Tile-SiPM Systems for AHCAL

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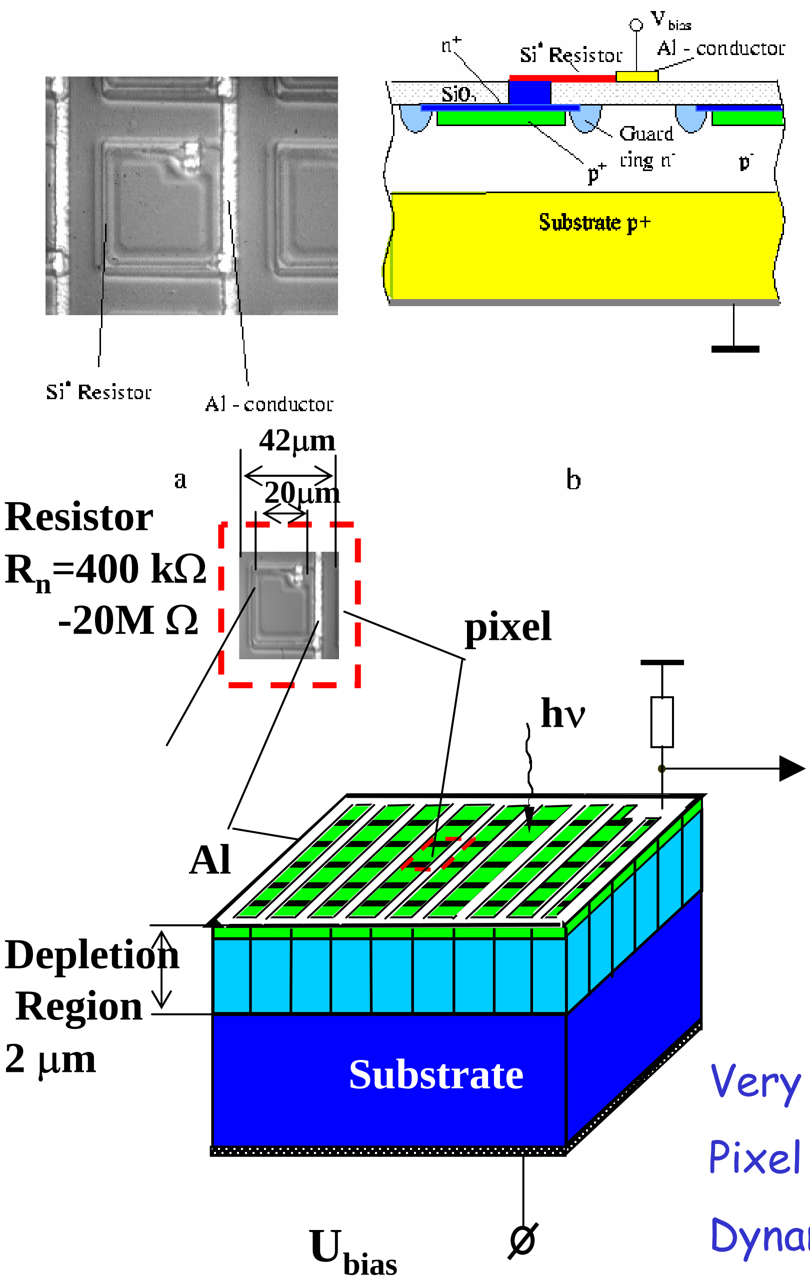
CALICE Collaboration

ECFA ILC Workshop Vienna 2005

SiPM main characteristics



- Pixel size ~20-30μm

- Working point: $V_{Bias} = V_{breakdown} + \Delta V$ ~ 50-60 V
  ΔV ~ 3V 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 efficiency

- Optical inter-pixel cross -talk:

-due to photons from Geiger discharge initiated by one electron and collected on adjacent pixel

Very short Geiger discharge development < 500 ps

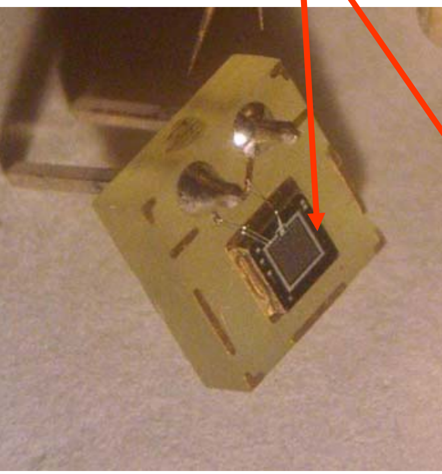
Pixel recovery time = (C_{pixel} R_{pixel}) ~ 20 ns

Dynamic range ~ number of pixels (1024)➔ saturation

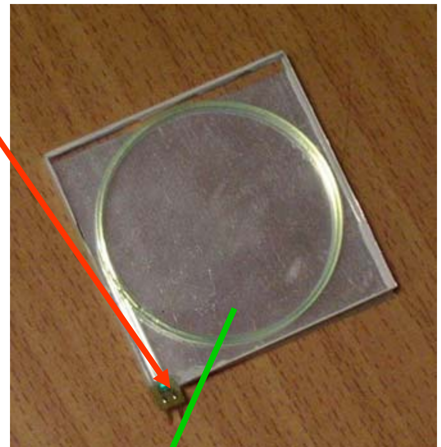
Experience with a small (108ch) prototype (MINICAL)

Moscow → Hamburg

SiPM

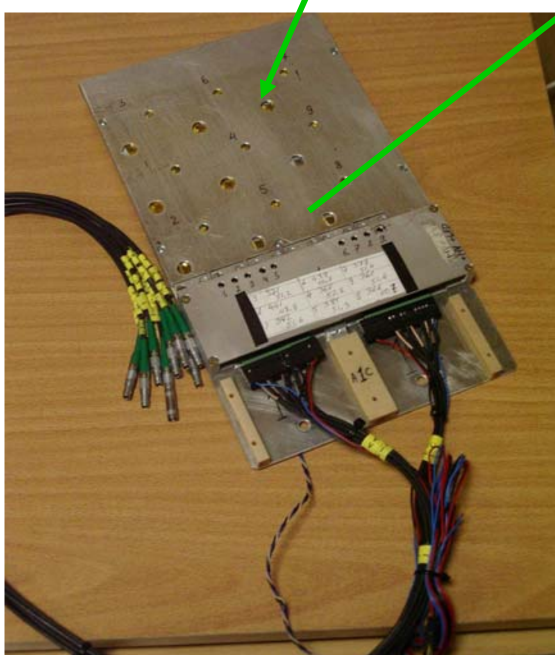


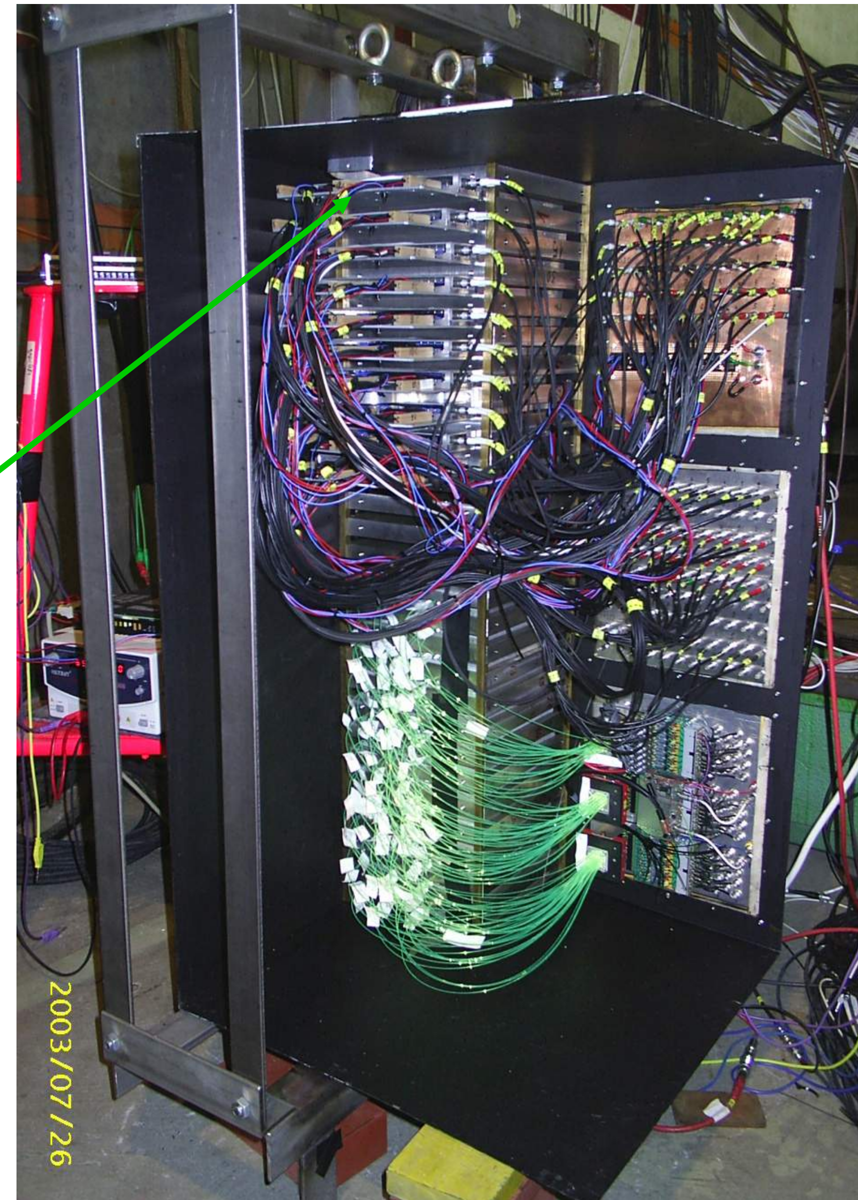
Tile with SiPM



cassette

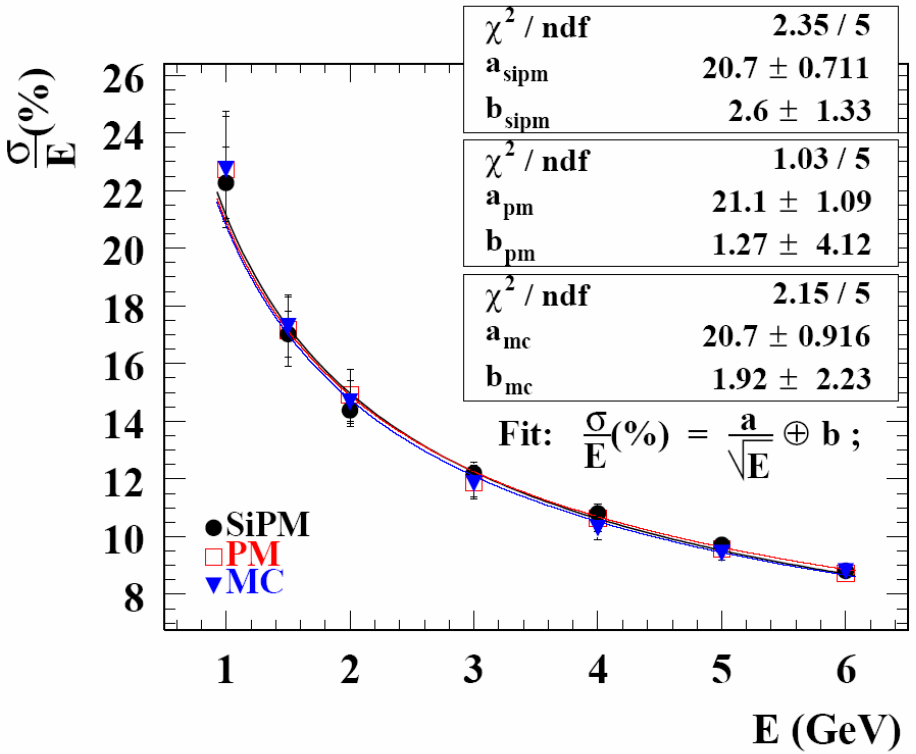
3x3 tiles

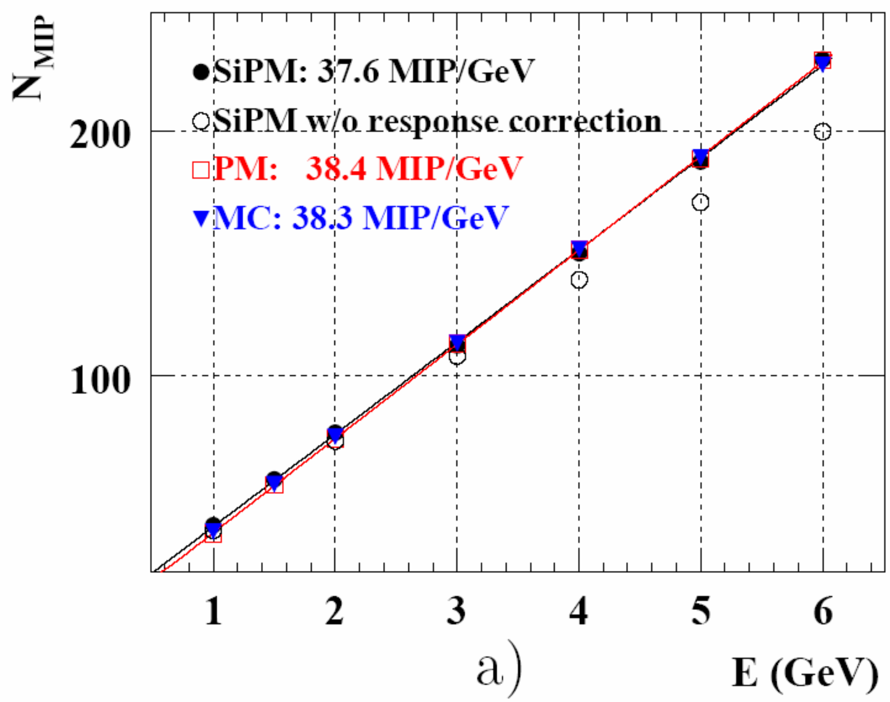




MINICAL tests with electron beam

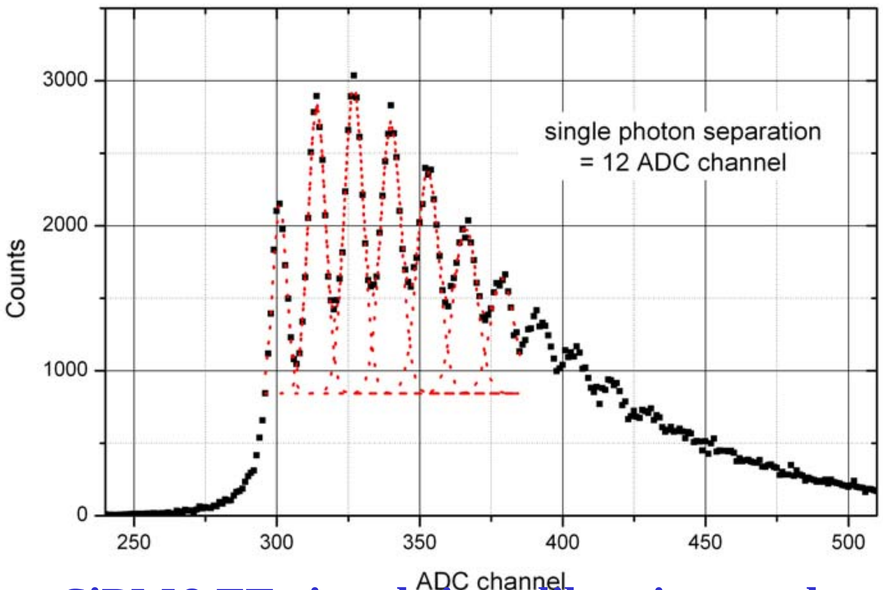
Measurement of electron energy with HADRON CALORIMETER ⇒ resolution modest



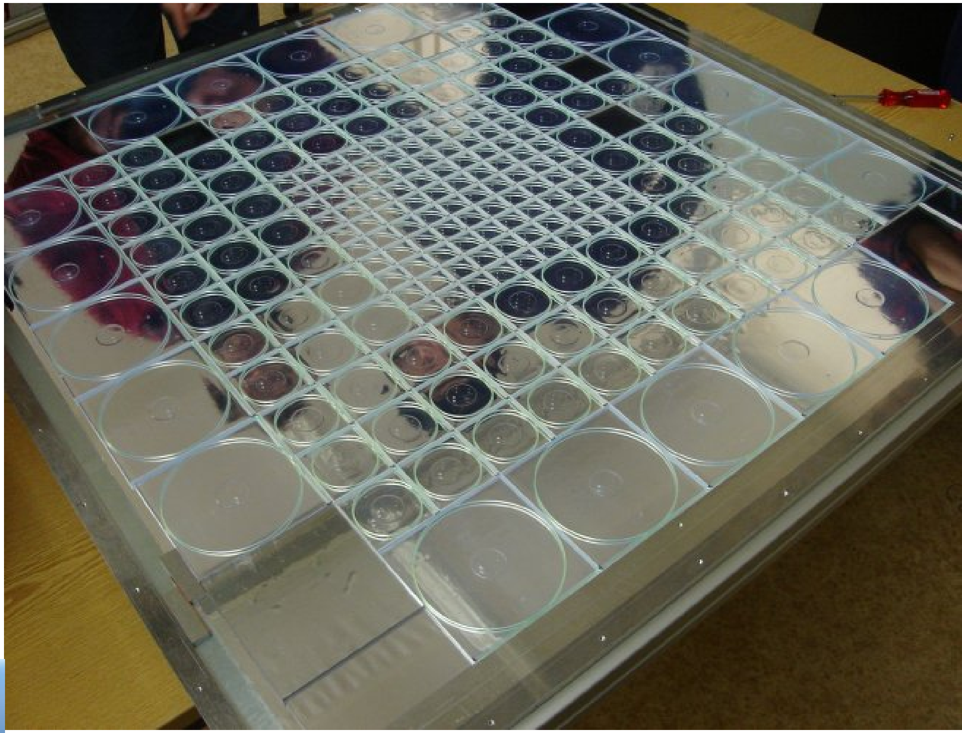


- ➔ Very good agreement between SiPM, MAPMT, APD(not shown) and MC in the whole range 1 - 6 GeV
- ➔ SIPM non-linearity can be corrected even for dense e/m showers for each tile and does not deteriorate resolution
- ➔ Possibility to observe peaks for different number of p.e. crucial for calibration
- ➔ Low sensitivity to constant term due to limited energy range

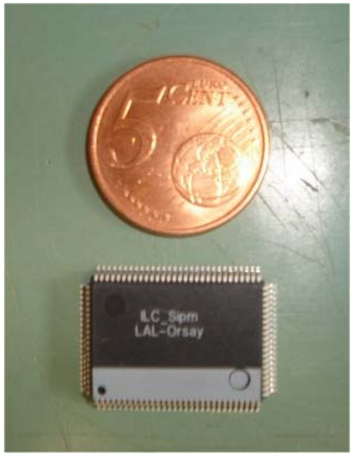
A big 8000 channel HCAL prototype with tail catcher is constructed by CALICE (DESY,ITEP,LAL,MEPHI,NIU,Prague,UK) for analog and semidigital modes



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



LAL 18 ch. SiPM FE chip

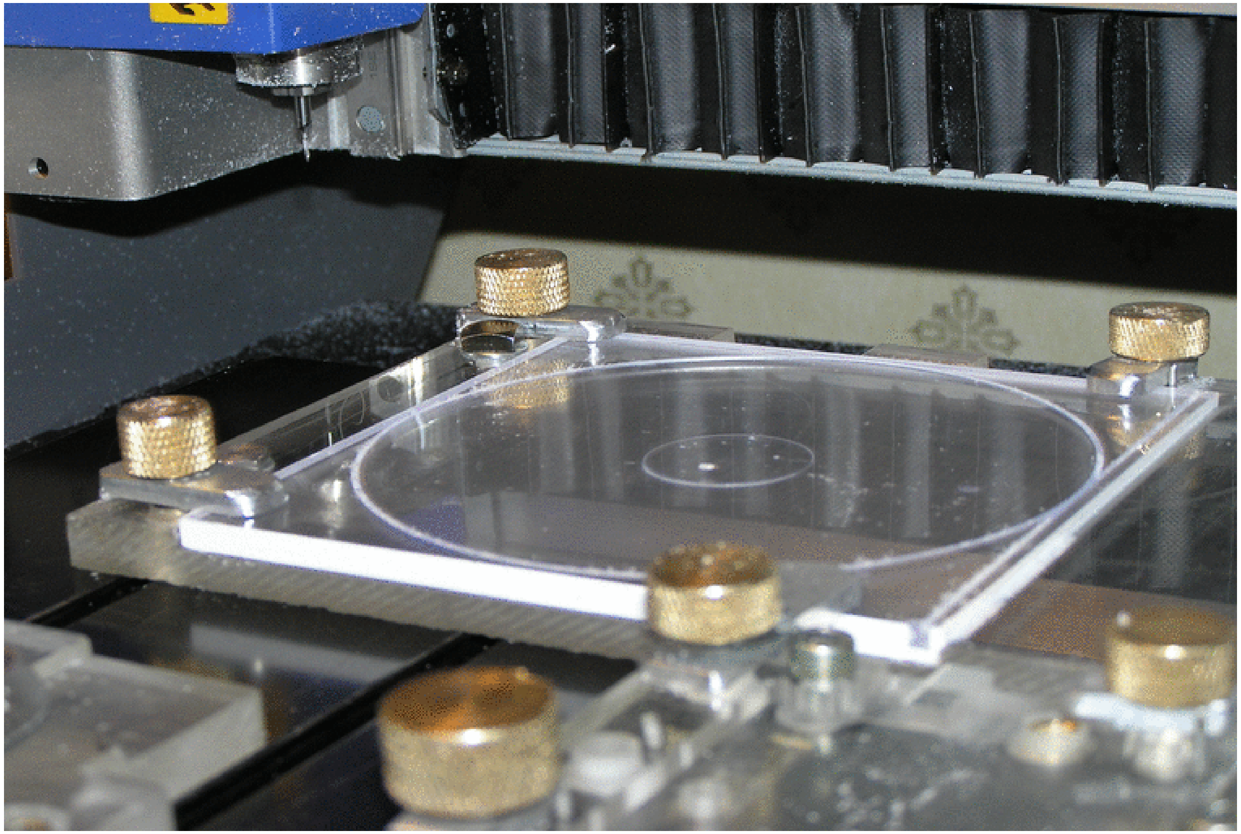
CALICE DAQ board for 8 planes (UK groups)

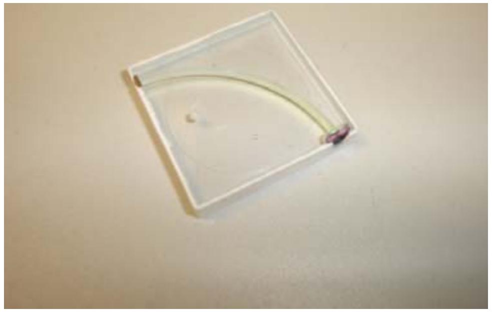
Molded and edge treated tiles are milled at ITEP.

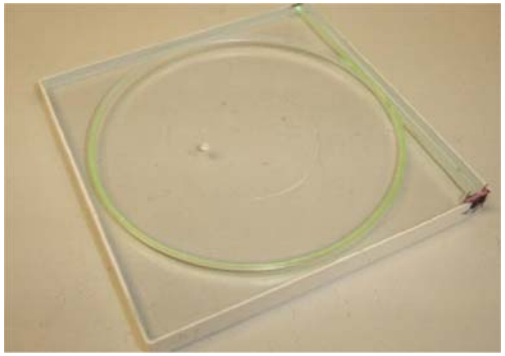
Grooves for WLS fiber, mirror and SiPM placing are produced by digital Desktop Engraver ROLAND EGX-300

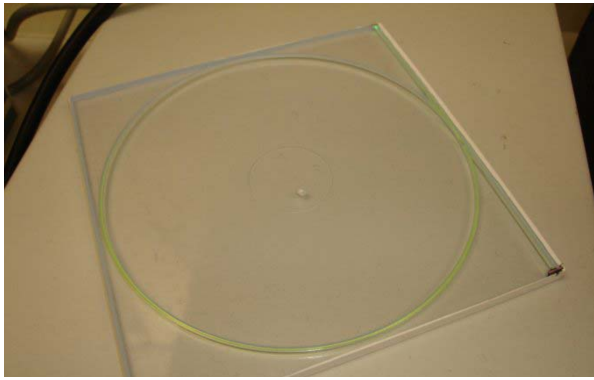
Accuracy – 10 µm

Use mills of 0.04'' which fit well 1mm fiber diameter









Tile production status

Tile size	$3x3\ cm^2$	$6x6\ cm^2$	$12x12\ cm^2$
To be produced	3500	4000	1000
Cut	3500	4000	1000
Fiber installed	3500	4000	500
Shipped to DESY	600	600	120

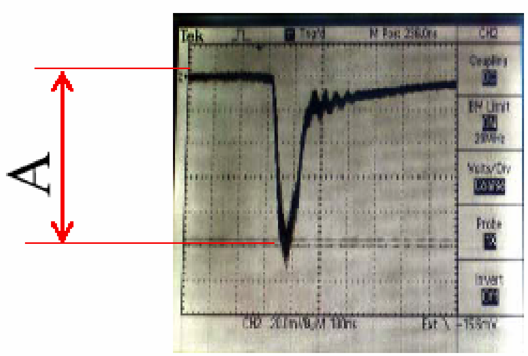
Fibers in 3x3cm tiles are ~0.1mm shorter than required =>LY reduction of ~2 p.e.

Will be corrected

PULSAR semiautomatic probe station for the initial SiPM selection on the uncut wafer

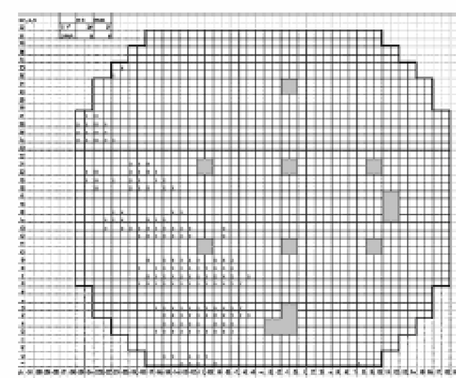
Selection criteria

- Proper Geiger signal to the LED pulse
- For operational voltage when SiPM response has amplitude A SiPM current should be less then certain value




```
START
file 401_4_14.def
time is: 15:57; data: 26.4.2005;
type: B
DATA
 x         y         U(V)     I(mkA)   comment
-17        -4        23.4071  44.1610  bad
-16        -4        23.4213  44.1637  bad
-15        -4        39.3215  1.2410   work
-14        -4        40.4247  1.2902   work
-13        -4        35.7515  32.0656  bad
-12        -4        40.7056  1.3321   work
-11        -4        41.0897  1.4401   work
-10        -4        40.8400  1.7106   work
-9         -4        41.3195  1.1611   work
-8         -4        41.2988  1.1396   work
-7         -4        41.6149  1.2367   work
-6         -4        41.7435  1.0789   work
-5         -4        41.3084  1.1884   work
-4         -4        41.9314  1.2043   work
-3         -4        41.7322  1.1300   work
-2         -4        37.8563  20.2680  discharges
-1         -4        42.2476  1.0396   work
0          -4        42.2311  2.6090   work
```

Selection map



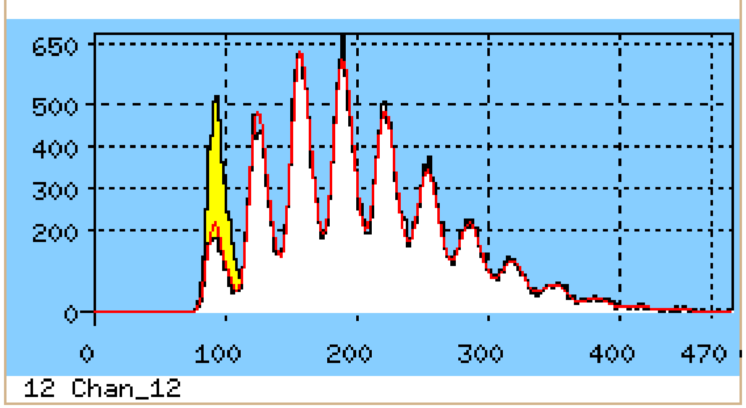
Max rate - 1000 SiPMs/day

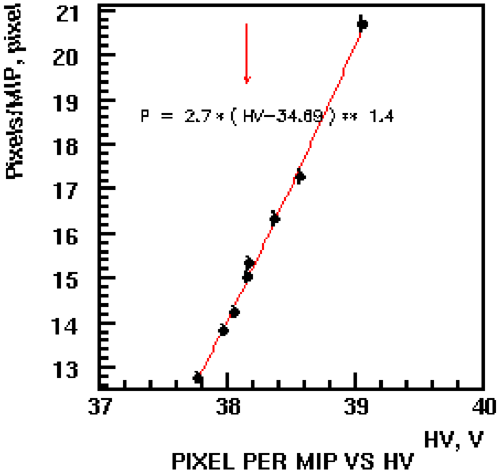
Beaune 2005 E.Popova MEPhI

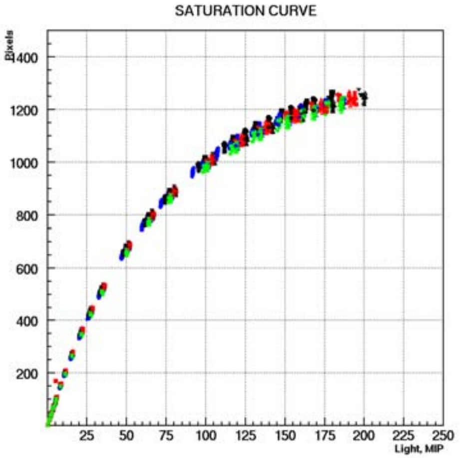
SiPM test procedure at ITEP

- Adjust bias voltage to 15 px/MIP
- Determine SiPM parameters:
  - gain
  - noise frequency at zero pixel and at ½ MIP levels
  - cross talk
  - efficiency
  - width of single p.e. peak
  - dark current and its variation
  - saturation curve 0.3-200MIPs
  - SiPM temperature during test

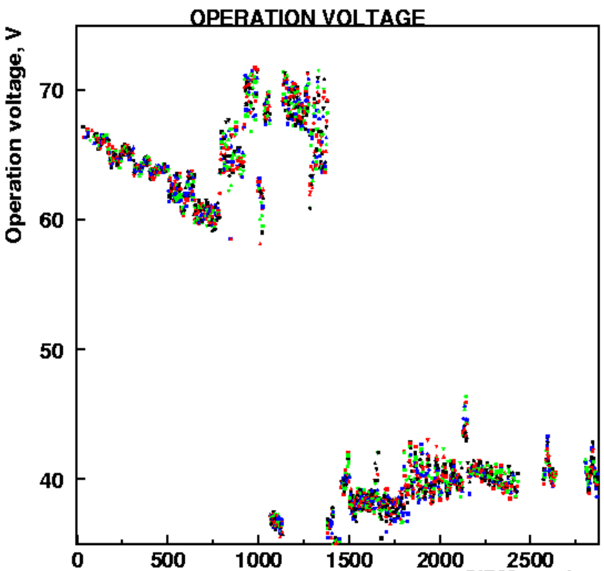
Store results in data base

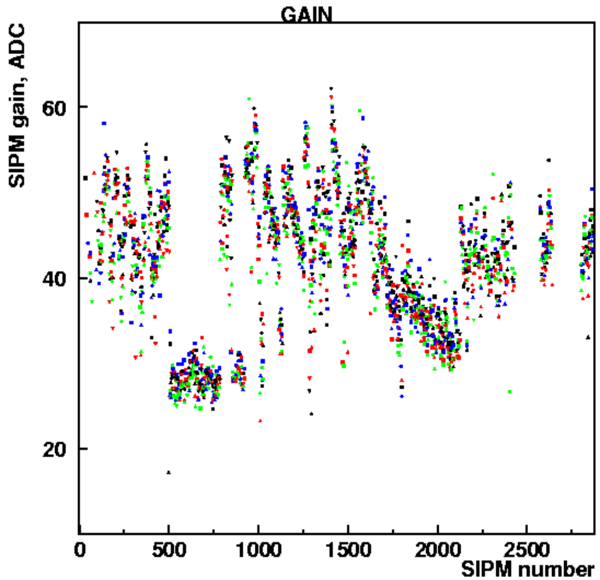


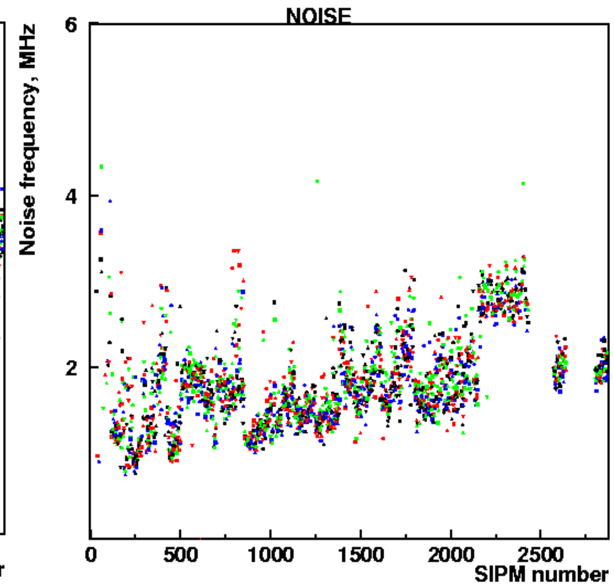


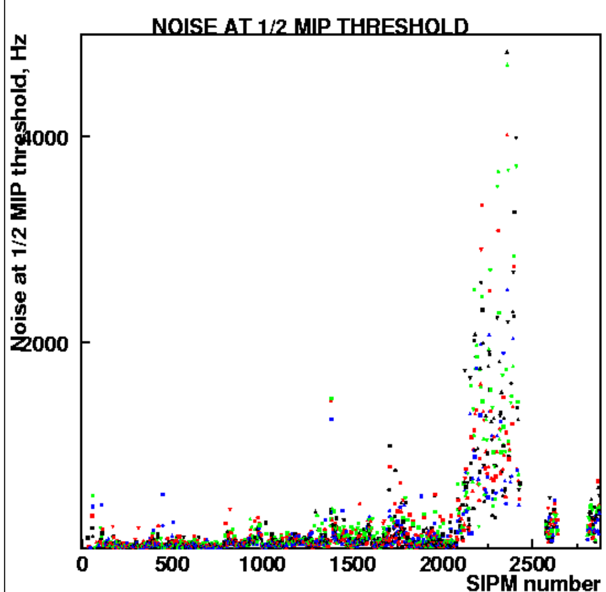


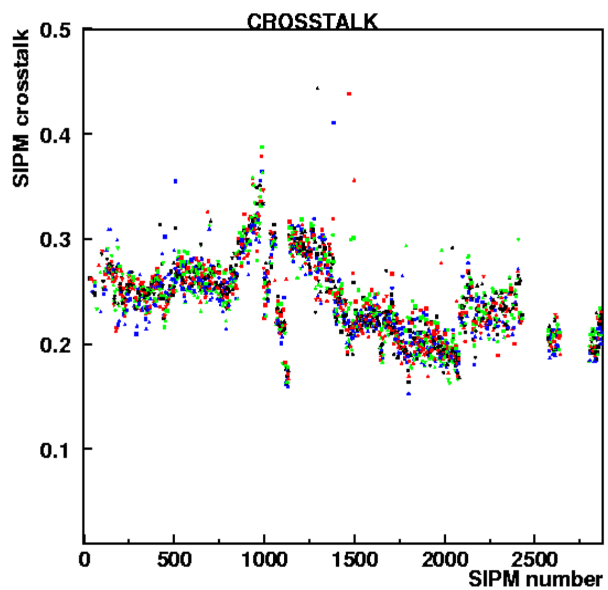
SiPM test results for 2600 detectors











SiPM selection

Ped RMS < 50 ADC channels

Gain > $4*10^5$ or 1 pixel > 26 ADC ch., corresponds to 1 pC/MIP

Cross talk < 0.35

At HV adjusted 14.25 < N_{pix}/MIP < 15.75

Noise frequency at zero threshold < 2.5 MHz - at higher frequency the fit procedure of LED spectrum fails often

Noise frequency at ½ MIP threshold < 500 Hz – this corresponds to 1 extra hit in 8000 channels per event (may be too tough)

Mean value of SiPM current < 2 μA

RMS of SiPM current during test < 20 nA

Number of pixels at maximal light (~200 MIP) > 900

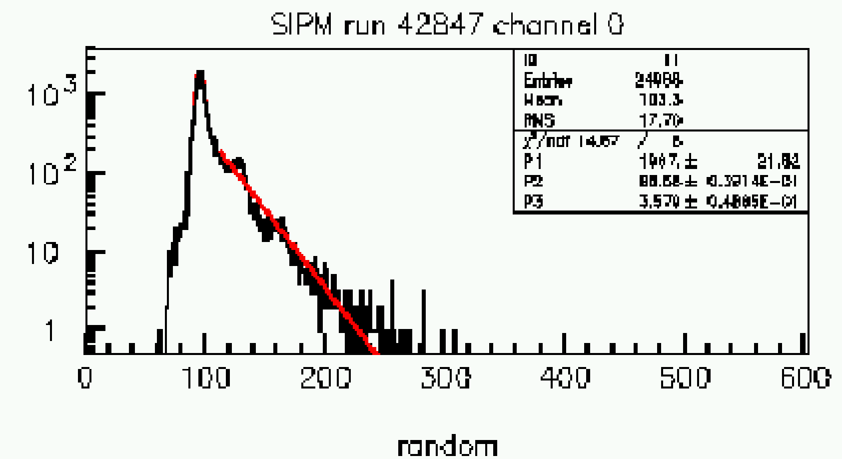
High noise is main reason for SiPM rejection (~20%)

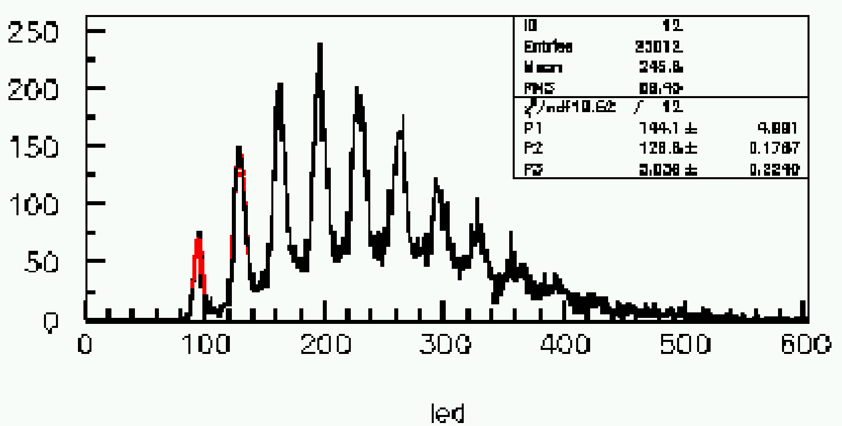
Spectra below show the difference between a good and a typical rejected SiPM

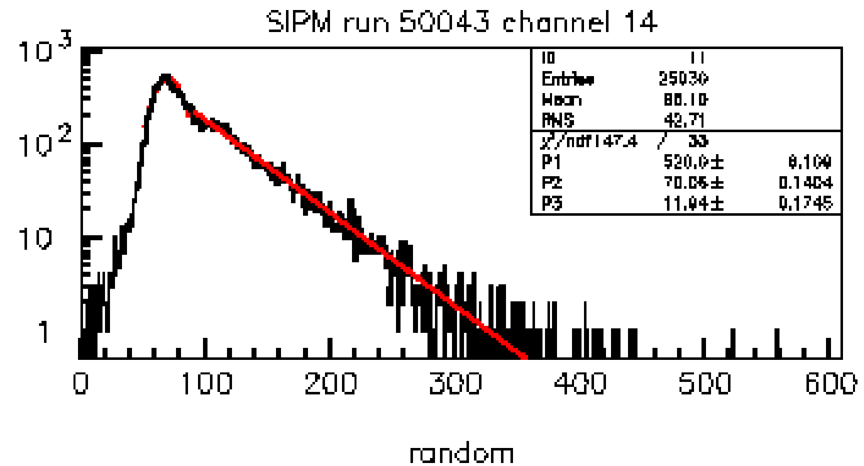
The left one has noise frequency – 1.5MHz

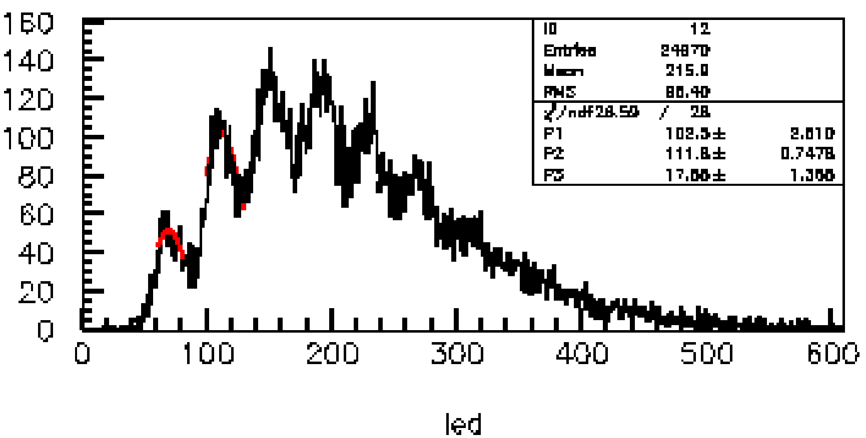
The right one has noise frequency 2.8 MHz, Noise at 0.5MIP is above 2kHz

Note the difference in pe peak separation and in the slopes of the tail in random trigger spectrum.



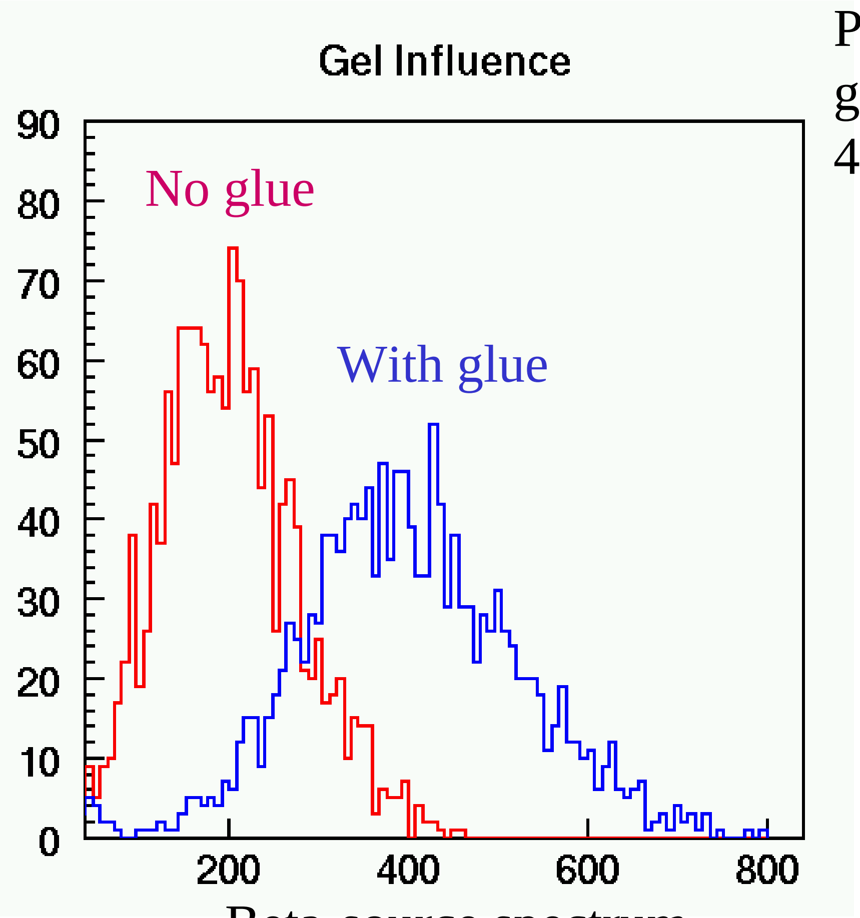






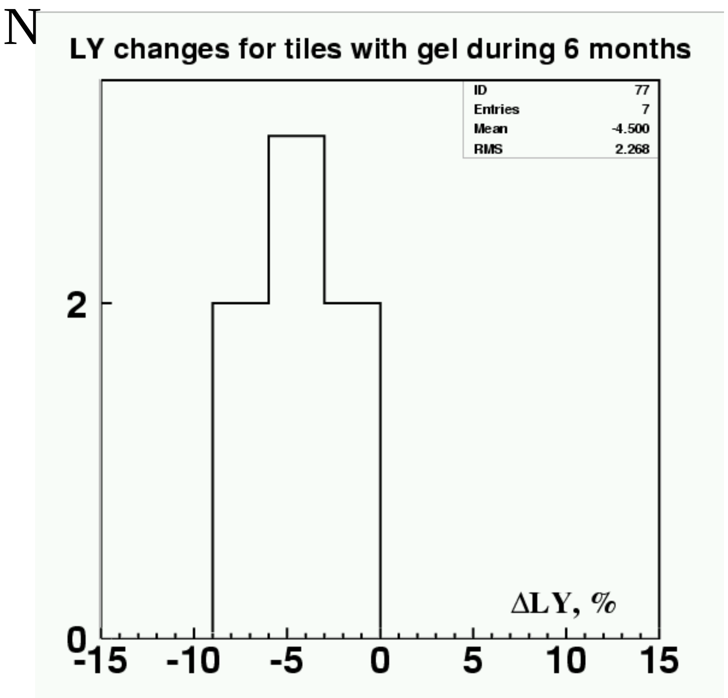
Increase of Light Yield relaxes requirements on SiPM noise rate

LY can be increased by a factor of about 1.9 by gluing fiber to SiPM with “SUREL SL-1” siloxane gel



Beta-source spectrum

Practically no ageing observed in 7 tiles with glue during 6 months.
4.2% LY decrease is comparable with errors ~2%



Decision to glue or not to glue will be taken in December

Another Problem:

About 10% of SiPM in the two first cassettes show long discharges (LD)

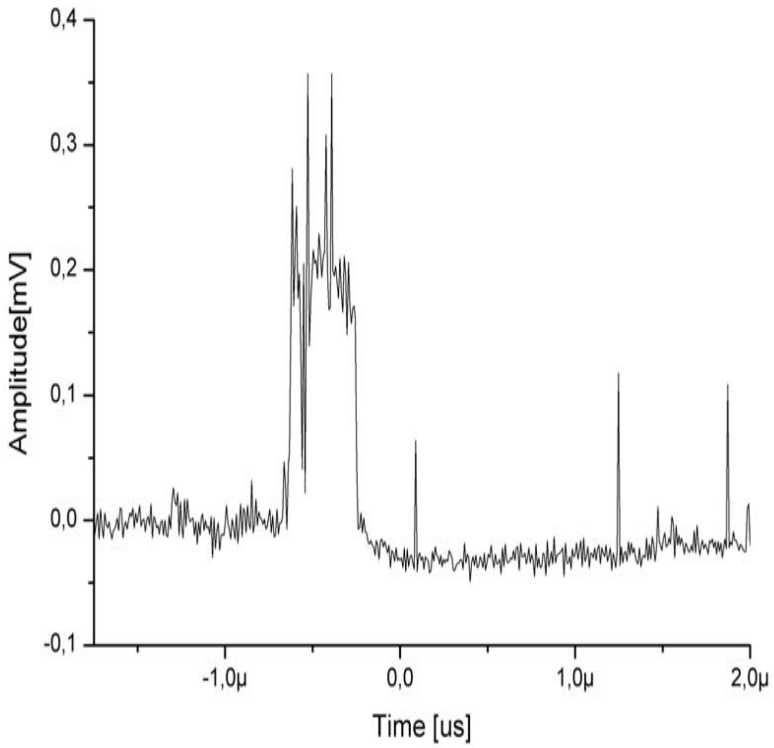
- Most probable reason is:

  Something happens with a quenching polysilicon resistor (its value is reduced from a few MOhm down to ≤100 kOhm for some pixel(s)

  ➡ quenching current rises up to ≥10μA

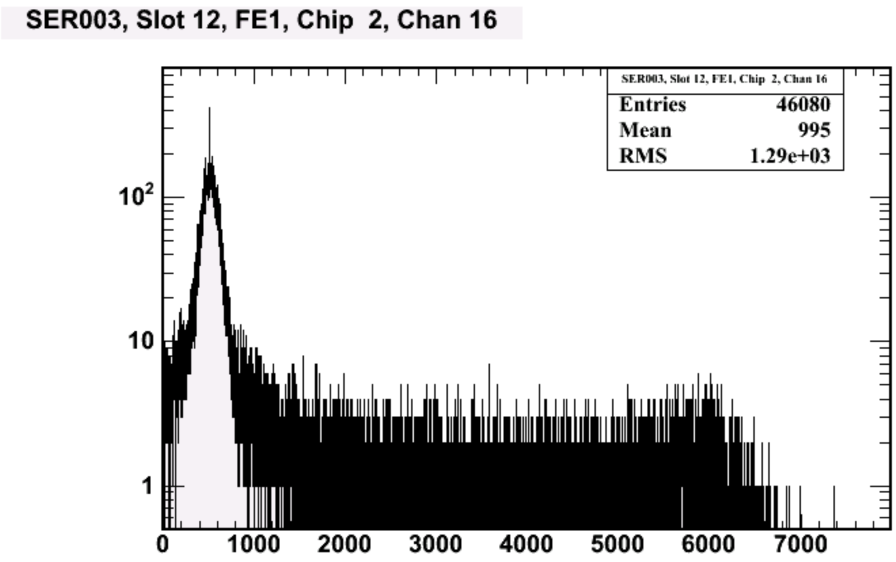
  ➡ quenching time rises up to ≥100 ns

Example of long discharge signal

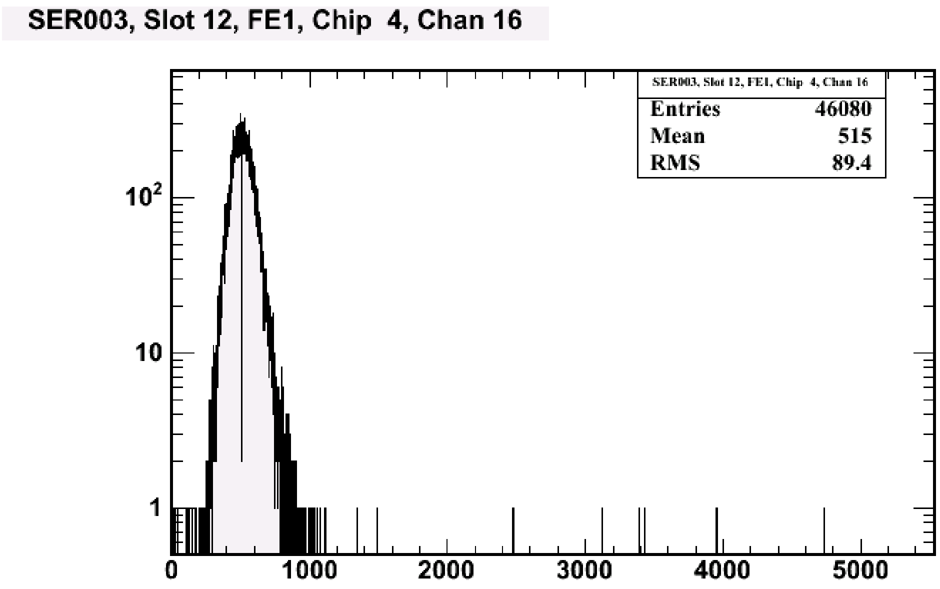


Noise amplitude spectrum for good and bad SiPM

~50000 events collected with longest shaping time and highest gain:



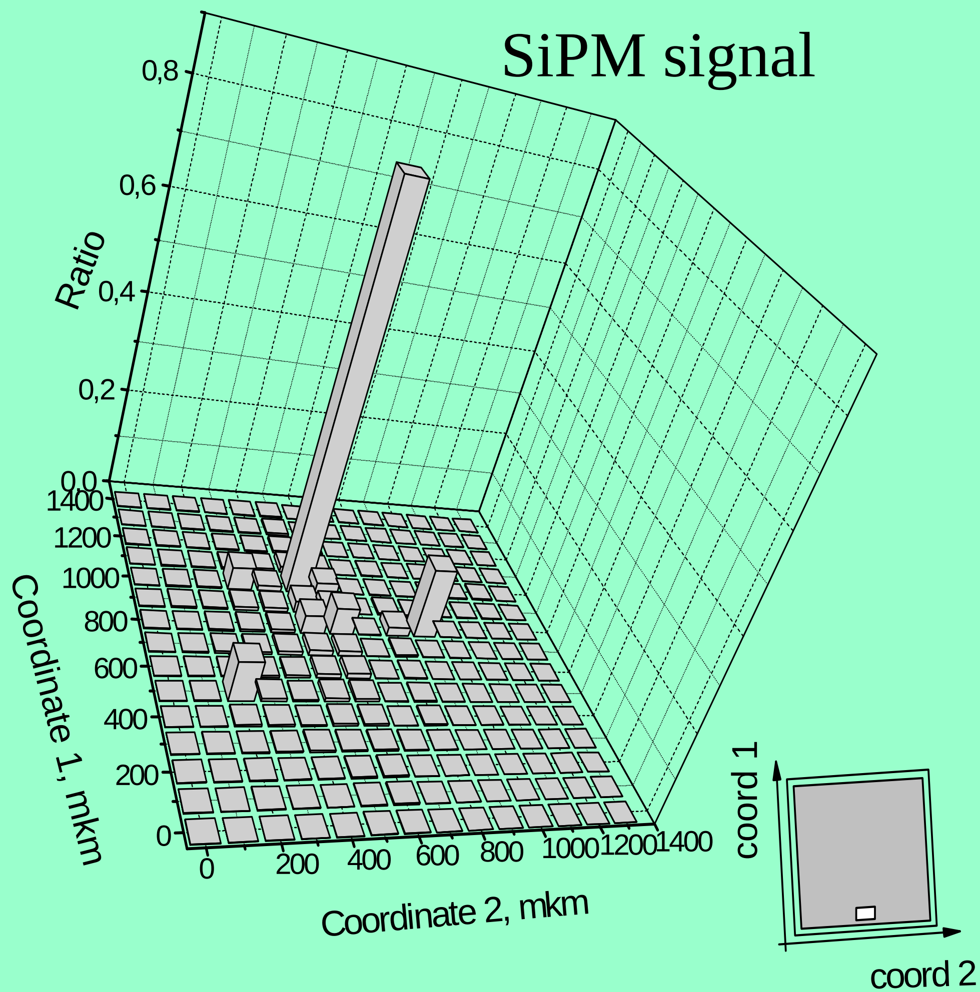
High frequency LD



Good SiPM

The special setup developed at MEPHI for scanning of the SiPM.

LED, optical fiber, step 100 micron

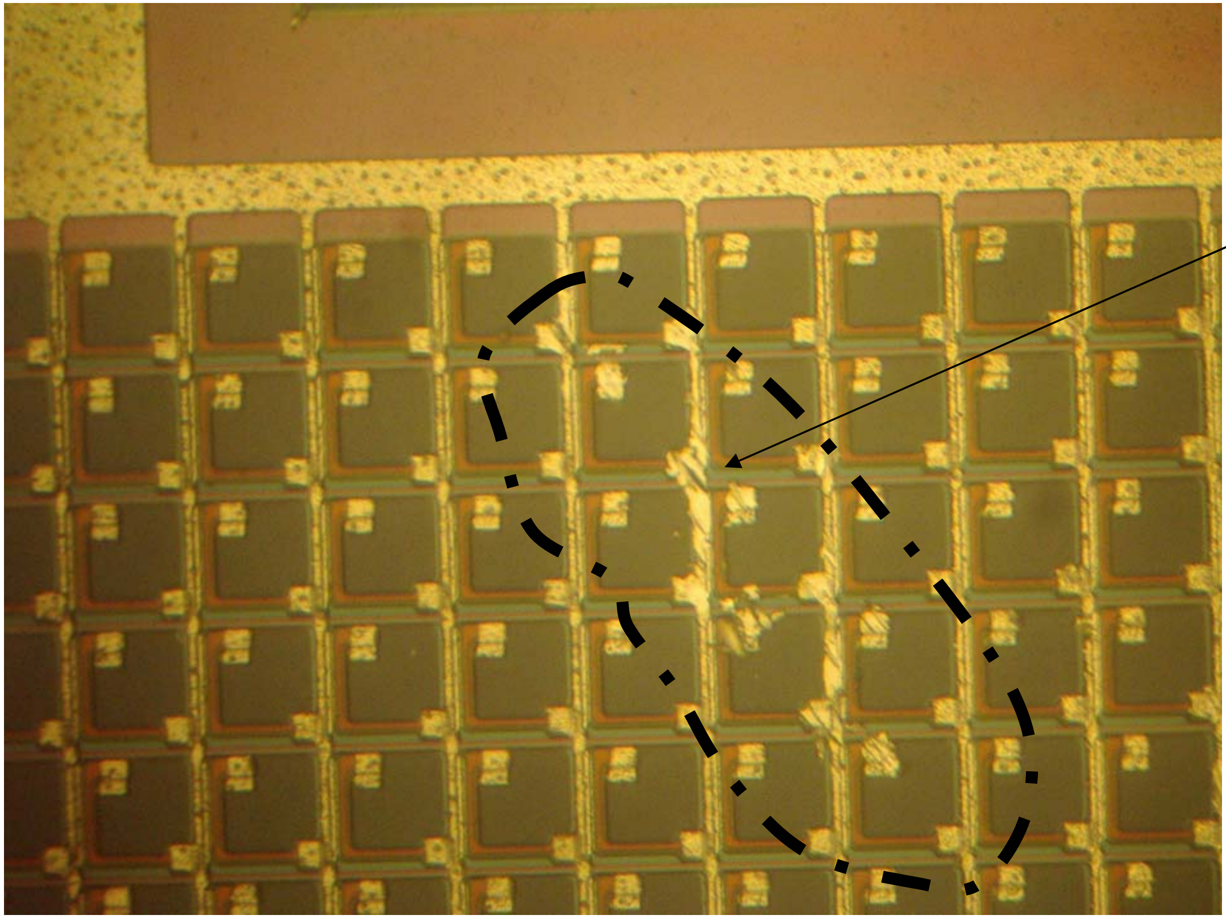


Localization of the problem region and investigation under microscope

After scanning it became clear – Long Discharge comes from local area – from 1 or few pixels

SiPMs with LD were scanned and investigated under high gain microscope

SiPM 2593

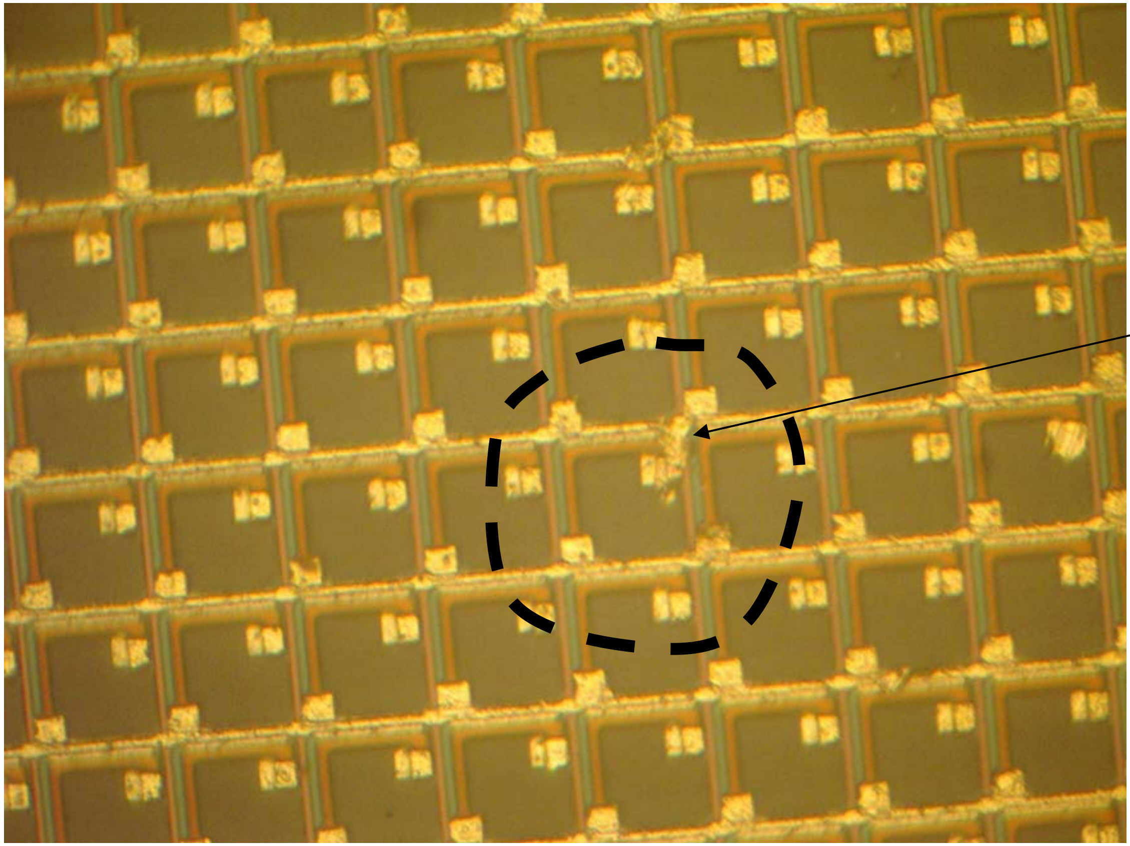


LD area

Al short circuit due to scratch

SiPMs with LD were scanned and investigated under high gain microscope

SiPM 2634

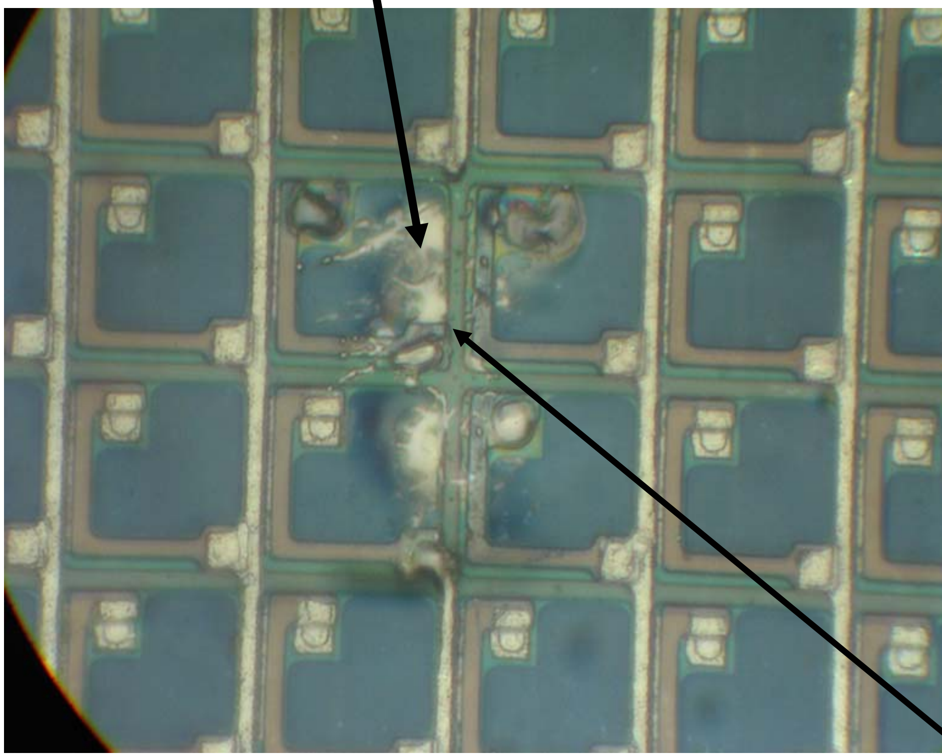


Pixel with LD

Al short circuit due to point like defect

Another example of damages due to resistor-Al bus discharge

Al (short circuit?)



No Al bus

Such damages can appear as a result of

• big overvoltages for reverse bias

•High voltages for direct bias

Conclusions on Long Discharges

1. SiPM is very sensitive to damaging during production and assembling operations.

   Actually each SiPM consists of ~1000 local points with very high electric field $3*10^4 - 3*10^5$ V/cm

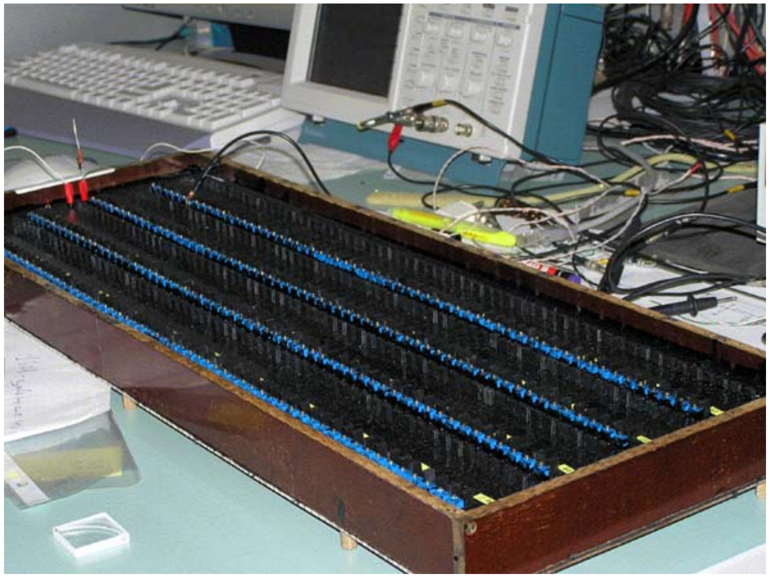
2. There are a strong indication of SiPM surface damaging during production and assembling stages and also technological imperfections, which can lead to short circuits between Al buses and polySi resistor.

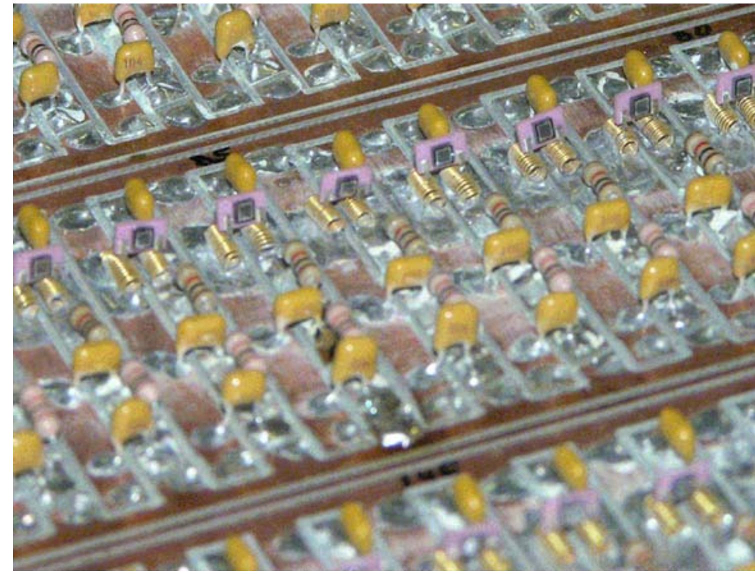
   ➡ Now SiPM's modification with additional SiO_2 layer for Al-polySi resistor isolation is under study.

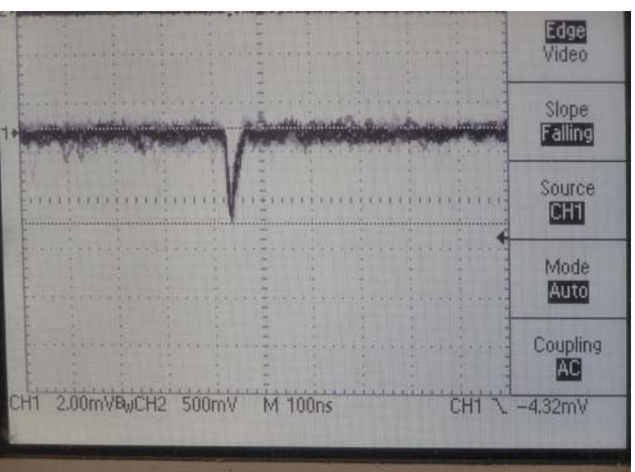
Long term stability test is added to SiPM test procedure

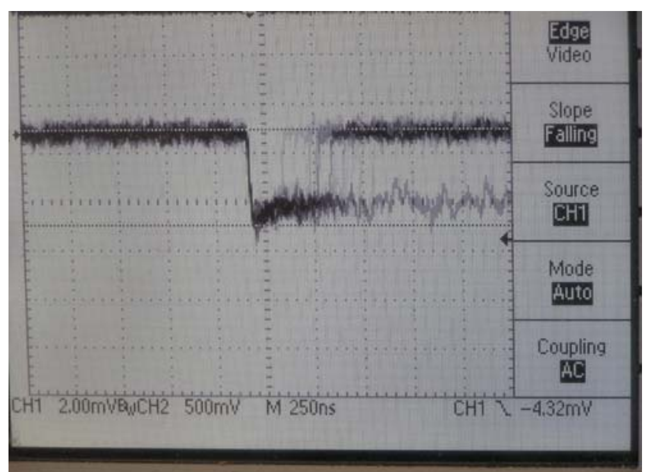
We have now a set-up to select SiPM's after long term test (240 channels).

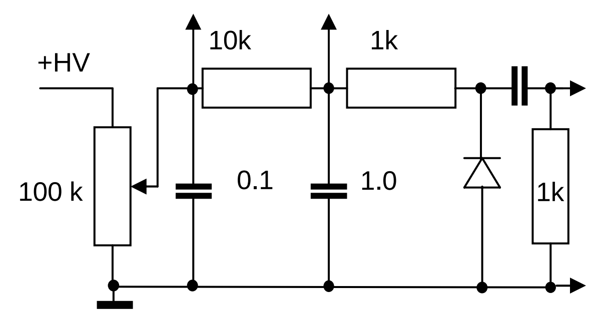
Individual bias voltage setting for each channel, outputs for current and pulse shape monitor



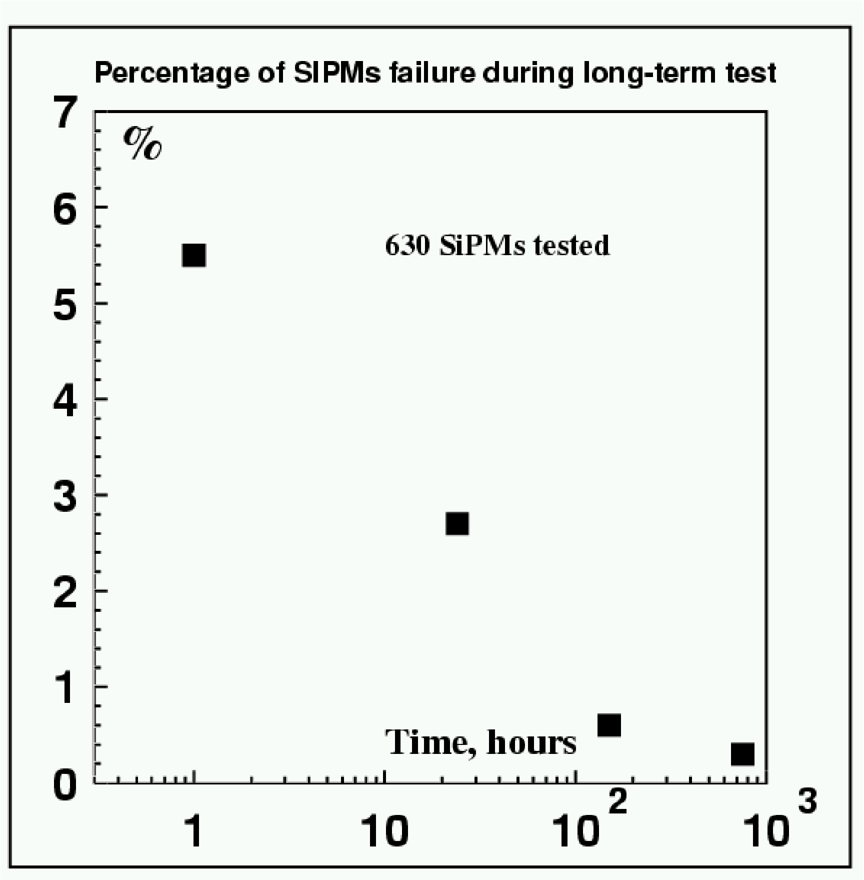








Long term stability test results for 630 SiPM



Burn in procedure can probably solve the problem with LD

New SiPMs with SiO2 protection layers have no problems so far:

30SiPM demonstrated no degradation after 20 days

Only 5 SiPMs have LD in cassettes 4,5,6 (out of 650 SiPMs)

We believe the LD problem will be solved soon (or solved already)

Tile-SiPM system tests

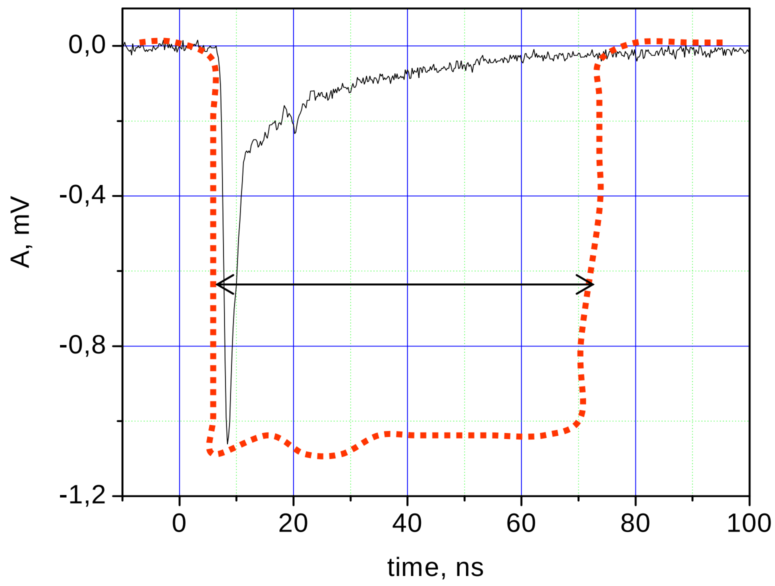
- Up to 16 tiles are loaded in the same time into box
- Computer driven carriage brings the β-source and the trigger counter to a tested tile. Source position is controlled by the computer readout sensor
- SiPM bias voltage is set according to SiPM test and temperature measurement
- Measurement of MIP response with help of triggered β-particles
- LED spectrum gives information about SiPM gain
- So, one may deduce the number of pixels in MIP peak
- Conditions and results of tile test are saved to data base for further use and analysis

Summary

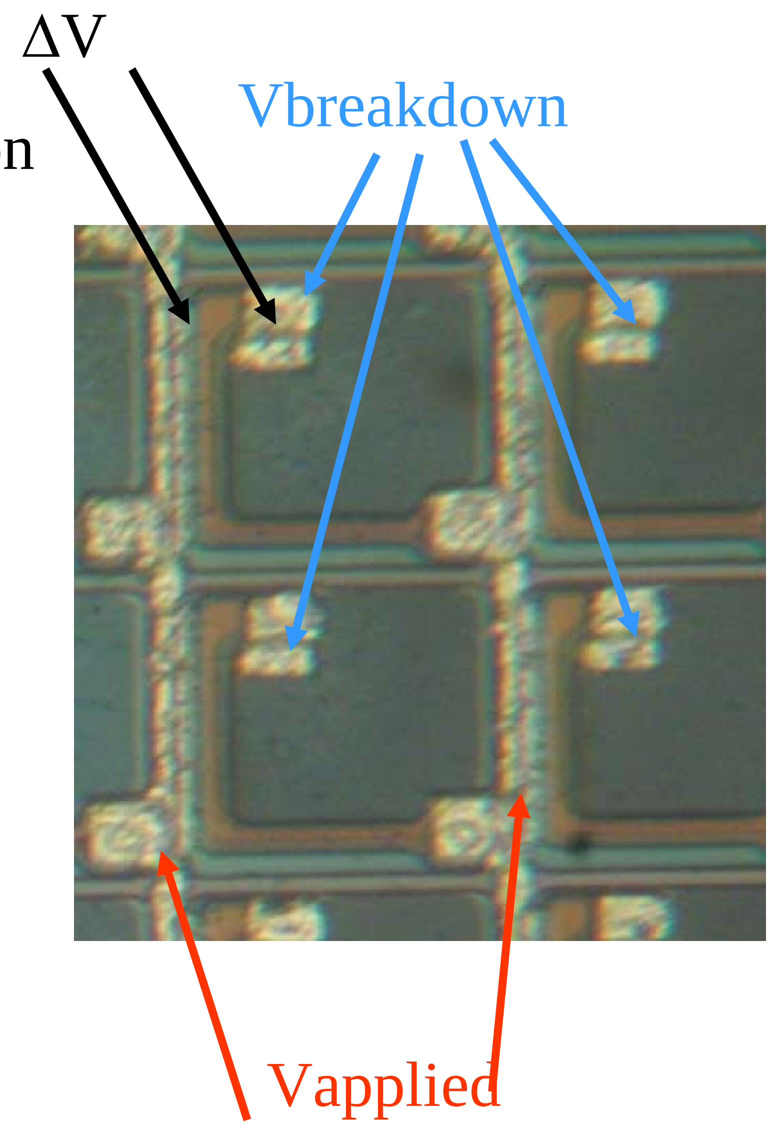
1. More than 2600 SiPMs have been tested.
   This is the first experience with the SiPM mass production
2. Main reason for SiPM rejection (~20%) is high noise
   (may be requirements are too tough – need more simulations)
3. Noise requirements can be relaxed by gluing SiPM to fiber
4. Long Discharges are caused by damage of polySi resistor
5. LD problem can be solved by burn in procedure and probably by SiO_2 protection layer
6. Tile+WLS fiber production is practically finished
7. 6 cassettes out of 40 have been assembled and will be tested at DESY e-beam (one has been tested already)
8. In spite of problems still hope to produce all cassettes for 2006 beam tests

Backup Slides

The study of LD origin



3 micron

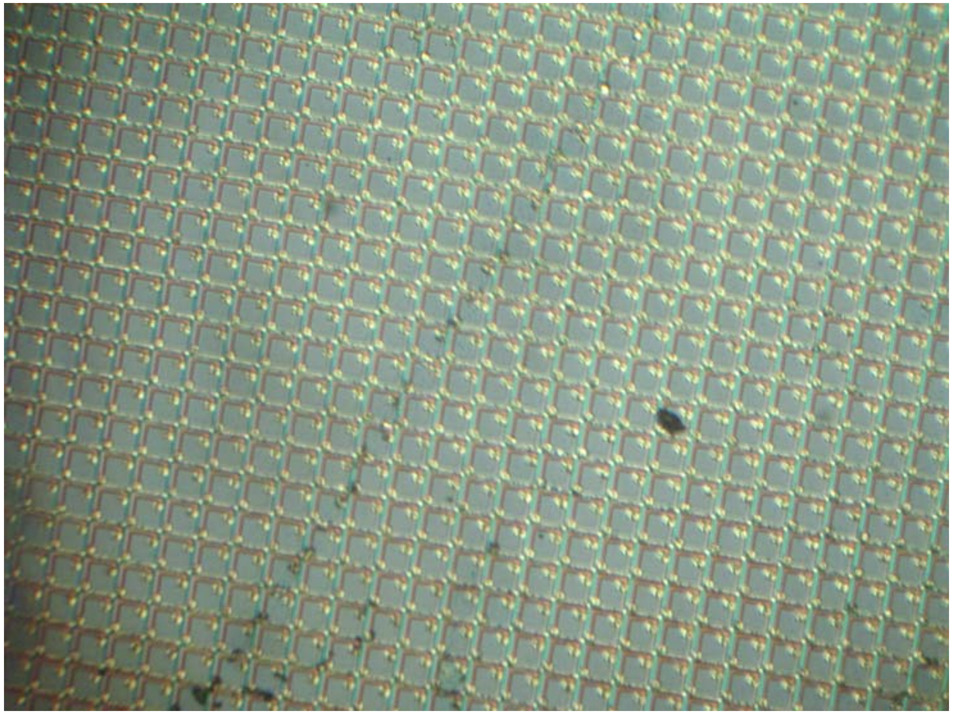


Random pulse length strongly increases with increasing of overvoltage

ΔV=Vapplied - Vbreakdown

Died SiPM (no signal and big current)

SiPM 2591



Big scratch

Collaborative effort