Status of SiPM Developments

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On behalf of MEPhI-MPI for Physics-Pulsar Collaboration(MMP)

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+ SiPM today: –

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- High gain,good S/N ratio
- Good single electron resolution
- Very good timing
- Small recovery time
- Very low nuclear counting effect
- Insensitivity to B
- Simple calibration and monitoring
- Vow bias voltage
- Low power consumption
- Compactness
- Room temperature operation
- Good T and V stability
- Not damaged even by ambient light
- Relatively low expected cost(low resistivity Si,simple technology)

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- Not very high PDE
- Small area
- High dark rate(~ area)
- Excess Noise Factor is Large enough due to Optical Xtalk
- Afterpulses

Optical crosstalk OC

One phe gives rise more than one pixel fired due to secondary photons
~ 3x 10*5 photons(~1000nm) per one electron in Geiger discharge

OC

-- does not depend on temperature
-- proportional to
Gain x Photon Detection Efficiency

The larger PDE
→ the larger pixel size
→ The larger Gain

Afterpulsing AP

Capture of avalanche electron by traps and its delayed release giving the secondary Geiger discharge in the same pixel

AP

-- proportional to
Gain x PDE
-- increases for low temperature the same recovery time because trap lifetime increase

Optical Crosstalk and Afterpulsing

→ Give rise the non-Poisson statistics of fired pixels (SiPM response).

→ As a result:

→ SiPM pulse hight resolution is worsening:

→(sigma/A)*2 > 1/N phe

Excess Noise Factor ENF >1

→Sci Spectrometry(PET etc.) ?

ENF: for PMT ~ 1.2

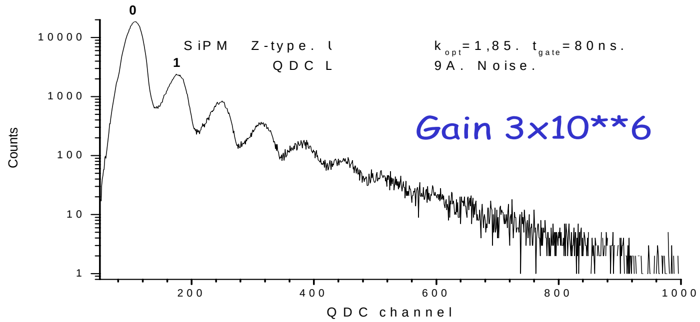
for APD ~ 2-2.5

for SiPM(desirable) < 1.05

Optical Crosstalk and Afterpulsing

→ Long tail in SiPM pulse hight distribution vs threshold

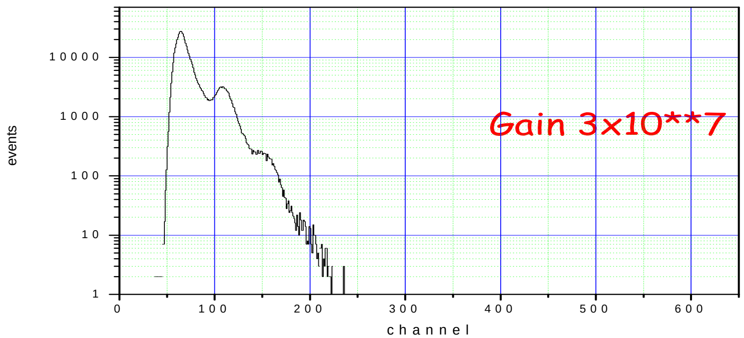
Optical crosstalk,SiPM 1x1 mm2,dark noise



Crosstalk→non-Poissonian distribution:

pixel fired/phe=1.7

ENF=1.6



Crosstalk suppression by special SiPM topology:

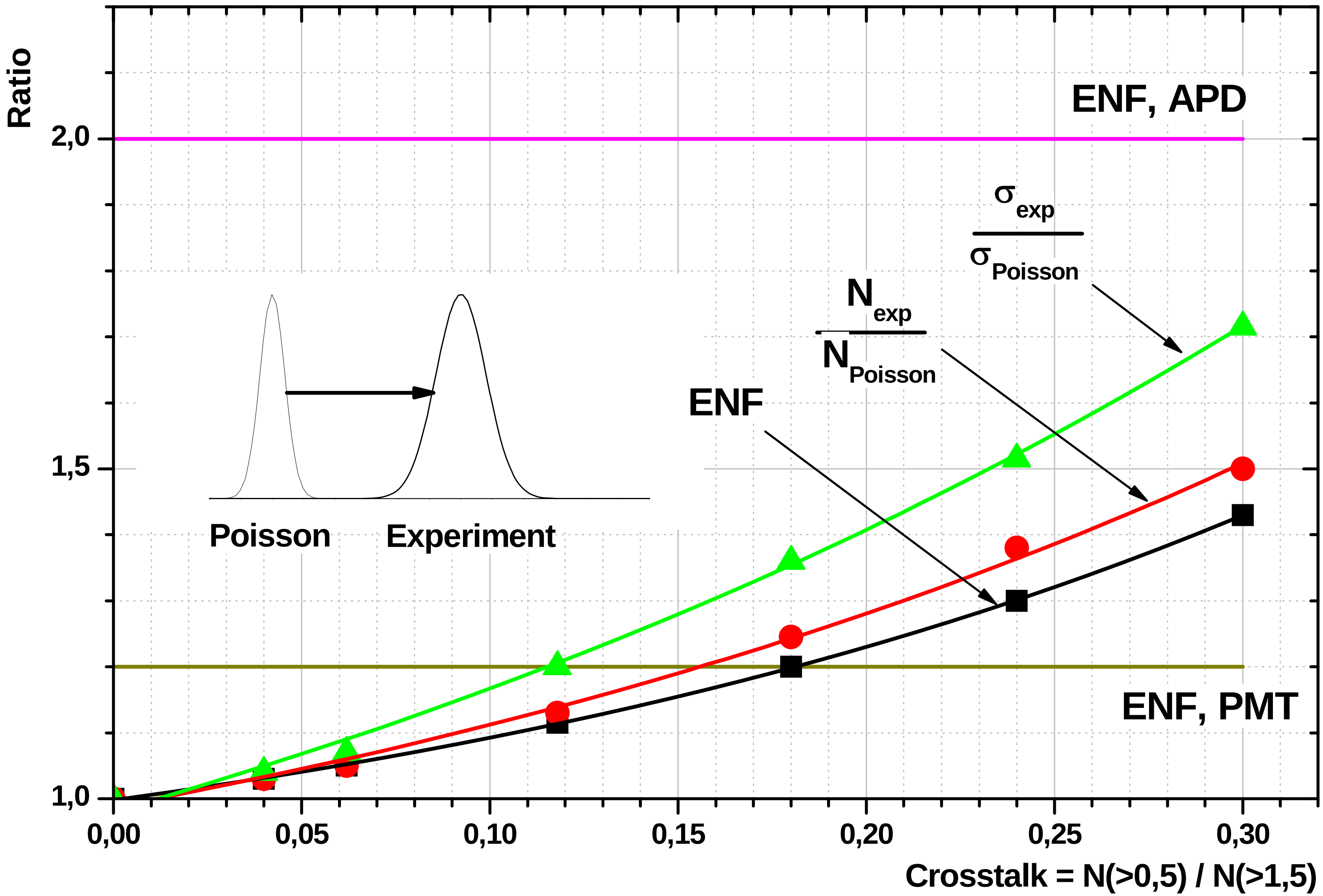
Poisson distribution:

pixel fired/phe= ~1

ENF= ~1

14

B.Dolgoshein,LIGHT06



Ratio
2,0
1,5
1,0
0,00
0,05
0,10
0,15
0,20
0,25
0,30
Crosstalk = N(>0,5) / N(>1,5)
ENF, APD
σexp
σPoisson
Nexp
NPoisson
ENF
ENF, PMT
Poisson
Experiment

The suppression of SiPM noise for as low threshold as possible is extreemly important for:

→Imaging Atmospheric Cherenkov Telescopes(e.g.MAGIC) or space-born fluorescent telescope EUSO

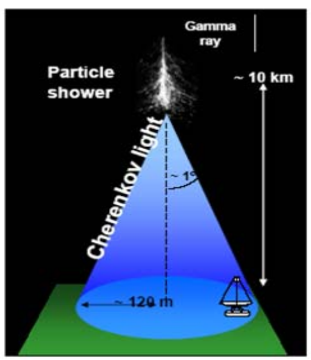
→ threshold ~ 1-2 phe

SiPM for astroparticle Physics

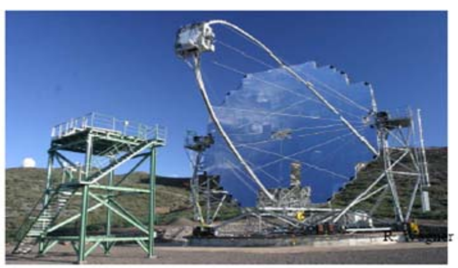
- A single photon counting

MAGIC

Major Atmospheric Gamma Imaging Cherenkov Telescope



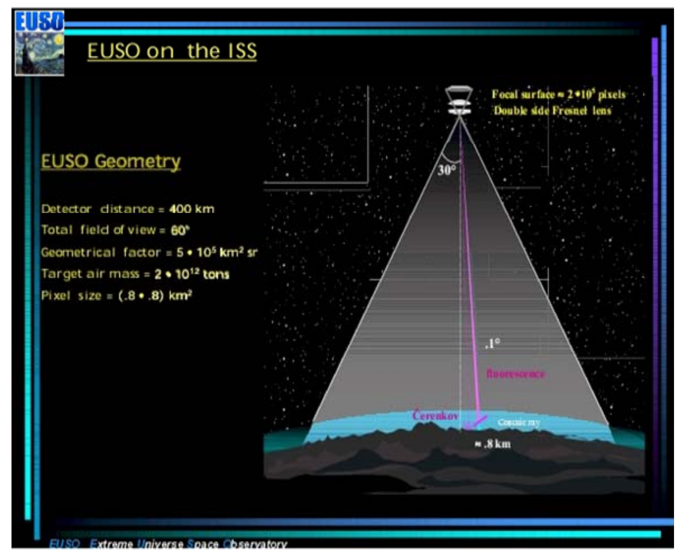
Observation of Cherenkov light from ground based telescope



http://hegra1.mppmu.mpg.de/MAGICWeb/

G.Lutz, Conf.on Photodetection, Beaune, June 19-24, 2005

5



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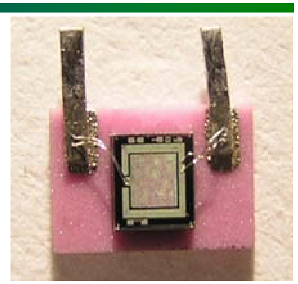
Another example of low SiPM requirements:

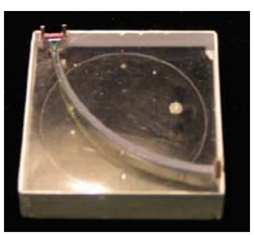
→Scintillation Calorimetry- for instance a SciTile Imagine Hadron Calorimeter for ILC (CALICE Collaboration),sci tile size:a few cm

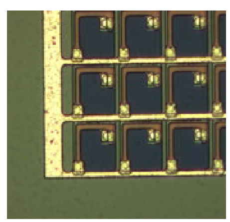
→Typical threshold is ~ 5-7 phe

SiPM tile fibre system

- SiPM developed by MEPhI/PUSAR
  - Gain ~10^6, bias ~ 50 V, size 1 mm^2, 1156 pixels
  - Eff (green) ~ 15%, quenching R ~ 1 - 10 MΩ
- SiPM tile fibre system integration: ITEP
  - 3x3x0.5 cm^3 tiles from UNIPLAST, Russia
  - WLS fibre Kuraray Y11(300) 1mm
  - Matted edges, 2% light xtalk per edge
  - Faces covered with EM mirror foil



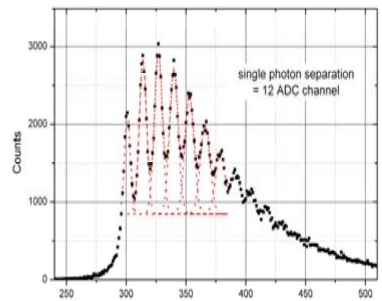




CALICE Calorimeter for ILC

MGPDs for calorimetry Felix Sefkow PD'07 June 27, 2007 13

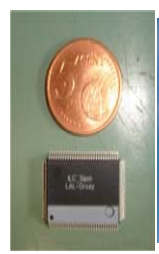
A big 8000 channel HCAL prototype with tail catcher is constructed by CALICE (DESY,ITEP,LAL,MEPHI,NIU,Prague,UK) for analogue and semidigital modes

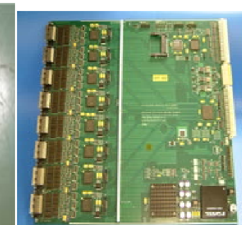


SiPM&FE signals in calibration mode

One plane with SiPMs and WLS fibers installed into 3x3, 6x6 and 12x12 cm^2 0.5 cm thick tiles

CERN test beam,2006





LAL 18 ch. SiPM FE chip

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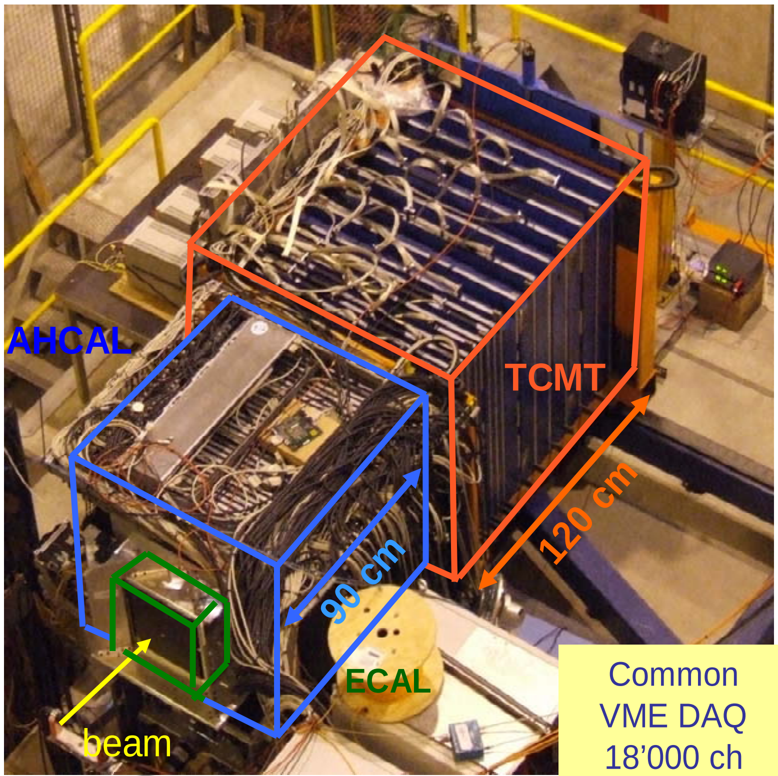
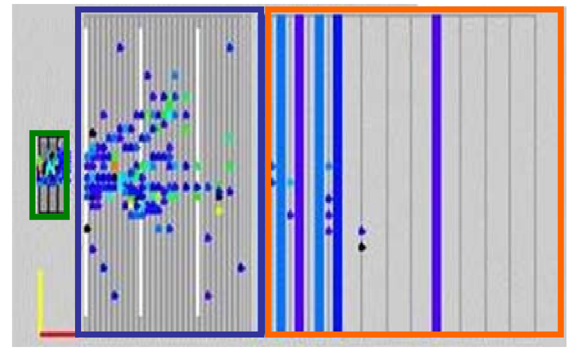
Test beam installation at CERN SPS





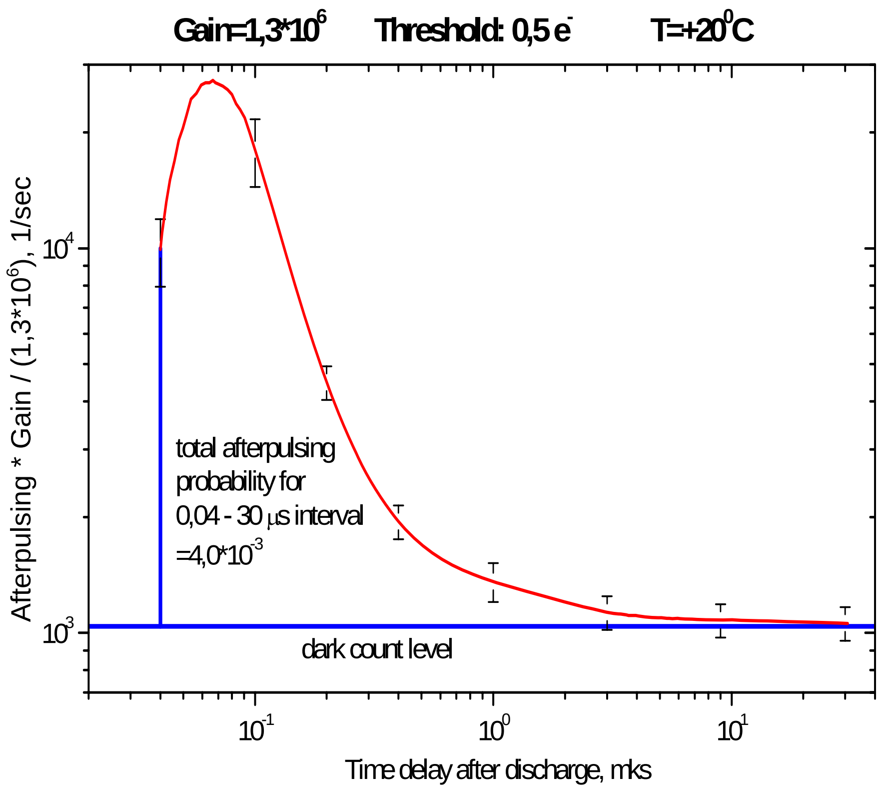
July - Nov. 2006
CALICE detectors installed in the H6b experimental hall at the CERN SPS

smooth commissioning, prepared at DESY

Hadron (electron) beam
6 - 100 (50) GeV

Afterpulsing AP

→ The lifetimes of trapped electron are mostly rather small: less than ~100 ns



Therefore a single pixel recovery time Rquench x Cpixel sould not be not very small and recommended at level of .5-1 mks

→Even for high Gain x PDE the Afterpusing has to be small enough:
AP(Gain=10*7)=~1%
for recovery time of >500ns

Optical Crosstalk OC

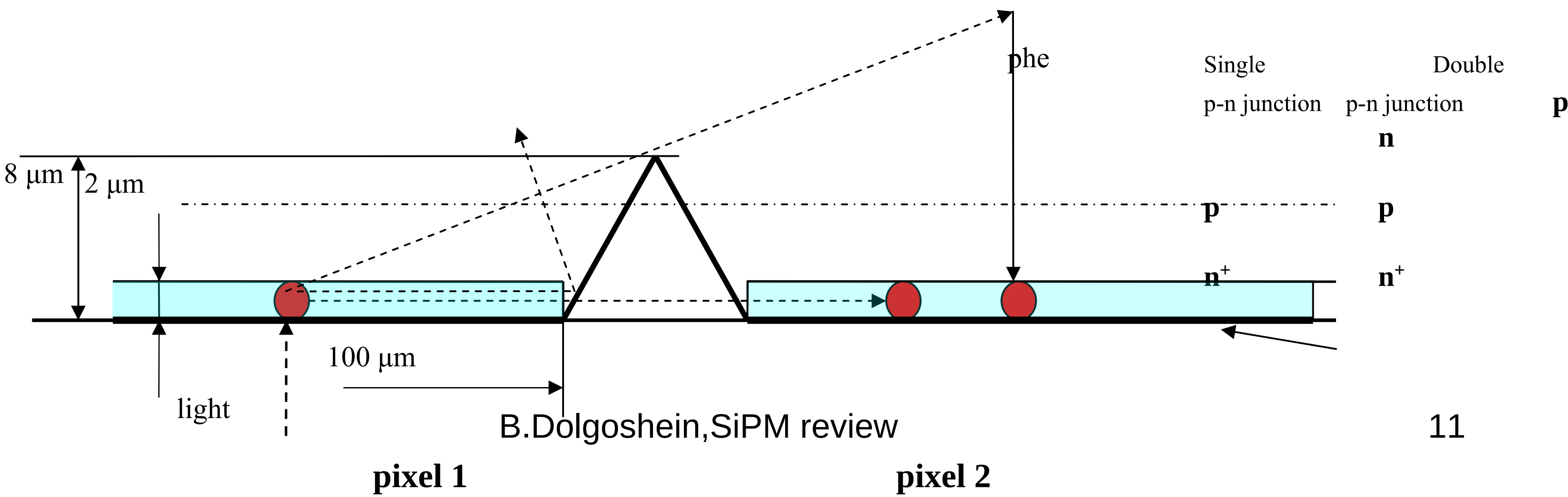
OC has two components

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

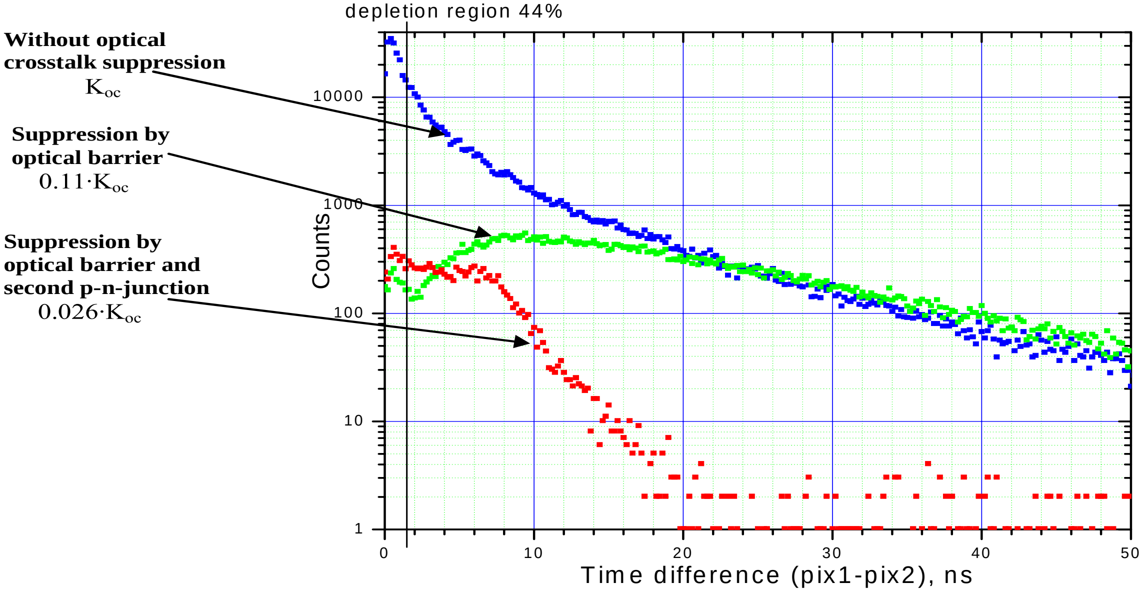
→this mechanism is very fast: ~1ns(prompt OC)

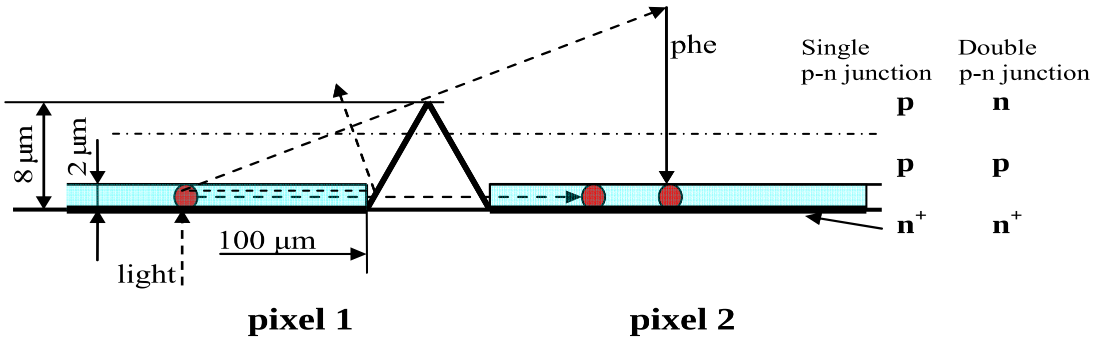
SECOND :The same in undepleted region and then the diffusion(or drift)to high electric field Geiger region of neibouring pixels

→this process is delayed: later than 1ns



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

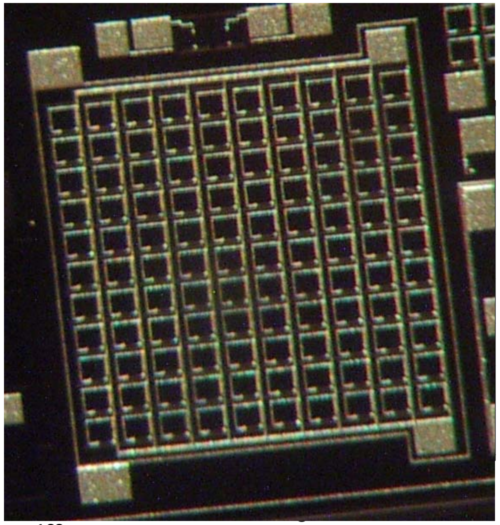
Total: ~40

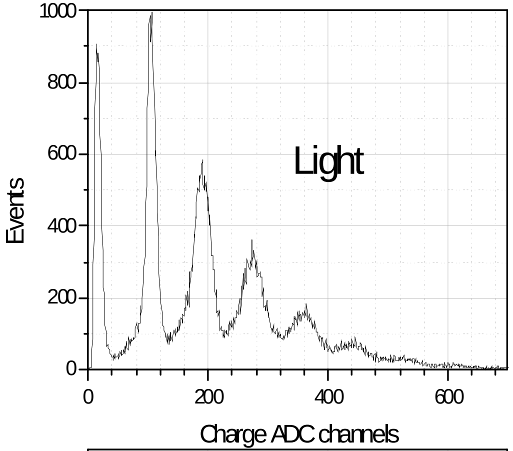
Production and performance of 5x5mm2 SiPM for MAGIC telescope with suppression of OC and AP

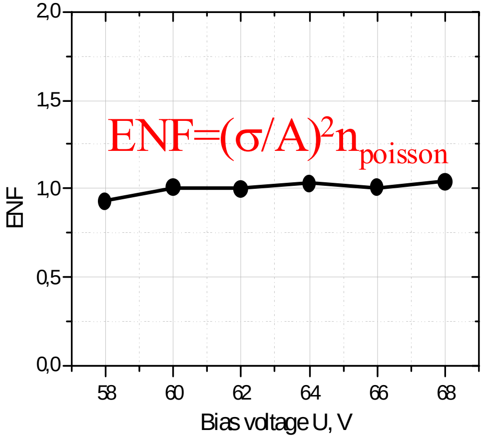
MAGIC requirements discussed:

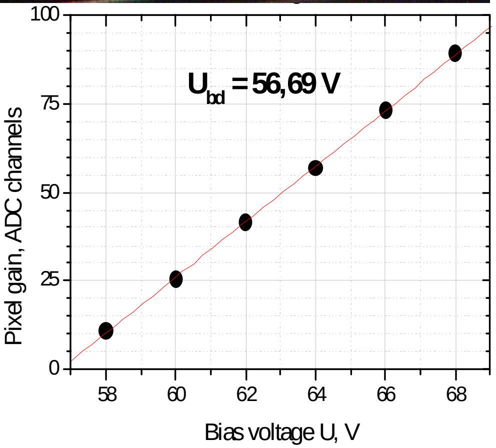
→ one cell of photodetector plane 2 cm2
with a photosensor 1 cm2
matrix of 4(5x5mm2) SiPMs
→ spectral response ~350-650 nm
→ PDE: as much as possible(compared to PMT)
→ Afterpulsing <1-2%
→ Optical Crosstalk <5%
→ single phe pulse width ~2ns
→ dark rate: less than Light Of Night Sky(LONS) =~600 kHz/mm2
→ ~300 KHz/mm2 or ~8 MHz/5x5mm2

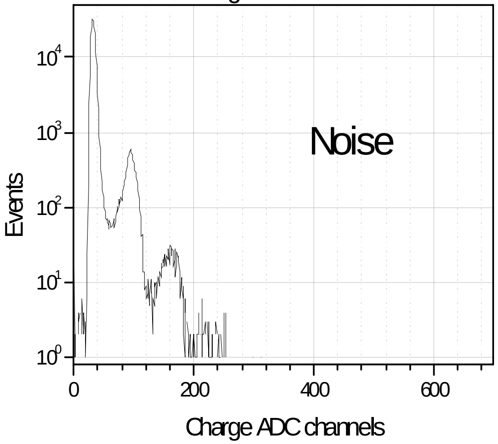
First step: SiPM 1.4x1.4 mm2 with OC suppression topology

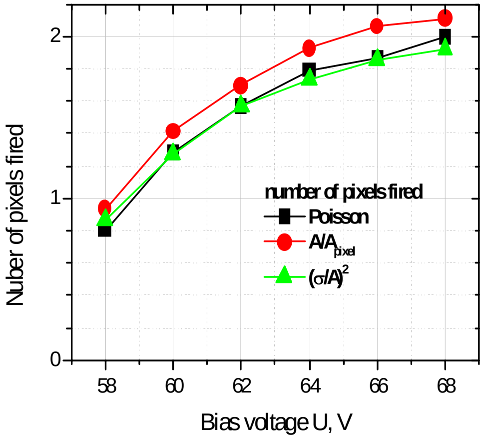












Second step: 5x5mm2 SiPM with OC and AP suppression

SiPM parameters:

➔ size	5x5mm2
➔ double junction structure with optical barriers 6mkm	
➔ number of pixels	1600
➔ pixel size	100mkm
➔ gain	2x10*7
➔ geometrical eff.(filling factor)	64%
➔ pixel capacitance	~1pF
➔ output SiPM capacitance	~160pF
➔ antireflection entrance window	
➔ single pixel recovery time	~ .5mks

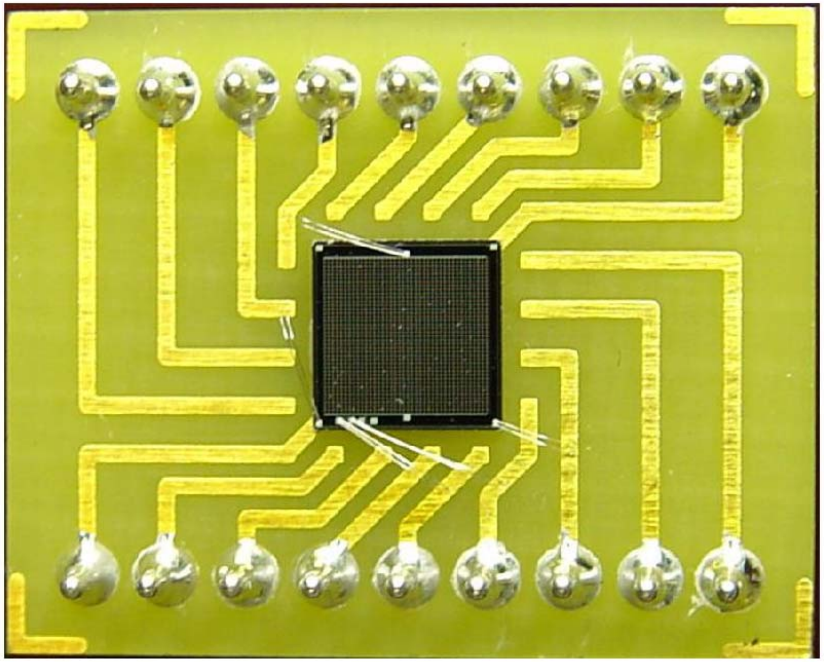


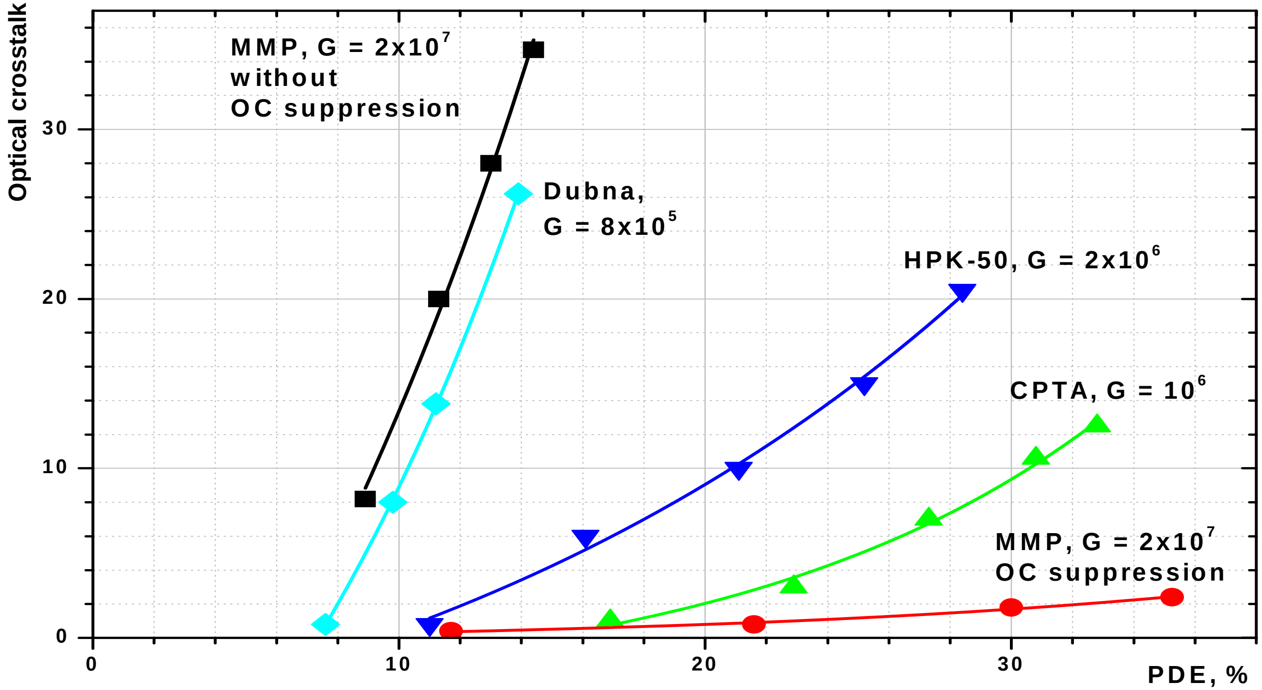
Figure 3: $25(5 \times 5)mm^2$ SiPM. It consists of the array of $1600(40 \times 40)$ micropixels with $100 \times 100\mu m^2$ size.

OC and AP suppression for 5x5mm2 SiPM Comparison with other producers devices

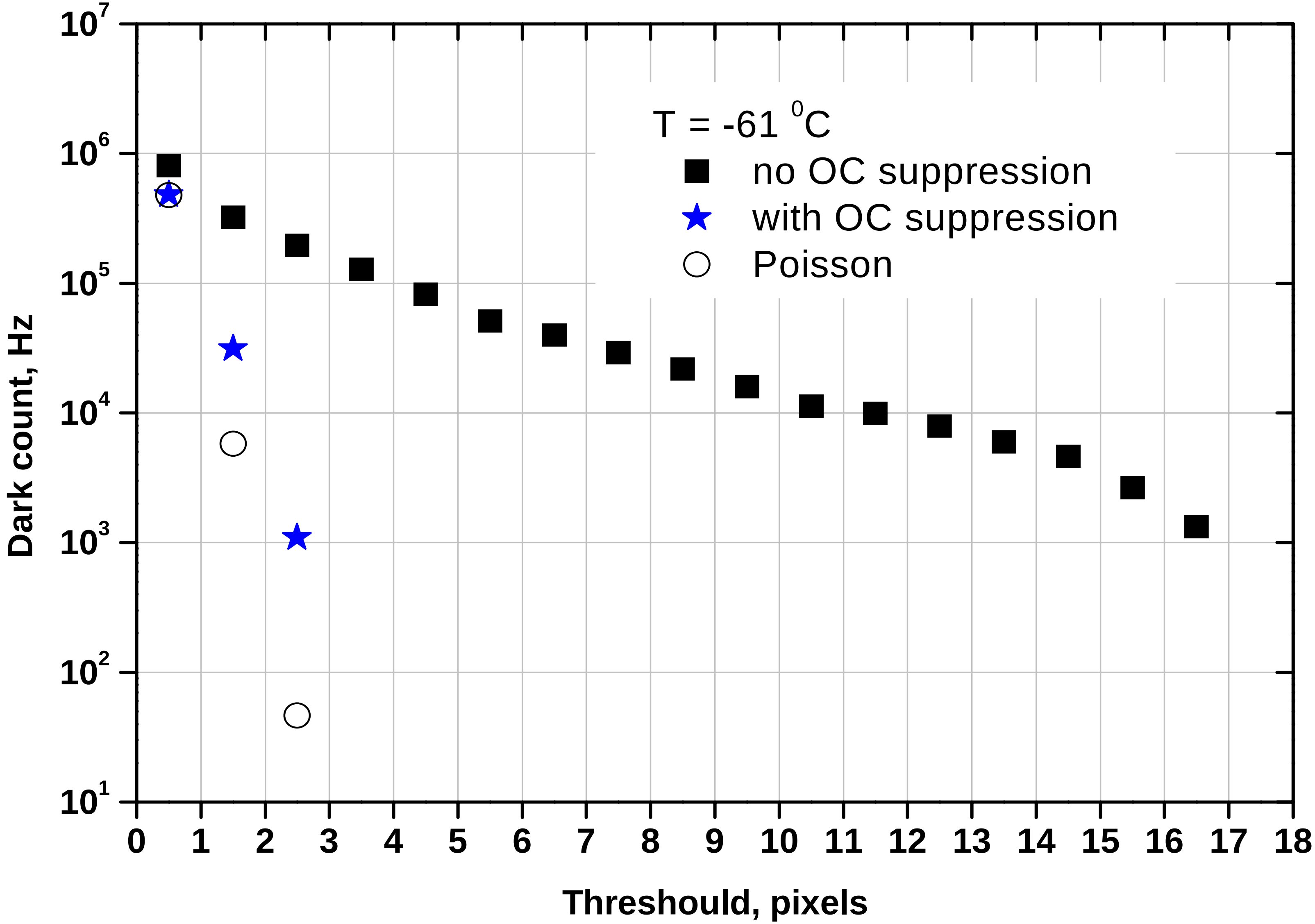
-extracted from measurements made by Yu.Musienko,PD07,Kobe,2007

- Let's define the Optical Crosstalk as

OC = N(threshold > .5 phe) / N(threshold > 1.5 phe)

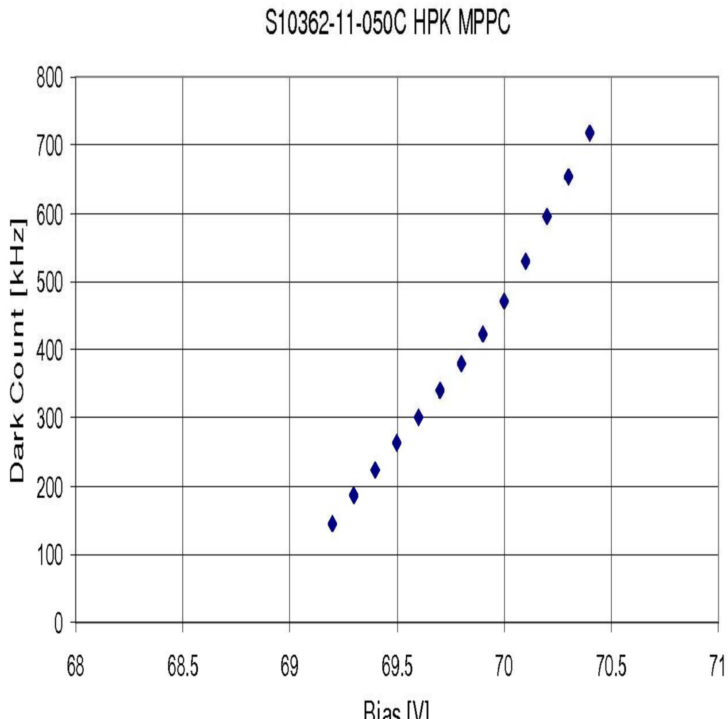


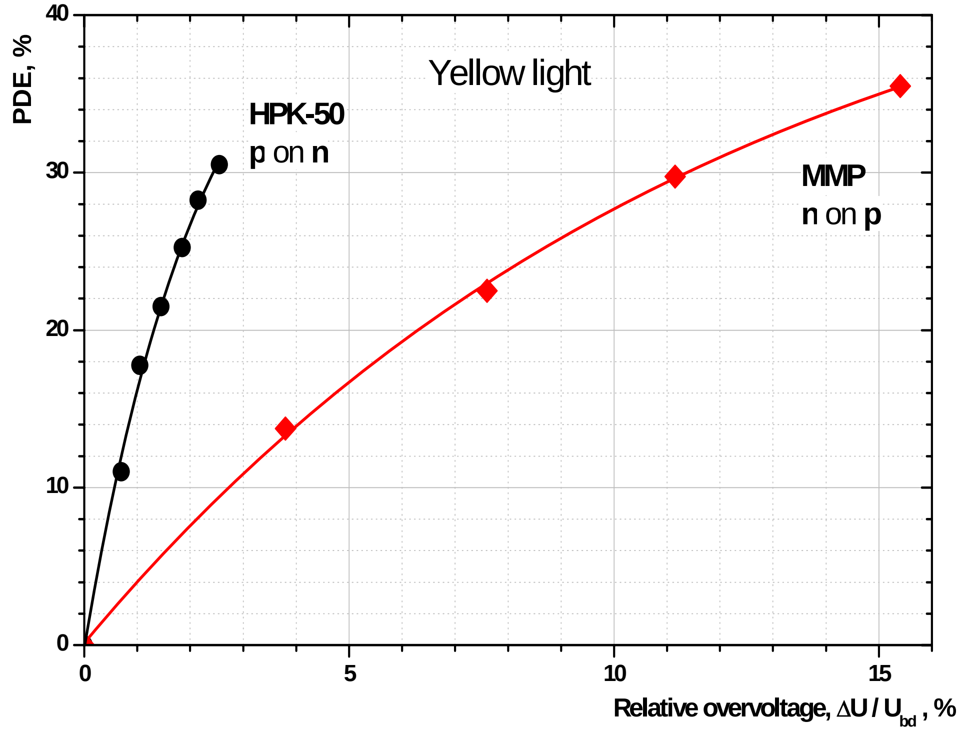
5x5 mm2 SiPM: OC+AP(RquenchxCpix = .5mks) =~2.5%, for PDE=36%,Gain+2x10*7



Dark count, Hz
10^7
10^6
10^5
10^4
10^3
10^2
10^1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Threshould, pixels
T = -61 0C
no OC suppression
with OC suppression
Poisson

Comparison the N on P structure(5x5mm2) with P on N structure(HPK-50)





<------------------->
Overvoltage ~ 2.5%

HPK-50 MPPC-measured by Yu.Musienko, Kobe,2007

Y. Musienko

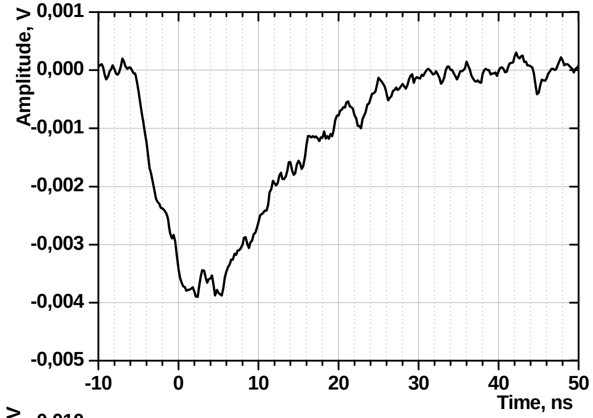
Much lower relative overvoltage for P on N structure (P entrance window) results much lower Dark Rate (~ order of magnitude less)

Timing by 5x5mm2 SiPM: signal shape

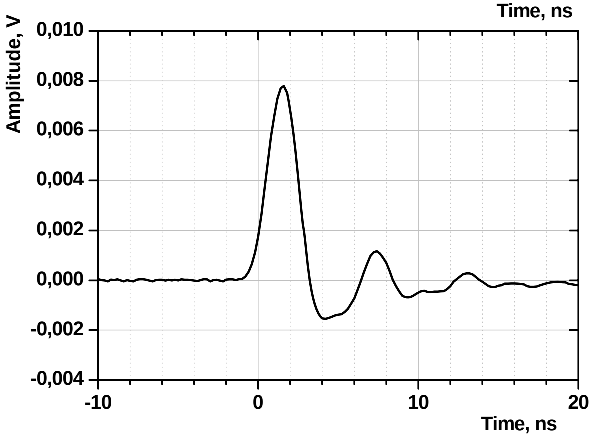
- Because high SiPM output capacitance (~160pF)

a special FE electronics has been developed:

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



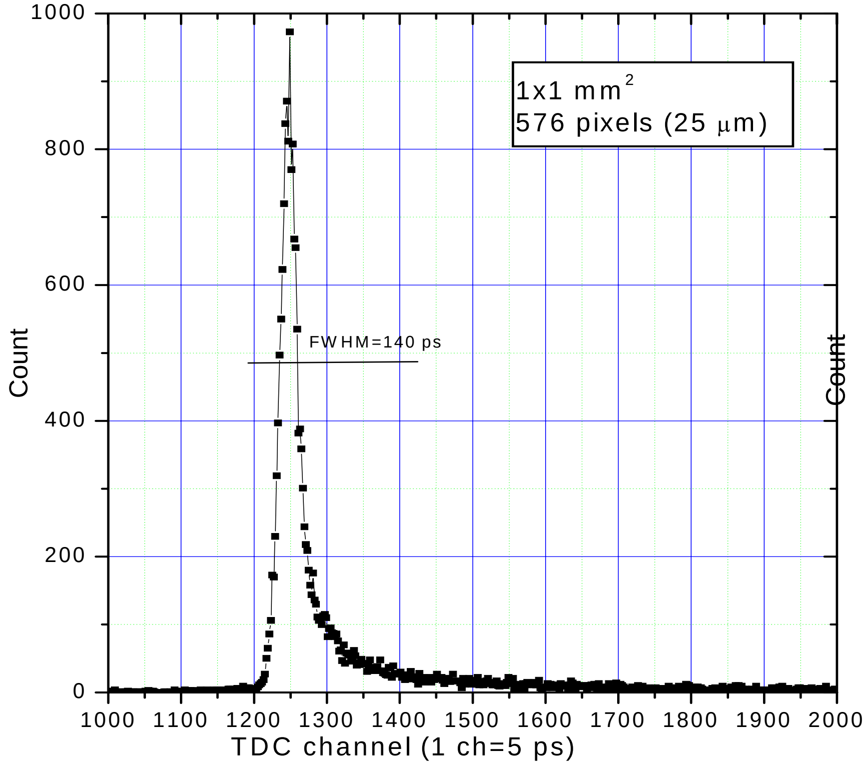
50 Ohm
FWHM
15ns

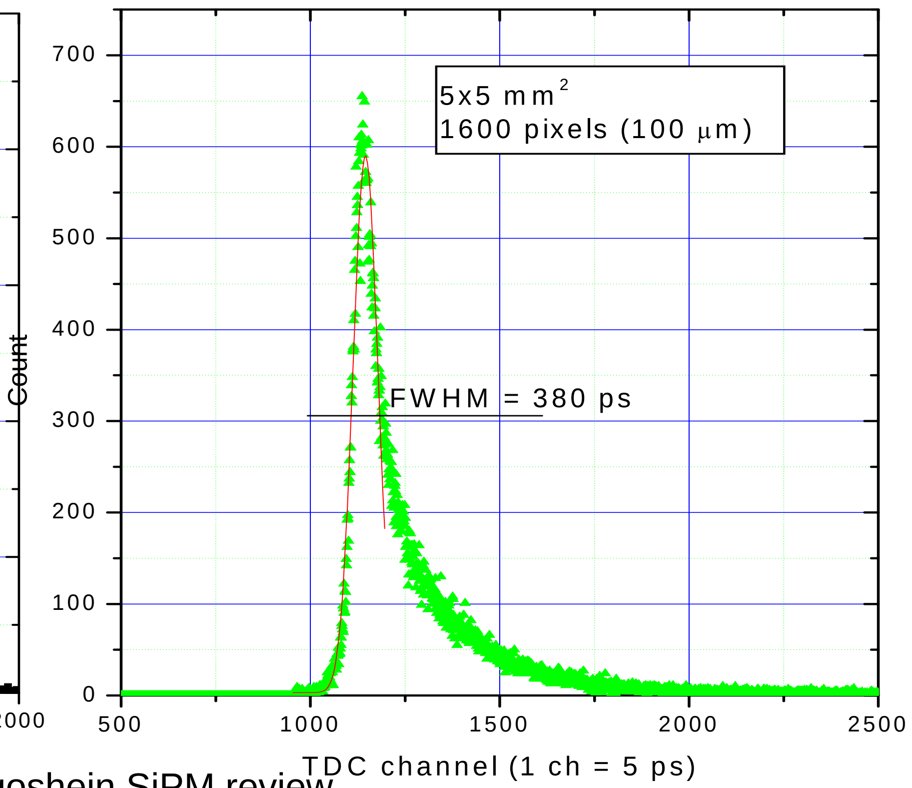


~ 7 Ohm
+shaper
FWHM
2,5ns

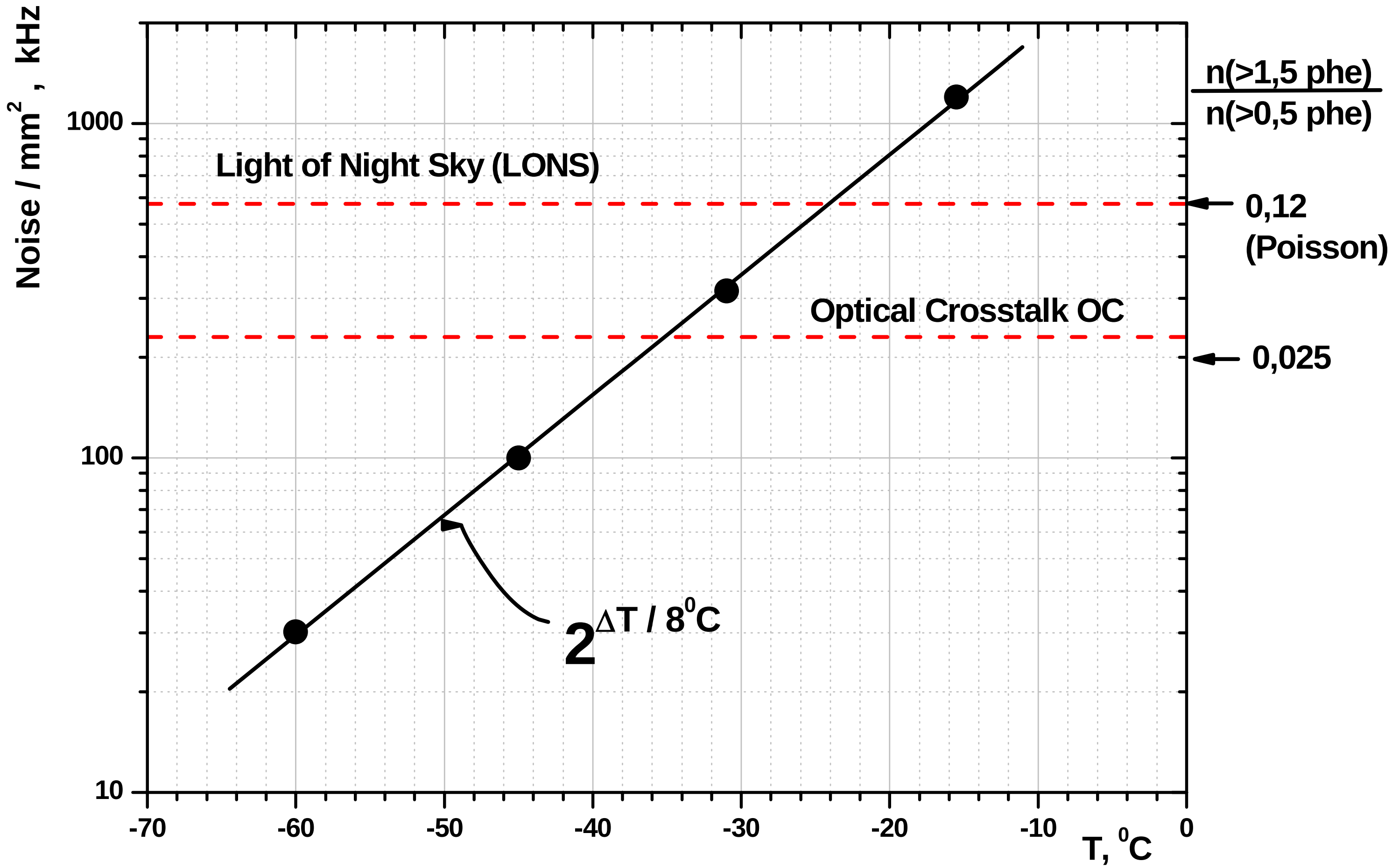
Timing by 5x5mm2 SiPM: a single phe resolution

Fig.'s below show the impact of SiPM size(size of one pixel and SiPM itself)on single phe resolution FWHM for SiPMs 1x1mm2(pixel size 25mkm) and 5x5mm2(pixel size 100mkm)



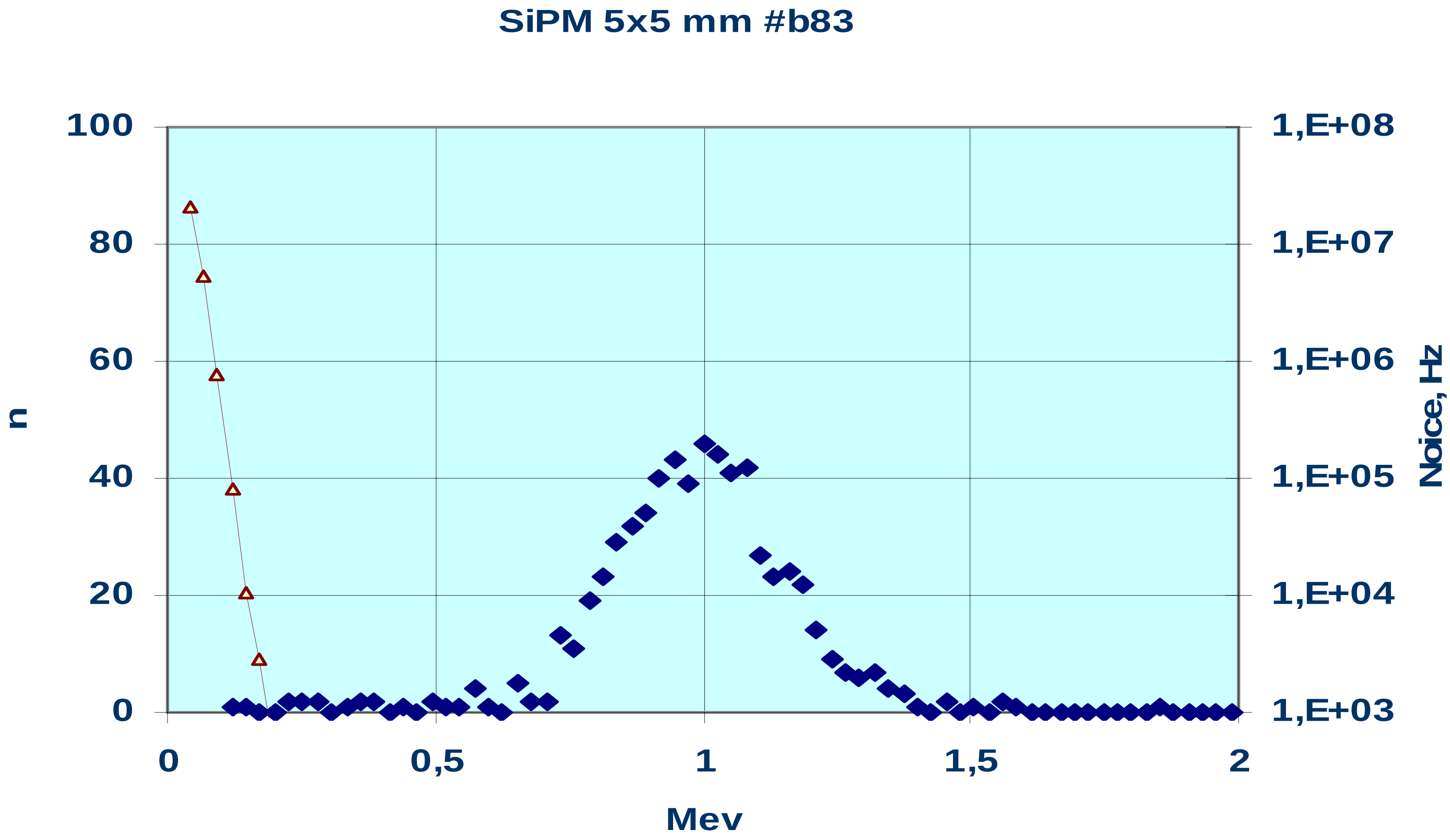


Dark Rate vs temperature ➔acceptable temperature



5x5 mm2 SiPM with OC suppression: performance at room temperature

- ➔ SiPM directly coupled with 5x5 mm2 plastic scintillator rod + Sr90 beta-sourse



CONCLUSIONS

- ➔ **5x5mm2 SiPM with supperssion of (OC + AP)down to 2-3% has been developed , produced and tested**

- ➔ **Excess Noise Factor measured is quite low (~2%)**

- ➔ **Special FE electronics for fast timing has been developed and tested**

  →significant improvement of trigger conditions for Imaging Cherenkov and fluorescent Telescopes and Sci systems

- ➔ Such a SiPM met the main requirements for MAGIC telescope except:

  PDE should be improved especially for UV

  →increase of filling factor,more thin entrance window

  Dark rate still too large,cooling system is needed

  → transition from N on P to P on N structure like MPPC