Status Report on Si-Photomultipliers (SiPMs)

MEPHI/PULSAR Results, March 2007

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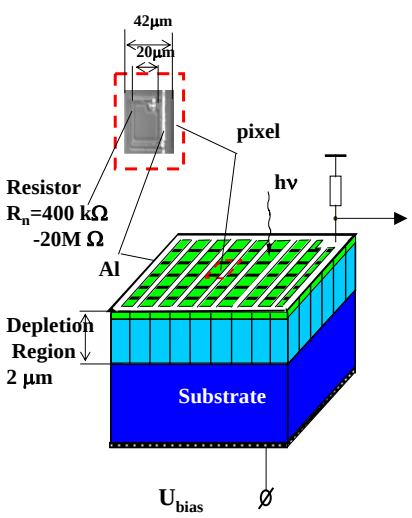
SiPM today – a reminder:



- Pixel side size ~20-100μm
- Working point: $V_{Bias} = V_{breakdown} + \Delta V$ ~ 20-60 V
  ΔV ~ 10-20% above breakdown voltage
- Each pixel behaves as a Geiger counter with $Q_{pixel} = \Delta V\, C_{pixel}$ with C_{pixel}~50fmF ➔ Q_{pixel}~150fmC=10^6e

Electrical inter-pixel cross-talk
minimized by:
- decoupling quenching resistor for each pixel
- boundaries between pixels to decouple them
➔ reduction of sensitive area
and geometrical (packing) efficiency

Very fast Geiger discharge development < 1 ns

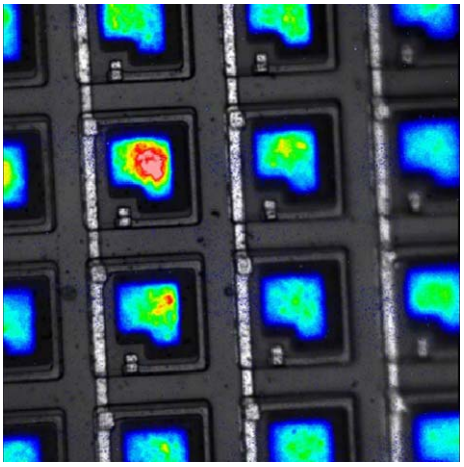
Pixel recovery time = ($C_{pixel}\, R_{pixel}$) ~ 20 ns …1mks

Dynamic range ~ number of pixels ➔ saturation

Microphoto of SiPM (type Z) under operation

(Max Plank Institute, Munich)

Dark rate of each pixel ~ 1 KHz → light from Geiger discharges (300 sec exposition)



B.Dolgoshein, Overview of SiPM development at MEPhI/Pulsar

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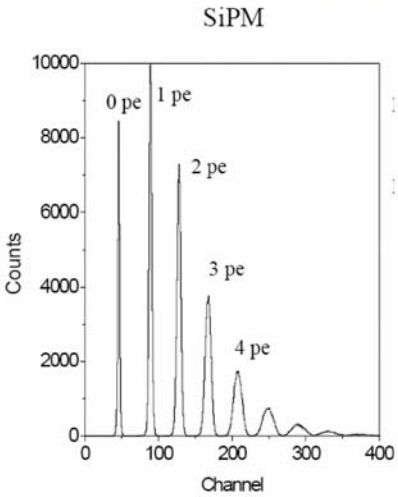
From PM to SiPM

Single photons clearly can be detected with SiPM's. The pulse height spectrum shows a resolution which is even better than what can be achieved with a hybrid photomultiplier.

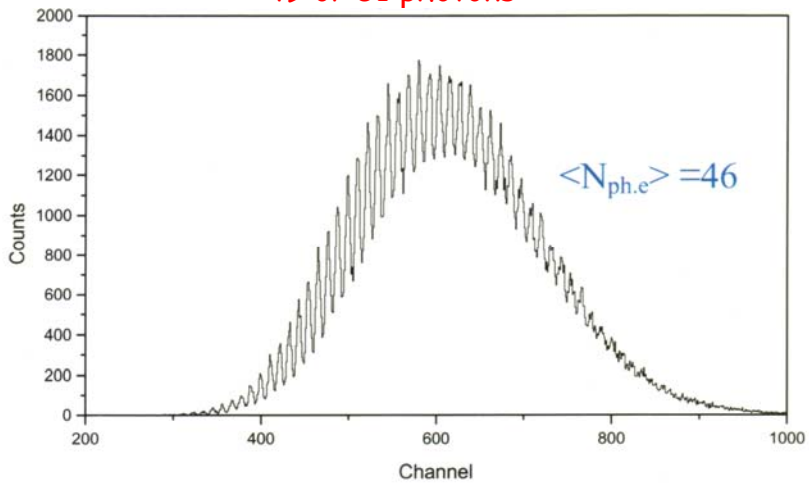


Picture taken from B. Dolgoshein's presentation in Beaune 2002 (NIM A 504 (2003) 48)

Beaune 2005

D. Renker, PSI

SiPM can resolve individual multi-photon peaks differentiating bunches of 50 photons from those of 49 or 51 photons



- SiPM's have been developed in Russia during last ten years (see International Conferences on New Developments in Photodetection ICNDP-1999, 2002, 2005)
- There are six SiPM's producers for the time being - at the level of test batches production:

  Center of Perspective Technology and Apparatus CPTA, Moscow

  MEPhI / Pulsar Enterprise, Moscow

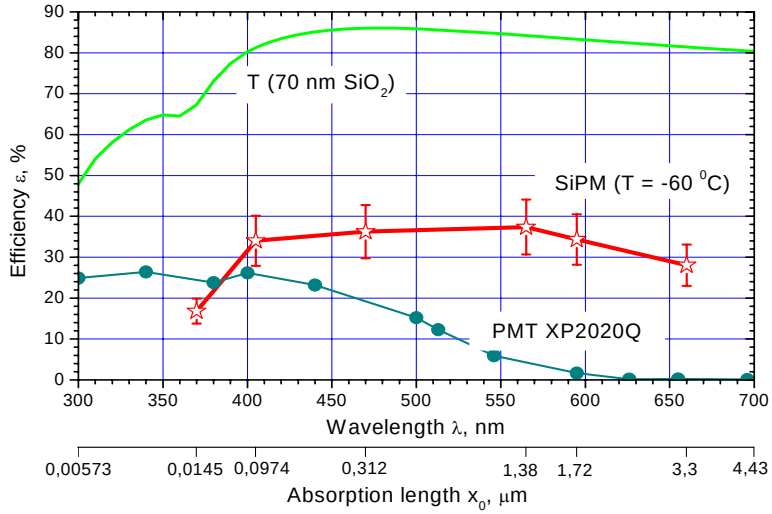
  JINR (Dubna) / Micron Enterprise

  HAMAMATSU has started SiPM (mass?) production

  SensL, Ireland

  ISTC-irst, Italy

No antireflection coating of SiPM



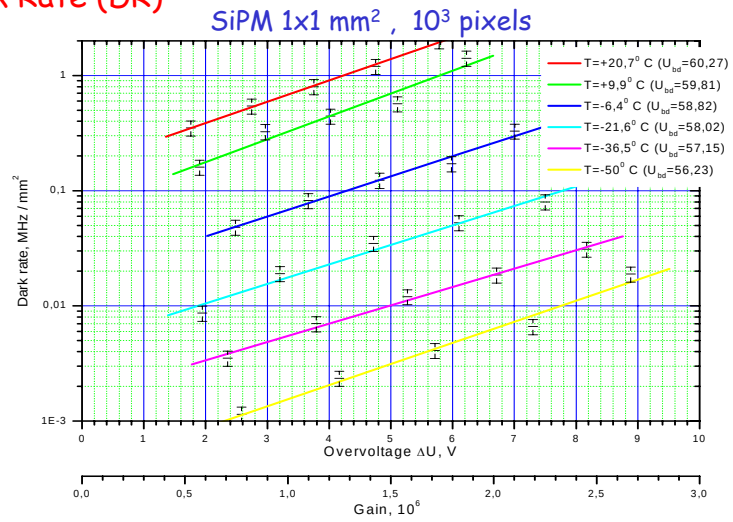
$$PDE = T_{SiO_2} \cdot \varepsilon_{packing} \cdot \varepsilon_{Geiger} \cdot QE$$

$\varepsilon_{packing} = 0.5$

$\varepsilon_{Geiger} \approx 1$

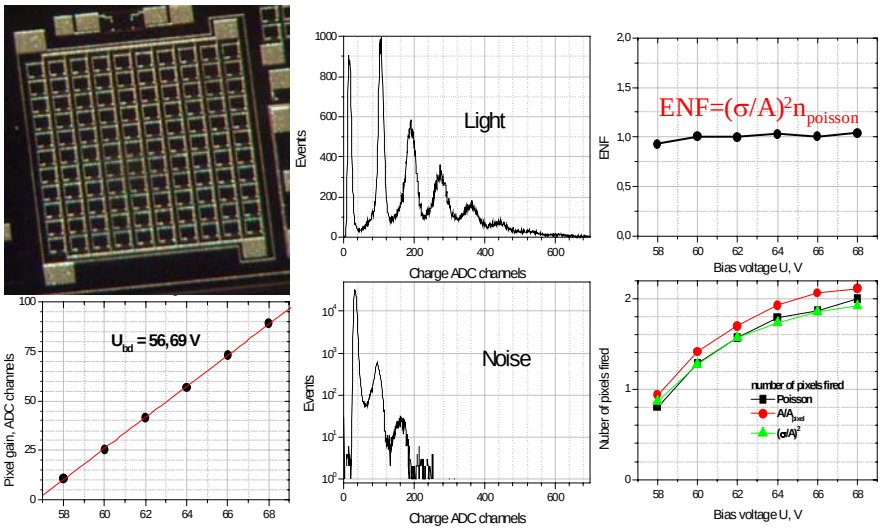
Dark Rate (DR)

SiPM 1x1 mm^2 , 10^3 pixels



- ➔ DR typically 10**6 1/mm2 or 10**8 1/mm2 area! (room T)
- ➔ Cooling helps (-50 C)
- ➔ DR increases with overvoltage (tunneling) -> deep cooling doesn't help!

Pixel-to-pixel crosstalk reduction → Poisson statistics → excess noise reduction down to 1 → almost ideal photodetector - for pixel size 100x100um2



B.Dolgoshein, Overview of SiPM development at MEPhI/Pulsar

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Properties and Problems: Timing

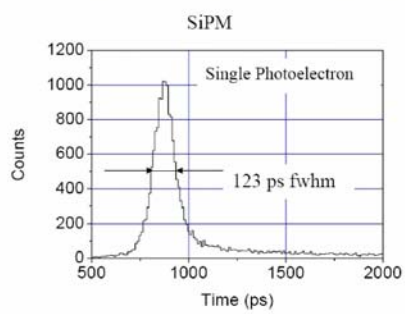
The active layers of silicon are very thin (2 to 4 µm), the avalanche breakdown process is fast and the signal amplitude is big. We can therefore expect very good timing properties even for single photons.

Fluctuations in the avalanche are mainly due to a lateral spreading by diffusion and by the photons emitted in the avalanche.

A. Lacaita et al., Apl. Phys. Letters 62 (1992)
A. Lacaita et al., Apl. Phys. Letters 57 (1990)

High overvoltage (high gain) improves the time resolution.

Merck

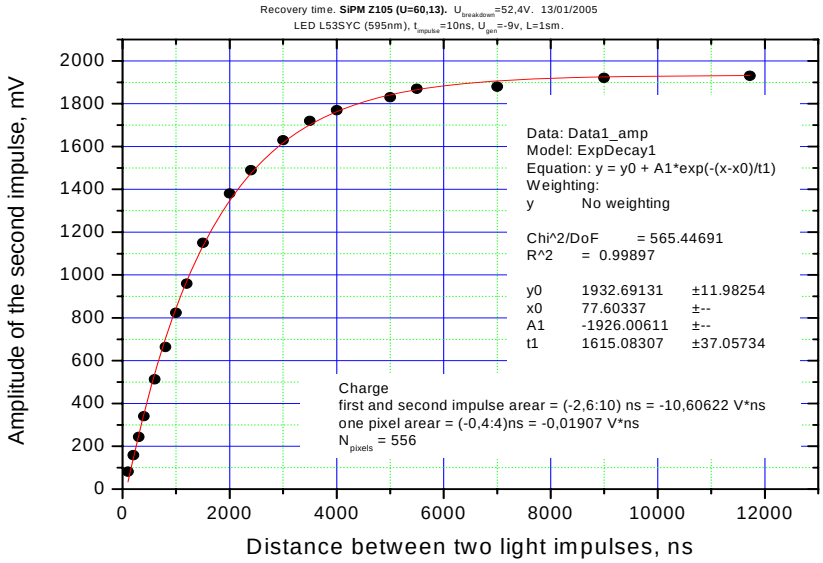


Contribution from the laser and the electronics is 40 ps each. → time resolution 100 ps FWHM

taken from B. Dolgoshein's presentation in Beaune 2002 (NIM A 504 (2003) 48)

Beaune 2005 D. Renker, PSI

Recovery time of SINGLE pixel: C(pix) x R(pix) --> 30ns..... few us



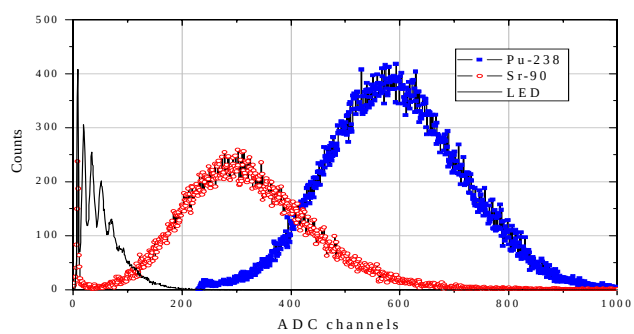


Fig3

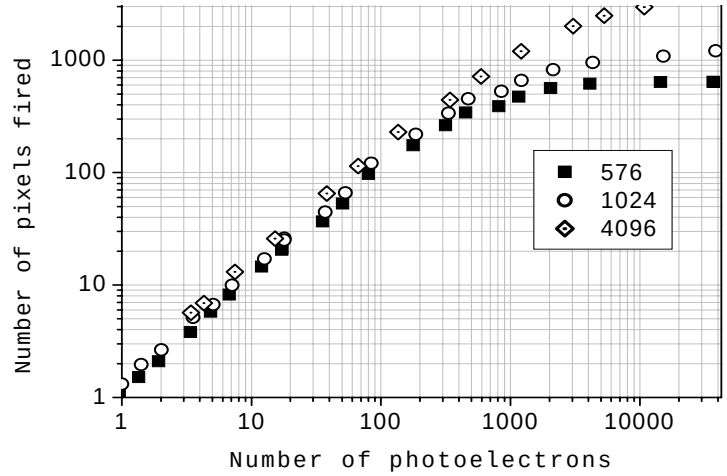
Monitoring and calibration with SiPM:

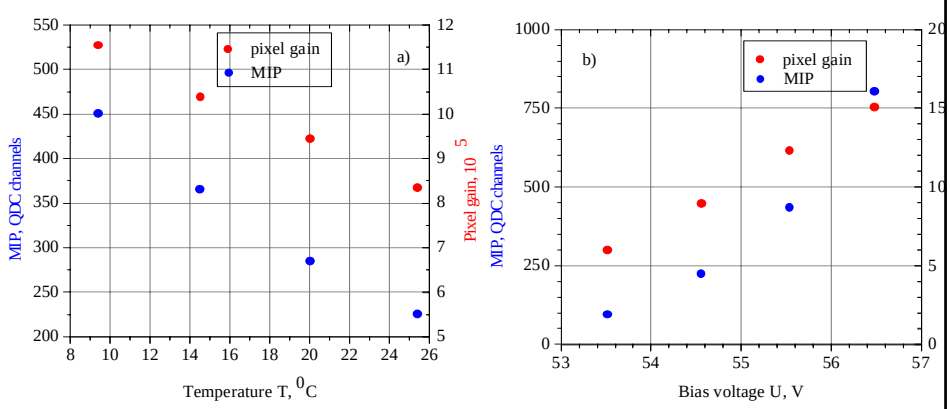
- Absolute measurement of SiPM signal per single phe
- Monitoring by measurement of MIP or alpha signals (with scint)

-> energy scale # of phe/MeV

SiPM signal saturation due to the limited total number of SiPM's pixels

Response functions for the SiPMs with different total pixel numbers measured for 40 ps laser pulses





Temperature and bias voltage dependence at low overvoltage (worst case):

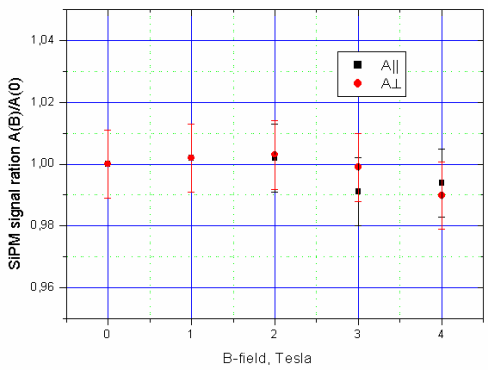
delta T (V)	Gain	Signal = Gain x PDE
-1 C	+2.2%	+4.5%
+0.1V	+4.3%	+7%

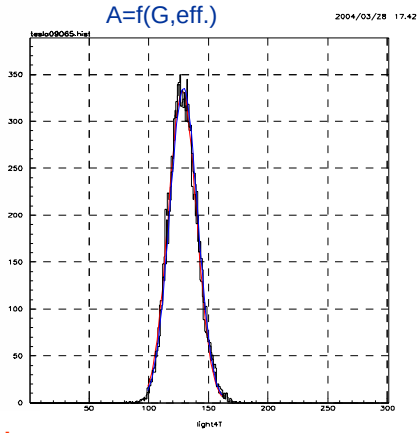
Comparison of the SiPM characteristics in magnetic field of B=0Tand B=4T

(DESY March 2004)

LED signal ~150 pixels

A=f(G,eff.)





No Magnetic Field dependence at 1% level

Note: Similar insensitivity in 9T magnet at Fermilab was shown by NIU

Long term stability of SiPM

20 SiPMs worked during 1500 hours

Parameters under control:

- One pixel gain
- Efficiency of light registration
- Cross-talk
- Dark rate
- Dark current
- Saturation curve
- Breakdown voltage

No changes within experimental errors

5 SiPM were tested 24 hours at increased temperatures of 30, 40, 50, 60, 70, 80, and 90 degrees

No changes within experimental accuracy

SiPM today:

+

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
Simplest electronics
Relatively low expected cost (low resistivity Si, simple technology)

-

Not very high PDE

Small area

High dark rate (~ area)

Excess Noise Factor is large due to Optical Crosstalk

Some examples of SiPM Applications:

1

Scintillator+WLS+SiPM System for calorimetry

--> Detector for International Linear e+e- Collider

--> High granularity Sci Tile Hadron Calorimeter: Energy Flow Technique for calorimetry with a goal of very good hadron jet energy resolution R&D, CALICE Collaboration

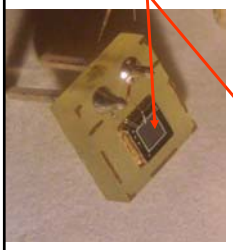
Scintillator tile analog or semi-digital HCAL (CALICE Collab.)

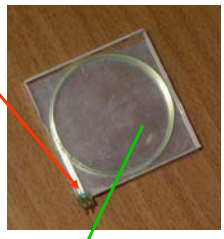
Small 108ch. prototype (MINICAL) with SiPM, MAPMT & APD was tested in e-beam

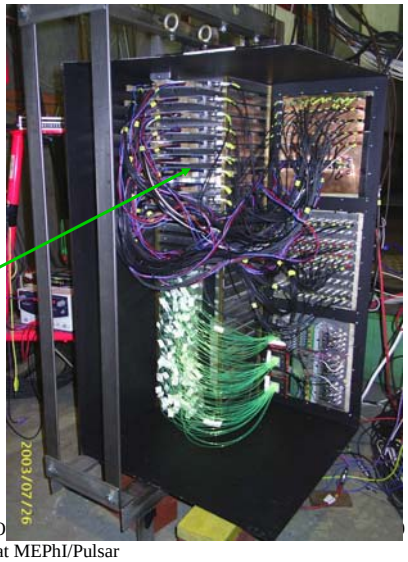
Moscow → **Hamburg**

SiPM

Tile 5x5x0.5cm³





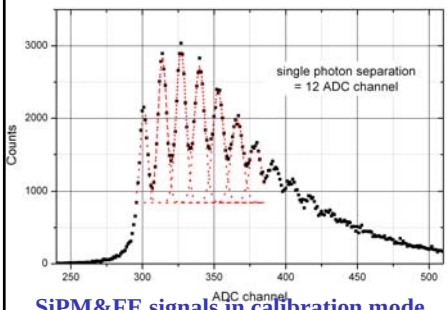


Cassette

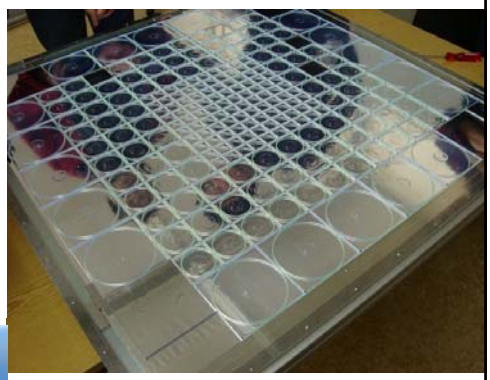
3x3 tiles

B.Dolgoshein, O
development at MEPhI/Pulsar

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



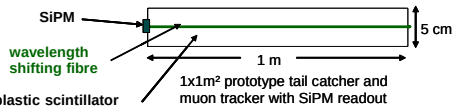
SiPM&FE signals in calibration mode



One plane with SiPMs and WLS fibers installed into 3x3, 6x6 and 12x12 cm² 0.5 cm thick tiles

Same DAQ for HCAL&TCMT

LAL 18 ch. SiPM FE chip



TCMT (NIU)

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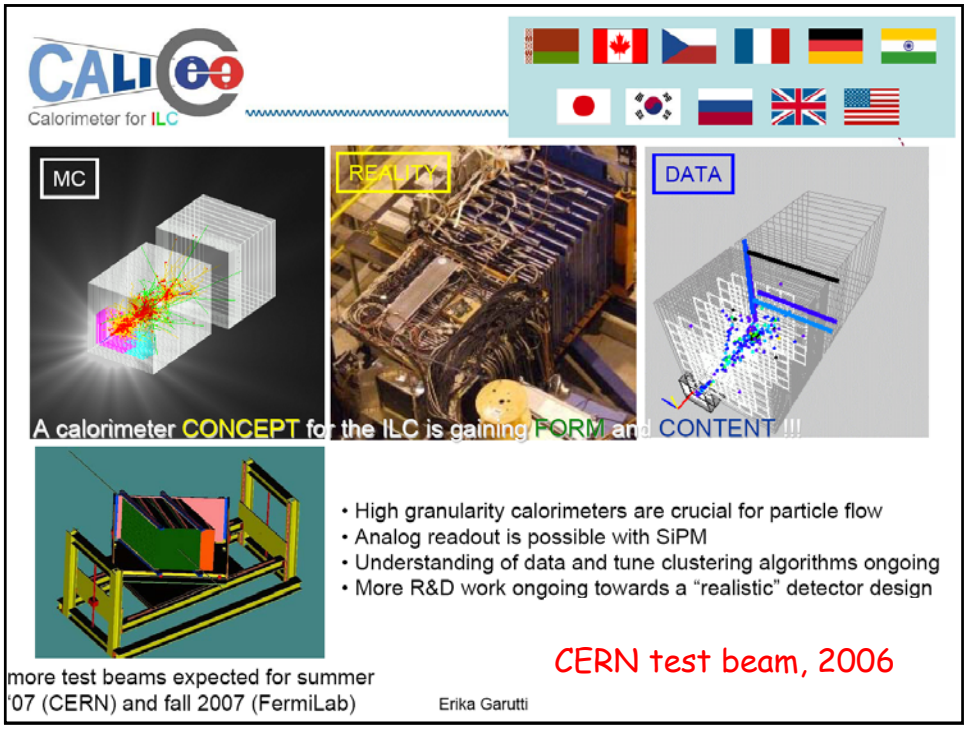
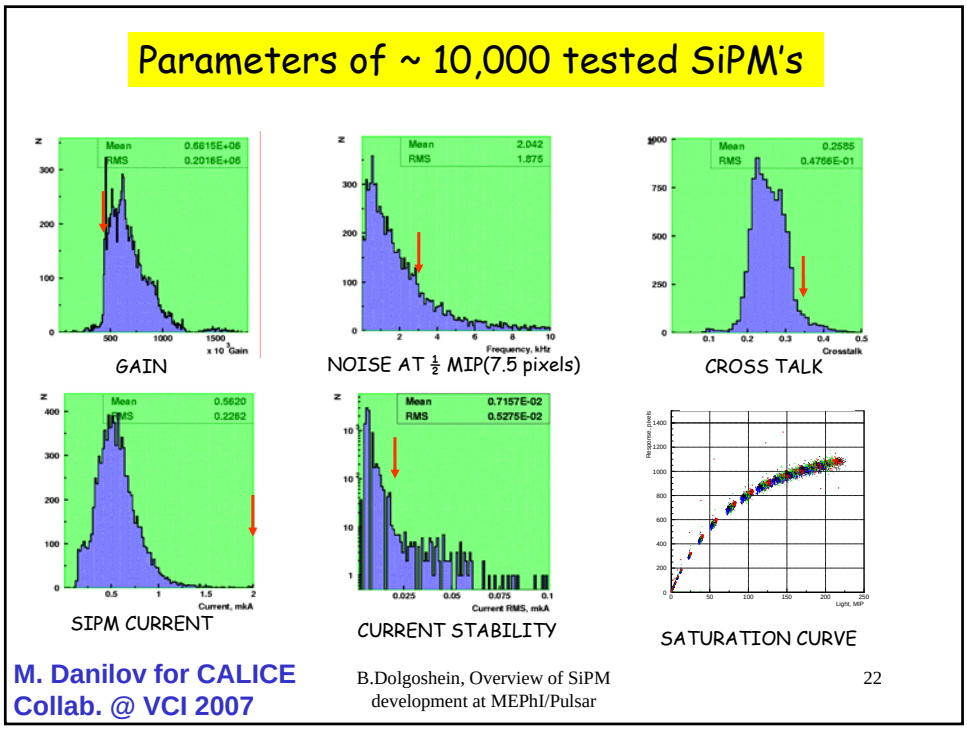

CALICE
Calorimeter for ILC
MC
REALITY
DATA
A calorimeter CONCEPT for the ILC is gaining FORM and CONTENT !!!
• High granularity calorimeters are crucial for particle flow
• Analog readout is possible with SiPM
• Understanding of data and tune clustering algorithms ongoing
• More R&D work ongoing towards a "realistic" detector design
CERN test beam, 2006
more test beams expected for summer '07 (CERN) and fall 2007 (FermiLab)
Erika Garutti


Parameters of ~ 10,000 tested SiPM's
GAIN
NOISE AT ½ MIP(7.5 pixels)
CROSS TALK
SIPM CURRENT
CURRENT STABILITY
SATURATION CURVE
M. Danilov for CALICE Collab. @ VCI 2007
B.Dolgoshein, Overview of SiPM development at MEPhI/Pulsar
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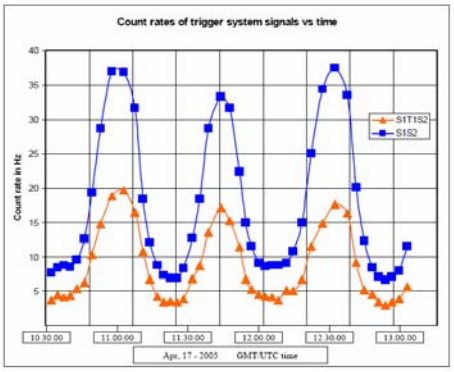
SiPM's in space ! International Space Station: launched on April 15, 2005

.Space experiment "LAZIO"(MEPHI-INFN Collaboration)

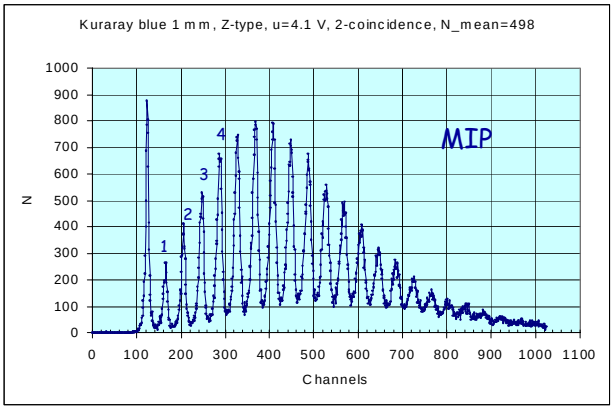


Latitude particle flux dependence

Scientific goal:The measurement of low energy particle fluxes and radiation monitoring by apparatus, including sci tile+WLS fiber+SiPM hodoscope system

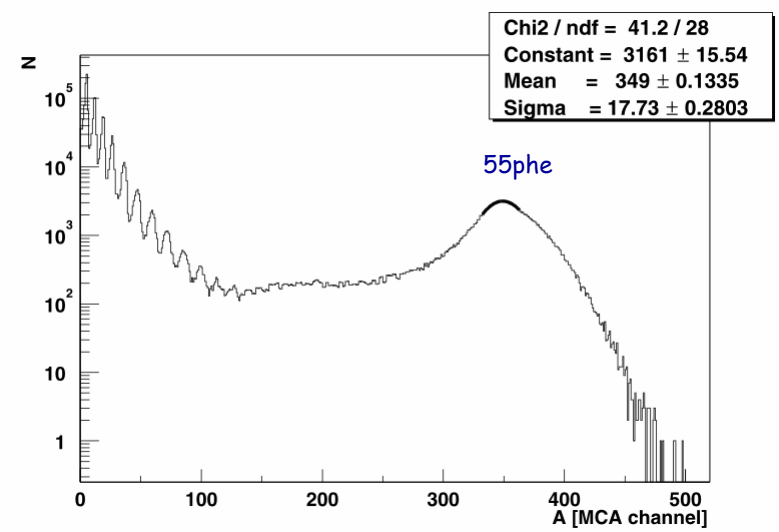
3 SiPM application for sci fiber MIP detection

Kuraray SCSF-78M,1mm, room temperature



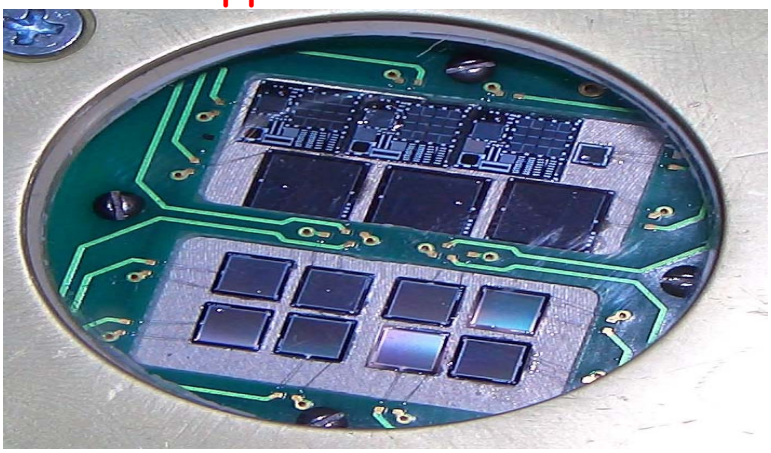
- SiPM at room temperature is as good as VLPC at 6.5°K

Am241 alpha-particle scintillations in LXe, 178nm, -95C



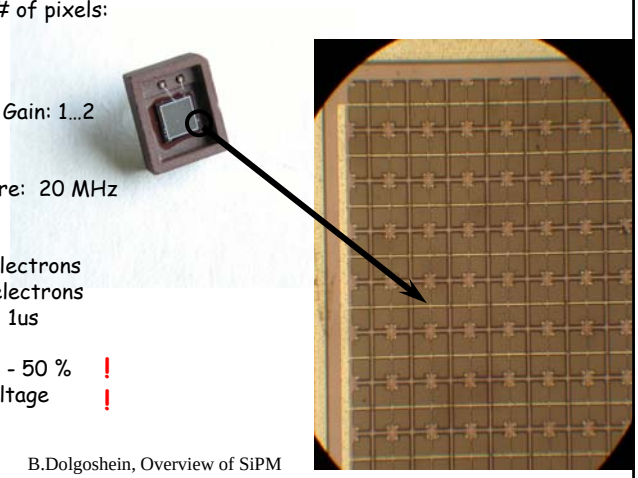
Photon Detection Efficiency (178nm) = 5.5%

Examples of larger area SiPM's (up to 5mm x 5mm available now) applications



3x3mm*2 SiPM parameters

- Sensitive area : 3x3 mm2 # of pixels: 5625
- Working voltage: 20…25 V Gain: 1…2 x10**6
- Dark rate.room temperature: 20 MHz
- SiPM noise(FWHM):
  room temperature 5-8 electrons
  -50 C 0.4 electrons
- Single pixel recovery time: 1us
- Optical crosstalk: appr. 30 - 50 % !
  ENF: appr. 1.5-2.0 (overvoltage dependent) !



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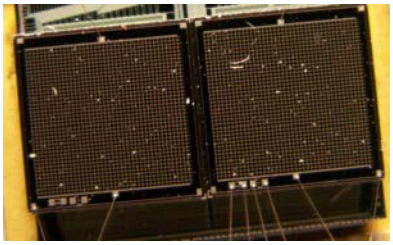
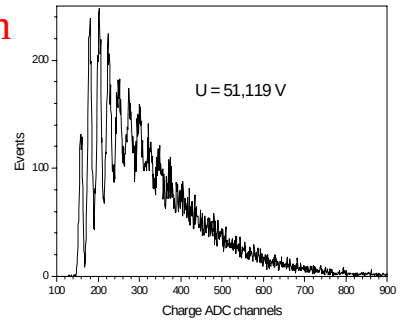
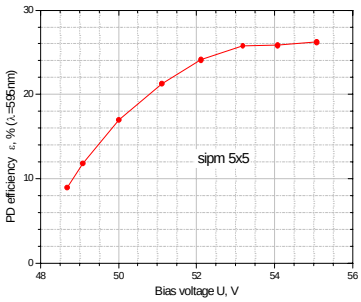
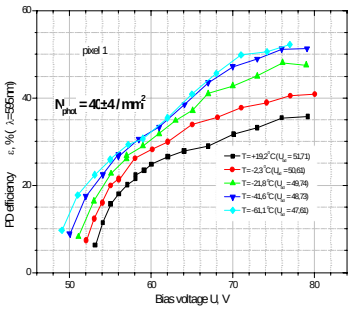
SiPM 5mm x 5mm









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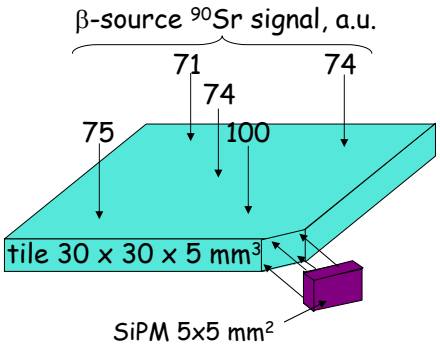
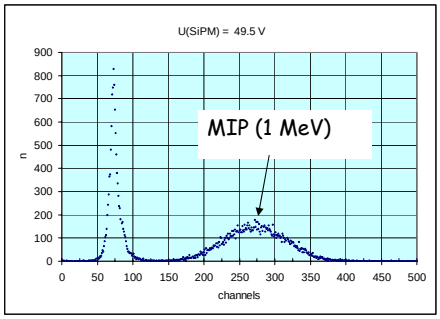
Another readout option-without WLS fiber-with 5mmx5mm SiPM is under study now



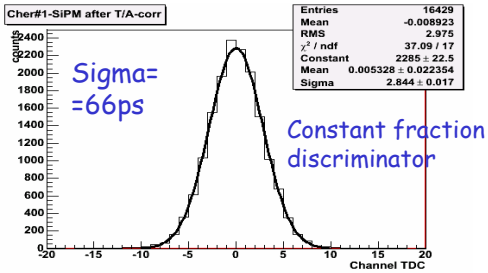
(available now)



•3x3 mm2 SiPM application for TOF

➲ TOF for MIP(3 GeV electron beam)

SiPM: MIP signal is appr.100 mV w/o amplification



Timing resolution between:
PMT (FEU 187) + Cherenkov radiator
and SiPM 3x3mm2+BC418 3x3x40 mm3

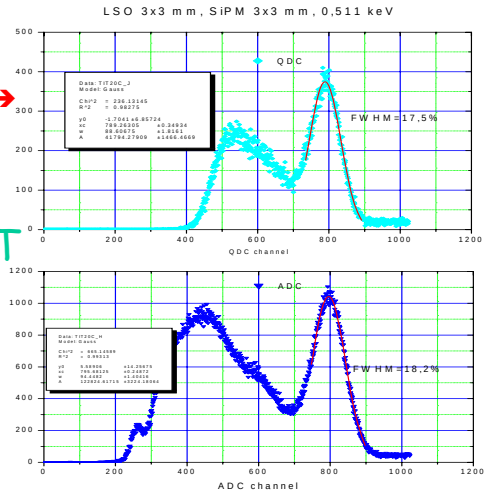
➔Sigma (SiPM+BC418) = 33 ps

3x3 mm2 SiPM for Positron Emission Tomography

➔ 3x3 mm2 area is well matched with typical size of PET crystals (LSO, LYSO)

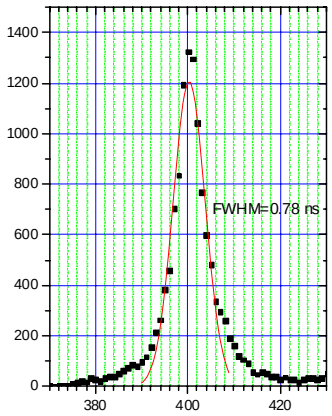
LYSO 20x3x3 mm2, SiPM 3x3 mm2➔

LYSO+SiPM for PET gammas E=511 KeV:



➔Timing resolution in PET

Pair of SiPM + LYSO crystals in coincidence for two gamma's of 511 KeV, constant fraction discriminator)



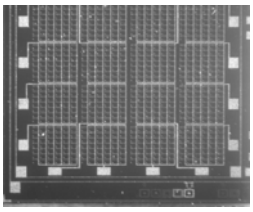
Timing : 0.78 ns FWHM

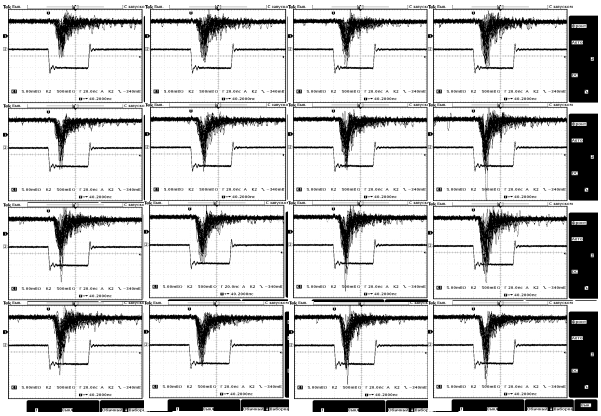
--> good suppression of accidental background

First results on monolithic SiPM matrix

Left - matrix of 4x4 SiPM, each of 0.75x0.75 mm2

Right - response to LED flash





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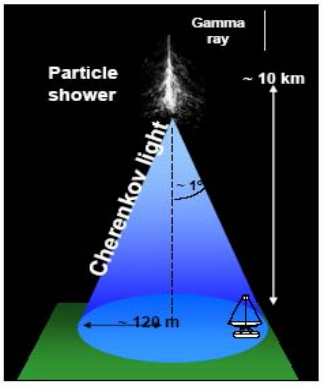
SiPM for astroparticle Physics

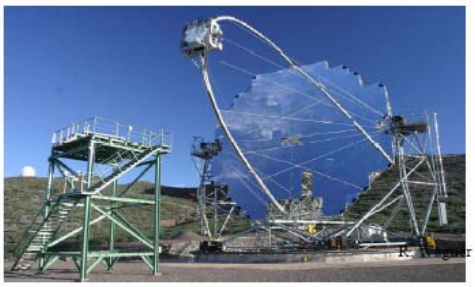
- A single photon counting

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

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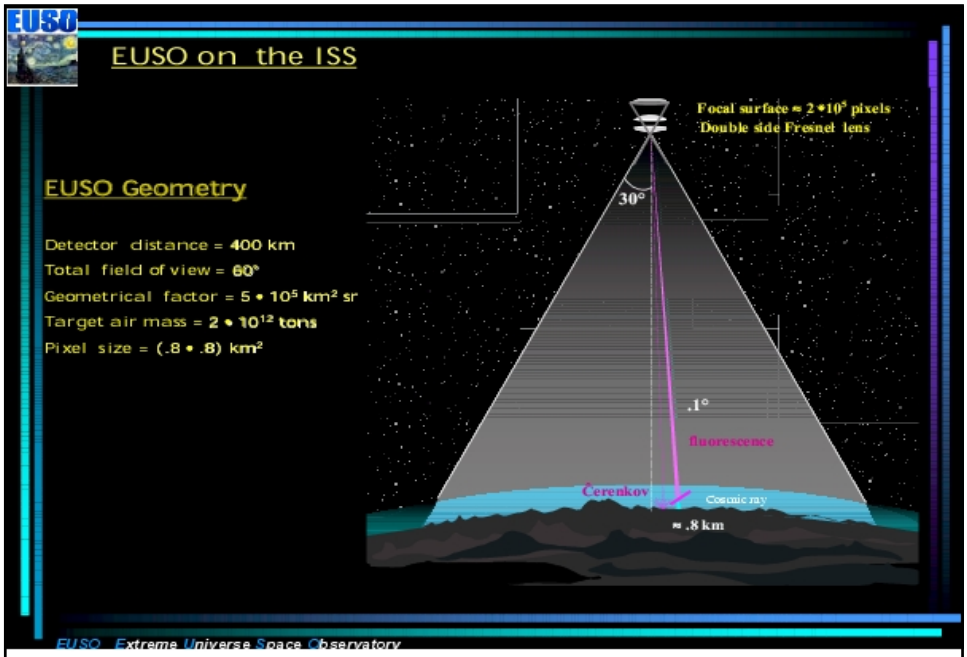
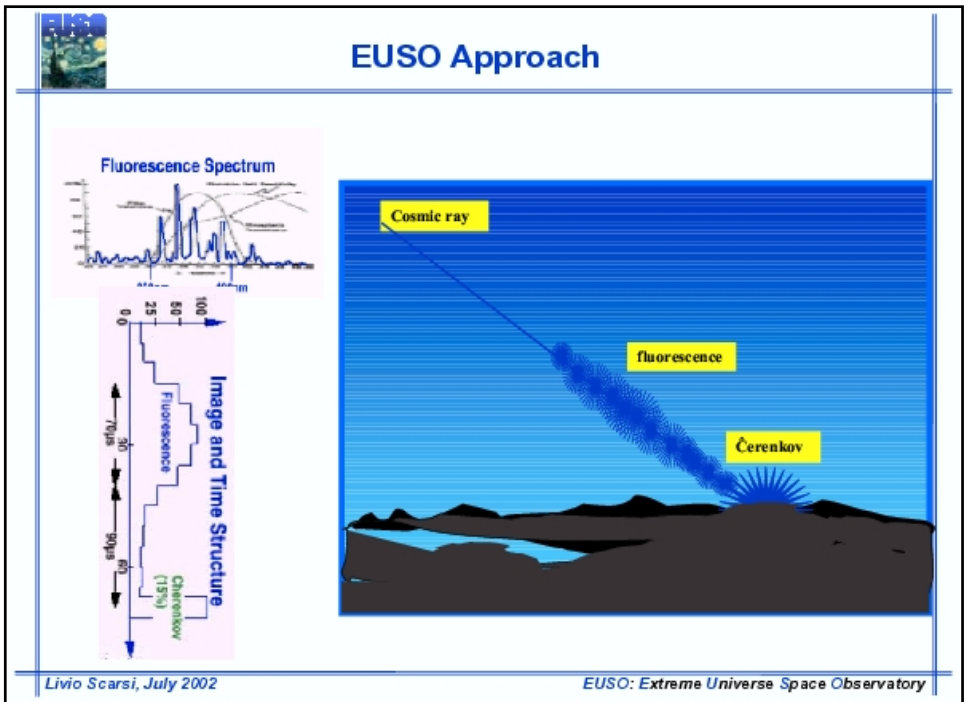

EUSO on the ISS
EUSO Geometry
Detector distance = 400 km
Total field of view = 60°
Geometrical factor = 5 • 10^5 km² sr
Target air mass = 2 • 10^12 tons
Pixel size = (.8 • .8) km²
Focal surface ≈ 2•10^5 pixels
Double side Fresnel lens
30°
.1°
fluorescence
Čerenkov
Cosmic ray
≈ .8 km
EUSO Extreme Universe Space Observatory


EUSO Approach
Fluorescence Spectrum
Image and Time Structure
Fluorescence
Čerenkov (15%)
Cosmic ray
fluorescence
Čerenkov
Livio Scarsi, July 2002
EUSO: Extreme Universe Space Observatory

MAGIC and EUSO needs:

- 300,000 (EUSO) Photodetectors,working in a single photon counting mode ("TPC Calorimeter")
- Sensitivity in > 300 nm range,PD eff --> 50%-60%
- Fast (<10 ns EUSO, < 2ns MAGIC)
- Size 5x5 mm (→10x10mm2)

Baseline option is PMT's (HPD's) ➢ SiPM's ?
(PDE, weight? power consumption? packing eff? compactness?)

Intensive R&D work on such a type of SiPM is in progress now within a framework of Collaboration MEPHI-Pulsar-MPI (Munich)

Conclusions:

- SiPM is becoming to be a good competitor for PMT and APD for number of applications
- New generation of SiPM's with suppression of:
  - optical crosstalk
  - dark rate

  is under development now in order to obtain the SiPM's with:

  Area: up to 10x10 mm2
  PDE: of 50-60% over wide range of wavelength
  ENF: < 1.05
  Subnanosecond timing

- It will increase significantly the number of SiPM application for: nuclear physics, nuclear medicine, high energy physics, astrophysics, biology, distance ranging, dosimetry, communications, cryptography, safety and security systems etc.

International Workshop on new photon-detectors

PD07

June 27 ~ 29, 2007 @ Kobe University, JAPAN

http://www-conf.kek.jp/PD07/

Main Topics

The workshop focuses on recent development of new photon-sensors.
Various types of new photon-sensors and the applications are covered, and a Geiger-mode multi-pixel photon device is one of the main targets this time.

Deadline of abstract submission: April 30, 2007

- Geiger-mode multi-pixel photon device
- Hybrid-PMT
- APD
- MCP-PMT
- New type of photon-sensors
- Applications of photon-sensors to High Energy Physics, Nuclear Physics, Cosmic-Ray Physics, Astronomy, Cosmology and Medical science

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