# Large area Silicon Photomultipliers: Performance and Applications

B.Dolgoshein,MEPHI

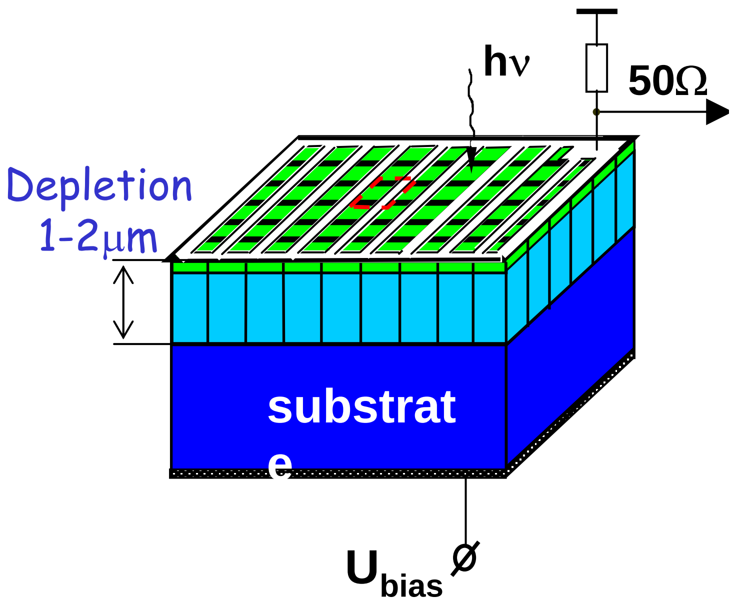
- Optimal parameters for large area SiPM's
- 3x3 mm2 SiPM: performance and characteristics
- Three examples of 3x3 mm2 SiPM's applications

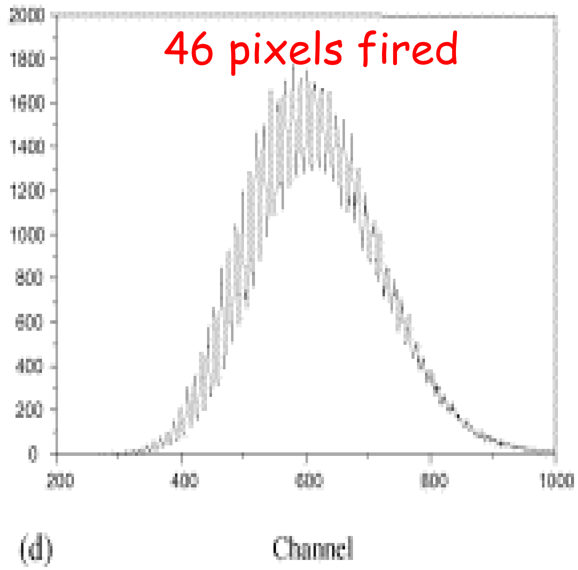
On behalf of MEPhI-Pulsar-MPI(Munich) Collaboration

# *TWO STEPS IN DEVELOPMENTS OF GEIGER MODE APD:*

- FIRST STEP: SINGLE PHOTON AVALANCHE DIODE (SPAD), based on single pixel ➔“photon counter”
- SECOND STEP: from SPAD to

## Silicon Photomultiplier (SiPM)

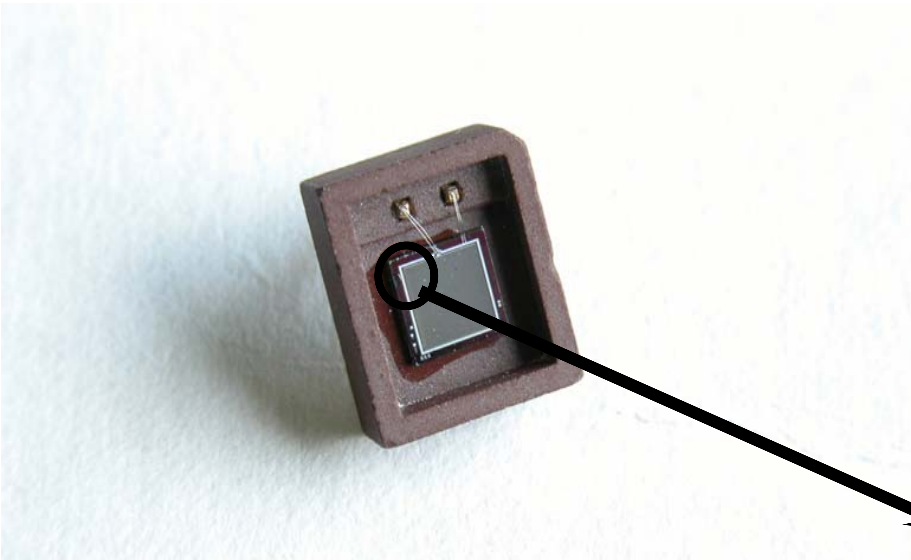


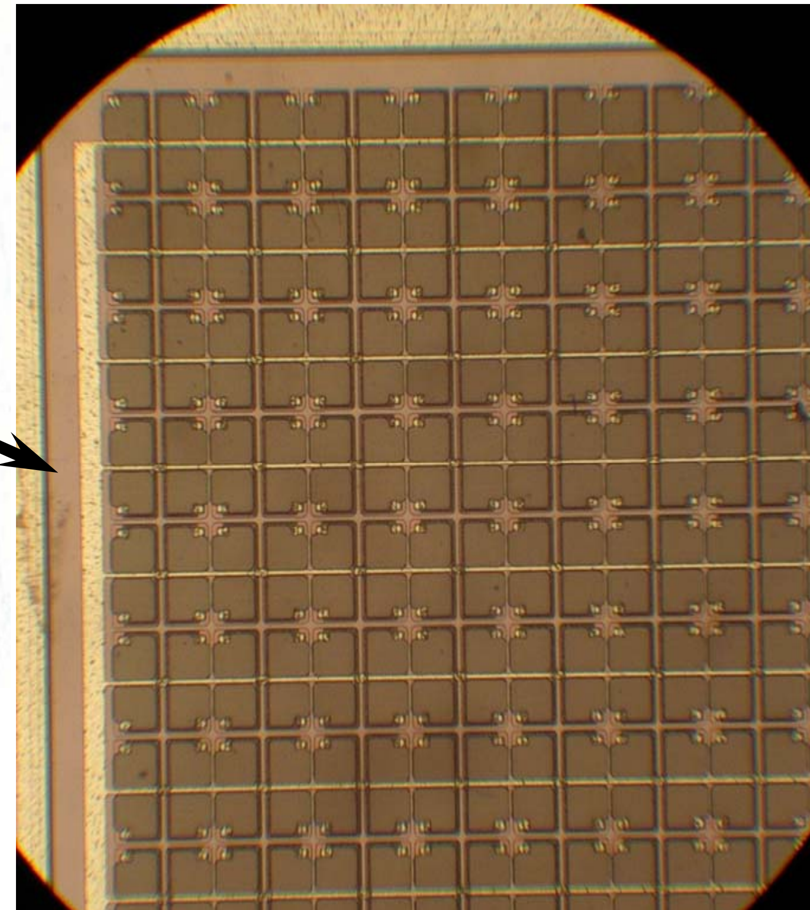




**Multipixel (typically ≤ 1 mm²) Geiger mode photodiode with common readout**

- NEXT STEP: Large area SiPM`s from 1x1 mm² => up to 10x10 mm²

# SiPM 3x3 mm$^2$, 5625 pixels





Larger area (up to 10x10 mm$^2$) is required for a number of applications:

- o astroparticle physics
- o PET
- o Particle physics
- o . . .

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## Optimal parameters for large area SiPM's

The main goal for multipixel SiPM's is:

➔ High Photon Detection Efficiency PDE

PDE = QE x packing efficiency x Geiger efficiency

Pixel area(capacitance) dependent

Overvoltage dependent

$$\text{Gain} = C_{\text{Pixel}} \times V - V_{bd}$$

**But Gain is limited !**

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Packing efficiency = sensitive area/total area

## Three reasons for Gain limitation

### Dark rate DR -fig.

- Typically 10**6 Hz 1/mm2 or 10**8 Hx for 10x10mm2 area ! for room temperature and gain 10**6
- Cooling helps
- DR increases with overvoltage(tunneling effect)

➔ deep cooling does not help much

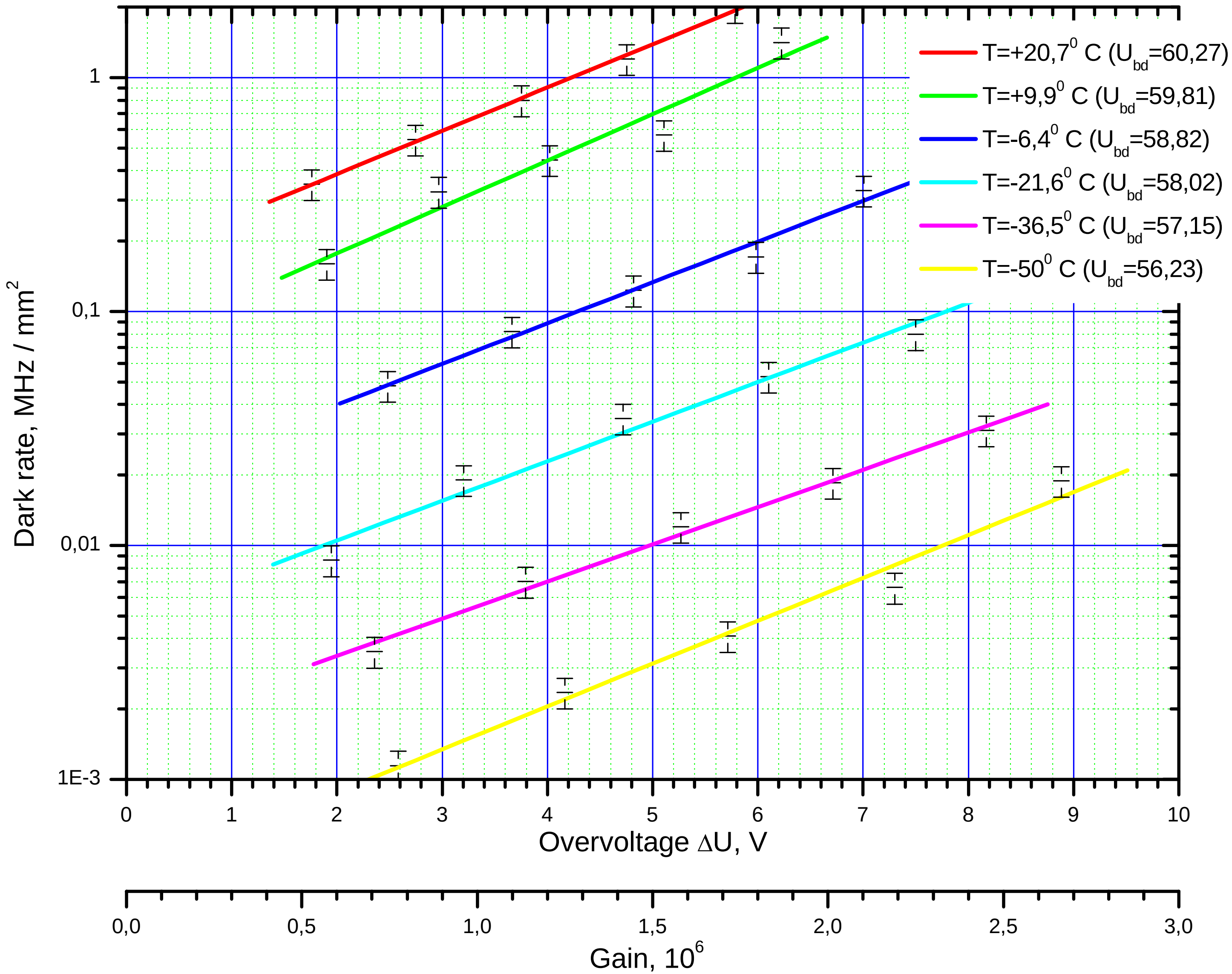
### Afterpulsing AP (trapping of the electrons during discharge and delayed release)–fig.

- AP is proportional to Gain –typically a few% x Gain/10**6
- AP increases the Dark Rate
- AP is high at small delays( < 1 mks)

➔ need a single pixel recovery time of 1-5 mks

➔ Cooling does not help because the increase of trap lifetime

# SiPM 1x1 mm$^2$ , 10$^3$ pixels

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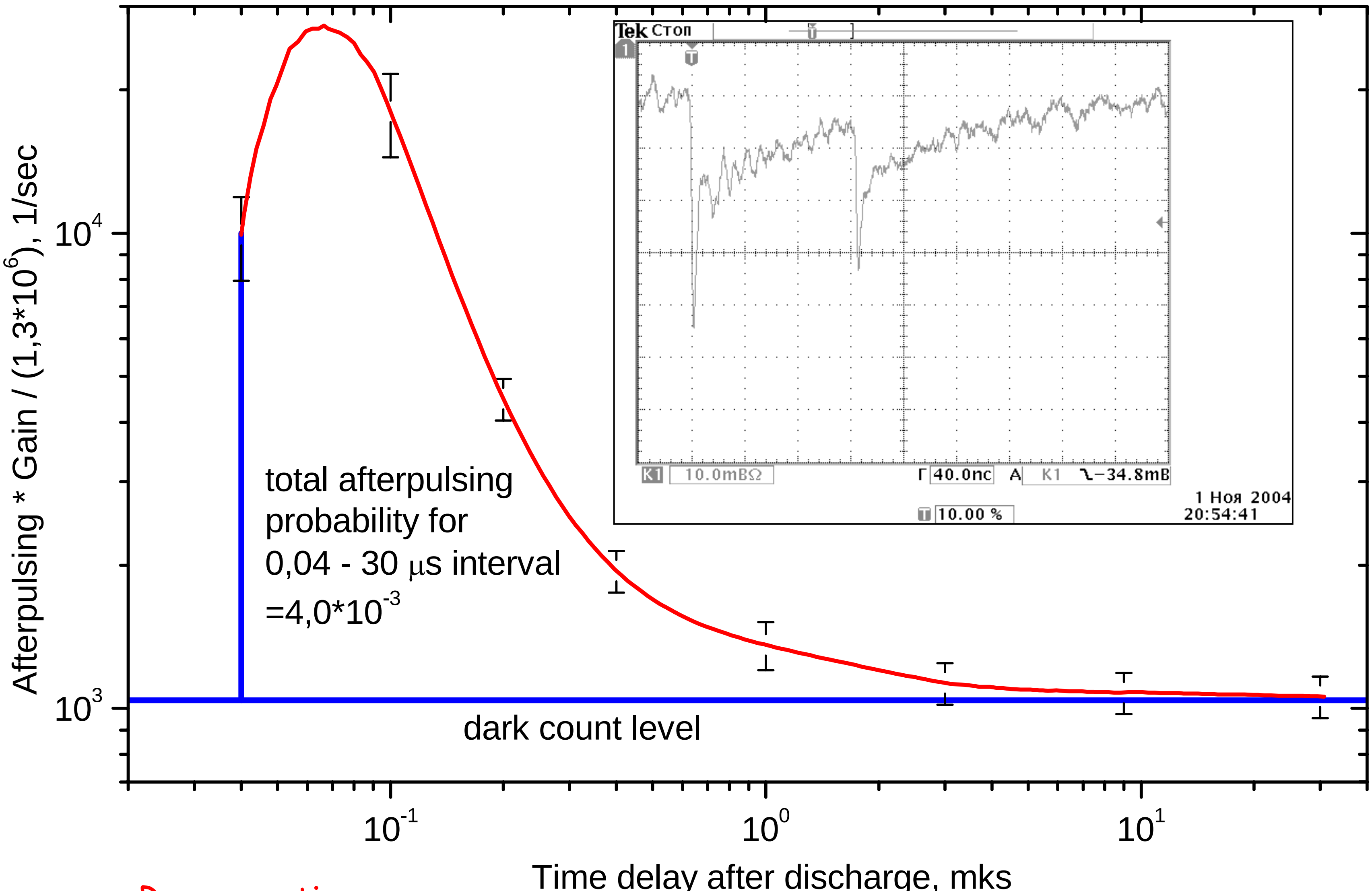
**Gain=1,3*$10^6$ Threshold: 0,5 $e^-$ T=+$20^0$C**




Recovery time
============→

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- Optical Crosstalk OC

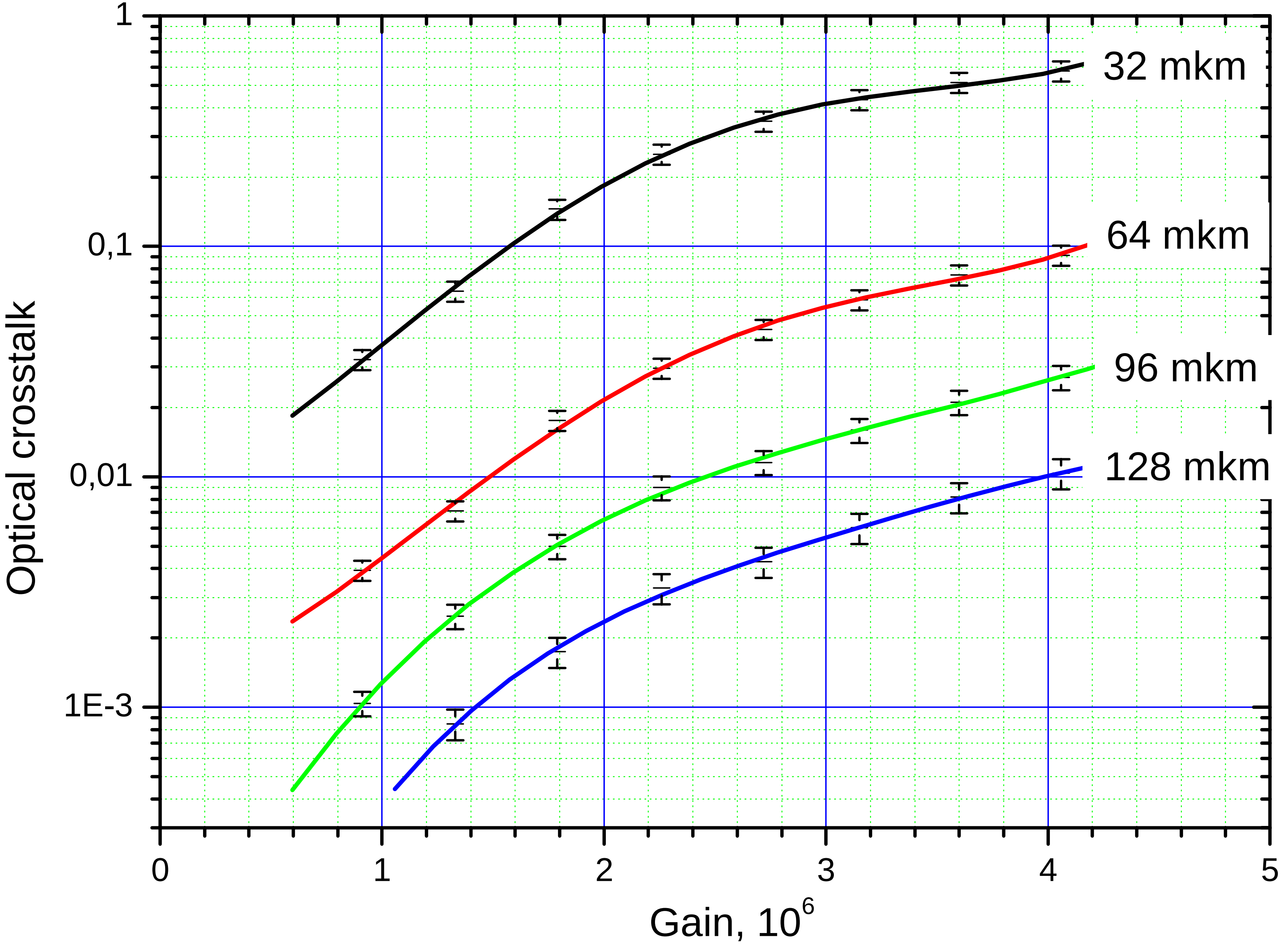
-due to secondary light emitted
in Geiger discharge: 10**-5 photons/one electron

➔ neighboring pixels are fired- fig's.

- OC increases drastically with a Gain

➔ becomes >1 for a Gain > few timesx10**7 ➔selfsustening discharge
➔ pixel independence and Poisson statistics of fired pixels are violated
➔ Excess Noise Factor ENF becomes too large

- Secondary light:
  Effective absorption length(Si)- appr. 50 mkm
  Effective wavelength- appr. 1000 nm

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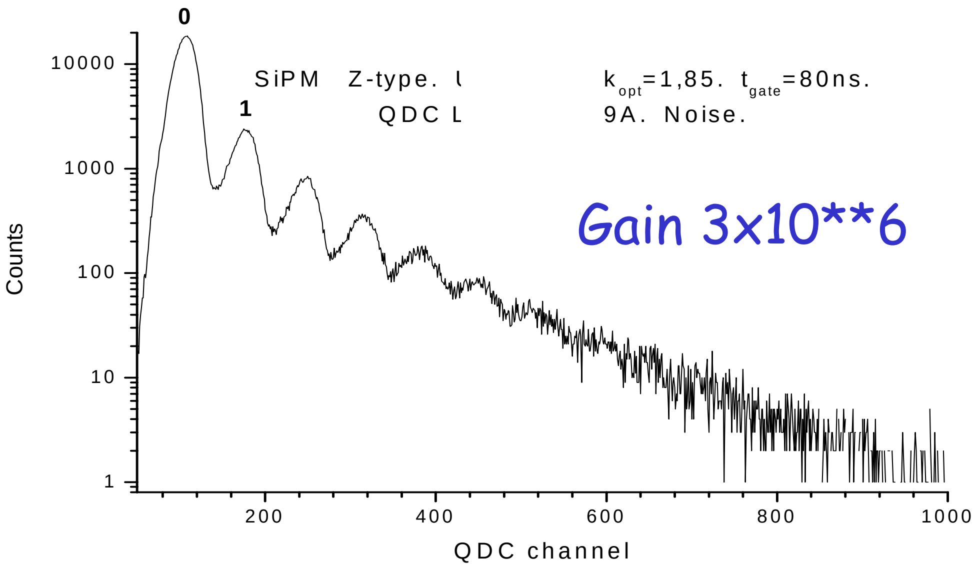
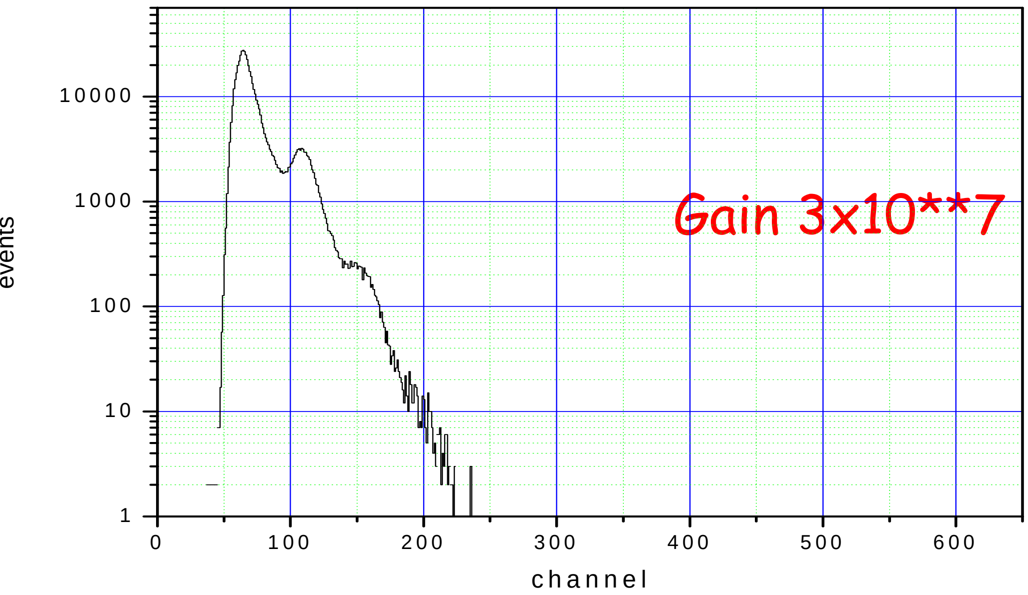
# Optical crosstalk,SiPM 1x1 mm2,dark noise




Crosstalk==>non-Poissonian distribution:

pixel fired/phe=1.7

ENF=1.6




Crosstalk suppression by special SiPM topology: test structure,PRELIMINARY!

Poisson distribution:

pixel fired/phe= 0.98+-0.03

ENF= 0.97+-0.05

## Optimal paramerers

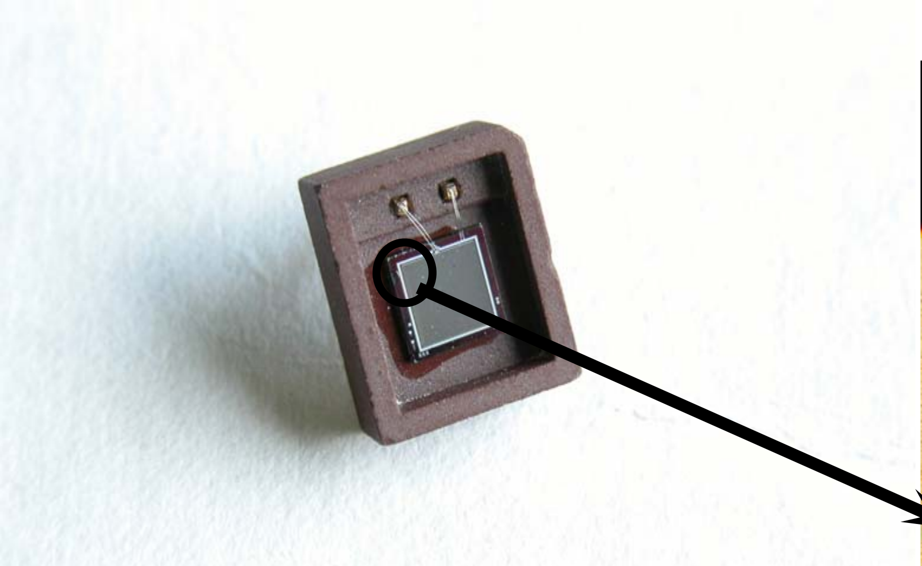
for high PDE,large area(up to 10x10 mm2) SiPM's

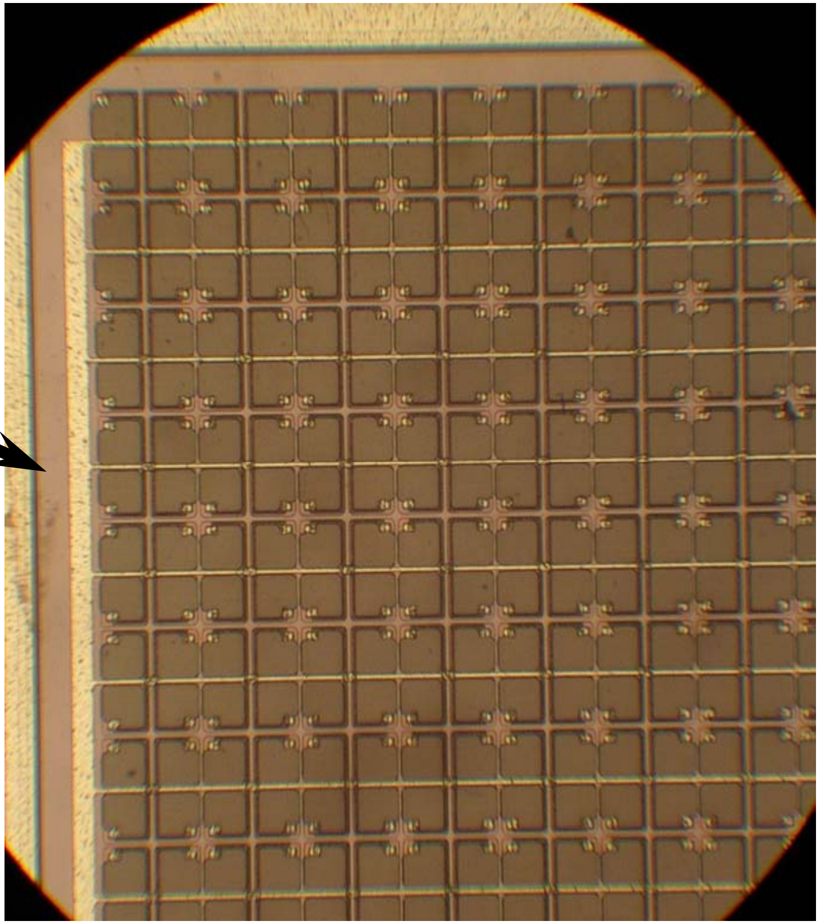
- For PDE=40-50% we need:
  - packing efficiency=75-80%
  - ➔pixel size of 100mkmx100mkm
  - ➔gain 2…5x10**7
  - Geiger efficiency= 80-90%
  - ➔ rel.overvoltage > 20%
- Dark Rate:
  - for single photon detection: < 10 KHz/mm2
  - ➔ cooling down -40…-50 C
  - for detection of >10…20 phe: appr. 1MHz/mm2
  - ➔ room temperature
- Afterpulsing
  - suppression down to < 10%(gain 2…5x10**7)
  - ➔ pixel recovery time 1…10 mks
- Optical Crosstalk
  - suppression down to a few %(gain 2…5x10**7)
  - ➔ special SiPM topology

# 3x3 mm2 SiPM's,properties and performance -fig.

- Main parameters:
  - sensitive area : 3x3 mm2
    # of pixels: 5625
  - Depletion region: appr. 1 mkm
    pixel size: 30 mkmx30 mkm
  - Working voltage: 20…28 V
    Gain: 1…2 x10**6
  - Dark rate.room temperature: 20 MHz
    SiPM noise equivalent(FWHM):
    room temperature 5-10 electrons
    -50 C .4 electrons
  - Single pixel recovery time: 1mks
    Afterpulsing probability: appr.1%
  - Optical crosstalk: appr. 30%-50%
    ENF: appr. 1.5-2.0(overvoltage dependent)

# SiPM 3x3 mm$^2$, 5625 pixels





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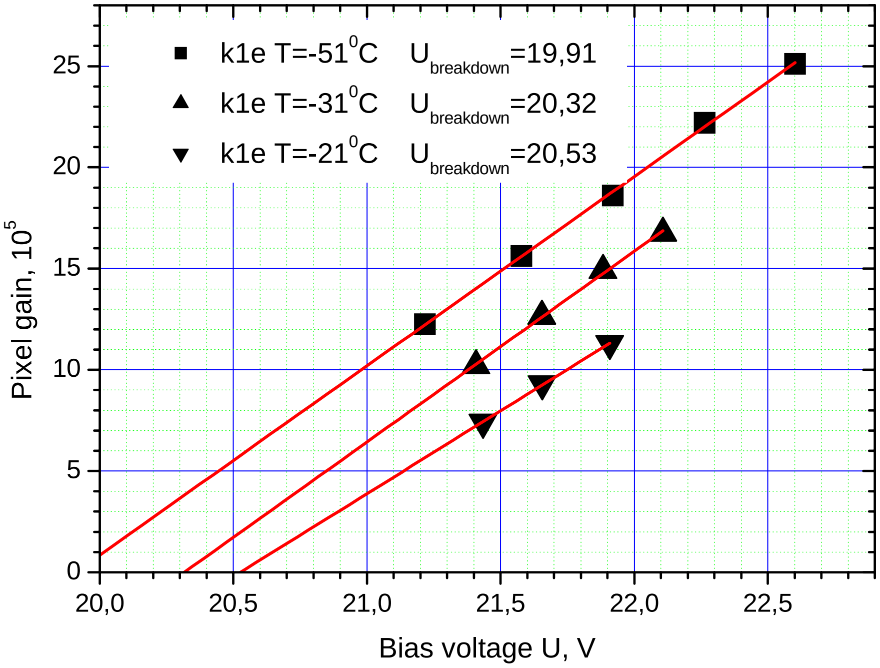
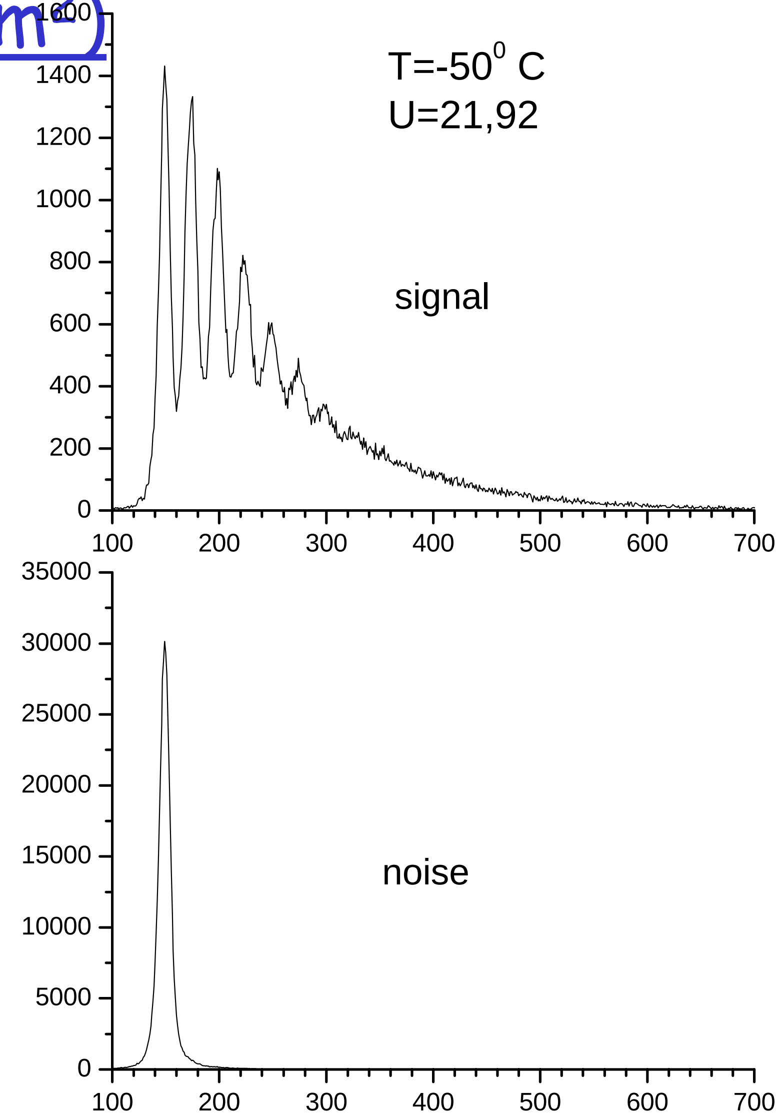
# ♦ SiPM with larger area (3x3 mm²)

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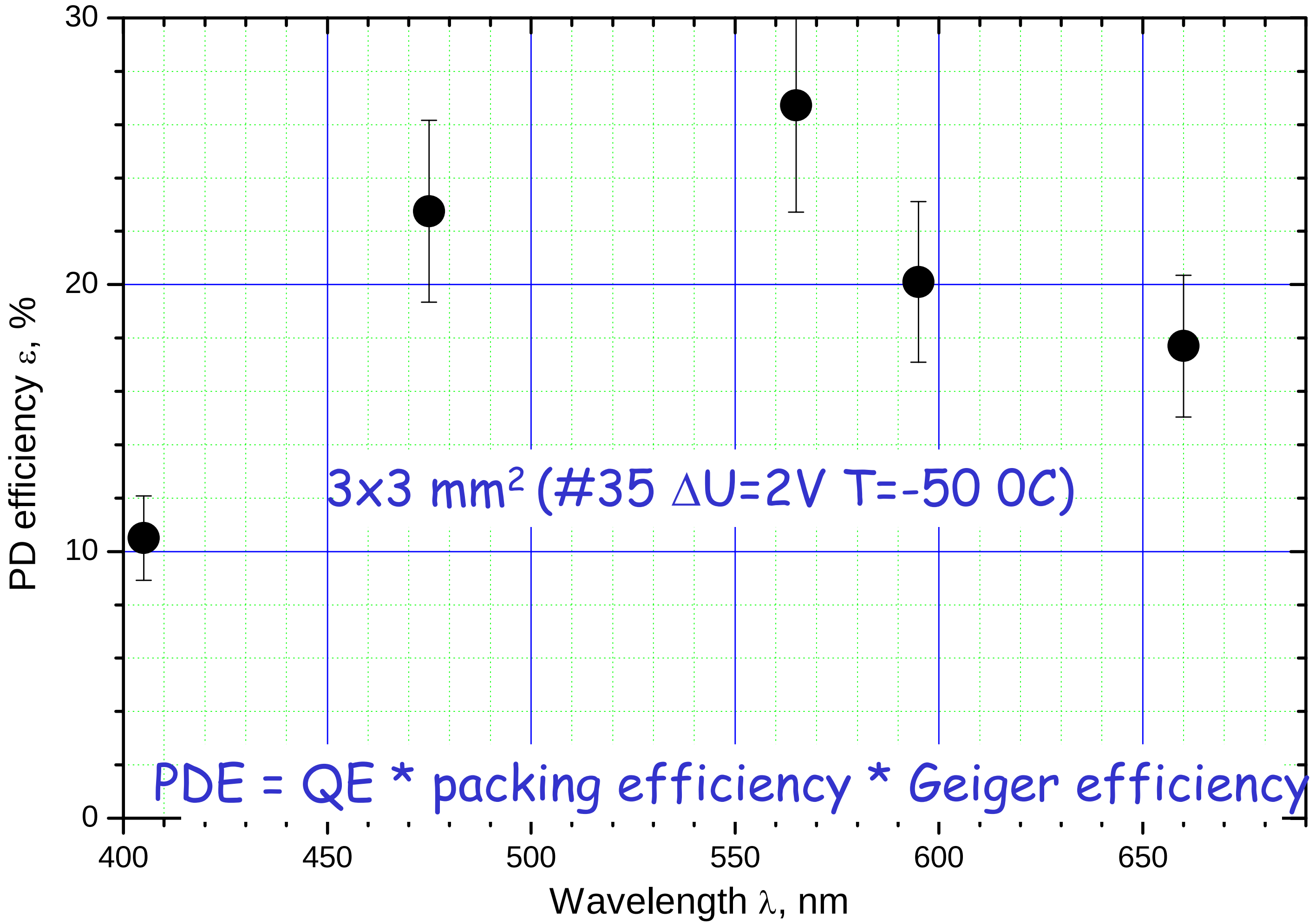
• pixel packing efficiency: ~50%
•Geiger efficiency: ~60%



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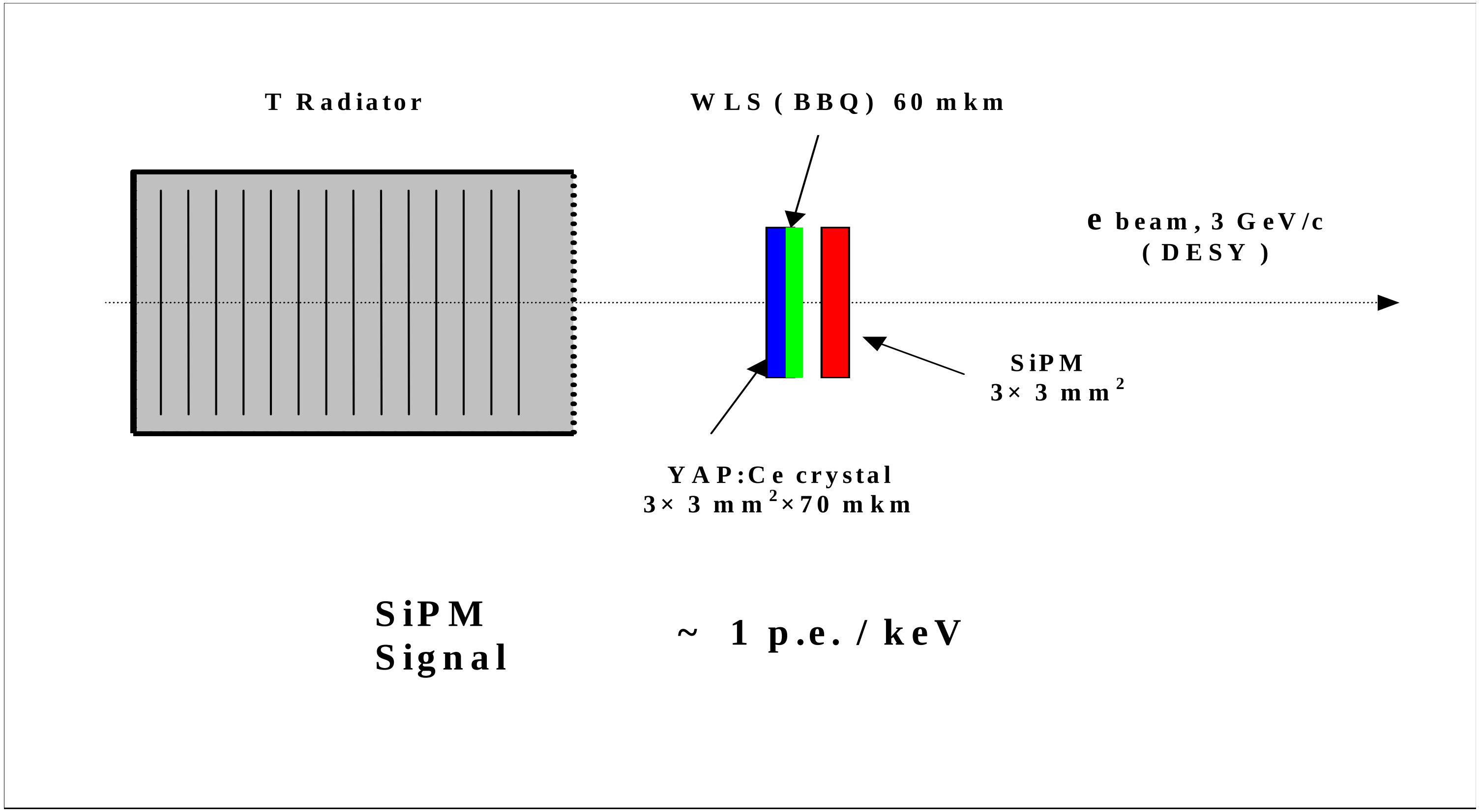
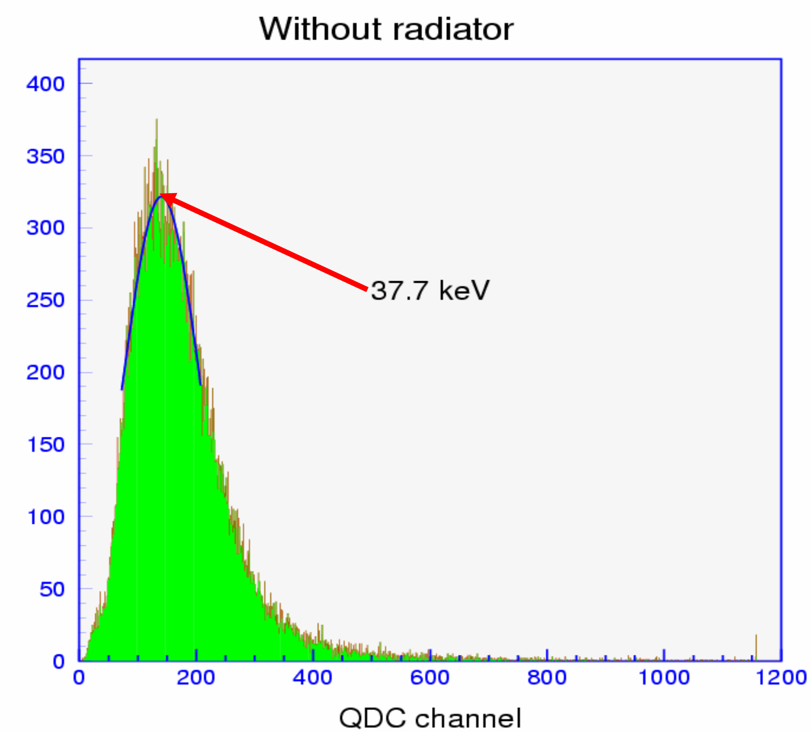
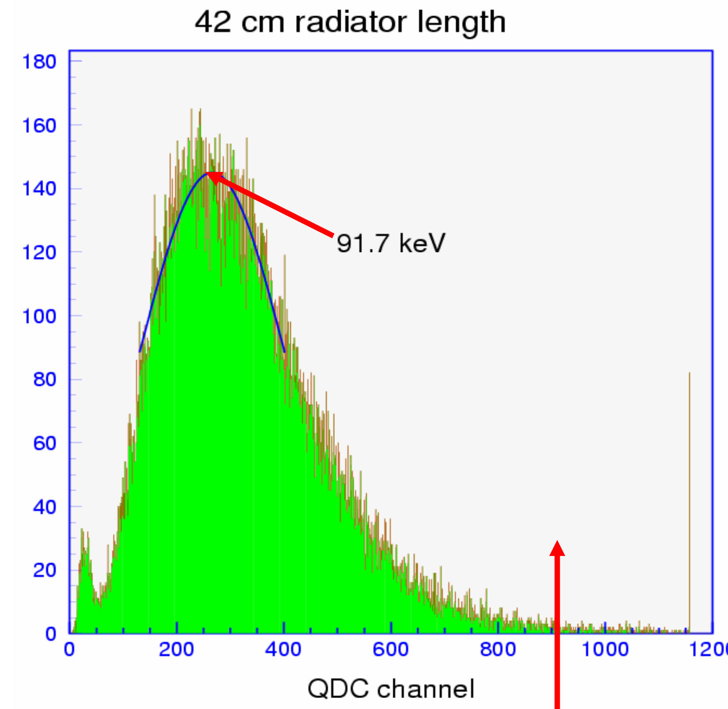
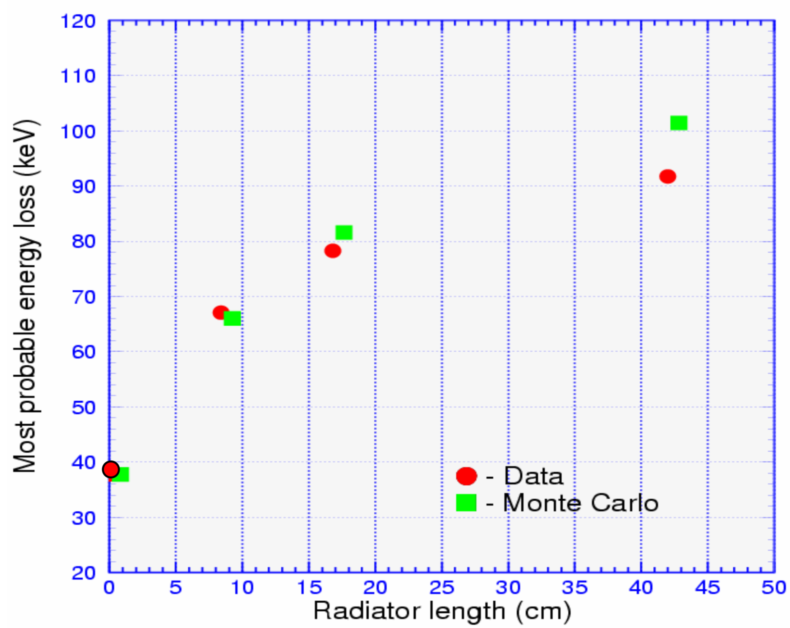
# Three examples of 3x3 mm2 SiPM applications.

- Transition Radiation X-rays detectors based
- on very thin heavy scintillators






Radiator: 1550 polypropylene foils

Mean number of absorbed TR X-ray photons(MK): 4.4

Mean energy of TR photon(MK): 18 KeV

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- Profit of the SiPM application for TR detection:

- compare to traditional Xe-based gas chambers
  no gas system

  no high voltage

- compared to PMT
  no high voltage

  multiset TR detector is possible because compactness and low mass( < 1% Xo)of SiPM

- Challenge:
- SiPM with 10 mmX10 mm area
- SiPM with crosstalk suppression
- --> ENF reduction

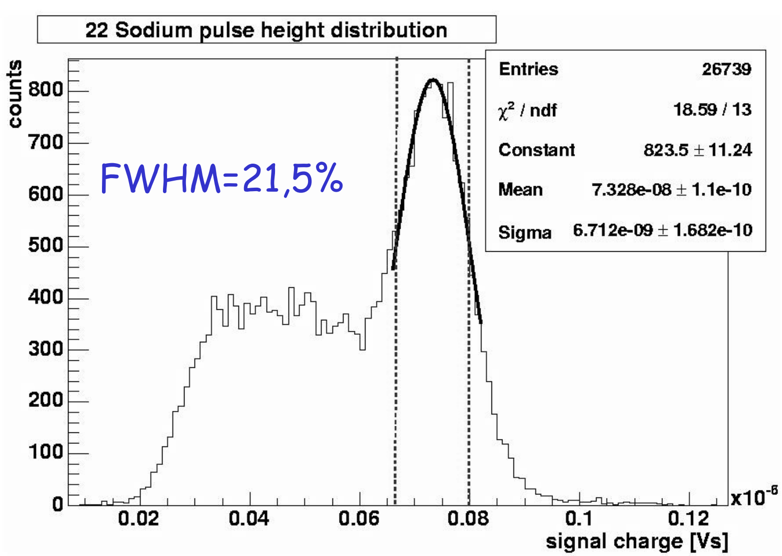
# 3x3 mm2 SiPM for Positron Emission Tomography

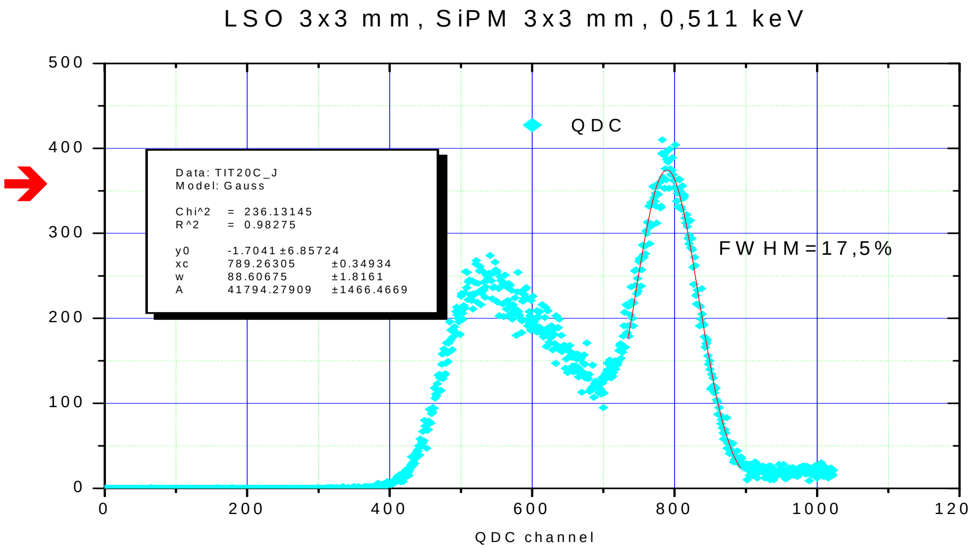
➔ 3x3 mm2 area is well matched with typical size of PETcrystals (LSO,LYSO)

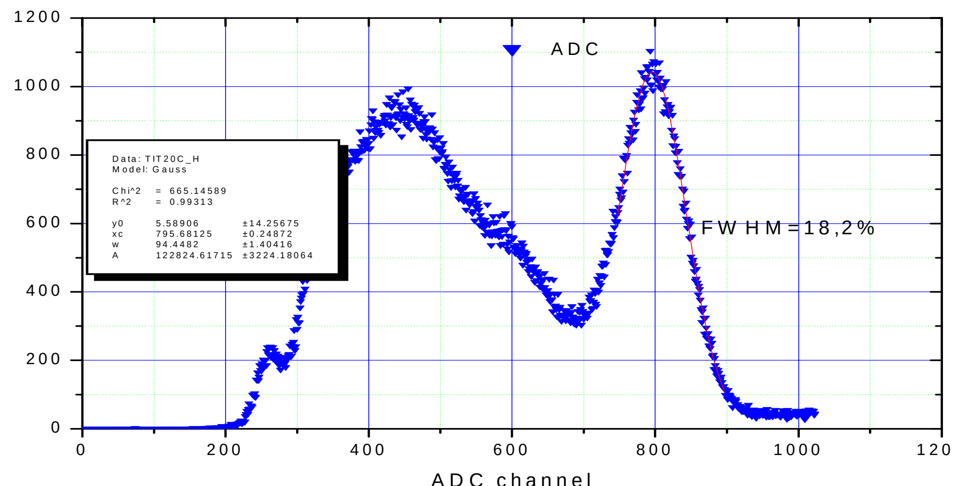
Comparison betweew two sets of LYSO+SiPM for PET gammas E=511 KeV:

LYSO 20x3x3 mm2,SiPM 3x3 mm2 ➔

LYSO 15x22x2 mm2,SiPM 1x1 mm2
A.N.Otte at al. NIMA.545(2005)705

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# Profit of SiPM+heavy crystal usage for PET:

- Compactness,low voltage of the SiPM
- Very good timing(see below)-low accidental background
- Possible usage with a crystals with better intrinsic resolution
- and light yield (LaBr:Ce)

Challenge:

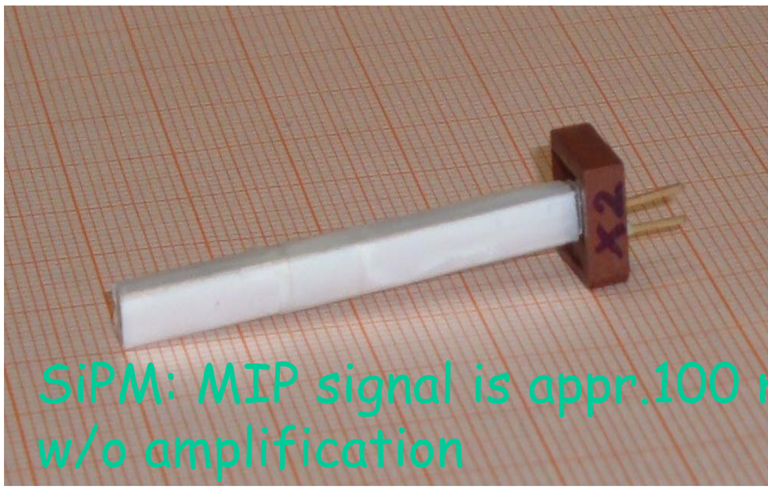
Better SiPM resolution(PDE,low optical crosstalk->reduction of ENF)

TOF in PET

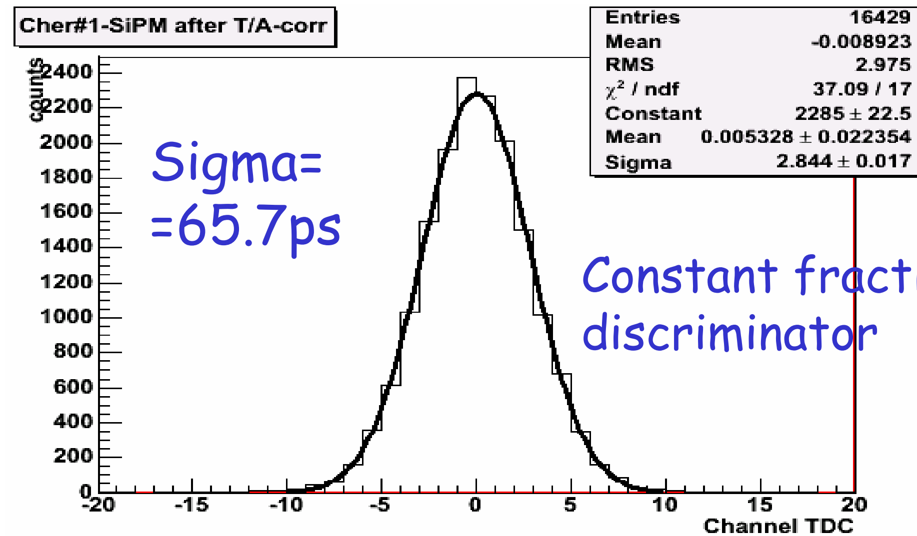
# •3x3 mm2 SiPM application for TOF

(see Poster: A.Karakash et al.,Timing by SiPM:possible applications for TOF measurements)

➲ TOF for MIP(3GeV electron beam)



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




Sigma= =65.7ps

Constant fraction discriminator

Timing resolution between :

PMT(FEU 187)+Cherenkov radiator

and SiPM 3x3mm2+BC418 3x3x40 mm3

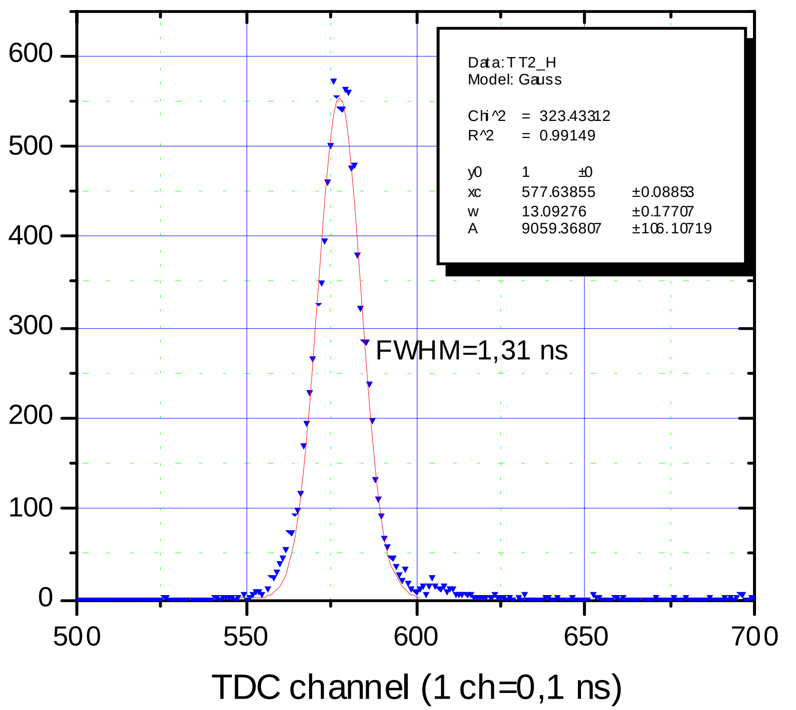
Results:

- sigma(PMT+Ch.rad)=48,5ps
- sigma(electronics) =31.7ps

➔Sigma(SiPM+BC418)=33.4ps

# ➔Timing resoluton in PET

Two SiPM+LYSO crystalls in coinsidence
for two gamma's of 511 KeV,consant fraction discriminator)




--> good suppression of accidental
➔Timing of 1.3ns FWHM
background

Challenge for TOF in PET:

- usage of LaBr:Ce(more light, decay time is less)
-increase PDE for 370nm
-ENF reduction(crosstalk suppression)



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# Conclusions:

New generation of SiPM's with suppression of:

- optical crosstalk
- afterpulsing
- dark rate

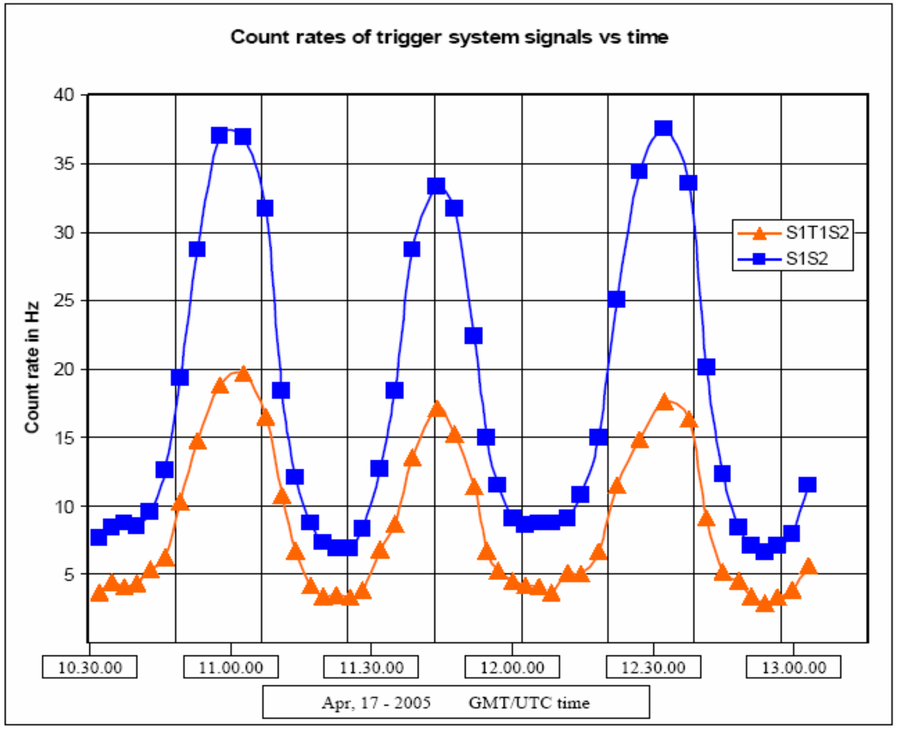
is under development in order to obtain the SiPM's with:

Area up to 10x10 mm2
PDE of 40-50%
ENF=1.0…1.05
Subnanosecond timing

➔ Increases significantly the number of SiPM applications

# SiPM's in space ! International Space Station: launched by 15th of April,2005

Space experiment "LAZIO"(MEPHI-INFN Collaboration)

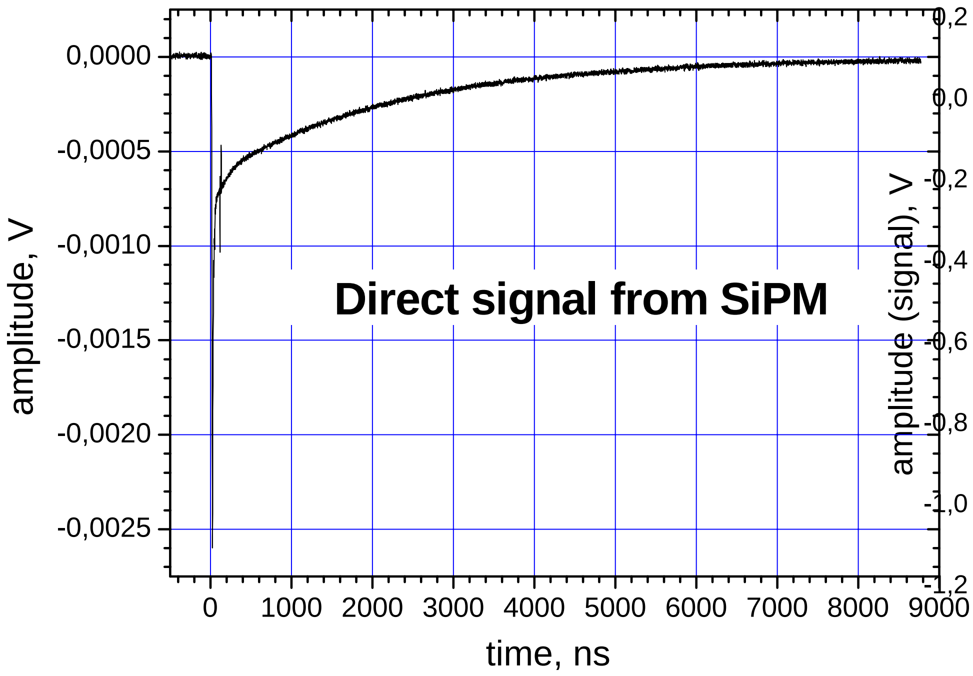



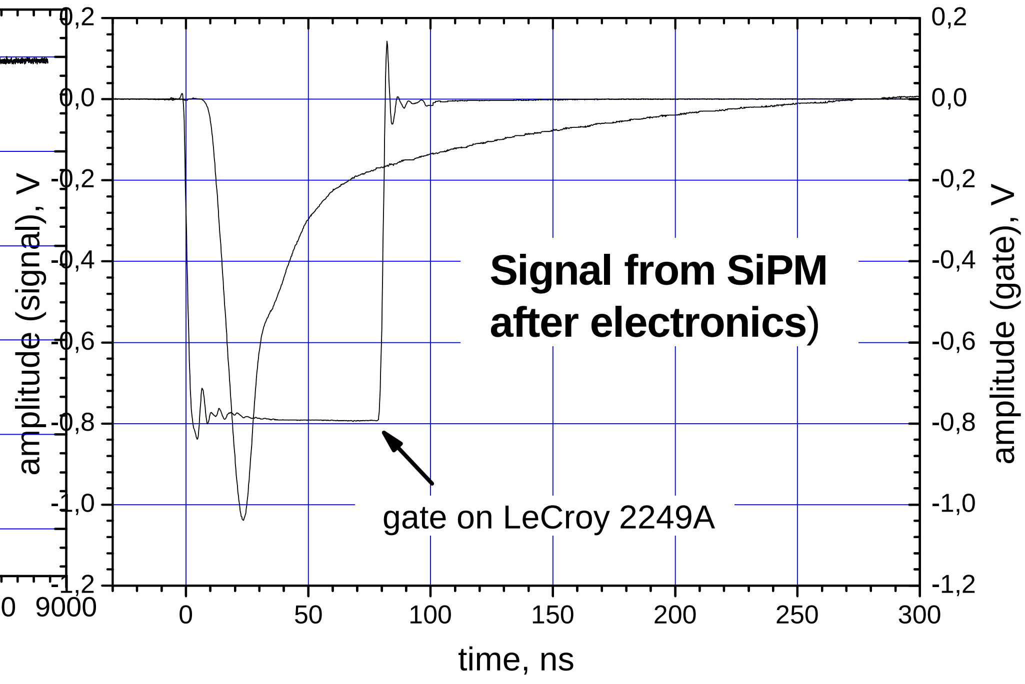

Latitude particle flux dependence

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

**Technological goal**: test of SiPM's in space flight conditions

# ♦ SiPM with larger area (3x3 mm²)



# Cs-137,662 KeV