Light Sensors for the CTA Project

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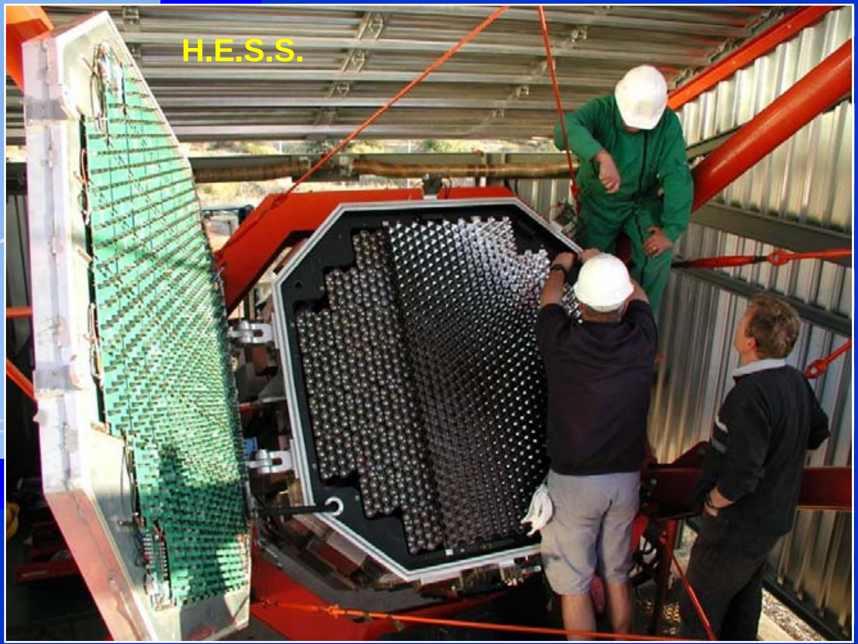
The most complex light sensors

These seemingly best-known imaging light sensors measure colour in the a relatively wide band (400 – 700 nm) as well as the light intensity within a

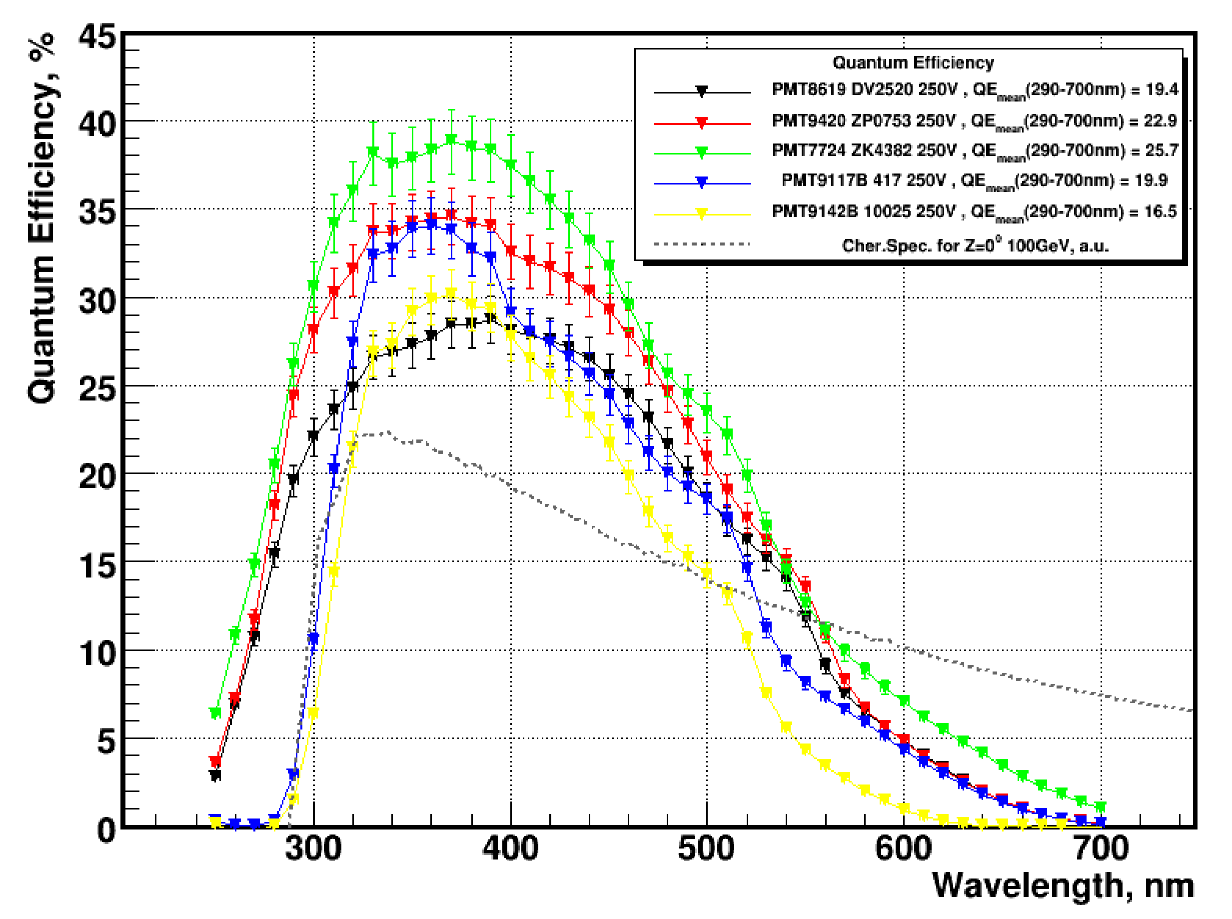
- dynamic range of 13 orders of magnitude !
- angular resolution ~ 1‘ (oculists call it 100 % sight)
- integration time ≥ 30 ms,
- threshold value for signals
  - 5-7 green photons (after few hours adaptation in the darkness)
  - 30 photons on average in the dark

Photograph of the 576-pixel imaging camera of MAGIC-I. In the central part one can see the 396 high resolution pixels of 0.10° size. Those are surrounded by 180 pixels of 0.20°.



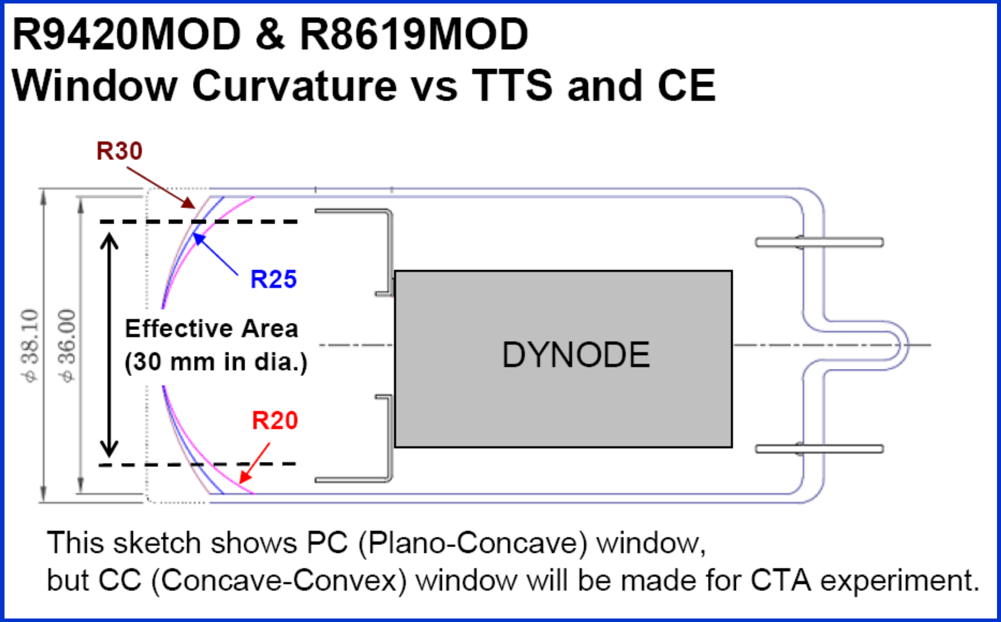
Instrumental/technological improvements

Running target: light sensor improvements. Successfully pushing the PDE higher up. Shown for several types of PMTs



- Some 6 years ago we have launched a QE improvement program with manufacturers Hamamatsu (Japan), Photonis (France) and Electron Tubes Enterprises (England).
- The results were very encouraging
- Since about 1.5 years a new program has been launched for CTA; the results are shown on the left

PMTs: improve the TTS and the Collection Efficiency



R8619MOD-100 DC Sensitivity and Data List for Trial Tubes

Date: Jul.14.2010

Serial Number	SK (uA/Lm)	SKb	SP (A/Lm)	Q.E. (%)			Operating Gain = 5E+04		Candidate
				300 nm	350 nm	400 nm	voltage (V)	AP/Noise(%)	
XA7105	63.9	10.6	14.3	22.5	25.7	25.5	950	0.0149	
XA7106	67.7	10.8	38.7	24.4	27.1	26.1	851	0.0133	
XA7107	96.8	12.2	56.9	24.1	26.9	26.4	845	0.0152	
XA7108	80.9	11.6	67.1	25.6	28.8	27.1	807	0.0172	
XA7110	128	14.8	71	33.3	36.4	35.2	861	0.0194	1
XA7111	77.2	11.7	47.9	24.9	28.1	27.5	827	0.0142	
XA7112	76.2	11.8	41.1	25.4	29.0	28.1	855	0.0138	
XA7113	71.9	10.5	34.4	24.9	28.0	27.2	846	0.0191	
XA7114	66.6	10.7	33.5	22.5	25.6	25.0	862	0.0223	
XA7115	85.2	12.7	53.2	28.2	32.1	31.8	821	0.0189	2
XA7116	133	14.6	72.1	32.3	34.9	33.1	876	0.0302	
XA7118	99.3	13	16.5	28.2	31.2	29.8	1005	0.0161	3
XA7119	123	14.6	54.5	33.5	36.5	34.9	896	0.0266	4
XA7120	125	14.4	49.7	31.2	33.4	31.7	882	0.0182	5
XA7121	124	14.5	59.1	31.8	34.4	32.6	863	0.0258	6
XA7122	124	14.9	43	33.8	34.1	33.0	917	0.0304	
XA7123	129	14.9	43.6	30.5	34.4	34.0	926	0.0511	
XA7124	132	15.1	33.3	31.9	35.9	35.1	954	0.0342	
XA7125	101	14.3	13.8	32.0	34.8	33.3	1027	0.0119	7
XA7126	111	14.9	47.7	33.6	37.6	36.9	884	0.0152	8
XA7127	90.1	12.9	33.2	29.1	32.8	32.6	892	0.0146	9
XA7128	73.6	11.7	18.8	26.4	29.9	29.3	922	0.0282	
XA7129	80.7	12.1	19.5	26.8	30.4	29.8	930	0.0186	10
XA7130	99.1	14.1	21.1	31.8	35.9	35.2	964	0.0135	11
XA7131	101	14	26.7	32.6	36.2	35.1	951	0.0137	12
XA7132	99.6	13.9	12.6	32.5	35.5	34.2	1034	0.0139	13
XA7133	103	14.5	22.1	34.4	38.4	37.4	960	0.0152	14

Ave-1	98.6	13.2	38.7	29.2	32.4	31.4	904	0.0202
Ave-2	110.4	14.1	38.5	31.5	34.7	33.6	925	0.0215

Ave-1: Average of all tubes
Ave-2: Average of tubes with light blue color

The most recent production of PMTs by Hamamatsu Photonics

Already now they came very close to requested parameters

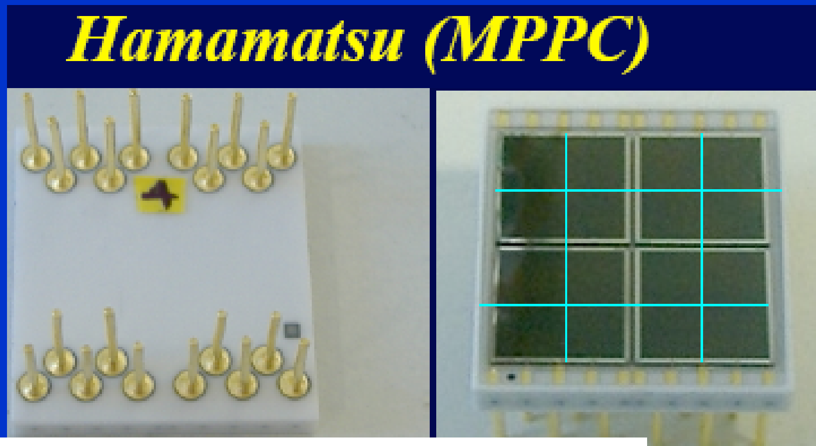
The <QE> peak is approaching ~ 35 %. The ph.e. collection efficiency is 95-98 %.

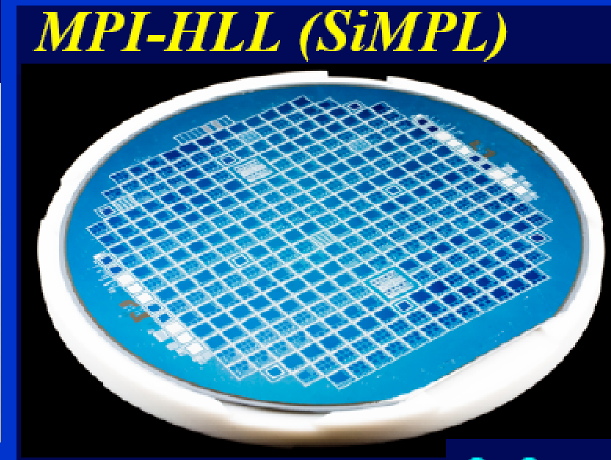
Requested afterpulsing < 0.02 %.

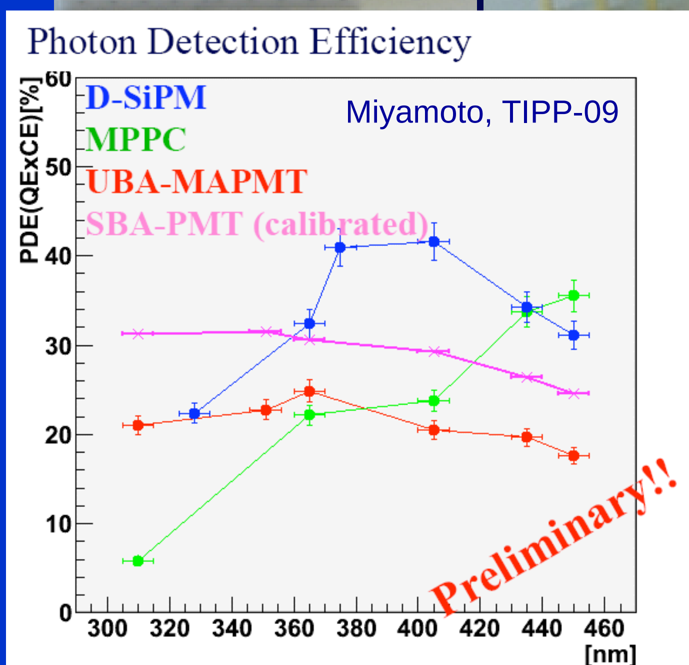
More improvements requested like much less variations in the gain of dynodes

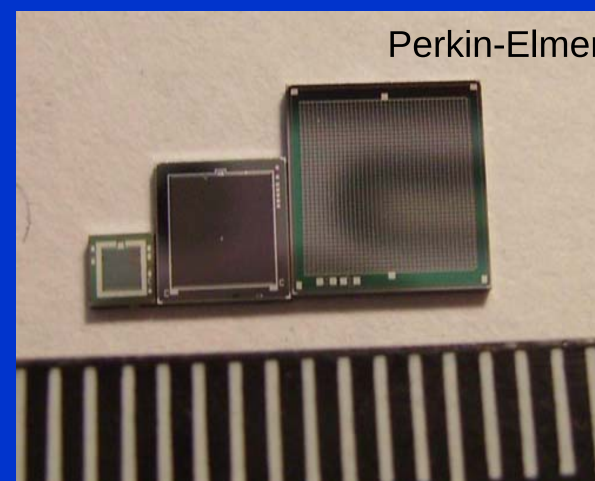
Currently launching a 2-year development contracts with Hamamatsu and ETE (England) Financial support by CTA

Few examples of SiPMs, still under development

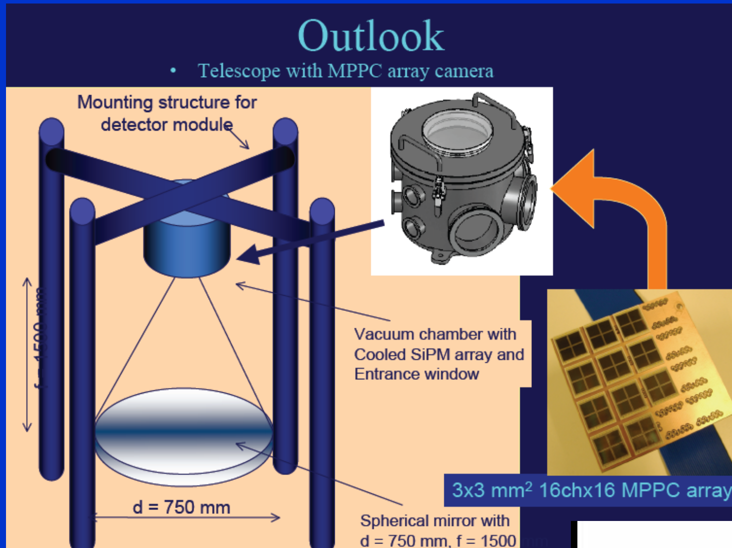


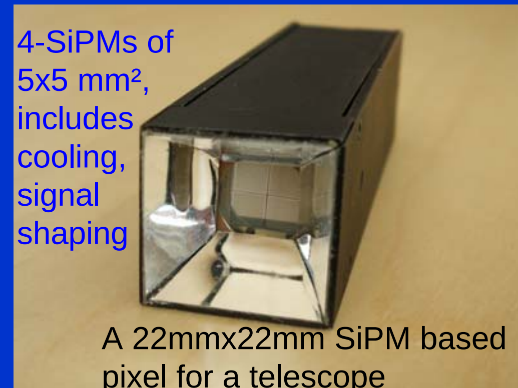


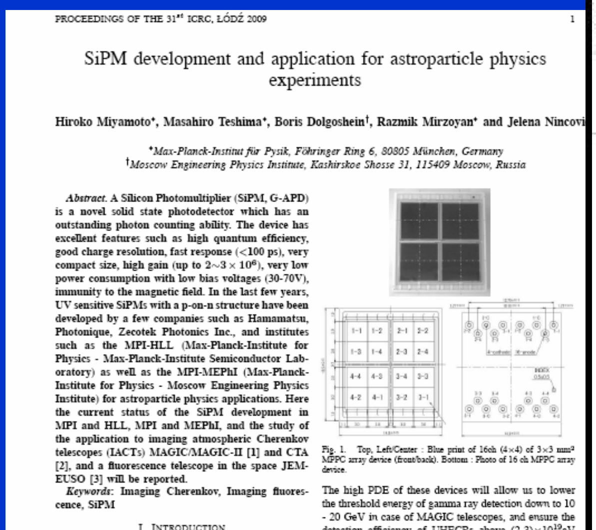




SiPMs with ~ 50-60% PDE and low cross-talk (< 1%) could be anticipated already in this year






PROCEEDINGS OF THE 31st ICRC, ŁÓDŹ 2009 1

SiPM development and application for astroparticle physics experiments

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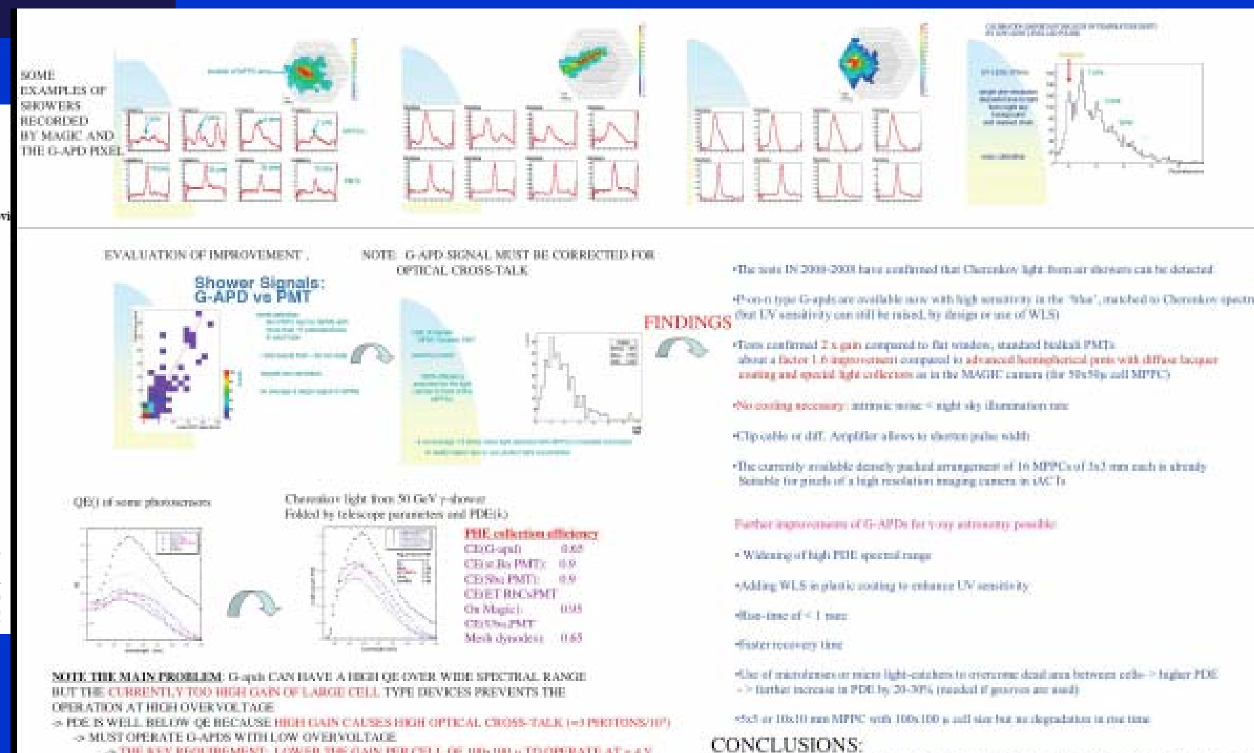
Abstract. A Silicon Photomultiplier (SiPM, G-APD) is a novel solid state photodetector which has an outstanding photon counting ability. The device has excellent features such as high quantum efficiency, good charge resolution, fast response (<100 ps), very compact size, high gain (up to 2∼3 × 10⁶), very low power consumption with low bias voltages (30-70V), immunity to the magnetic field. In the last few years, UV sensitive SiPMs with a p-on-n structure have been developed by a few companies such as Hamamatsu, Photonique, Zecotek Photonics Inc., and institutes such as the MPI-HLL (Max-Planck-Institute for Physics - Max-Planck-Semiconductor Laboratory) as well as the MPI-MEPhI (Max-Planck-Institute for Physics - Moscow Engineering Physics Institute) for astroparticle physics applications. Here the current status of the SiPM development in MPI and HLL, MPI and MEPhI, and the study of the application to imaging atmospheric Cherenkov telescopes (IACTs) MAGIC/MAGIC-II [1] and CTA [2], and a fluorescence telescope in the space JEM-EUSO [3] will be reported.

Keywords: Imaging Cherenkov, Imaging fluorescence, SiPM

I. Introduction

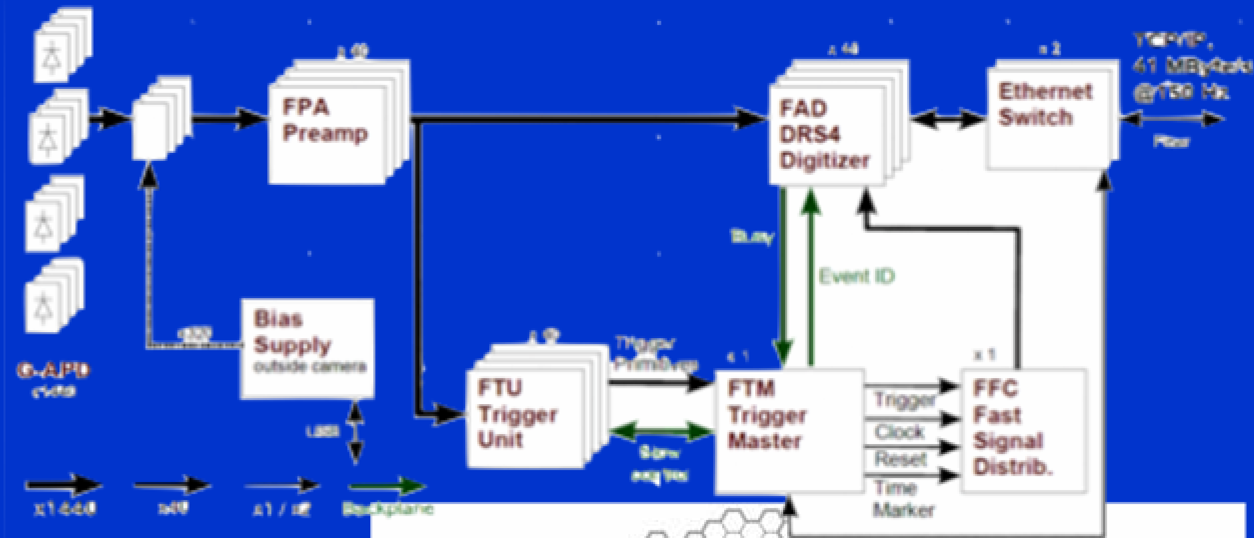
Fig. 1. Top, Left/Center : Blue print of 16ch (4×4) of 3×3 mm² MPPC array device (front/back). Bottom : Photo of 16 ch MPPC array device.

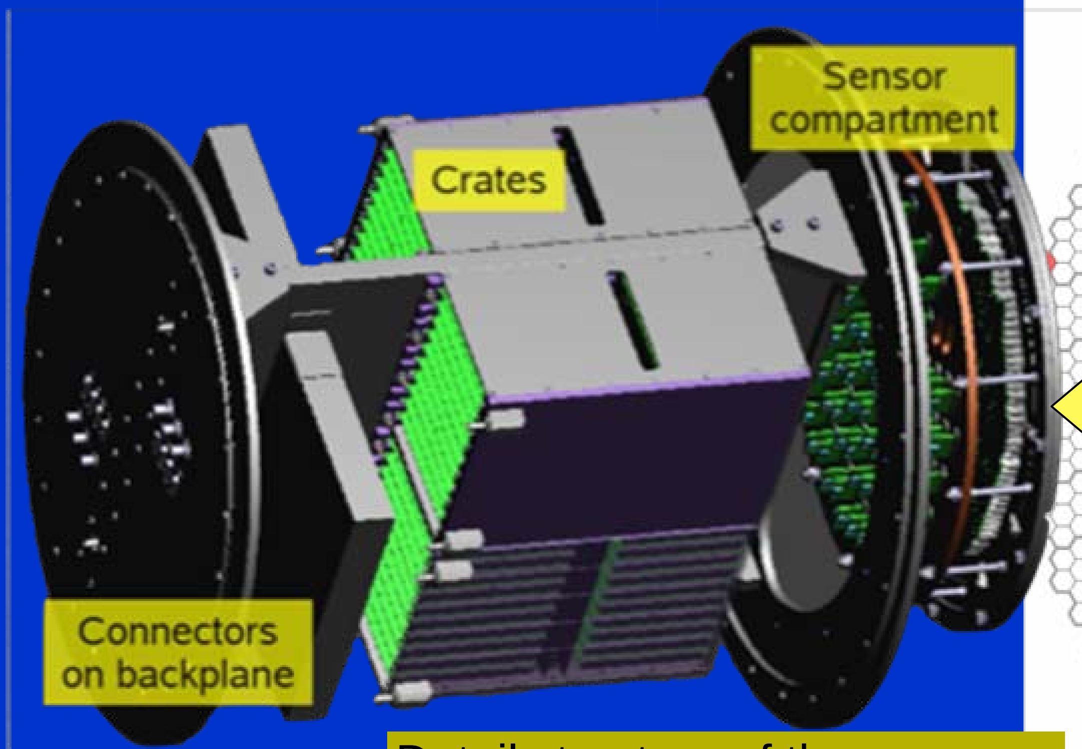
The high PDE of these devices will allow us to lower the threshold energy of gamma ray detection down to 10 - 20 GeV in case of MAGIC telescopes, and ensure the detection efficiency of UHECRs above (2-3)×10¹⁹eV



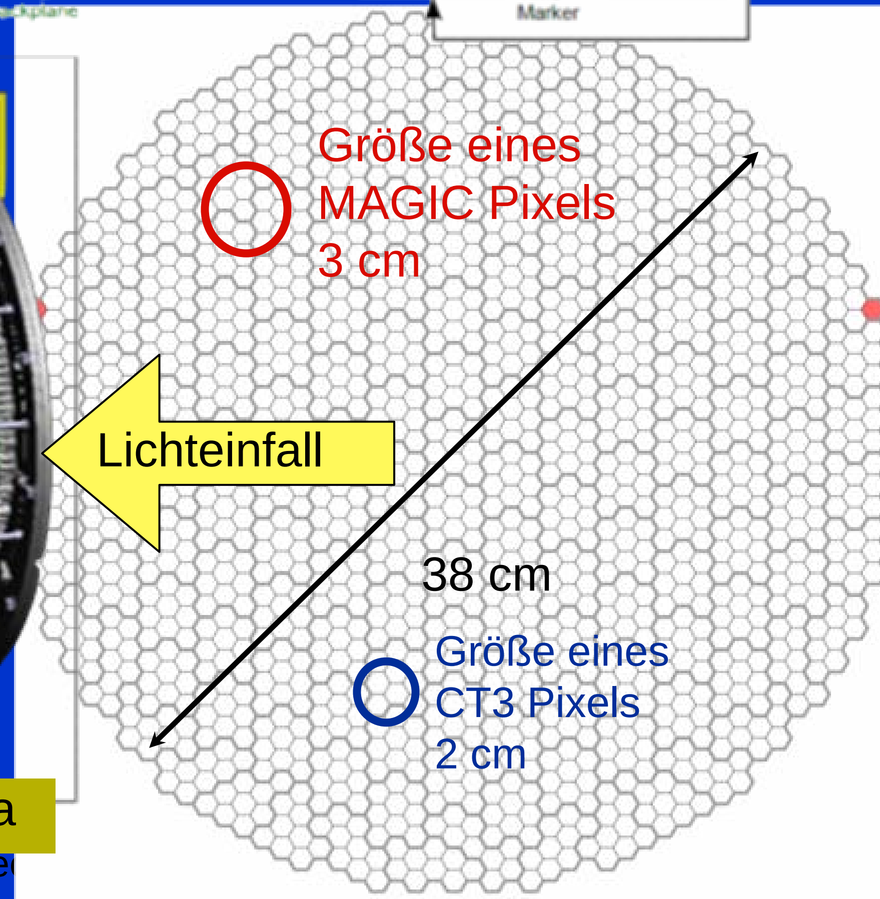
2010: 1440-Pixel G-APD-Kamera

DAQ in Kamera integriert

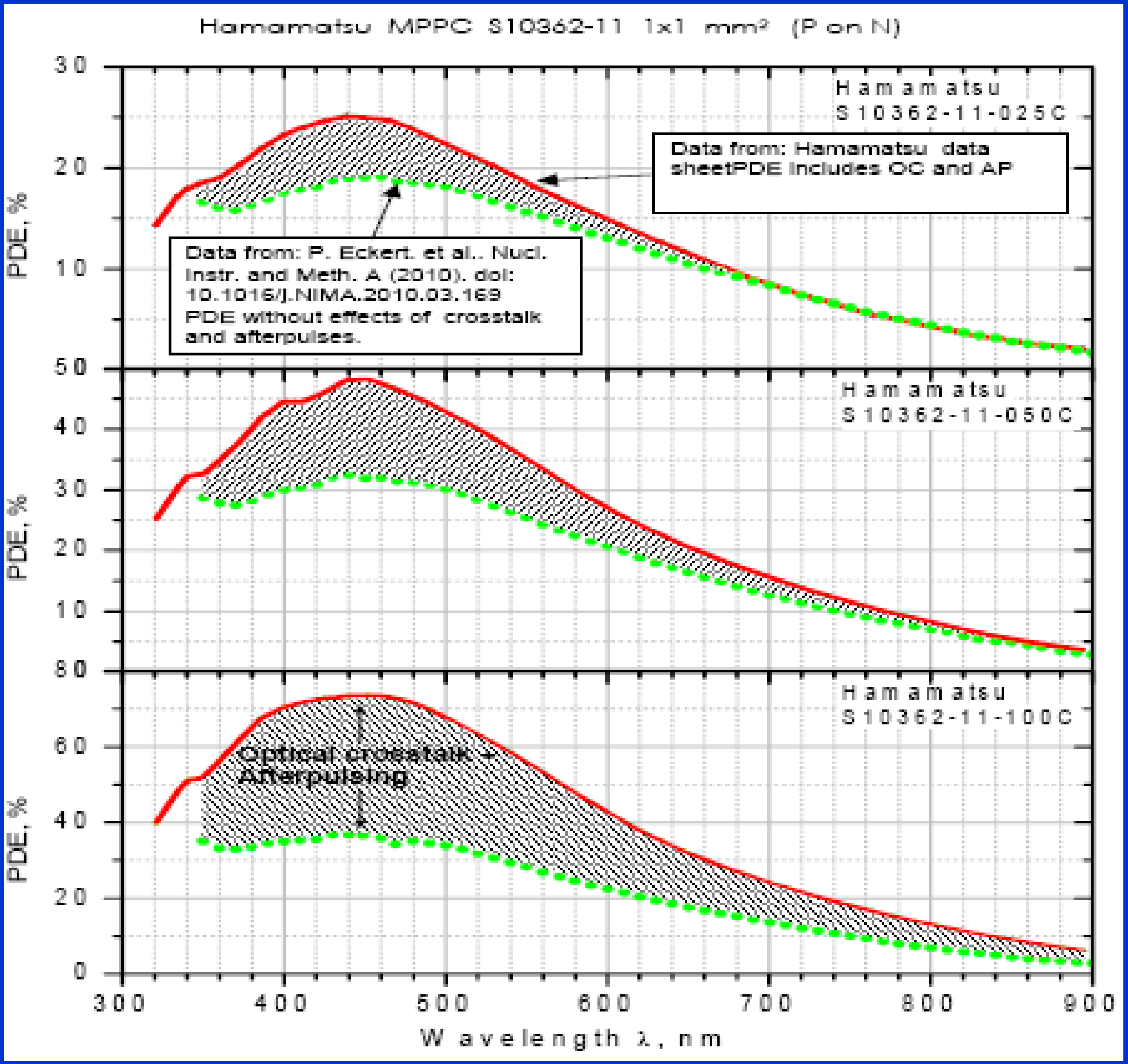




Detail structure of the camera



High Optical cross-talk and afterpulsing

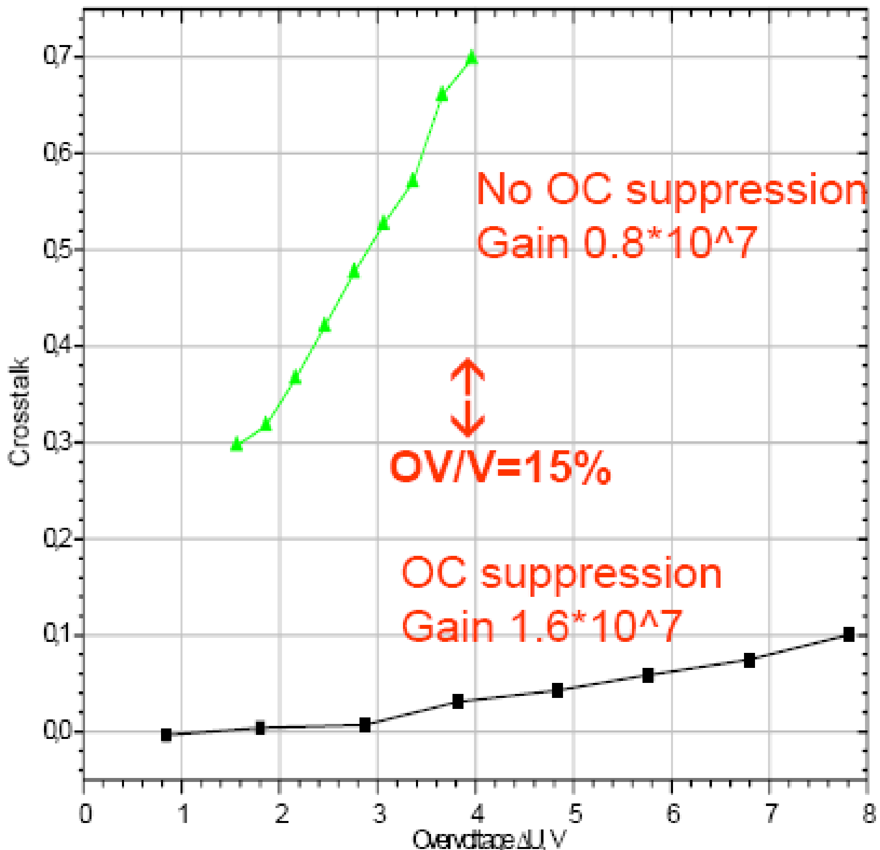


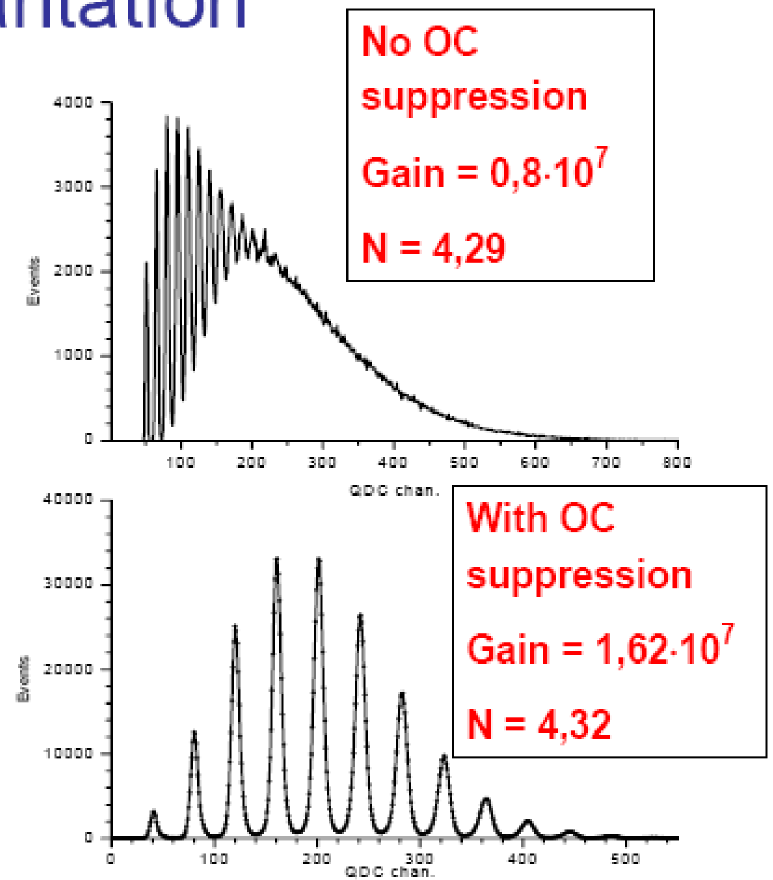
Current status of SiPM and the prospects

- Currently there is a lot of enthusiasm about the new devices but the deep understanding is not simple, it comes only slowly
- It is not easy to measure the PDE, that shall be disentangled from the X-talk and afterpulsing.
- The afterpulsing in PMTs is a ~1% effect (@single ph.e.) while for current MPPC's (Hamamatsu) it is a 20-30 %
- Often real value of PDE is << than the claimed (advertised) one. The reason is low applied overvoltage.
- For ~100 % Geiger efficiency and a high PDE one needs to apply overvoltage ~15 %. Most commercially available devices cannot do this yet
- Hamamatsu, Philips, Perkin-Elmer, Zecodec,… and more companies are working on it.

Prompt OC suppression using Si damaged by ion implantation

(Patent pending)



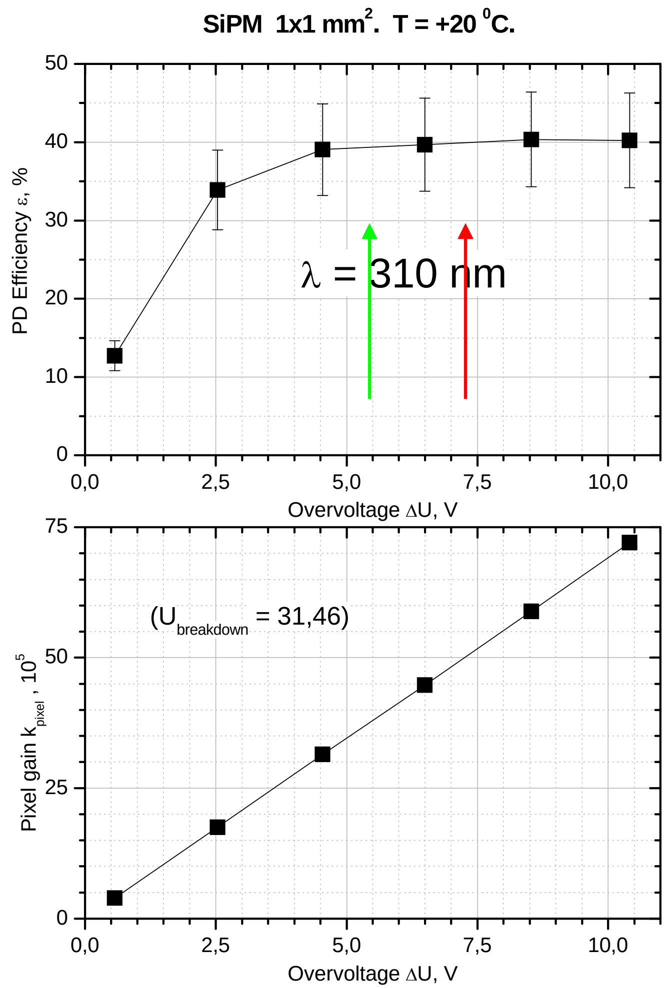


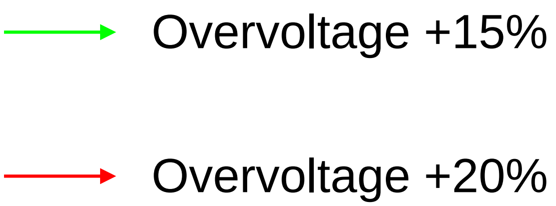
SiPM 1x1 mm^2

10-Jun-2010 B.Dolgoshein Silicon PM 27

A PDE and gain of a 1x1 mm² SiPM produced by team of Dolgoshein in cooperation with PEI measured at +20°C

Overvoltage = operational voltage – breakdown voltage





Conclusions

- It is very likely that in a time scale 1-2 years from now one can buy SiPMs with outstanding characteristics, probably from several manufacturers.
- Their sizes could span initially 1-3-5 mm, but later perhaps also until 8-10 mm.
- SiPM cost will be reduced due to the availability of full CMOS designs. Several USD per mm^2 is not unrealistic.
- They could offer PDE of 60-65 %, x-talk < 1% and low temperature and voltage dependences.
- These devices are going to substitute classical PMTs and APD in many applications, including those in physics instrumentation in, for example, nuclear medicine (time-of-flight PET,…).

Optical Crosstalk OC

P. Buzhan, B. Dolgoshein, et al., 2009

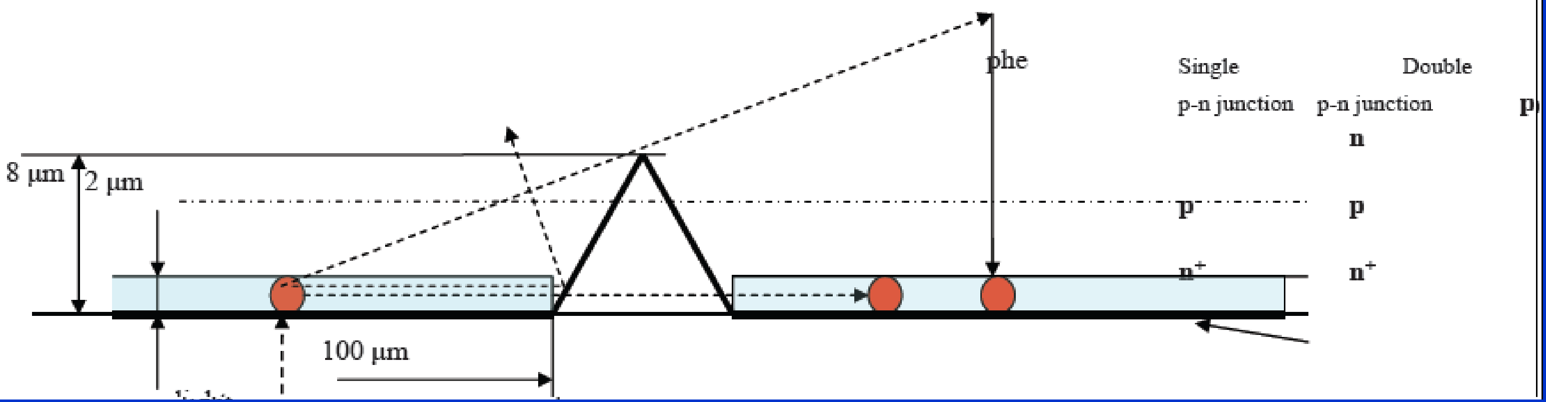
OC has two components

FIRST:phe's are induced in high electric field depletion region of neibouring pixels

→this mechanism is very fast: ~1ns(prompt OC)

SECOND :The same in undepleted region and then the diffusion(or drift)to high electric field Geiger region of neibouring pixels

→this process is delayed: later than 1ns

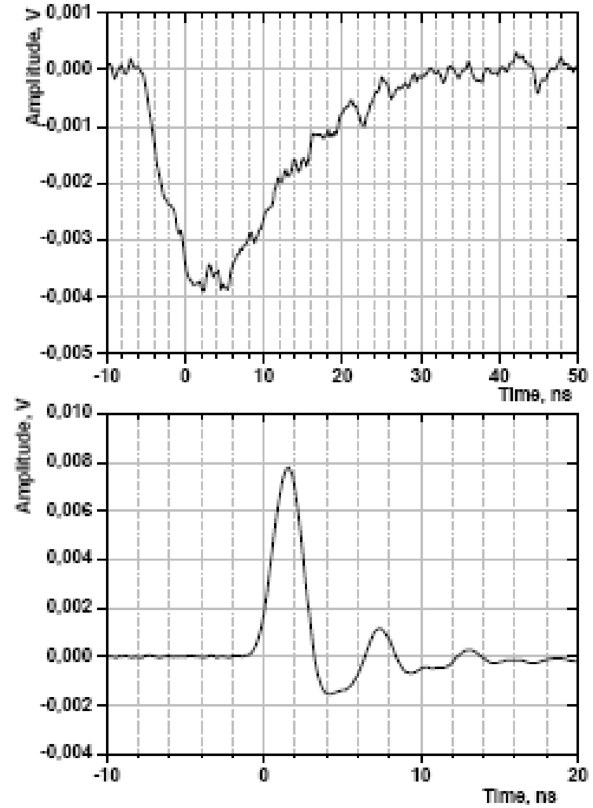


Timing by 5x5mm2 SiPM: signal shape

➔ Because high SiPM output capacitance (~160pF)

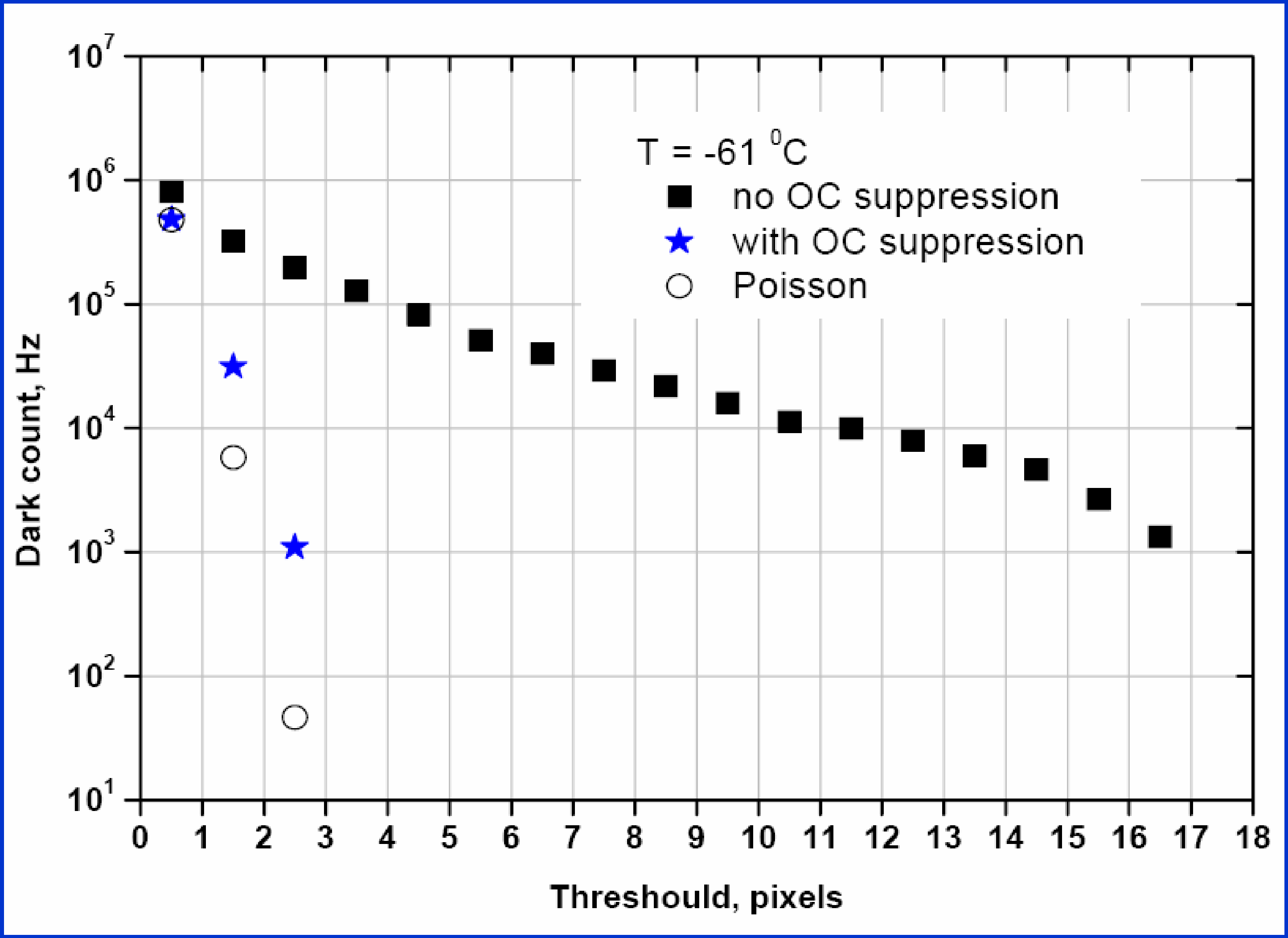
a special FE electronics has been developed:

low imput impedance(a few Ohm) current amplifier+shaper



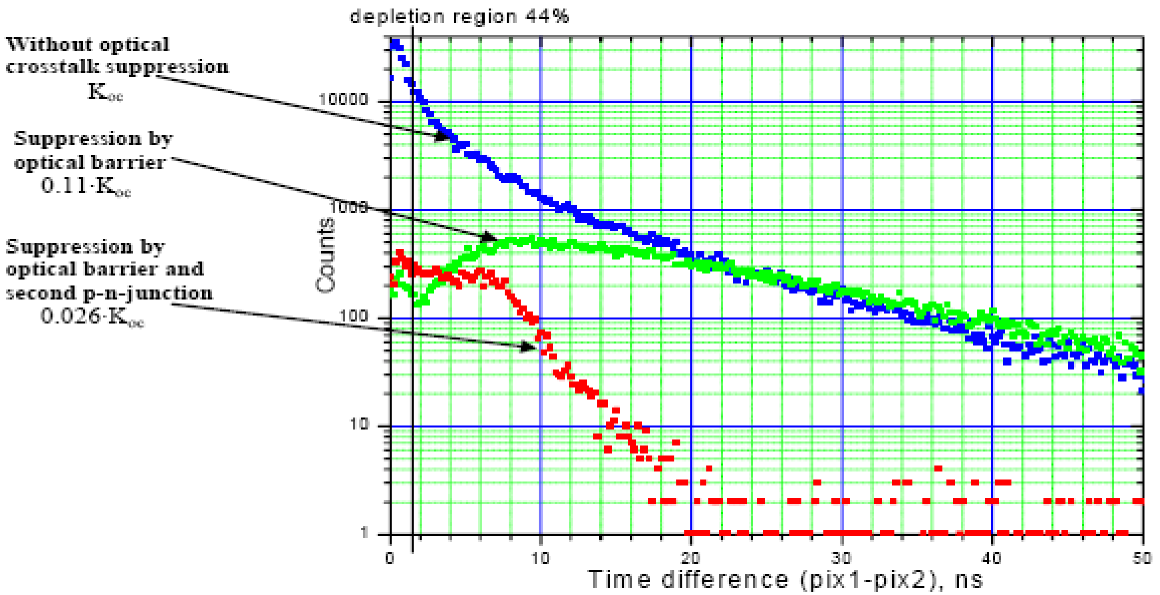
50 Ohm
FWHM
15ns

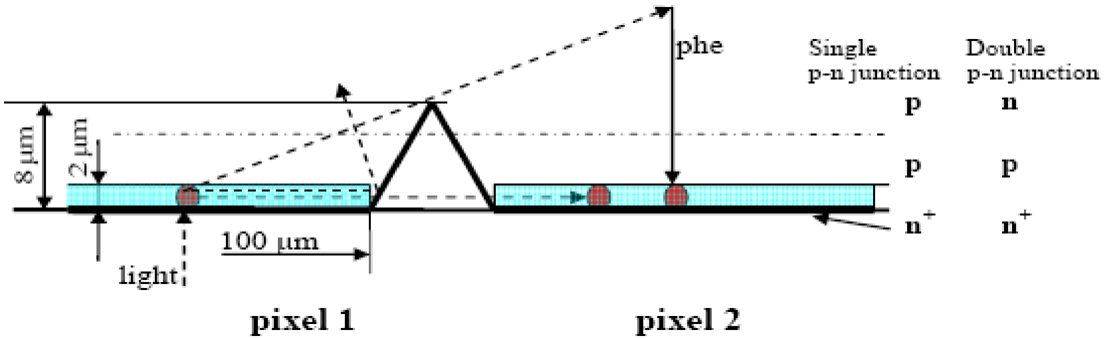
~ 7 Ohm
+shaper
FWHM
2,5ns



T = -61 ⁰C
no OC suppression
with OC suppression
Poisson
Dark count, Hz
Threshould, pixels

Optical Crosstalk studies





Optical crosstalk between two separate pixels

Results of Optical Crosstalk studies

two separated pixels
pixel size 100mkm,pitch 130mkm
gain 2 x 10*7
recovery time > 1mks
PDE=35%

OPTICAL CROSSTALK:

→ prompt (< ~1ns.phe in depletion region) ~50%
→ delayed(> ~1ns ~50%

OPTICAL CROSSTALK SUPPRESSION FACTOR:

→ with optical barriers(tranches,8mkm deep) ~9
→ with optical barriers + second n-p junction ~4.5

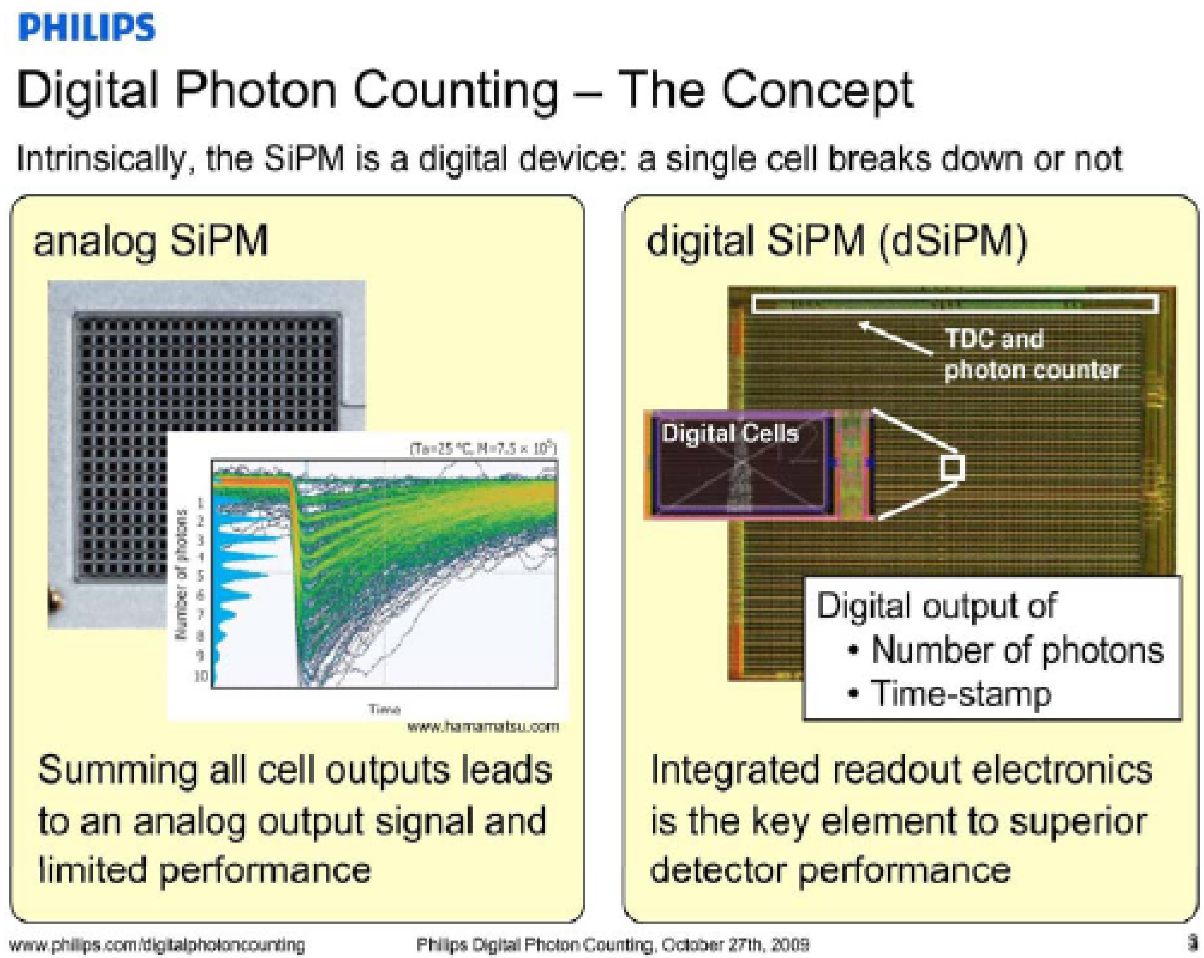
Total: ~40

Digital SiPM

→single pixel dark count rate is lower by factor of 1.5-2 (~physical limit)
→digital output is more convenient for system integration

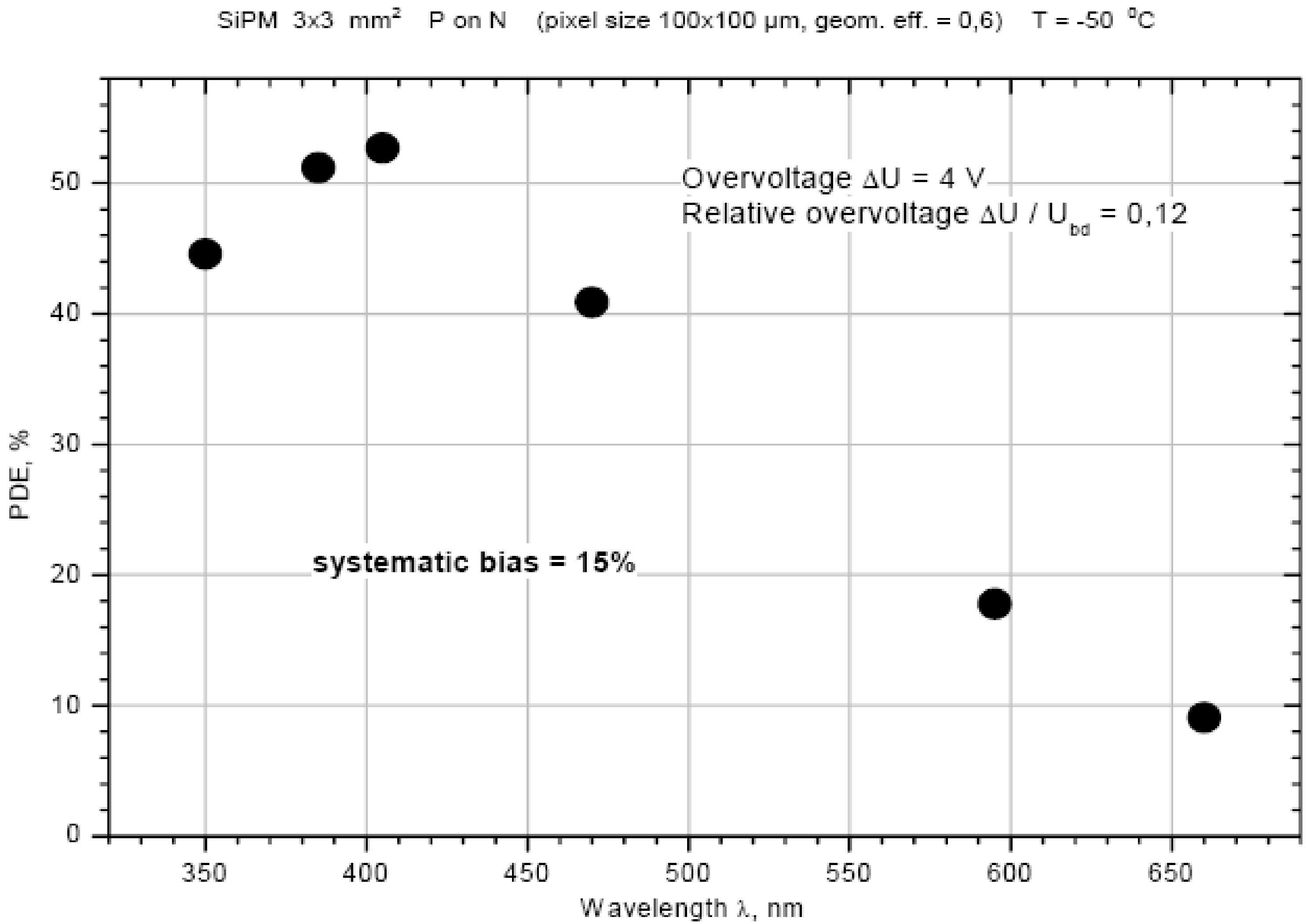
→PDE loss (filling factor is less due to electronics on chip)
→problems with Optical Crosstalk and Afterpulsing have to be solved

Fabrication cost?

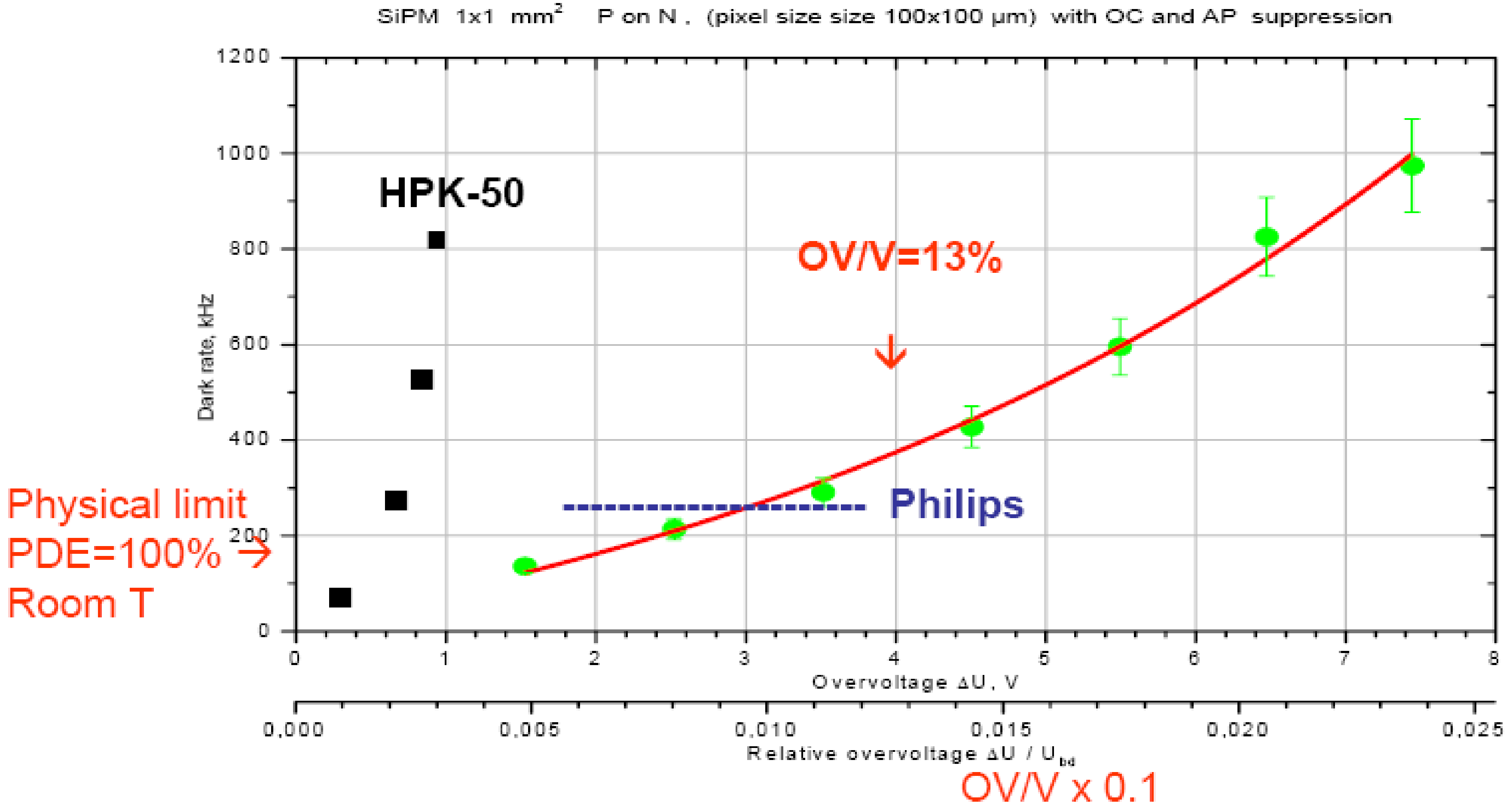


PDE ,SiPM p on n,3x3 mm^2, OV/V=12% +OC suppression

Test-product of PEI



Dark count rate:
SiPM 1x1mm^2, OC=4%,AP=1%
room temperature



The 17m Ø MAGIC IACT project for VHE γ astrophysics at E~ 25 GeV - 30 TeV