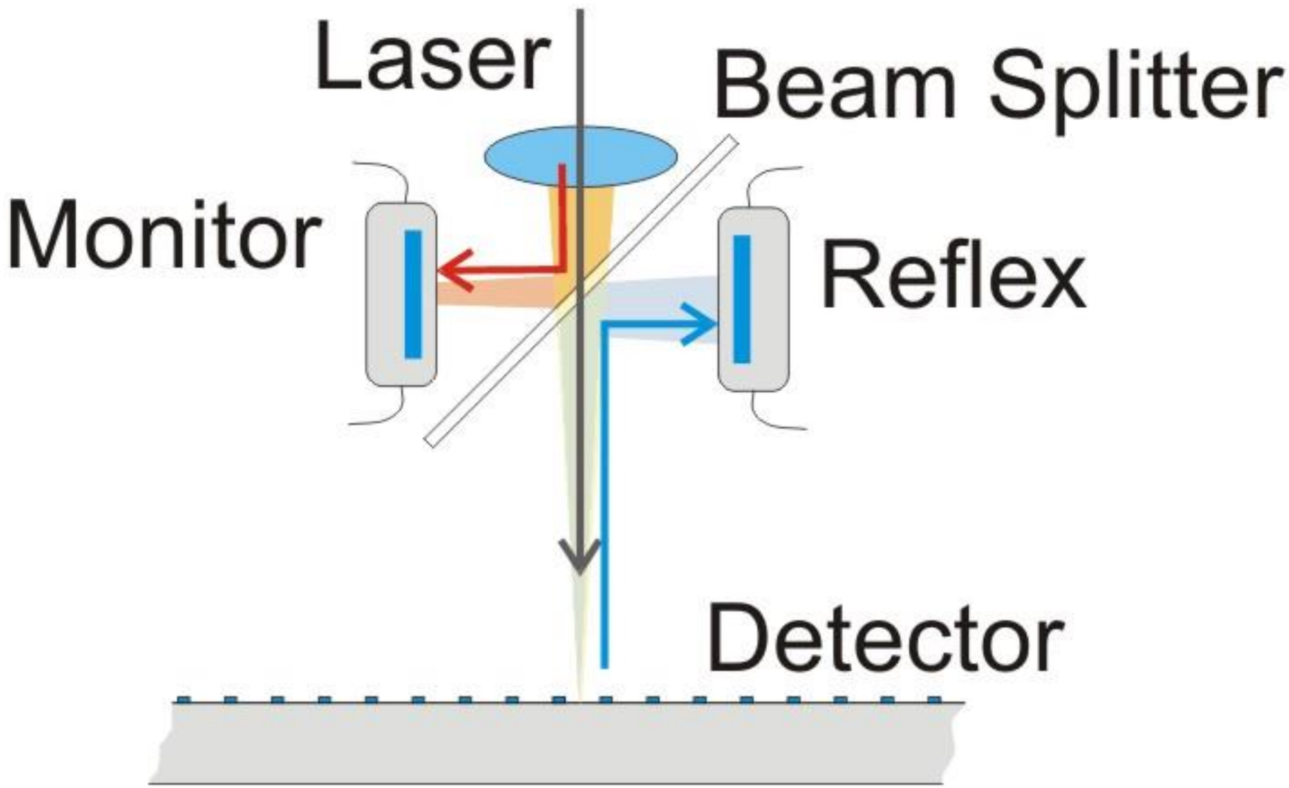
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Tricks and hints

Optical head – reflectance measurements, calibration and absolute power measurements



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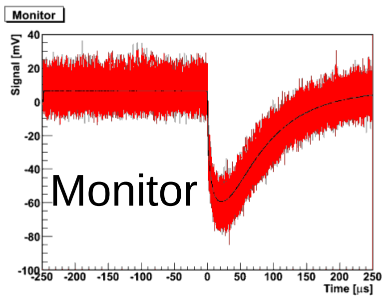
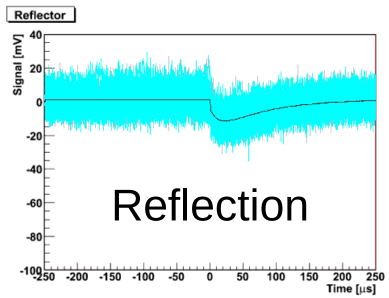
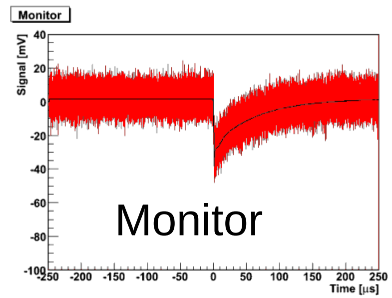
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Tricks and hints





1055nm laser pulse

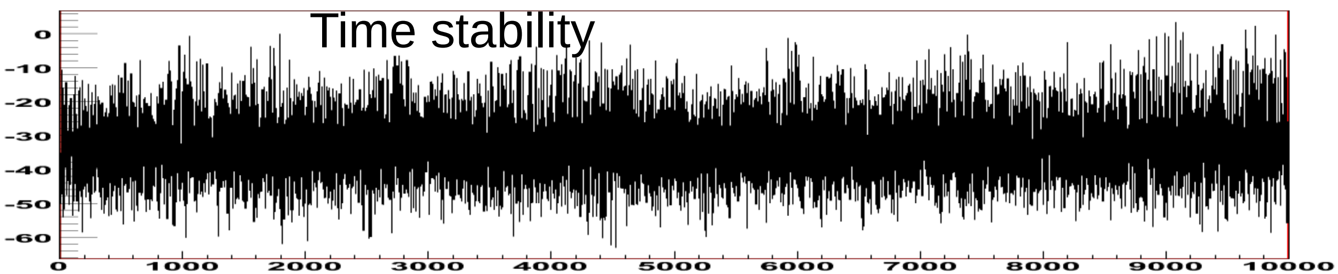


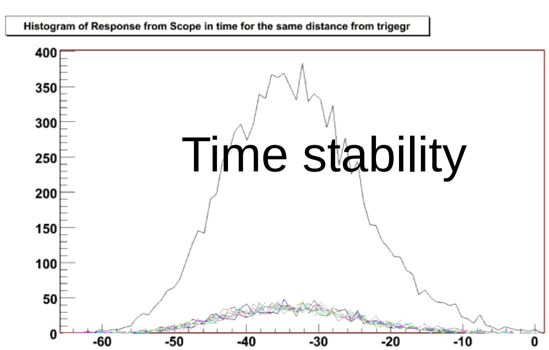
682nm laser pulse

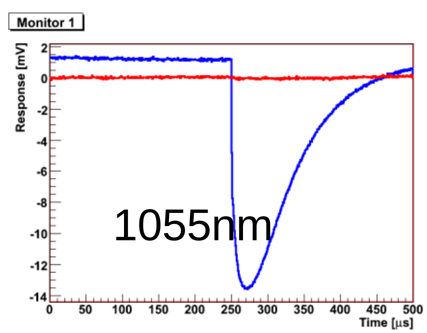
Optical head –

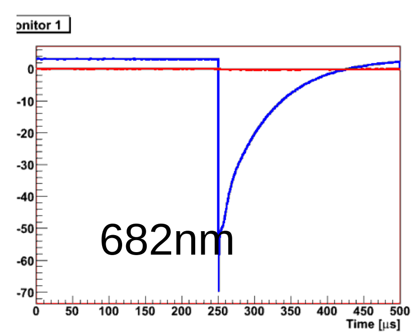
Monitoring diodes affect pulse shape – wavelength dependence

Thickness of light penetration in non-depleted photodiode









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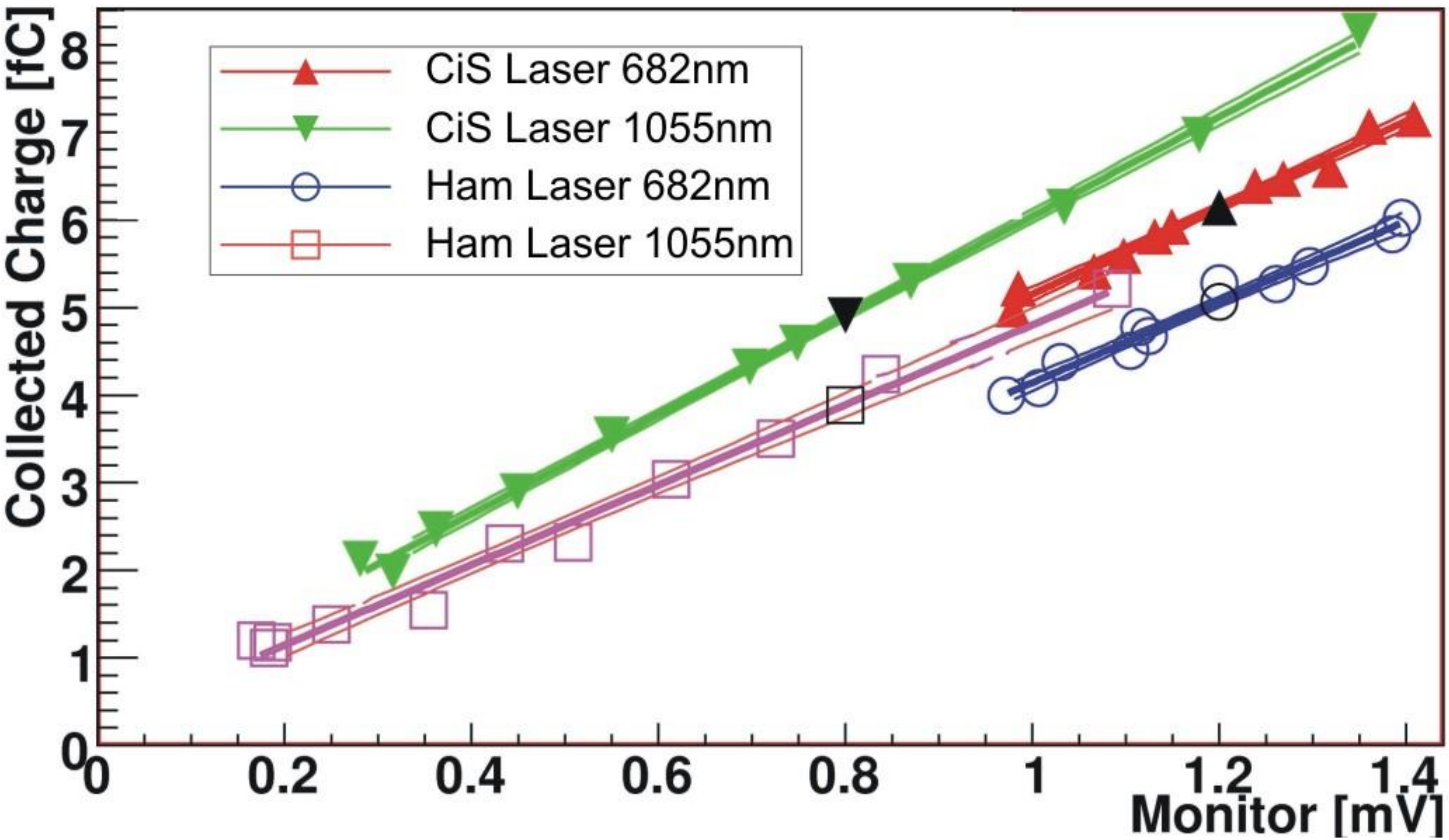
Comparison of collected charge from two producers of sensors



Calculation of quantum efficiency of two wavelengths

(Calibration of light power: NEWPORT 2832C + calibrated silicon detector):

Laser:	infrared	red
Wavelength:	1055nm	682nm
Nominal pulse width:	15ns	15ns
Real pulse width:	3.8ns	7.5ns
Source current:	2400mA	2050mA
Pulse energy:	90aJ	20aJ
Photons in pulse:	565000	126000
Input power:	90.6fC	20.2fC
Detected energy:	33.1fC	11.3fC
QE of silicon sensor:	**0.37**	**0.56**

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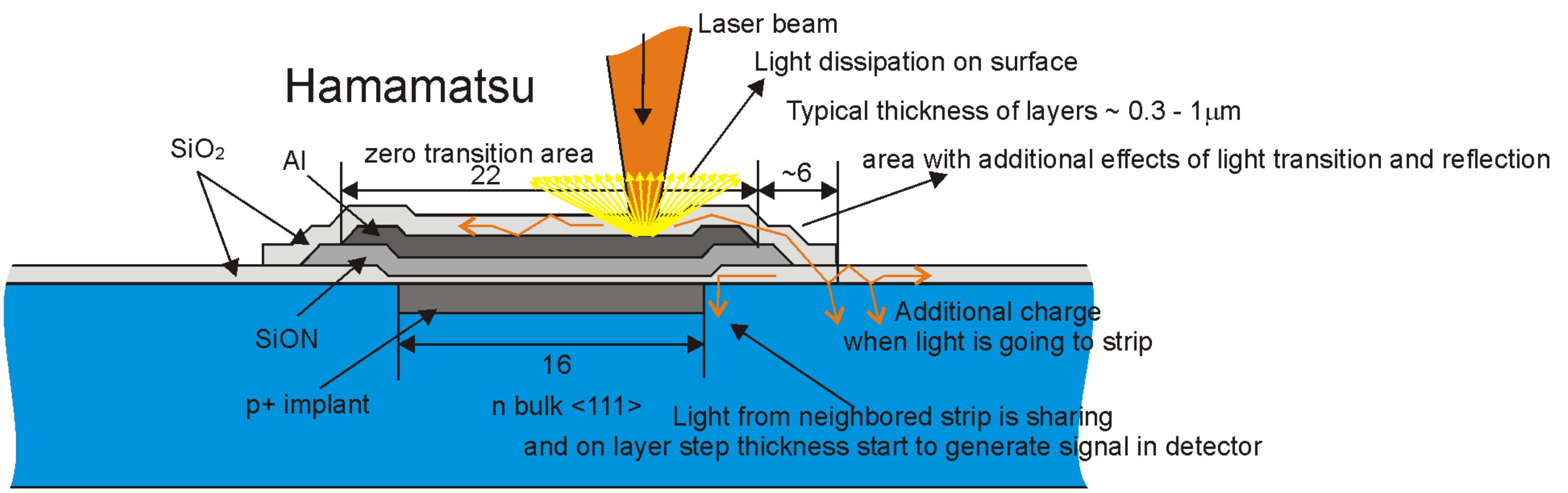
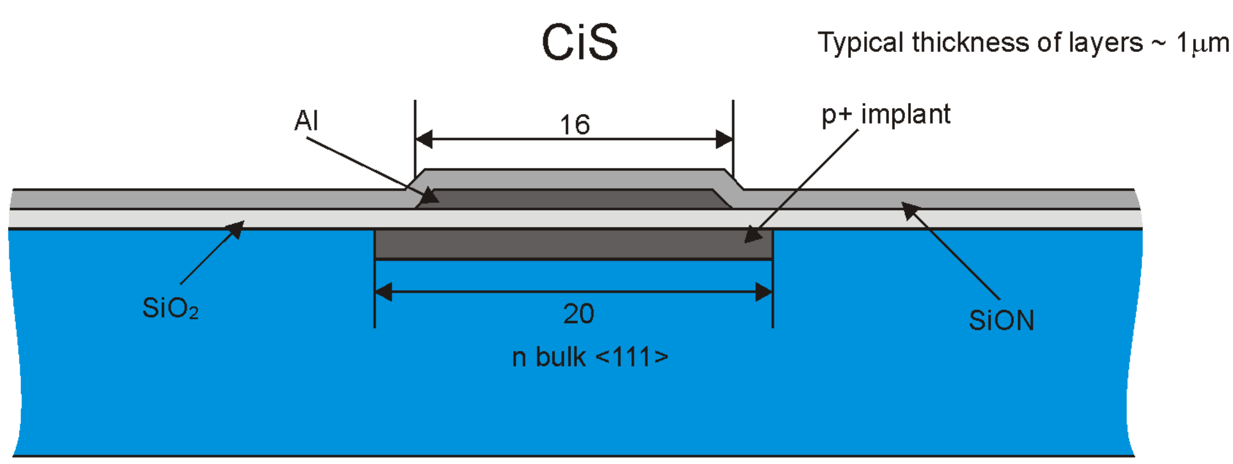
Properties of laser tests specific for silicon sensors at high energy physics (HEP)

Tricks and hints

Light sharing in protection layers – fake signal





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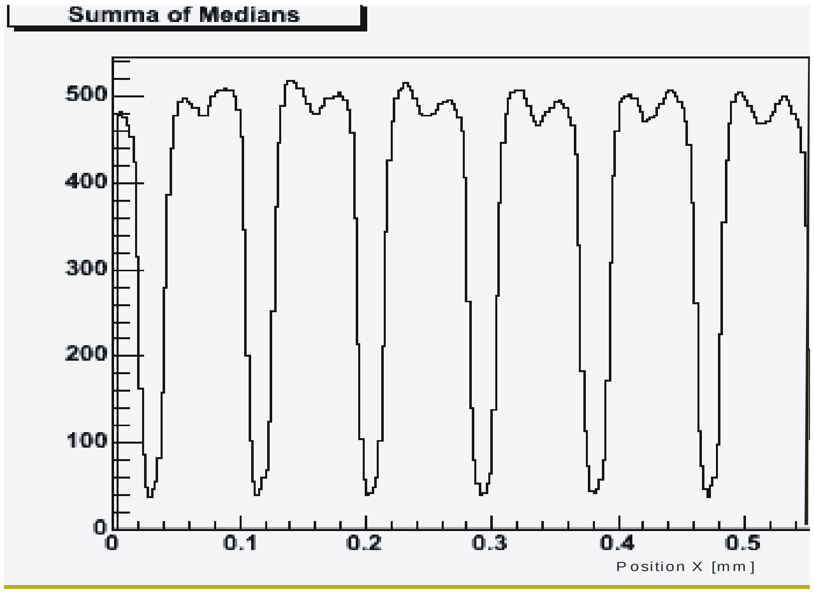
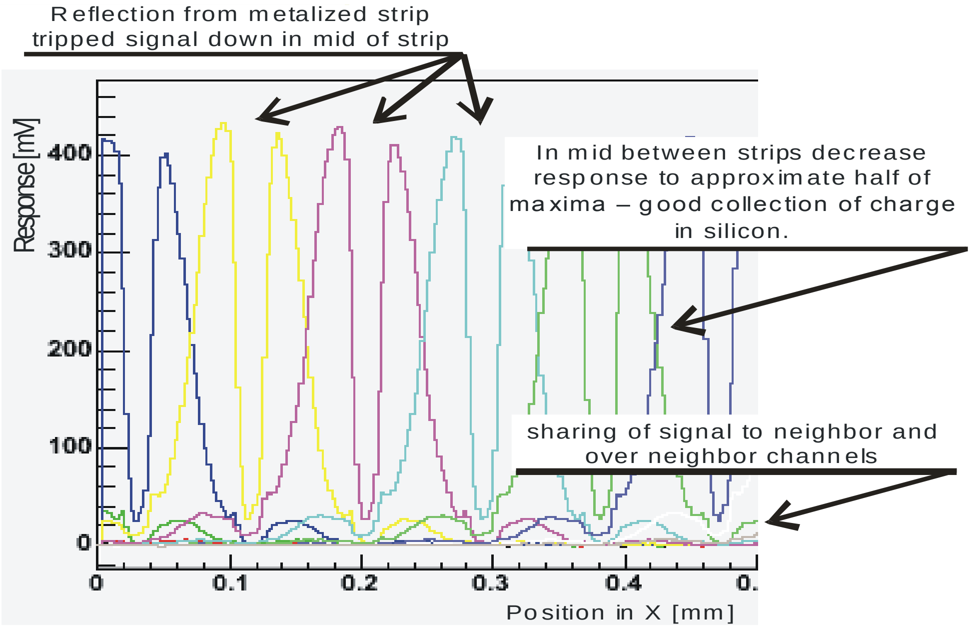
Tests of strip detectors

Inter-strip position in laser measurement



Sum of signal of 12 adjacent strips show that collected signal in one channel is 85% from whole collected charge in detector.



Typical response from few channels if laser beam moves across strips in best focused point.

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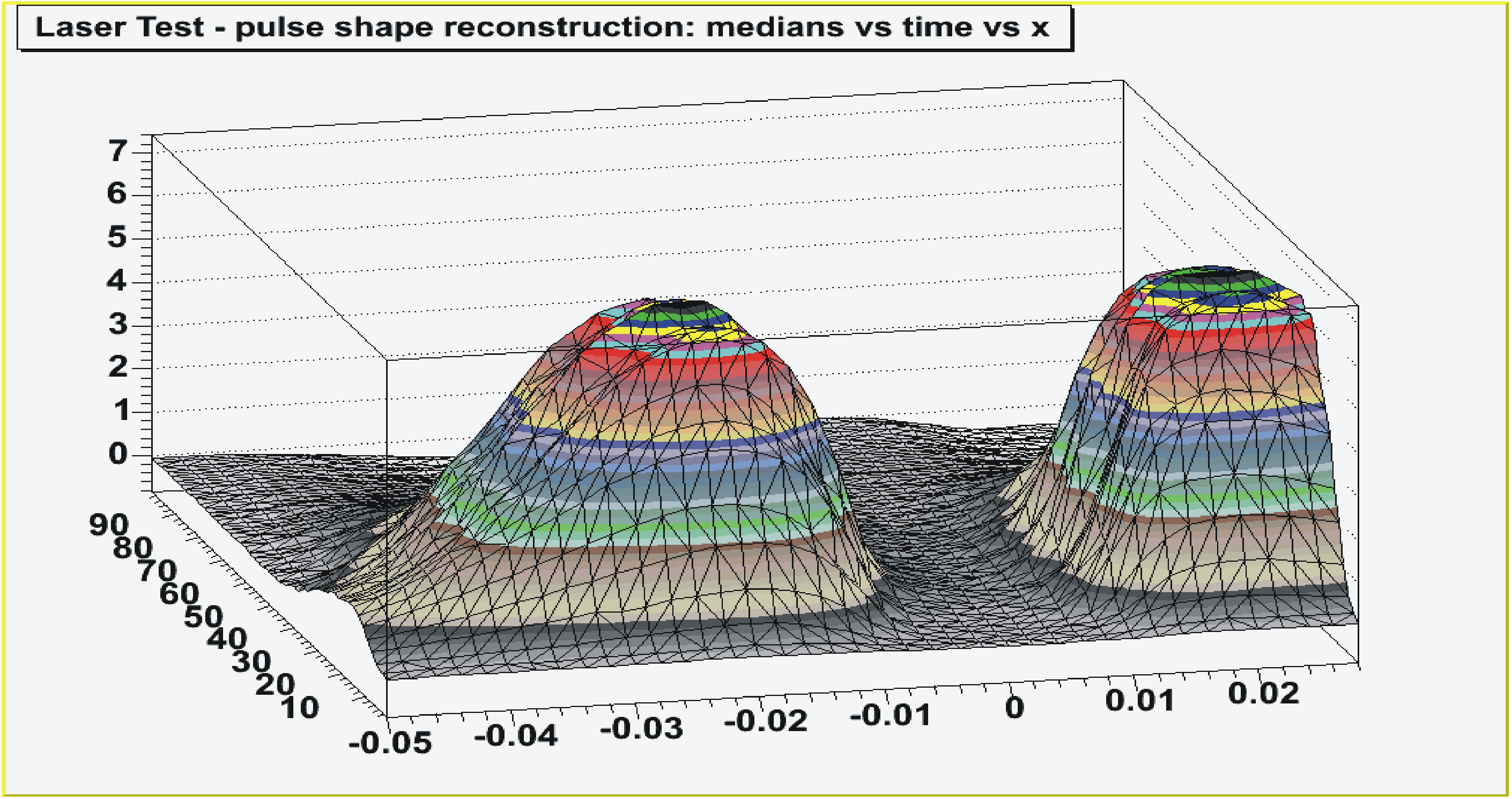
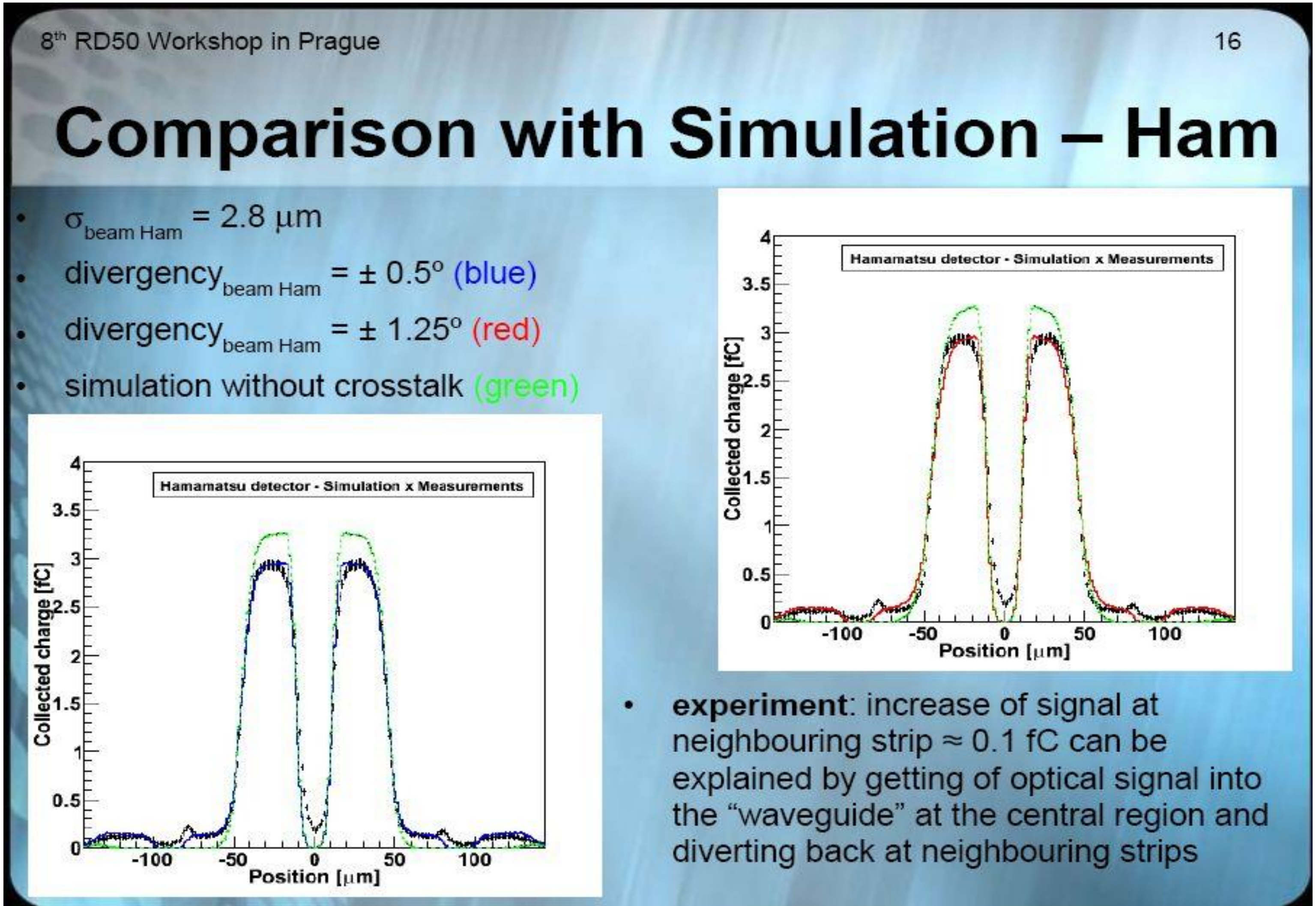
Tests of strip detectors

Pulse shape: inter-strip position vs. time



Tests of strip detectors



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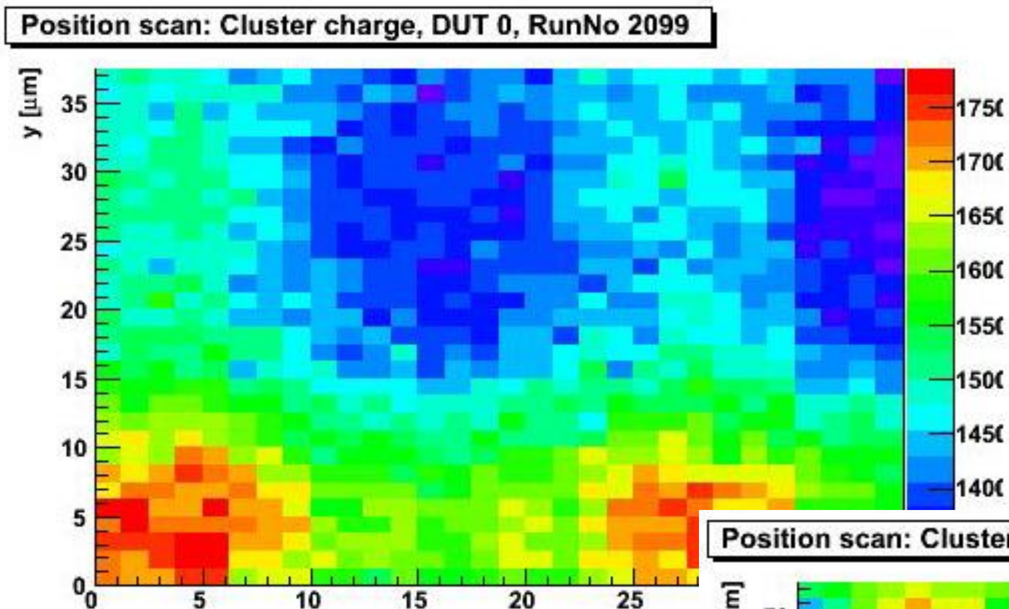
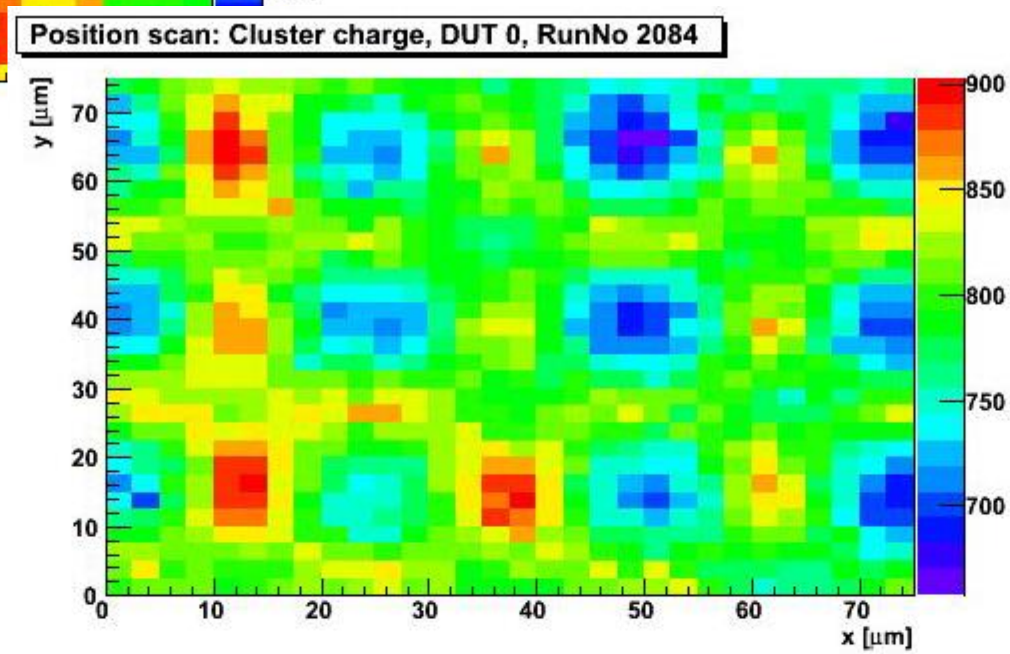
Tests of pixel detectors

DEPFET Pixel Detector Laser tests



Collected charge of ~ 1.3MIP
Test of acquisition homogeneity
Identifying of low efficiency area
Tuning of set of voltages



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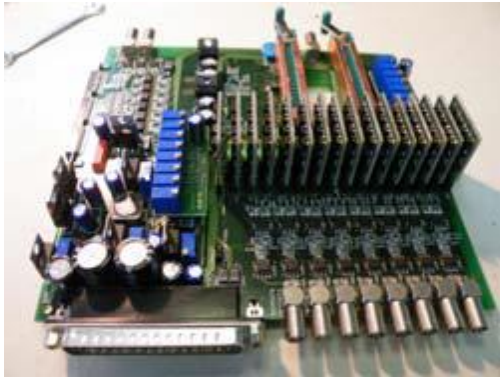
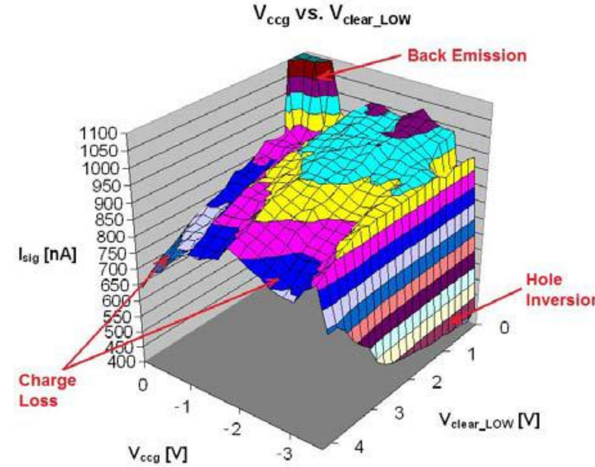
Tests of pixel detectors

DEPFET Pixel Detector Minimatrices

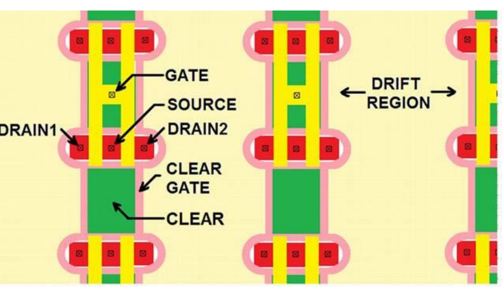


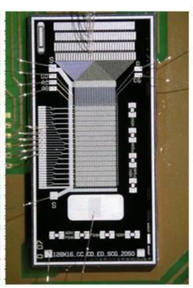
Special sensor function testing: gated mode

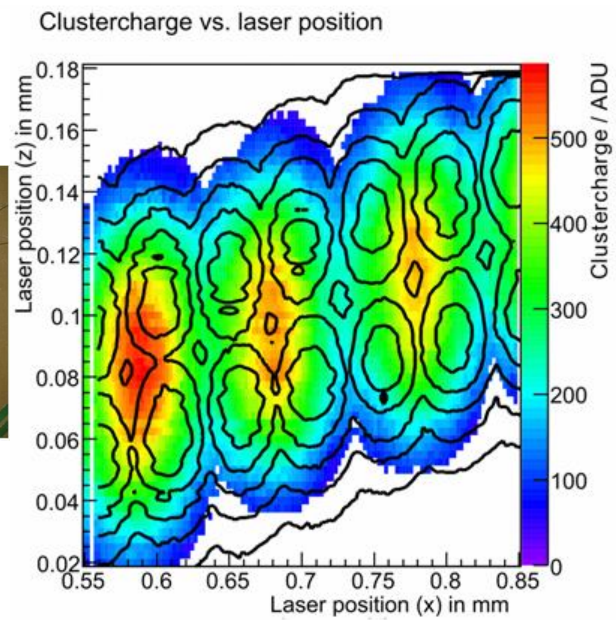
Operation voltage sweep for DEPFET, measured in Prague laser setup

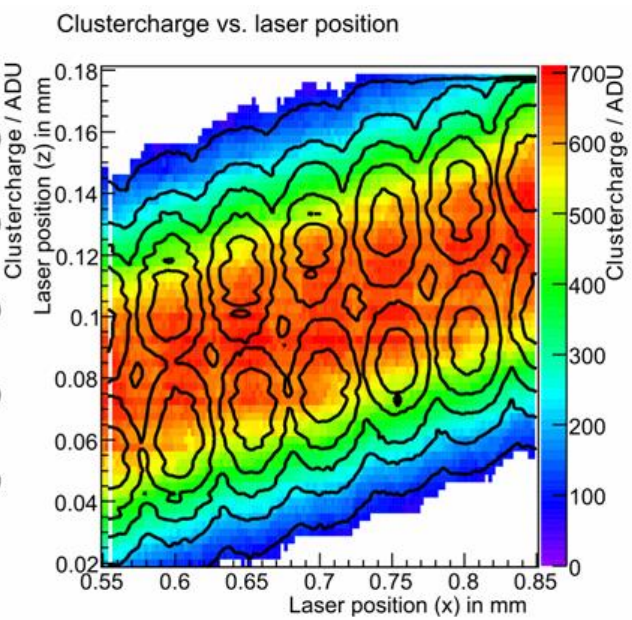


Left: Pixel layout. Middle: laser scan with non-optimal voltages. Right: laser scan with optimized voltages









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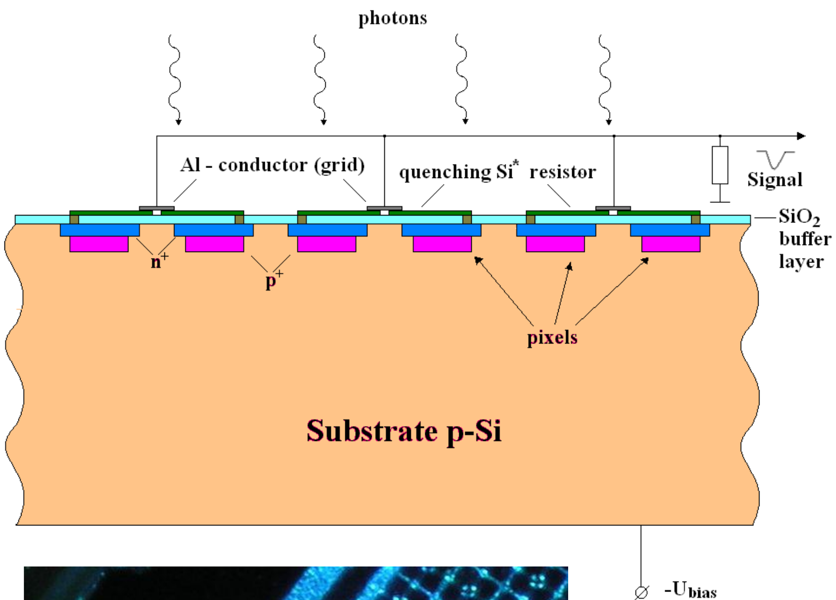
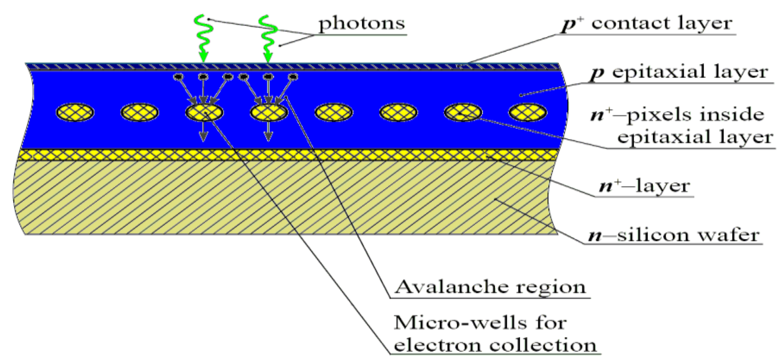
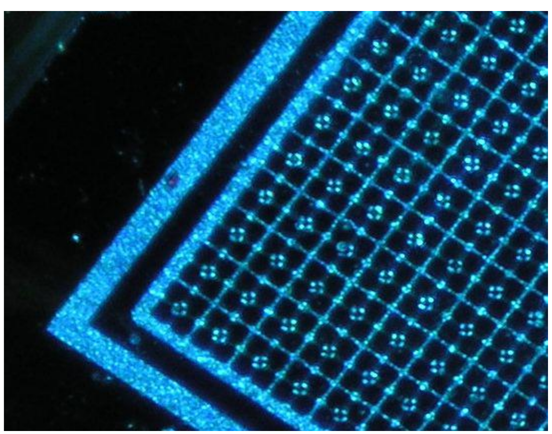
Tests of silicon avalanche photodiodes

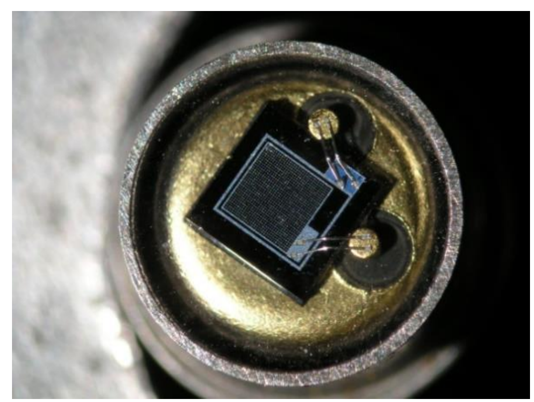
Matrix Geiger-Mode Avalanche Micro-Pixel Photo Diodes

Different names of MAPD:
MRS APD, MAPD, SiPM, MPPC, SSPM, SPM, APDg, et al.









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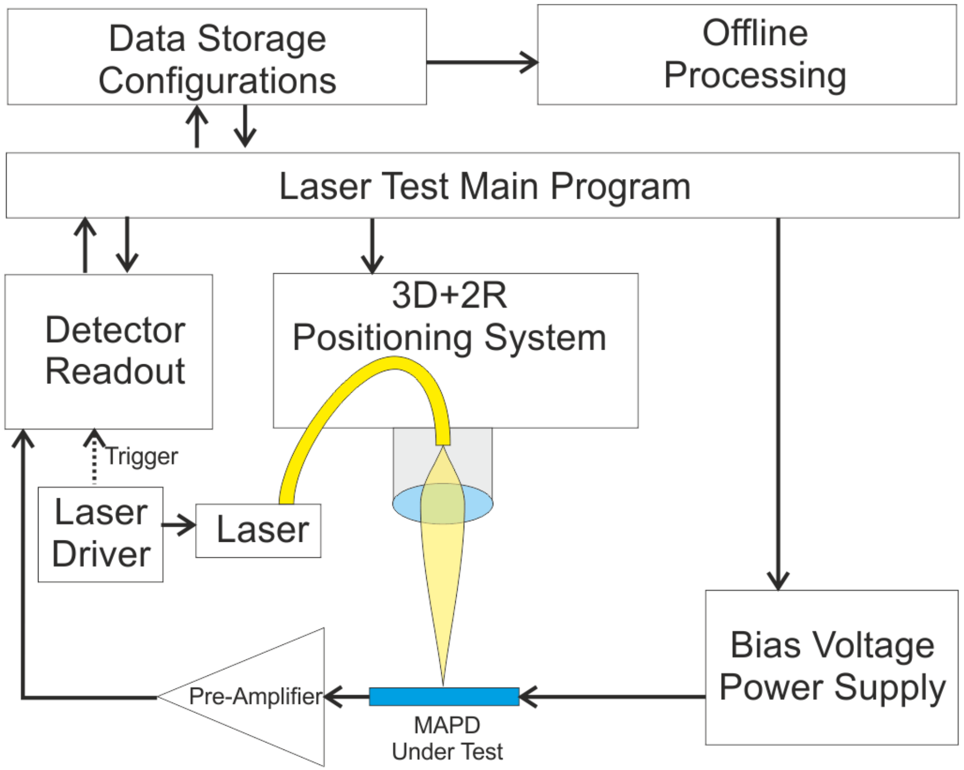
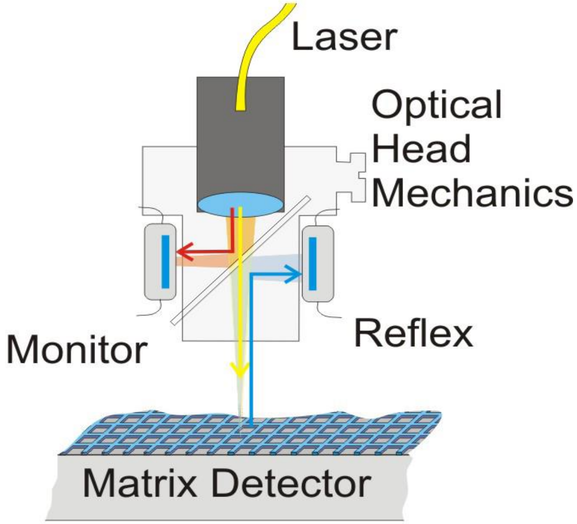
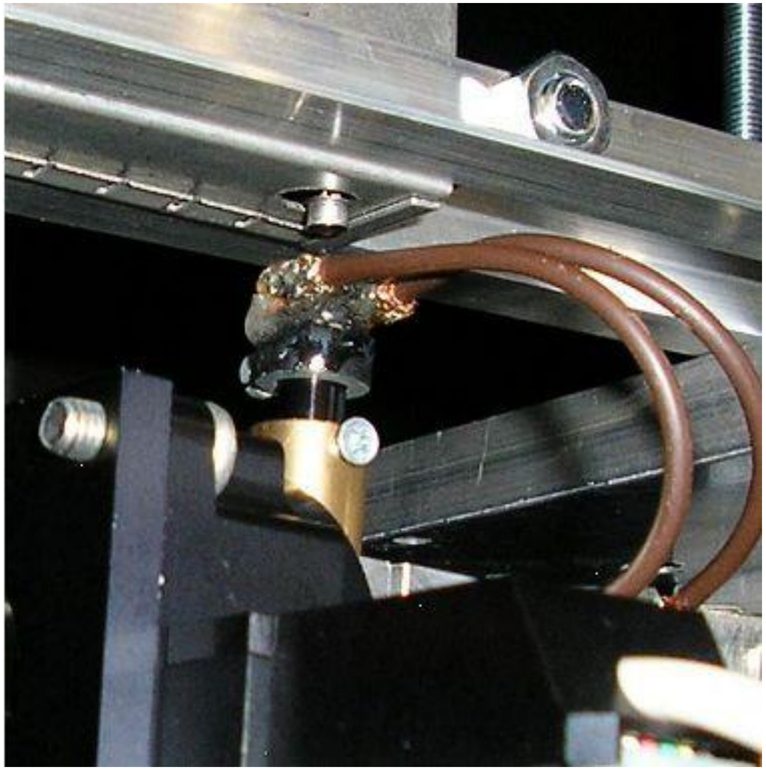
Tests of silicon avalanche photodiodes







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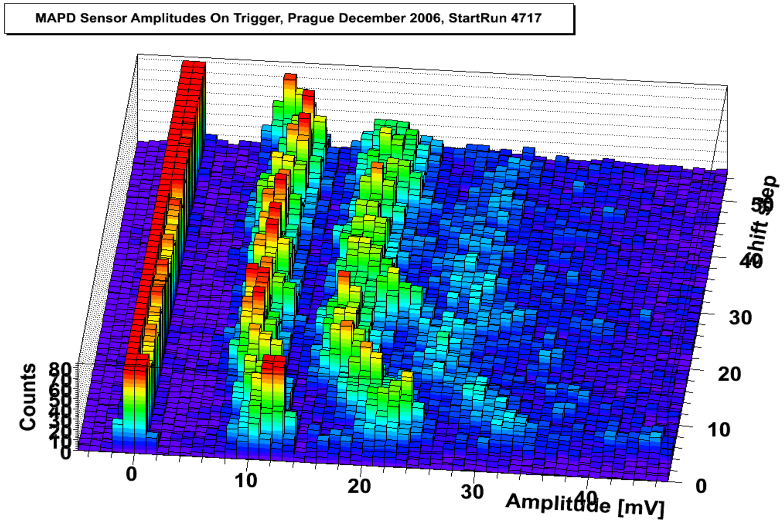
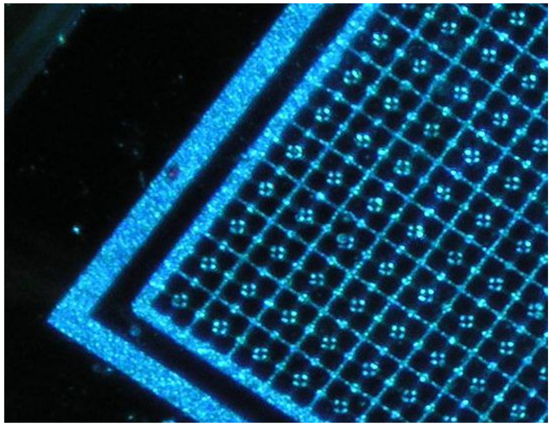
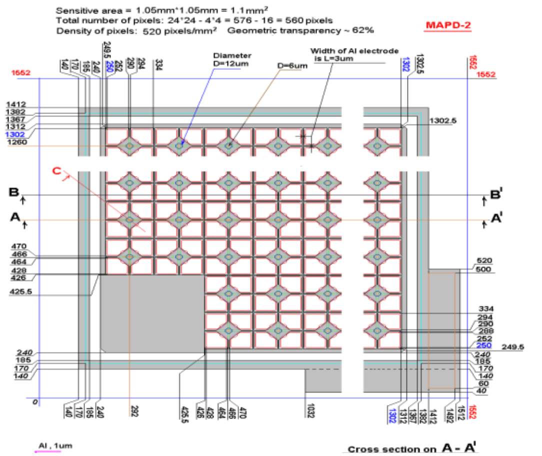
Tests of silicon avalanche photodiodes

Single photon detection



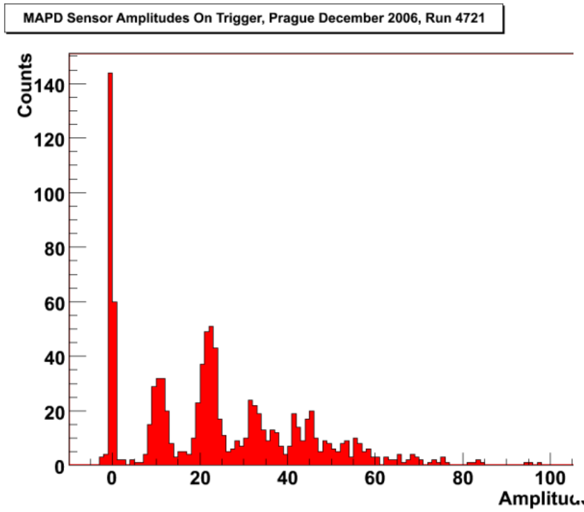


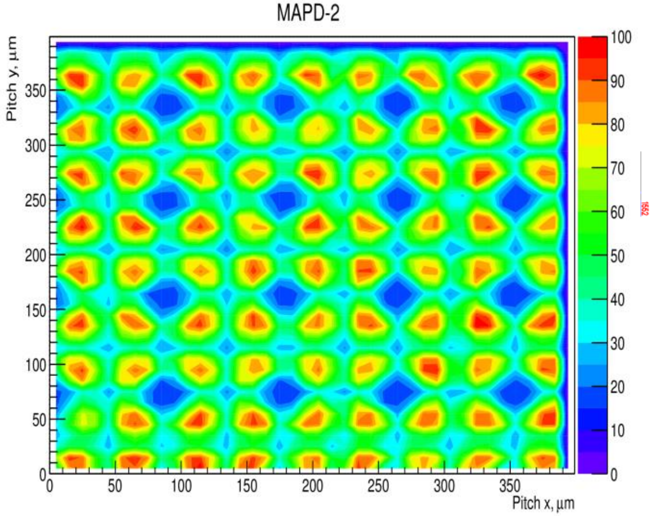


Experimental fill factor 0.58 +/- 0.07 (Calculated as an average PDE over all plot)

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

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





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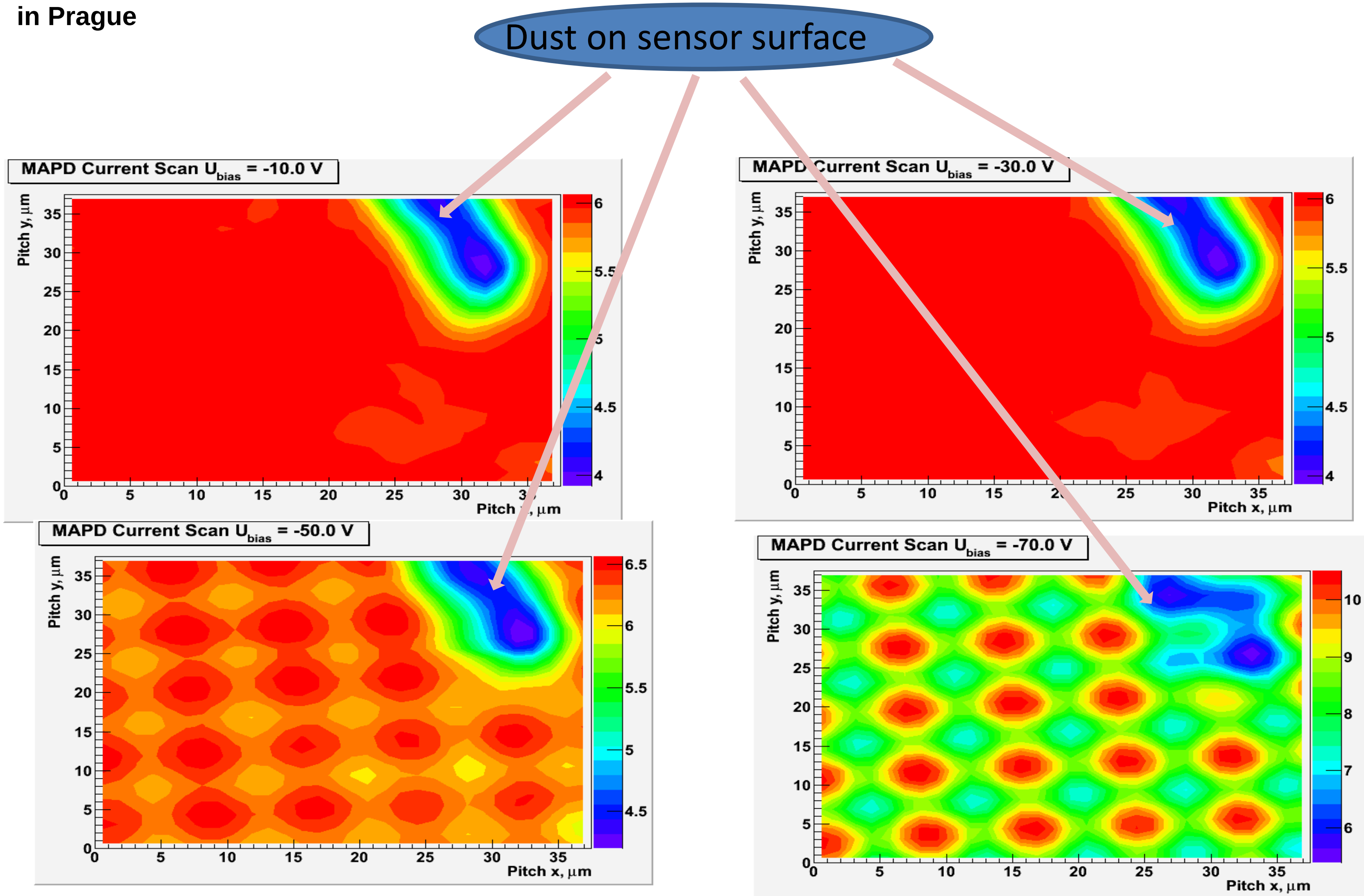
Tests of silicon avalanche photodiodes



On low voltages MAPD works like PIN-photodiode

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

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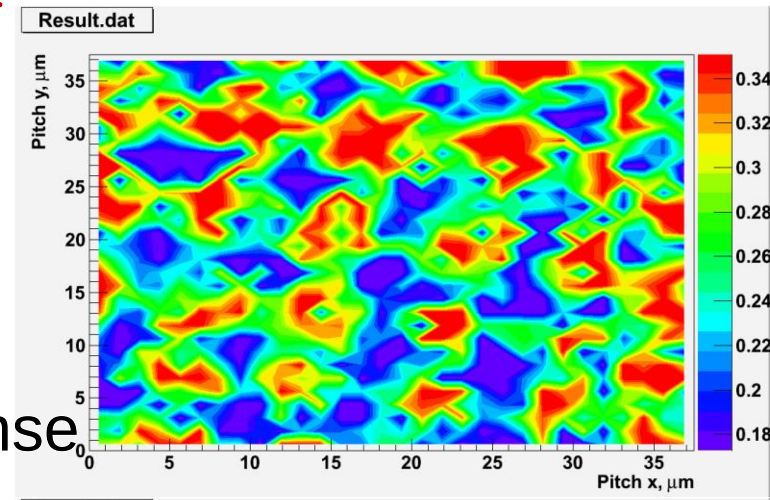
Tests of silicon avalanche photodiodes

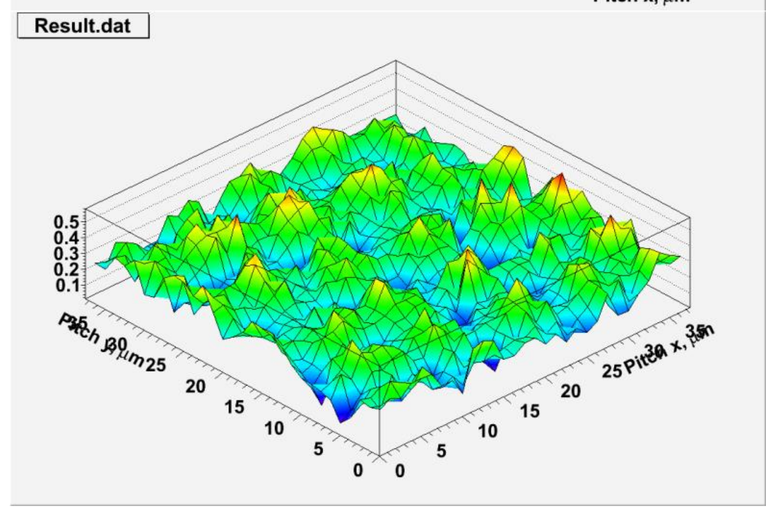
Measurements in single-photon mode

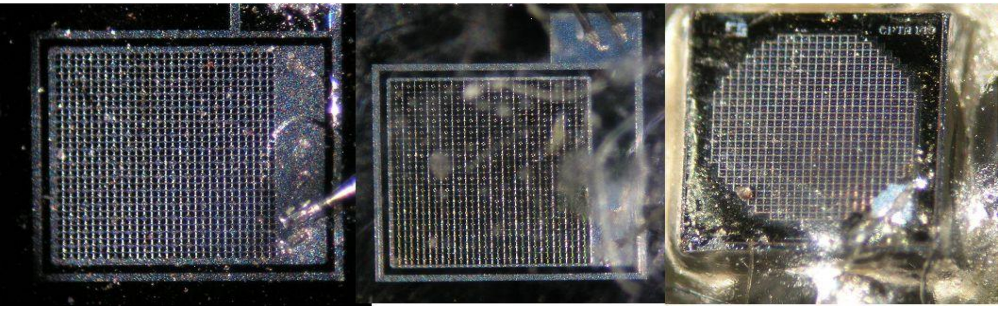
Pixel structure is clearly visible ->
geometrical factor is not 100%
for red light



MAPD laser test potentials:

- Detailed single pixel and in-pixel response
- Homogeneity of pixel matrices response
- Edge effects close to sensitive area
- Surface and epoxy cover quality
- Pixel gain uniformity





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For Experts: lab equipment used

- Thermally isolated test chamber (Black box, producer: ELMOS - Vanek s.r.o., Slovakia) on heavy rock stage
- Active thermal stabilization (Julabo CF31) - stabilization of temperature within 0.2deg range
- 3-axis laser focuser positioning stages (Standa) - step 0.2 micron in 3D + 2 rotations - fully automated with PC remote control
- Deep modulation laser sources (660nm, 1060nm, less 1mW)
- Laser sources (Omicron LDM658.50.A350, 658nm, less 50mW)
- Optical fibre calibrated splitter for 1060 nm
- Optical Attenuator (OZ Optics Motor-Driven DD-100-MC In-Line) - calibrated for 660nm, 1060 nm
- Optical Power Meter (Kingfisher KI7600 Power Meter)
- Equipment for standard readouts: CAMAC, VME, NIM with modules for signal processing (Ortec, LeCroy, Canberra, Caen, Viener...)
- LV and HV power supplies
- Oscilloscopes
- HP Pulse Generator 81101A 50MHz
- Microscope and camera for visual control inspections
- Source of dry air or nitrogen for cooling up to -30deg
- cooling system for stable temperature setting up to -30deg (Julabo)
- 2-axis positioning stages (Standa) - step 2.5 microns in 2D - fully automated with PC remote control
- Rotation stages (Standa 8MR190-90-59 Motorized rotation stage) - mass up to 60/25kg - fully automated with PC remote control
- 2-axis positioning stages - step 5-200 microns in 2D - fully automated with PC remote control
- DRS4 Evaluation-Board for 4 channels (quick scope)
- Ultrasonic cleaner (BANDELIN DT 255 H)
- LV power supplies (Agilent E3649A, TTi PCX400SP)
- HV power supplies (Keithley 2410, Keithley 248)
- Waveform generator (Agilent 33210A)
- LCR meter (Agilent 4263B)
- Mixed signal oscilloscope (MSO 7104A)
- Oscilloscopes (LeCroy Waveace 232)
- Differential probe (Agilent N2790A)
- Pulse generator (HP 81101A)
- Thermal camera (FLIR i7)
- 3-axis laser focuser positioning stages (Standa) - step 1.25 micron in 3D - fully automated with PC remote control
- Low noise DEPFET readout system (MiMa)

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Conclusions

Laser tests are one of three basic methods for silicon detector testing for high energy physics. Good understanding of interactions of light and silicon gives us useful tool to develop vertexing and tracking detectors for new particle physics experiments as well as for other application.

Thank you for your attention