28th of October 2013

Simulation and measurements of Geiger discharge transverse size in a SiPM cell.

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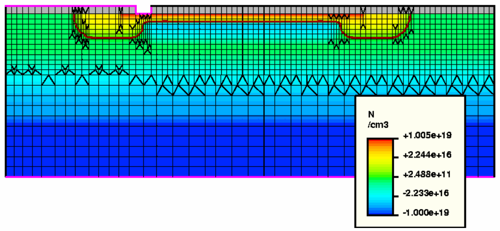
Geiger discharge in a SiPM cell

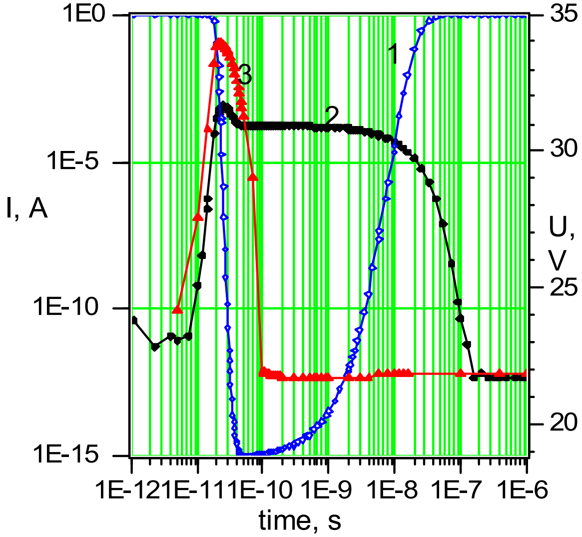
Example ISE TCAD simulation



$$\nabla \cdot \varepsilon \nabla \psi = -q\left(p - n + N_{D^+} - N_{A^-}\right)$$

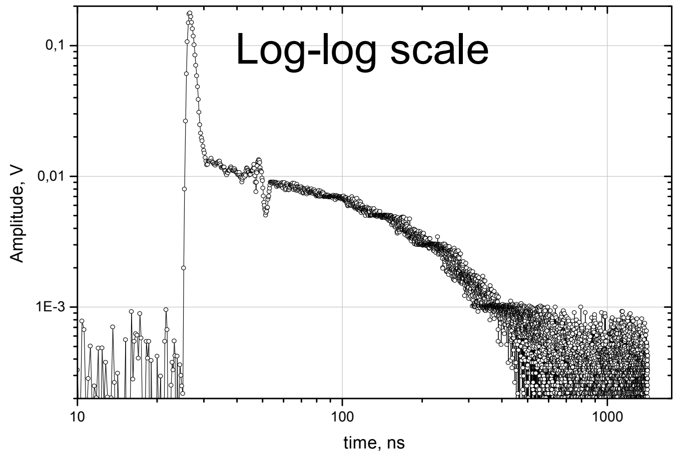
$$\nabla \cdot \overline{J_n} = qR + q\frac{\partial n}{\partial t},$$

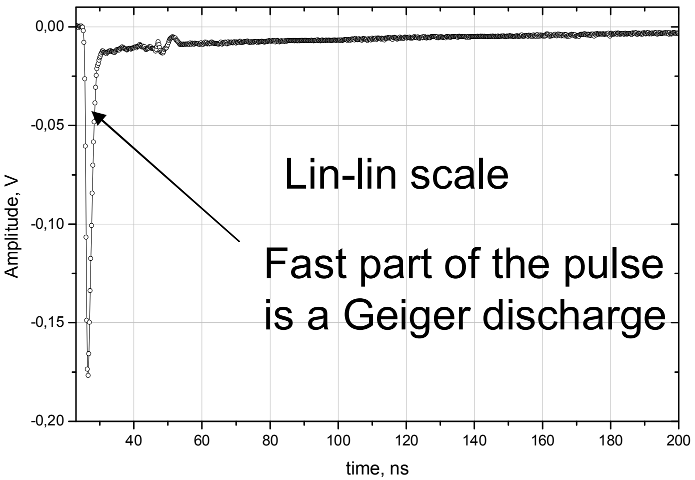
$$-\nabla \cdot \overline{J_p} = qR + q\frac{\partial p}{\partial t}$$



1. voltage on pn-junction
2. Current through contacts
3. Current inside pn-junction

Scope SiPM pulse





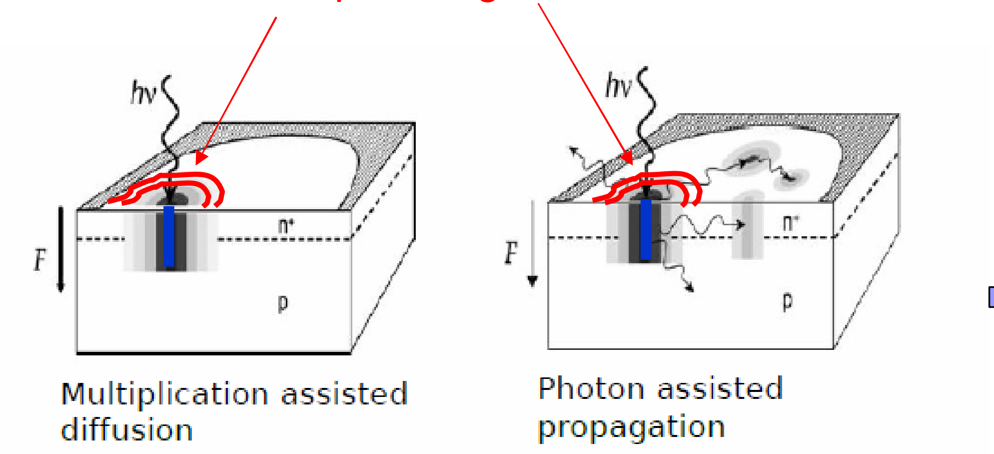
SPAD Geiger discharge development

A.Lacaita, et al."Observation of avalanche propagation by multiplication assisted diffusion in p-n junction" Appl.Phys.Lett. 57, 489-491 (1990)
A.Lacaita, S.Cova et al."Photon-assisted avalanche spreading in reach-through photodiodes" Appl. Phys. Lett., 62, 606-608 (1993)
A.Lacaita, et al.:"Avalanche transients in shallow p-n junctions biased above breakdown", Appl. Phys. Lett. 67, 2627-2629 (1995)
A. Spinelli, A. Lacaita"Physics and Numerical Simulation of Single Photon Avalanche Diodes"IEEE Trans. Electron Devices, 44, 1931-1943 (1997)

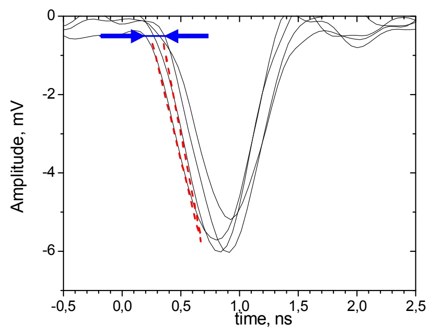
Photon absorption

longitudinal build-up of avalanche process

transversal spreading of avalanche



SiPM cell



Similar approach can be applied to SiPM cell

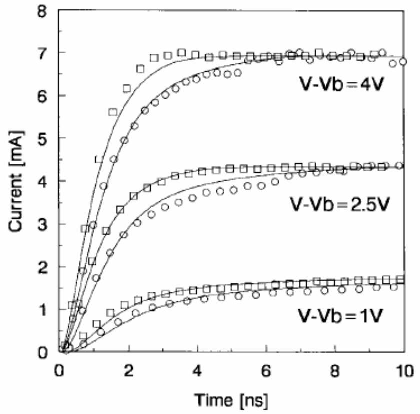
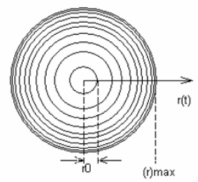


Fig. 18. Experimental data for avalanche triggered in the center of the active area (squares) and at one edge (circles). The solid lines are the corresponding simulation results. The active area of the SPAD is $140 \times 14\ \mu m$.

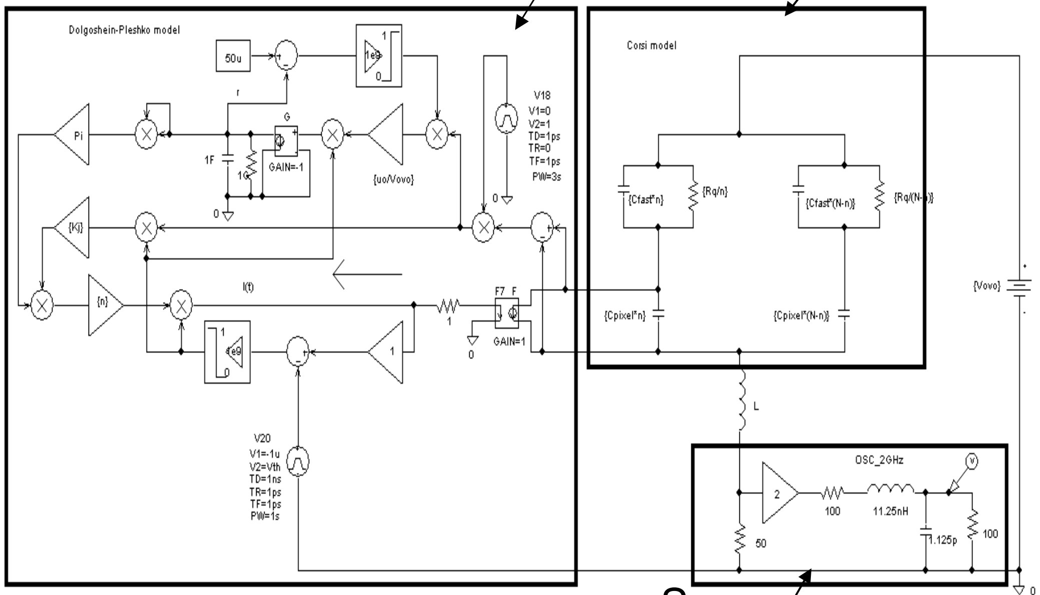
Spice model of avalanche development in a SiPM cell (transversal propagation)



Transversal avalanche propagation & Avalanche current selfquenching

Corsi model

Dolgoshein-Pleshko model



Scope

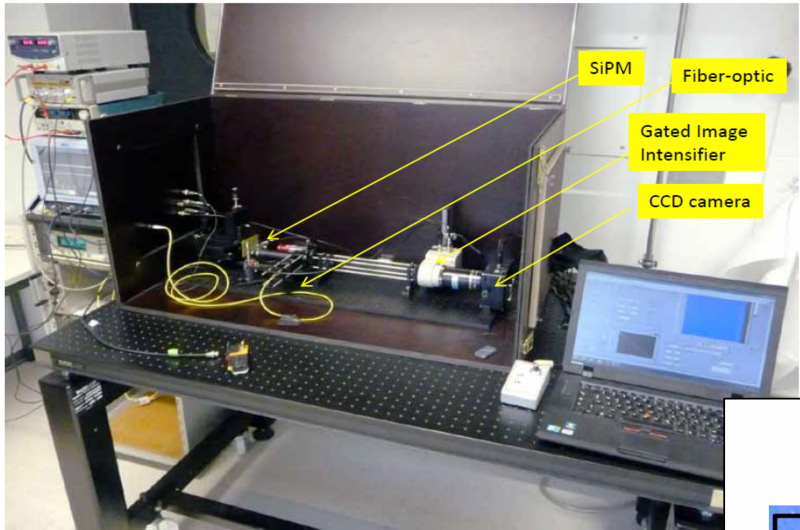
- Geiger discharge starts in a tiny spot inside a cell (1st disk)
- Current $J(t)=K_J*Vov(t)$, where Kj- is disk specific conductivity
- Discharge spreads from spot to 1st elementary ring, 2nd,…, with velocity u(t) = $u_0 \times V_{OV}(t)/V_{OV0}$,
- The capacitor of the cell discharges through the Geiger-avalanche current, after a while overvoltage drops down to 0

V_{OV0}-initial overvoltage, $V_{OV}(t)$ – momentary overvoltage

***K_j, u_0** - are experimental parameters*

$$I(t) = J(t)S(t) = J(t)\times \pi r^2(t) = \pi k_J V_{ov}(t)[\int_0^t u_0 \frac{V_{ov}(t')}{V_{ov\,0}}]^2 dt'$$

Light-Emission Microscopy (LEM) applied to SiPM



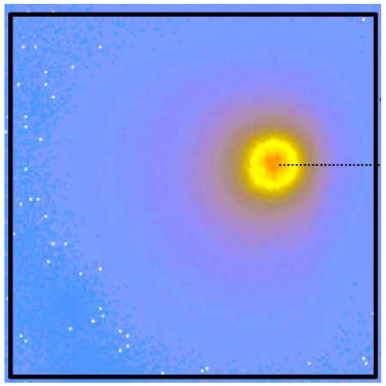
31 October2012, NSS & MIC, IEEE, Anaheim, CA, USA — Razmik Mirzoyan, MPI for Physics: X-talk, Avalanche Size & Calibration of SiPM

Double Peltier element cooled low-noise CCD camera "CLARA" from ANDOR

Integration time ~600 s

laser 70 ps 405nm

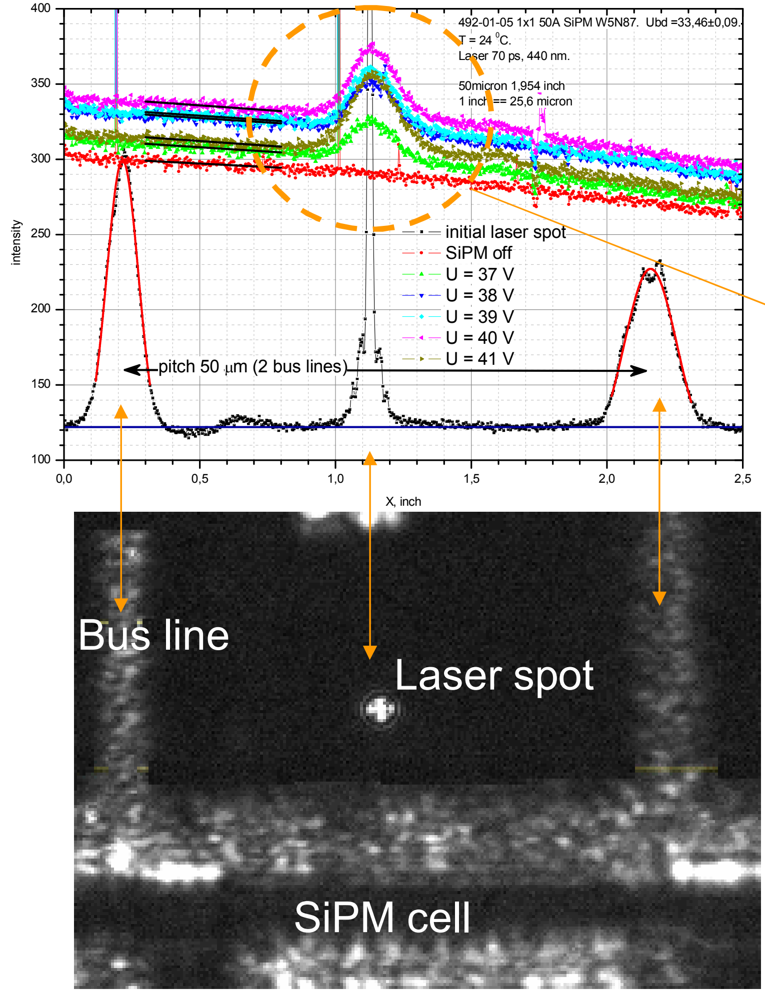
LEM Applied to Single SiPM Cell

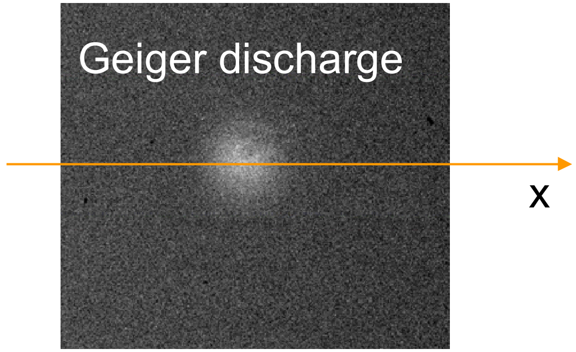


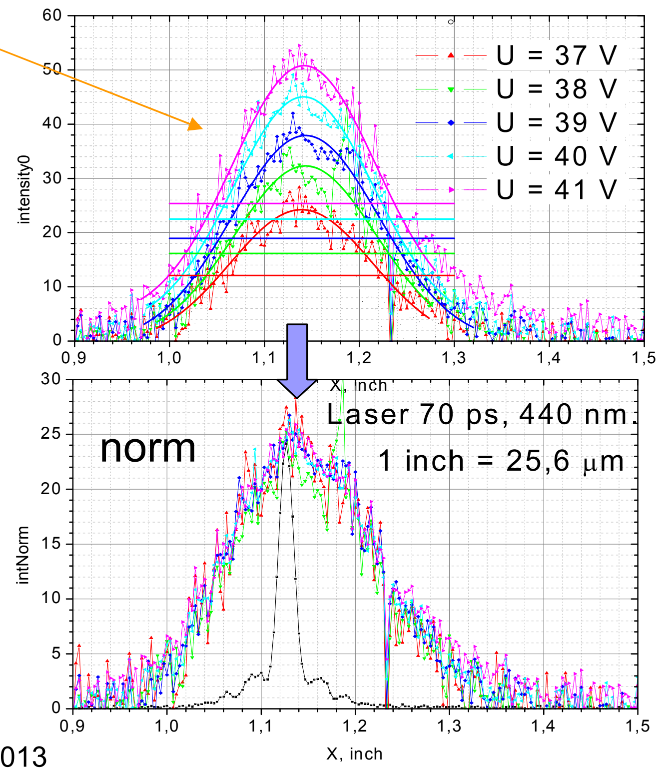
- Shooting with laser to a cell of 100x100µm^2 size
- The laser light is focused to a spot size of ~2µm
- Observing that the avalanche occupies only a small part of the cell

31 October2012, NSS & MIC, IEEE, Anaheim, CA, USA — Razmik Mirzoyan, MPI for Physics: X-talk, Avalanche Size & Calibration of SiPM — 7

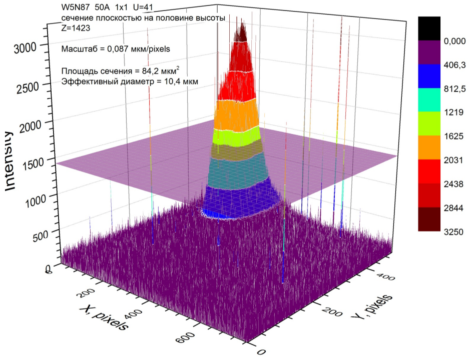
Geiger discharge light

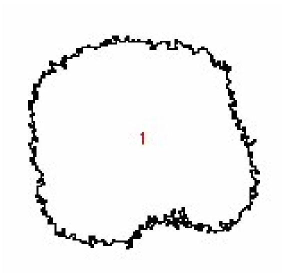




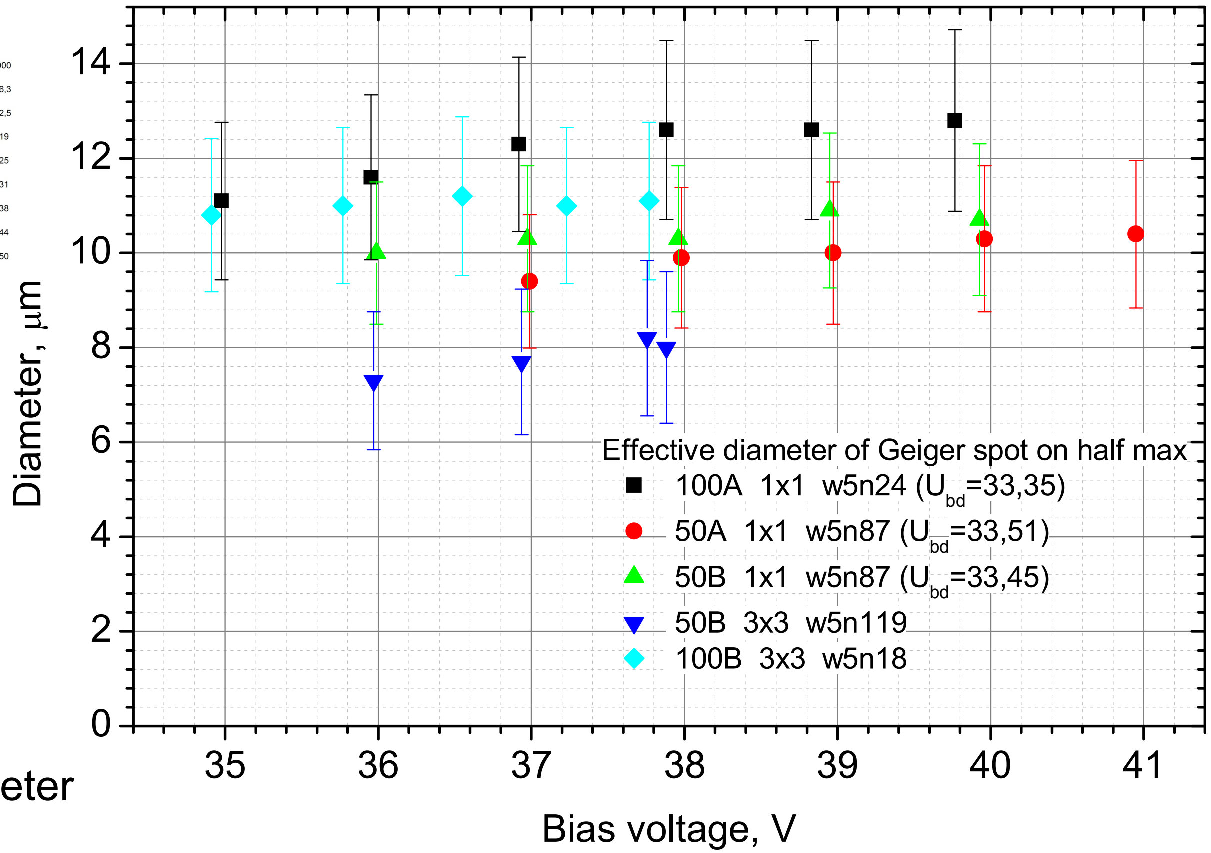


Geiger discharge light



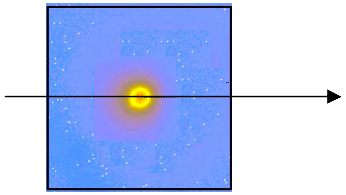


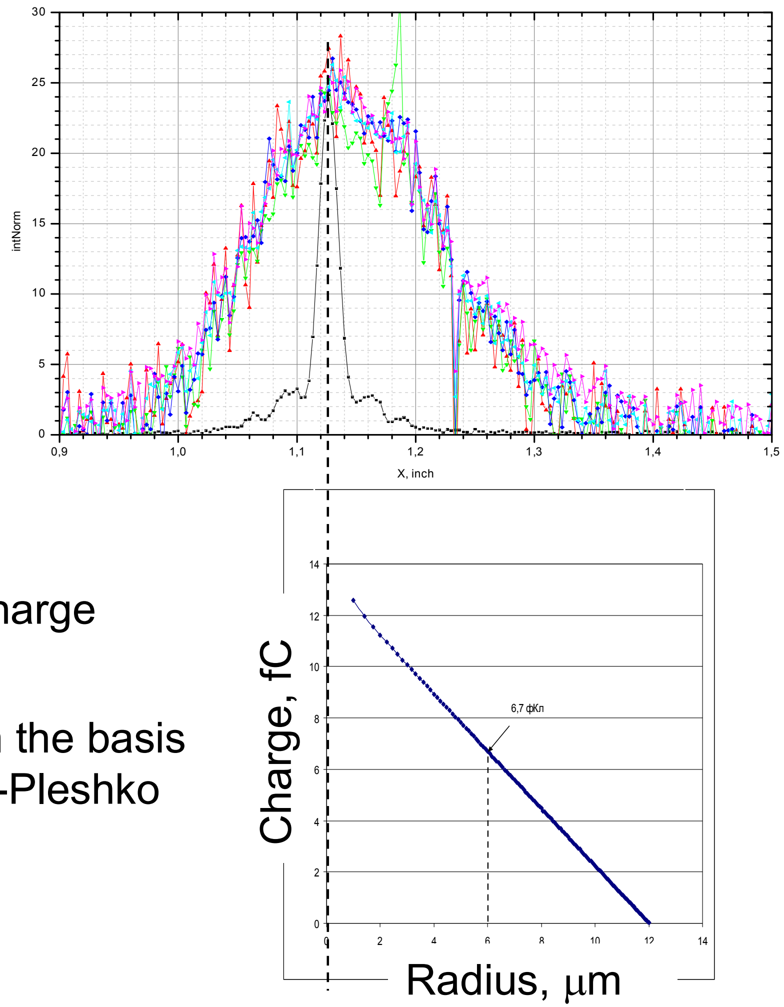
Area ->effective diameter



Spot size of Geiger discharge doesn’t depend from overvoltage

Dolgoshein-Pleshko SPICE model



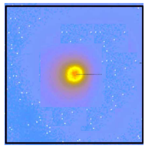


Light intensity

Geiger spot charge distribution.

Calculation on the basis of Dolgoshein-Pleshko SPICE model

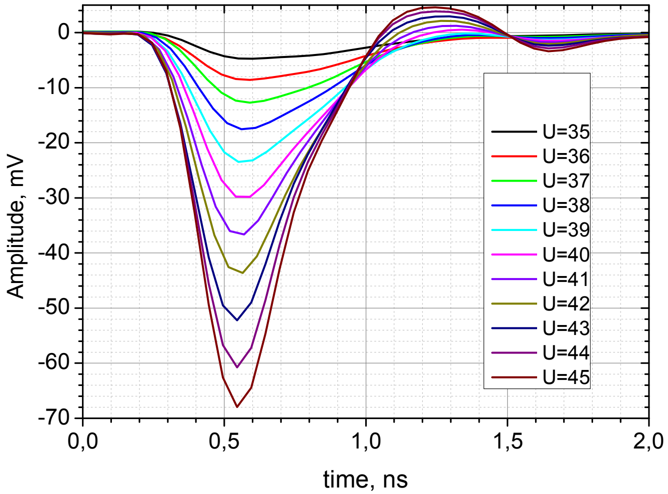
SiPM cell study with digital oscilloscope LeCroy WaveRunner 620Zi 2GHz

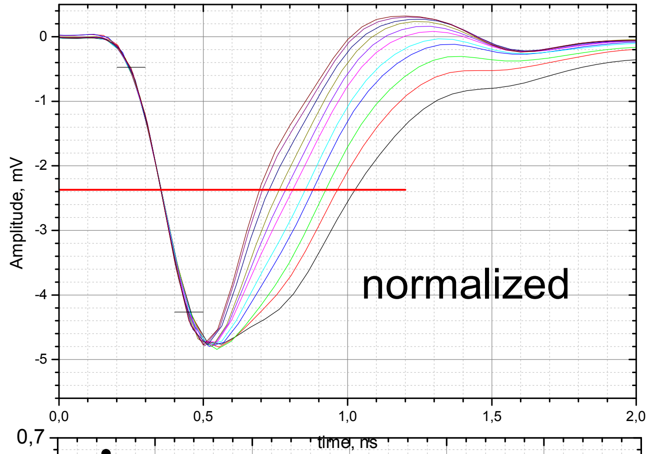


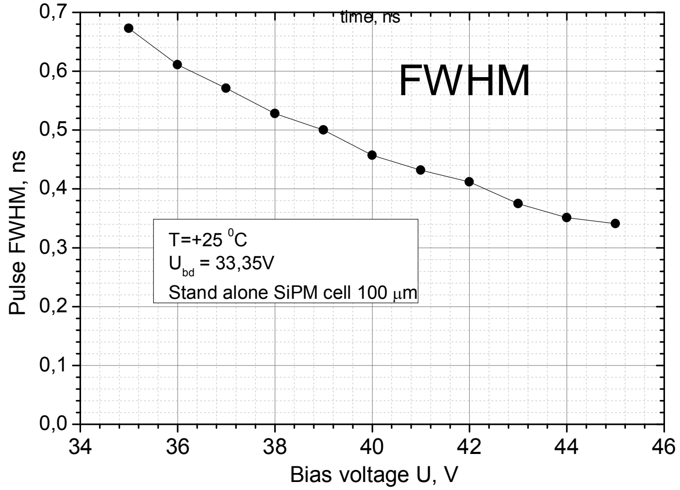
Width of the SiPM stand alone cell signals for different voltages

Focused laser beam into center of SiPM cell (pulse duration 40ps, 660nm)

Average cell pulse for voltage range
From U=35V to U=45V ($U_{Breakdown}$ =33.35V)







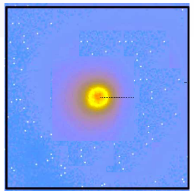
SiPM cell pulse width decreases with increasing of overvoltage

Charge Q from cell is proportional to applied overvoltage

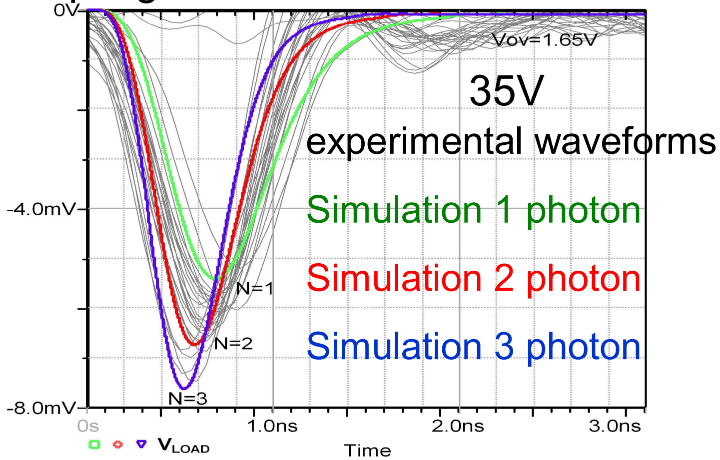
Amplitude grows faster then linear

Signals from stand alone cell

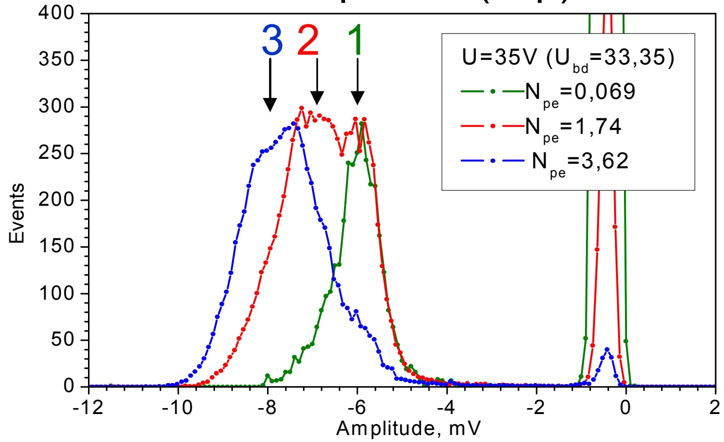
Fixed overvoltage ΔU=1.65V, different light intensity

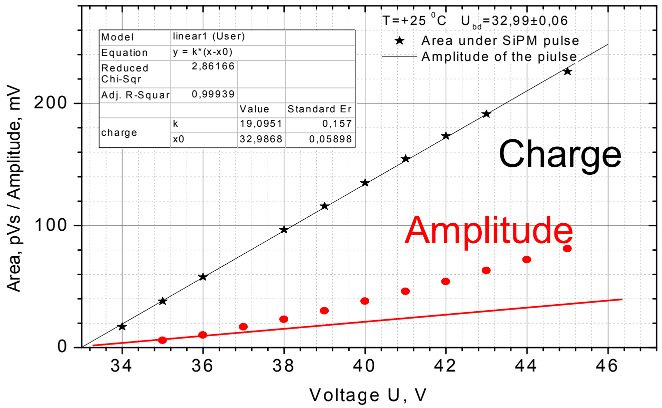


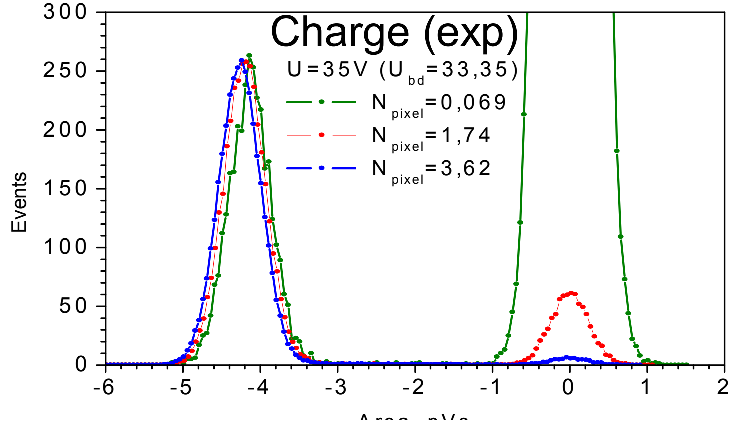
Exp signals & SPICE simulations



Amplitude (exp)



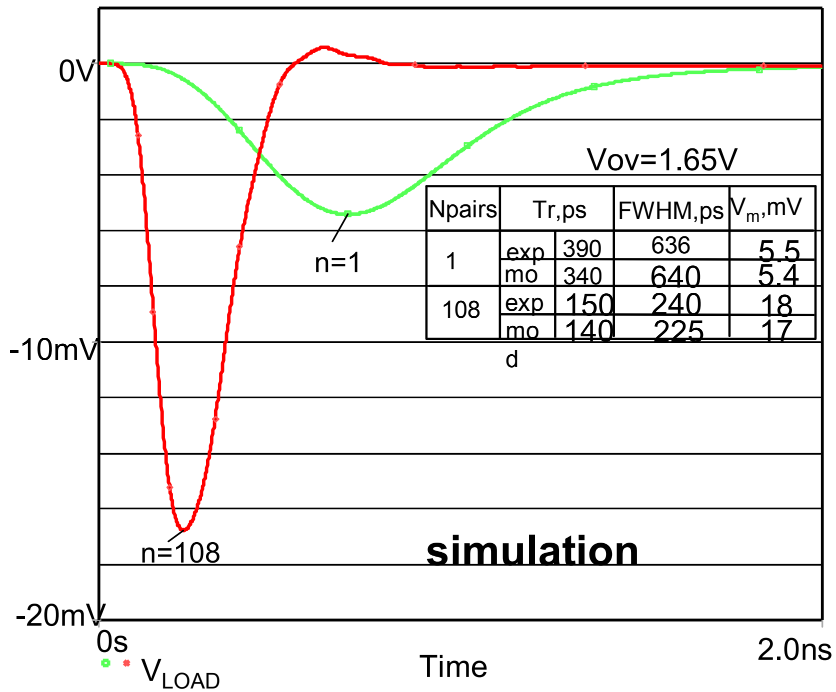




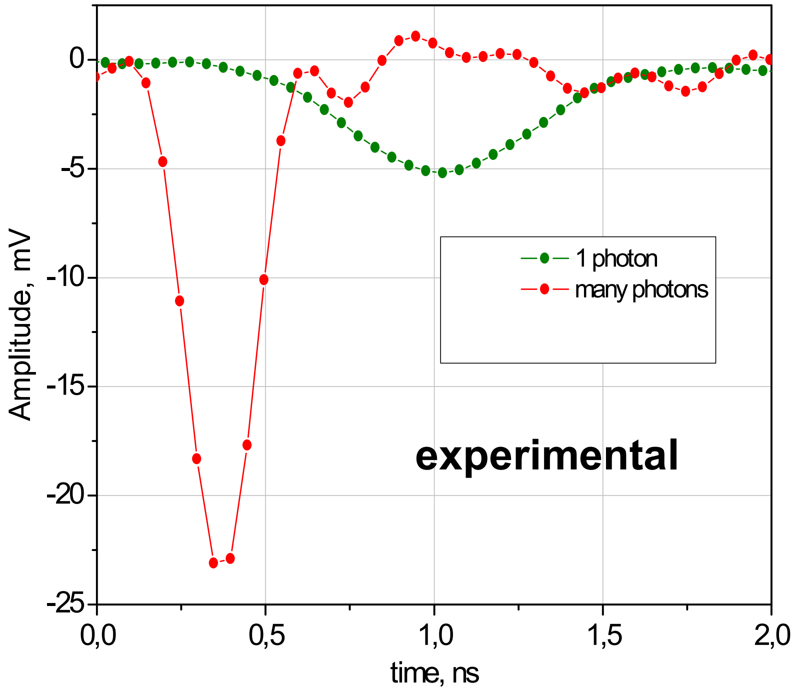
Even for very low light intensity we have “2-photons” amplitudes from cell -> it maybe an evidence of photon assisted discharge propagation

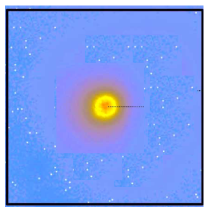
Signals from stand alone cell.

Comparison of SPICE simulation and experimental results. Light of different intensity.

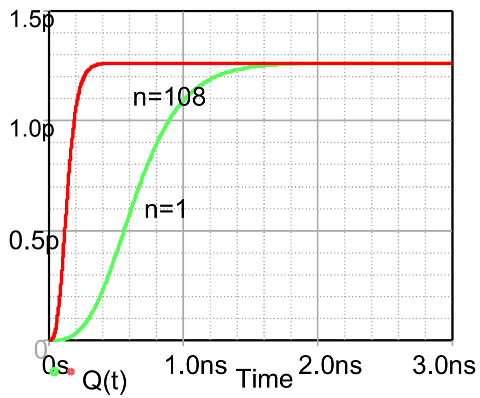


Npairs		Tr,ps	FWHM,ps	V_m,mV
1	exp	390	636	5.5
	mod	340	640	5.4
108	exp	150	240	18
	mod	140	225	17

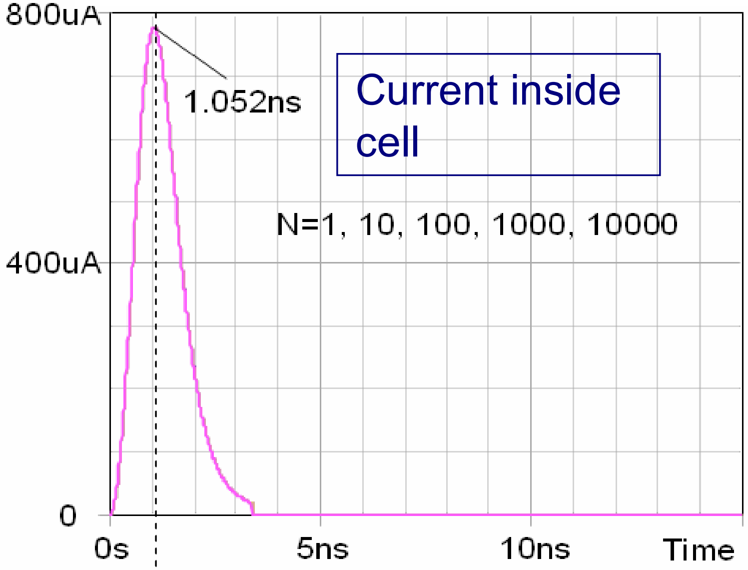


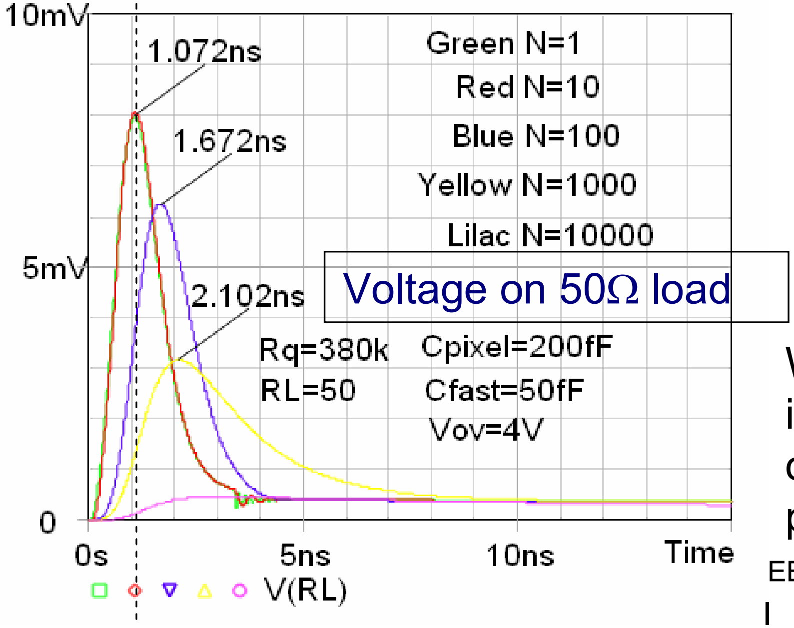


Simulation charge



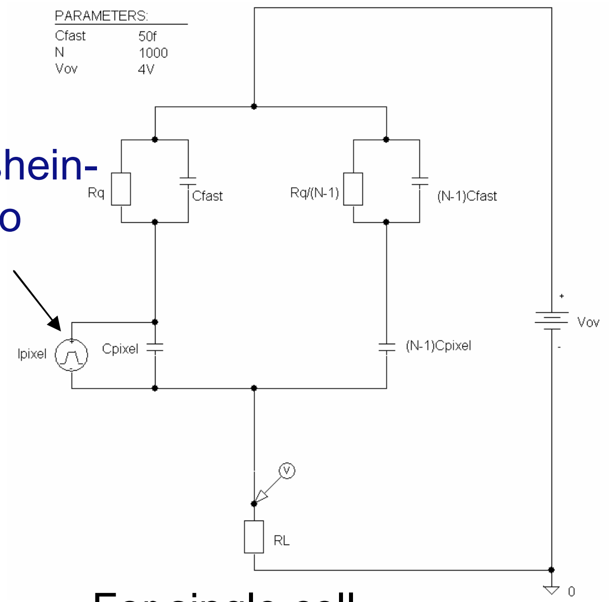
Different number of cells N inside SiPM





SiPM SPICE model with
Transversal current expansion

Dolgoshein-Pleshko model

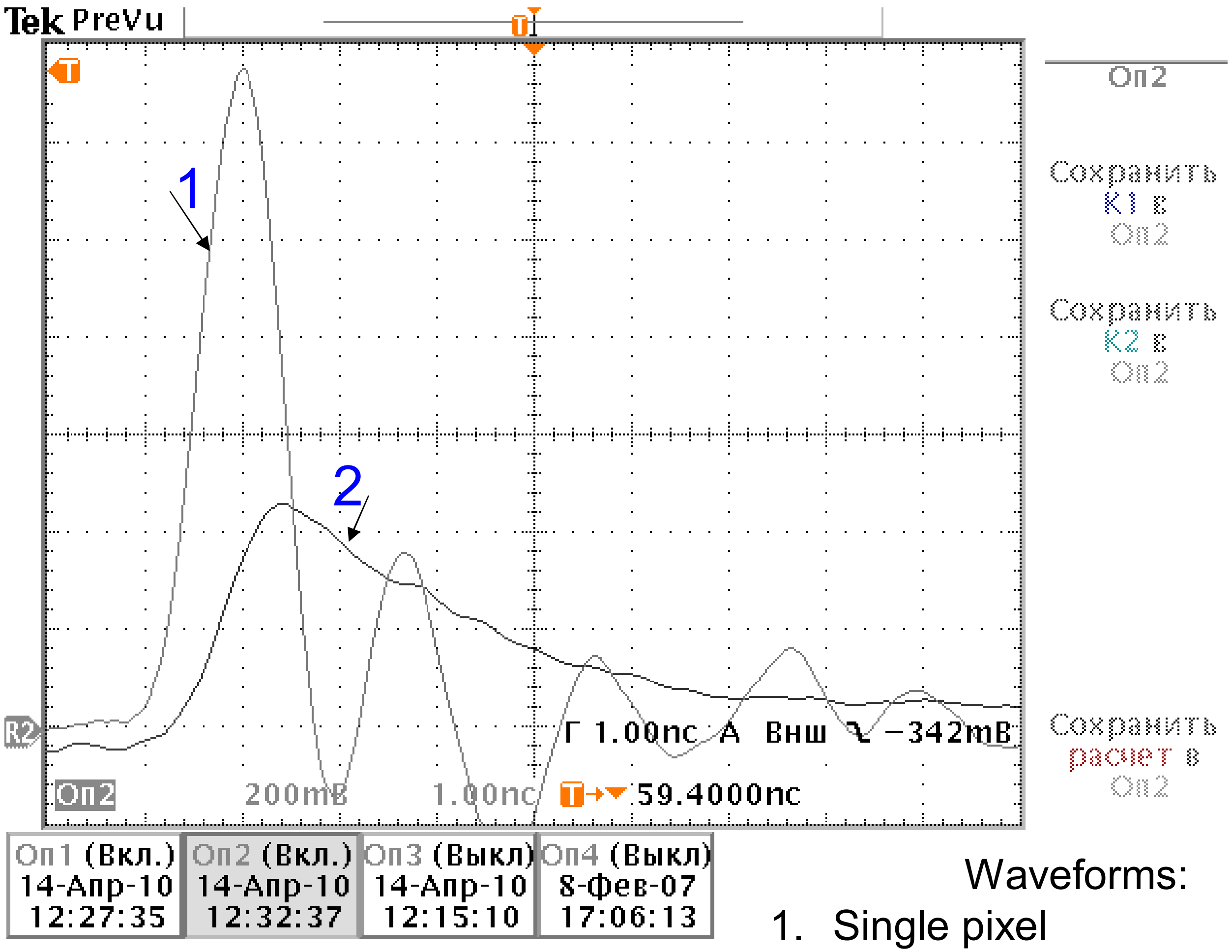


For single cell

$I_{load}=[C_{fast}/(C_{fast}+C_{pixel})]*I_{inside}$

I_{load} = 8mV/50Ω=160μA

With increasing total number of cells inside SiPM we decrease amplitude of single cell signal and obtain more slower pulse front



Waveforms:

1. Single pixel
2. One pixel from 1x1mm2 SiPM the same topology

SUMMARY

- Geiger discharge inside the SiPM cell has a limited spot size at the level of 8-10 microns (Light Emission Microscope studies)
- Spot size of Geiger discharge doesn't depend on overvoltage
- Single SiPM cell pulse width decreases with overvoltage
- Spice model of transversal avalanche propagation & Geiger discharge self quenching in SiPM cell has been developed (Dolgoshein – Pleshko) on the basis of Light Emission Microscope studies and cell waveform analysis
- SPICE model nicely predict waveform of SiPM signals and can be useful for SiPM itself or FE electronics engineering.

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