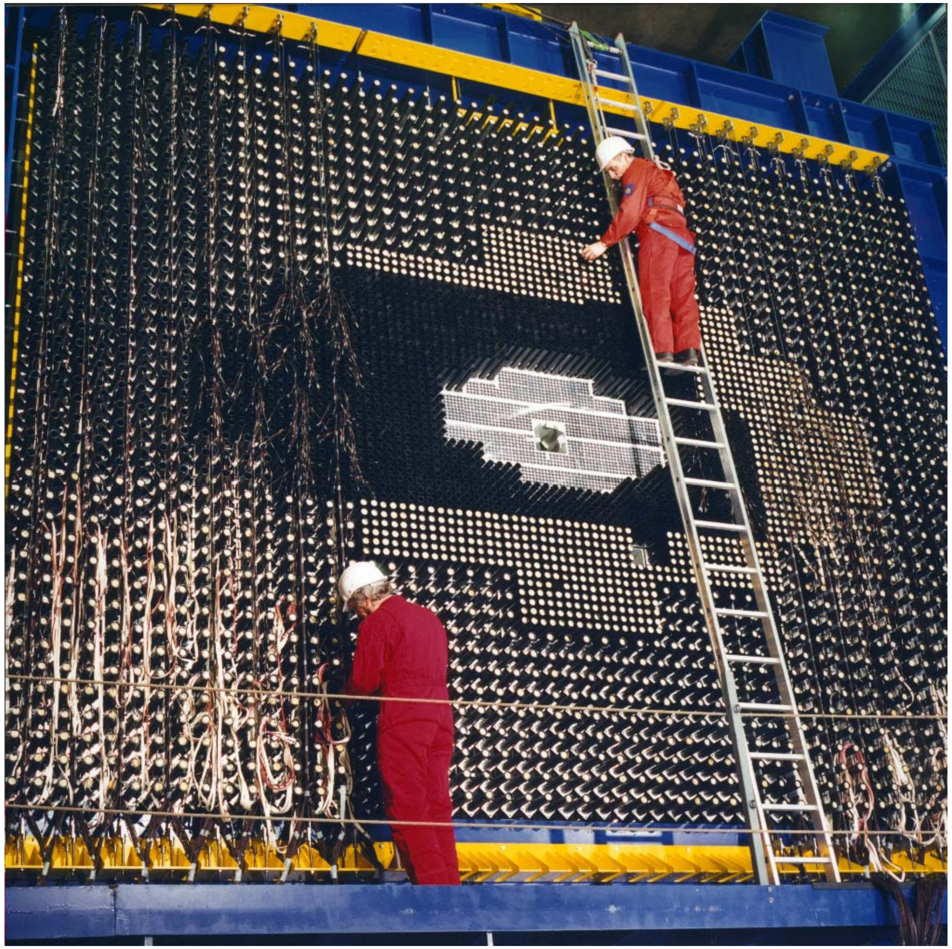
PSD08 GLASGOW
3.09.2008

Novel Photo-detectors and Photodetector systems

M.Danilov, ITEP, Moscow

Outline

1. From PMT to SiPM
2. SiPM properties
3. SiPM applications
4. New developments



HERA-B Electromagnetic Calorimeter
(ITEP)

PMT is the most popular photo-detector

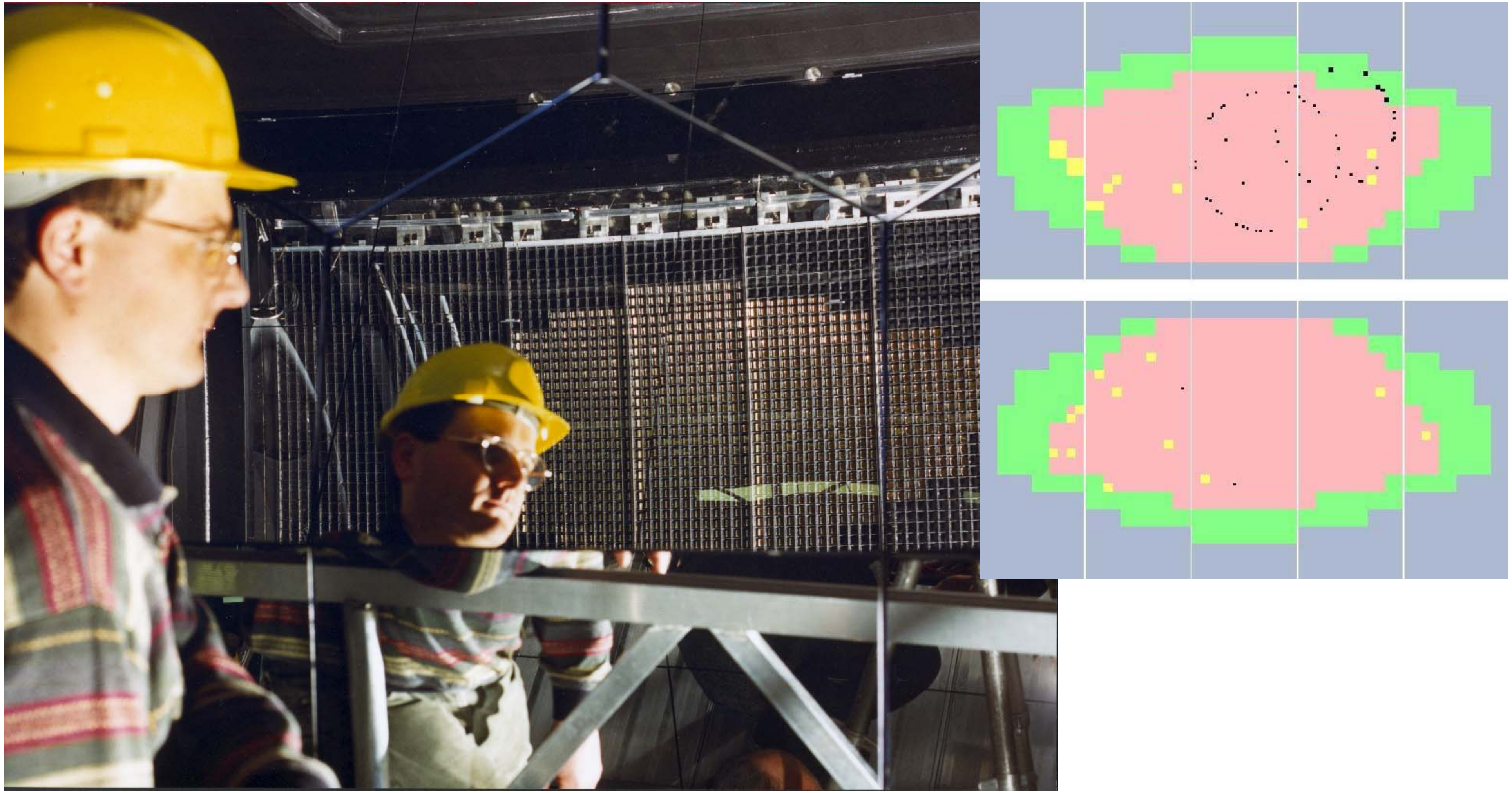
1. Very sensitive
2. High gain
3. Single photon resolution
4. Fast
5. Large sensitive areas
6. High counting rate
7. Reliable
8. Vast experience
9. …

However it has many drawbacks

1. Sensitive to magnetic field
2. Large size, low granularity
3. Need of High Voltage
4. Expensive
5. …

Some drawbacks can be (partially) cured

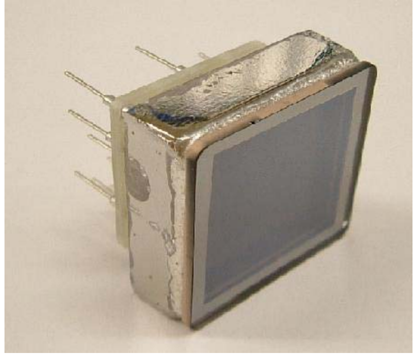
Granularity can be increased using MAPMT

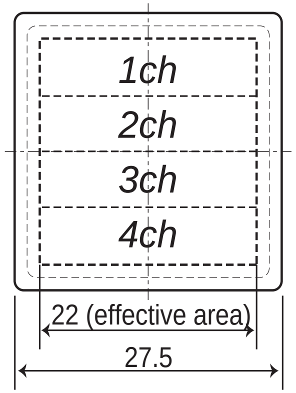


HERA-B RICH with 27 thousand channels (Hamamatsu R5900-00-M16)

PMT does not work in magnetic field
-> Partially solved in MCP PMT

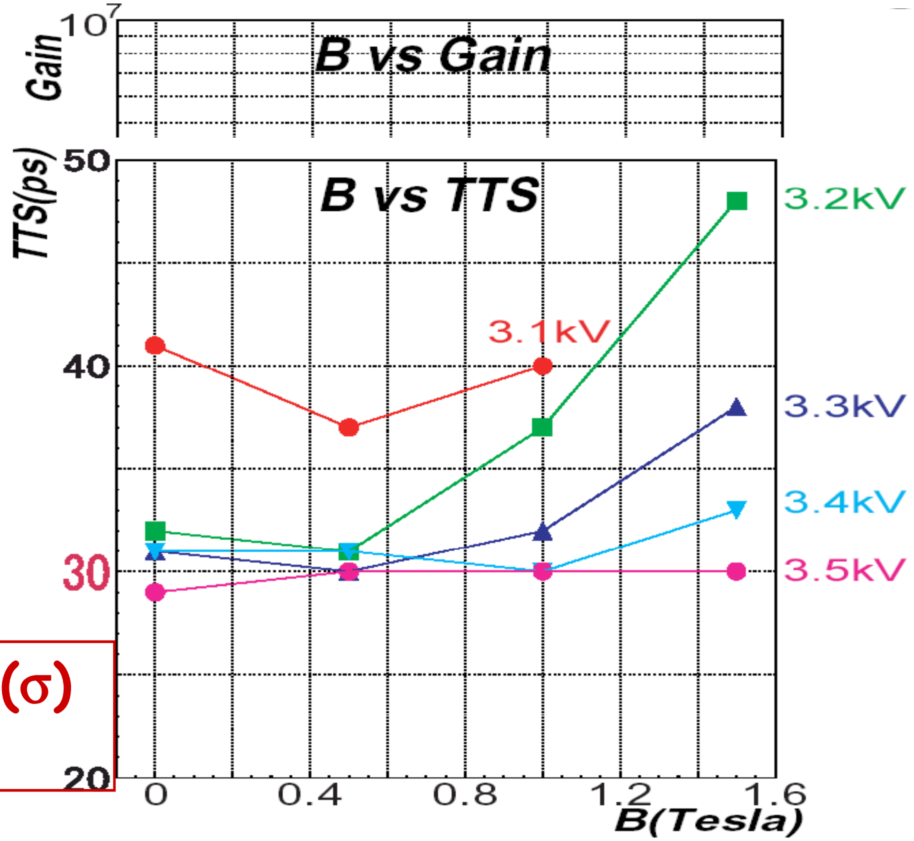
Example:
1x4 MCP-PMT (SL10)





- 1x4 linear-anode MCP-PMT for TOP readout.
- Developed under collab. with Hamamatsu Photonics.

#MCP stage	2
Gain (HV)	2×10^{6} (-3.5KV)
MCP hole dia.	10μm
Geometrical collection eff.	50%
#pixel /size	1x4 / 5mmx22mm
Effective area/ Total area	64%



Confirmed gain > 10^6 & TTS=30ps(σ) in B=1.5T magnetic field.

Solid state Photo-detectors offer many advantages

1. Not sensitive to magnetic field
2. High QE
3. Very high granularity
4. Compact
5. No High Voltage
6. Cheap
7. …

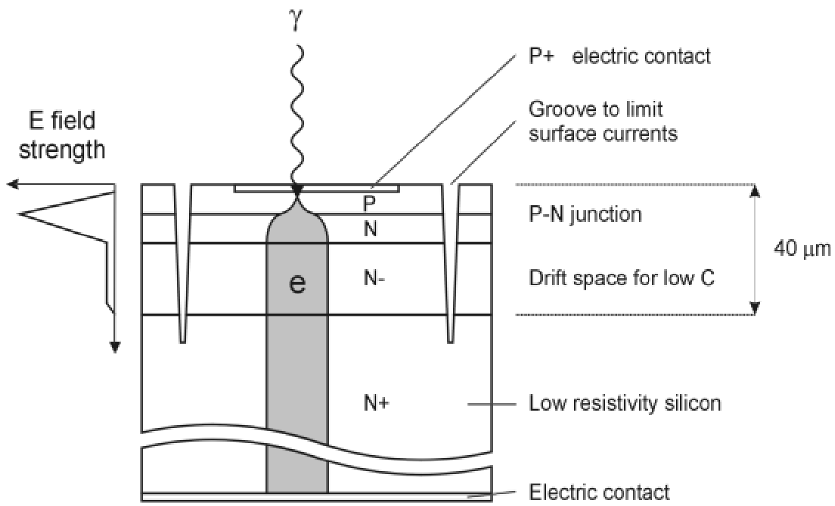
Simplest example – PIN Diode

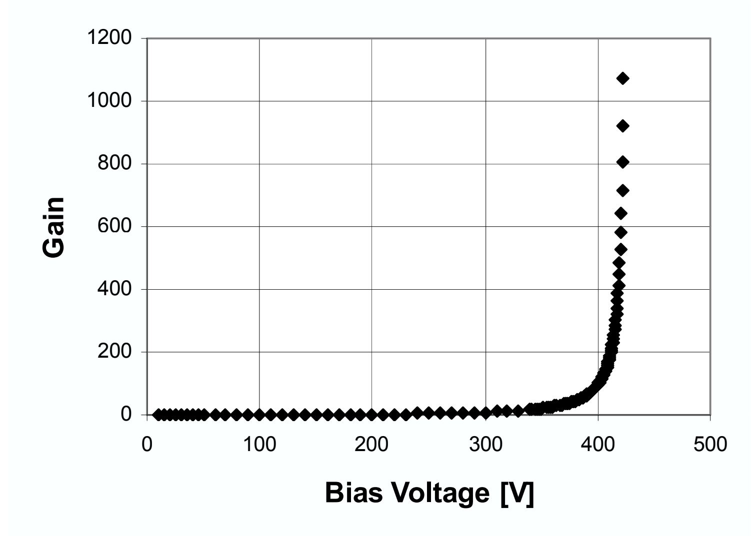
No amplification => Very stable
High (80%) QE optimal for CsI(Tl) => Wide use in CLEO, BaBaR, BELLE, Glast …

Thick (~300 micron) sensitive layer => large NCE (MIP deposits 30k e-hole pairs)
No amplification => Can not be used with low light yield scintillators

APD – Photo-diode with amplification

Electrons produced in the thin (deff ~ 6 μm) p-layer by photo-conversion or by ionising particles induce avalanche amplification at the p-n junction.
Electrons produced in bulk are not amplified => small NCE





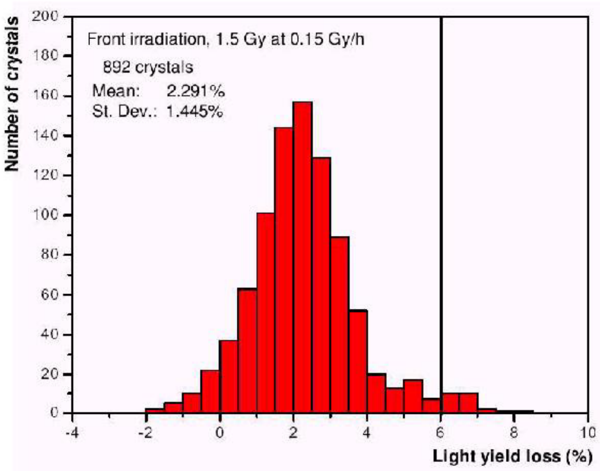
1/M dM/dV ~ M (~7% at M=200)
-1/M dM/dT ~ M (~ 5% at M=200)

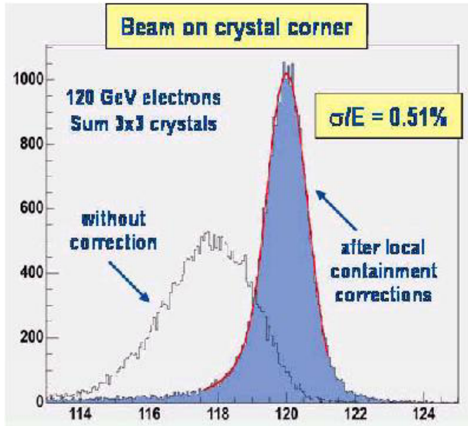
=> Hard to operate at higher amplifications

Fluctuations in avalanche development => large ENS~M (typical values > 2)

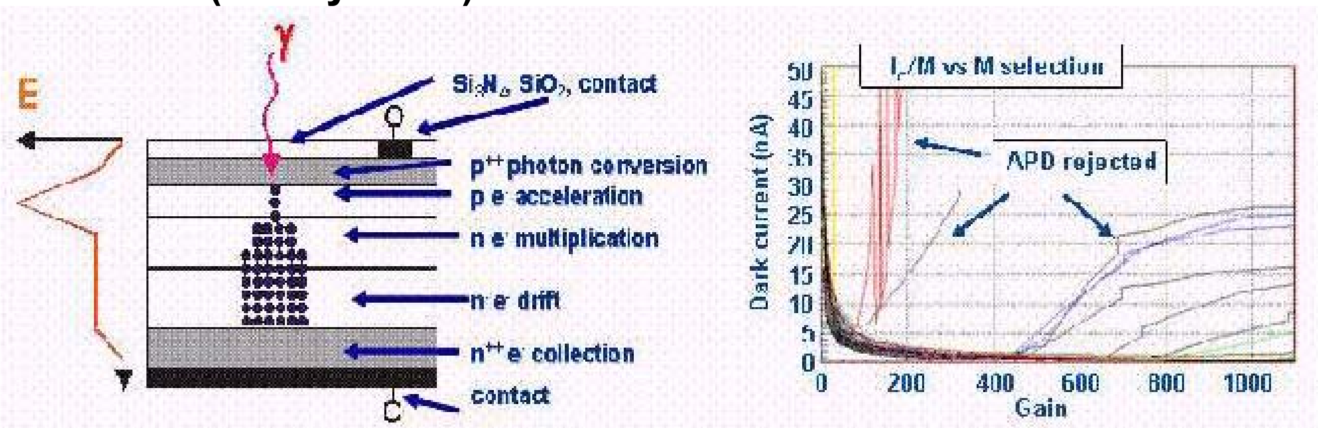
CMS Electromagnetic Calorimeter

Choice of Lead Tungstate is driven by small X_0 =0.89cm, R_M=2.19cm, τ~10ns and radiation hardness with Y/Nb doping and optimized growth
Crystals produced at Bogoroditsk(Russia)
In spite of small light yield of ~8p.e./MeV excellent energy resolution is obtained

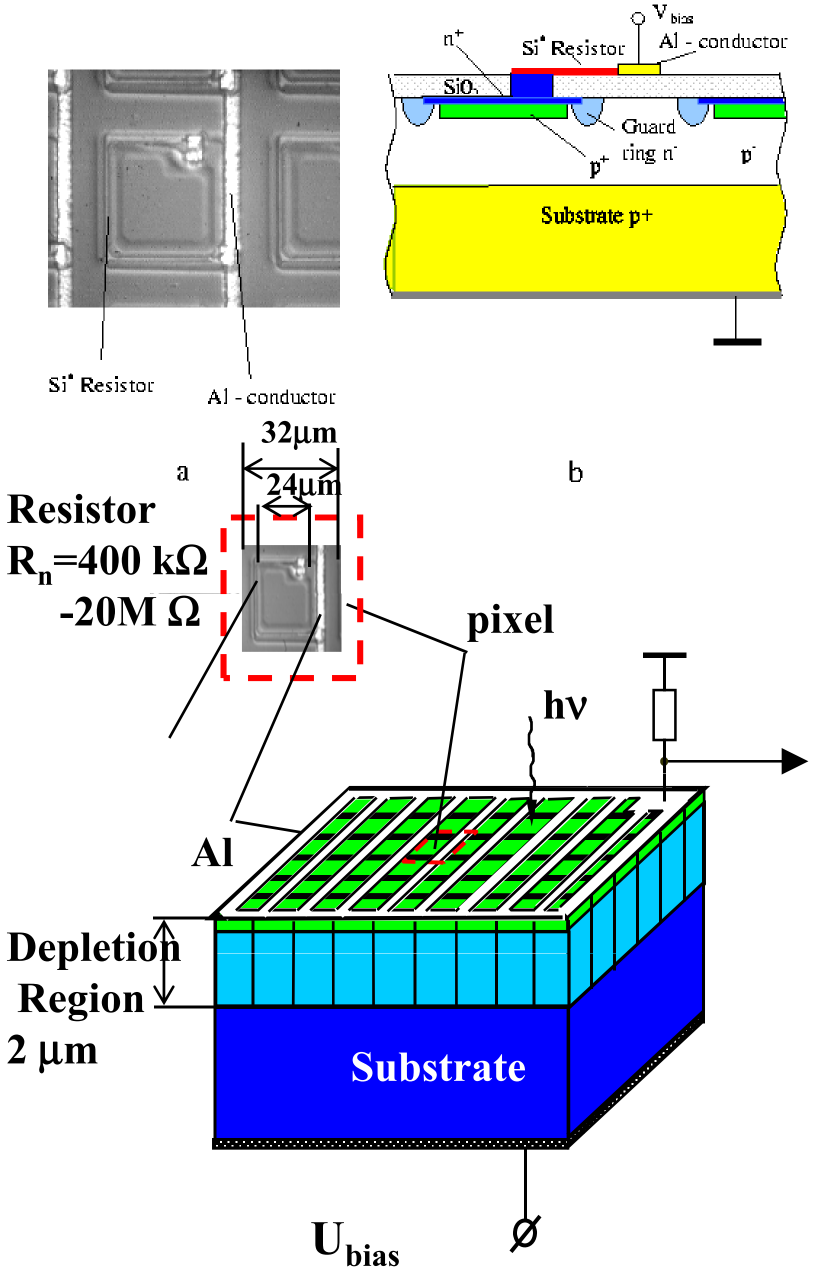




10 years of R&D with Hamamatsu resulted in excellent APD operated at gain 50
130.000 APD passed very strict tests with 500 kRad irradiation and accelerated ageing
Vacuum phototriodes with QE~20% (RIA, St.Petersburg) are used in end caps
They are radiation hard (20kGy tests)



SiPM main characteristics (MEPhI-Pulsar example)



- 1156 pixels of $32 \times 32 \mu m^2$ (actvive area 24x24)
- 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}~50fF ➔
  Q_{pixel}~150fC=10^6e

- Noise at 0.5 p.e. ~ 2MHz

- Optical inter-pixel cross -talk:
-due to photons from Geiger discharge initiated by one electron and collected on adjacent pixels
-Xtalk grows with ΔV. Typical value ~20%.

-PDE ~15% for Y11 WLS fiber spectrum

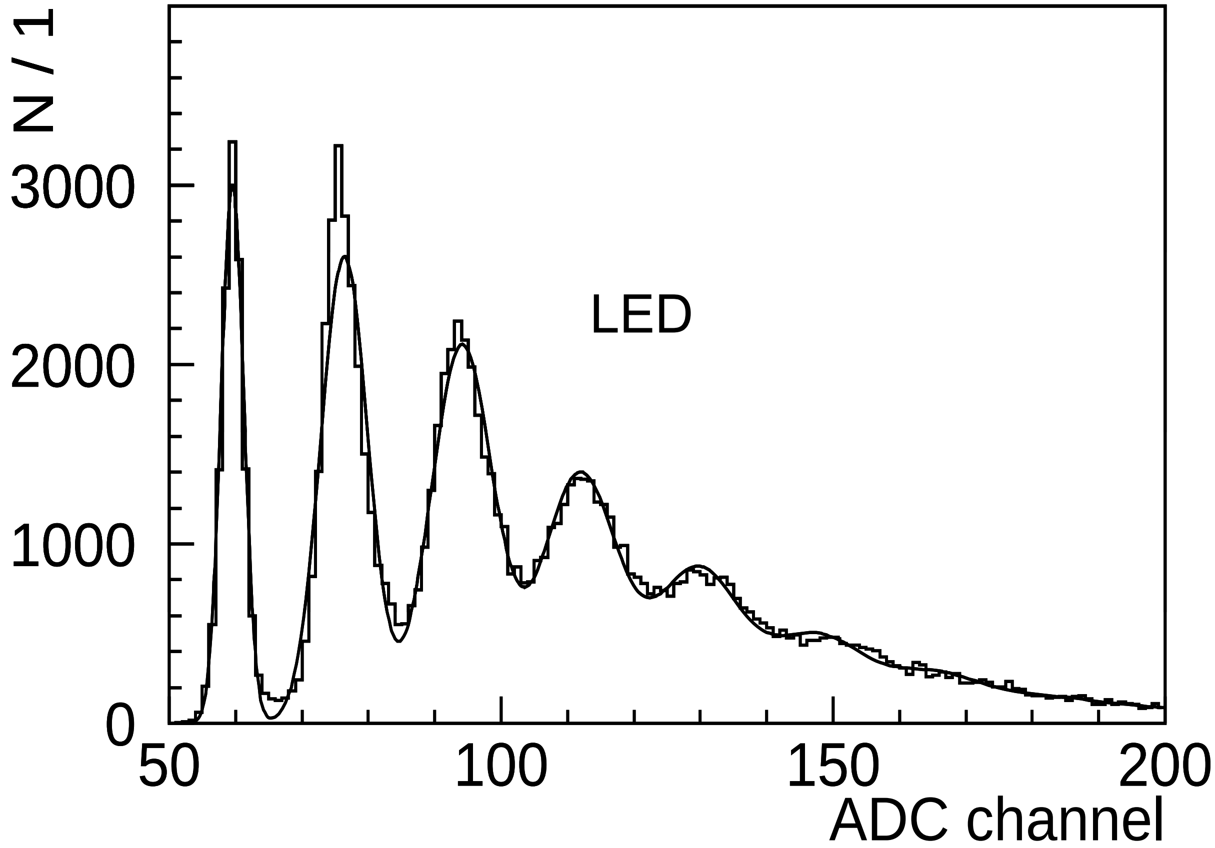
Insensitive to magnetic field (tested up to 4Tesla)

Very short Geiger discharge development <100 ps

Pixel recovery time ~ $(C_{pixel} R_{pixel})$ ~ 20 ns (for small R)

Dynamic range ~ number of pixels (1156)➔ saturation

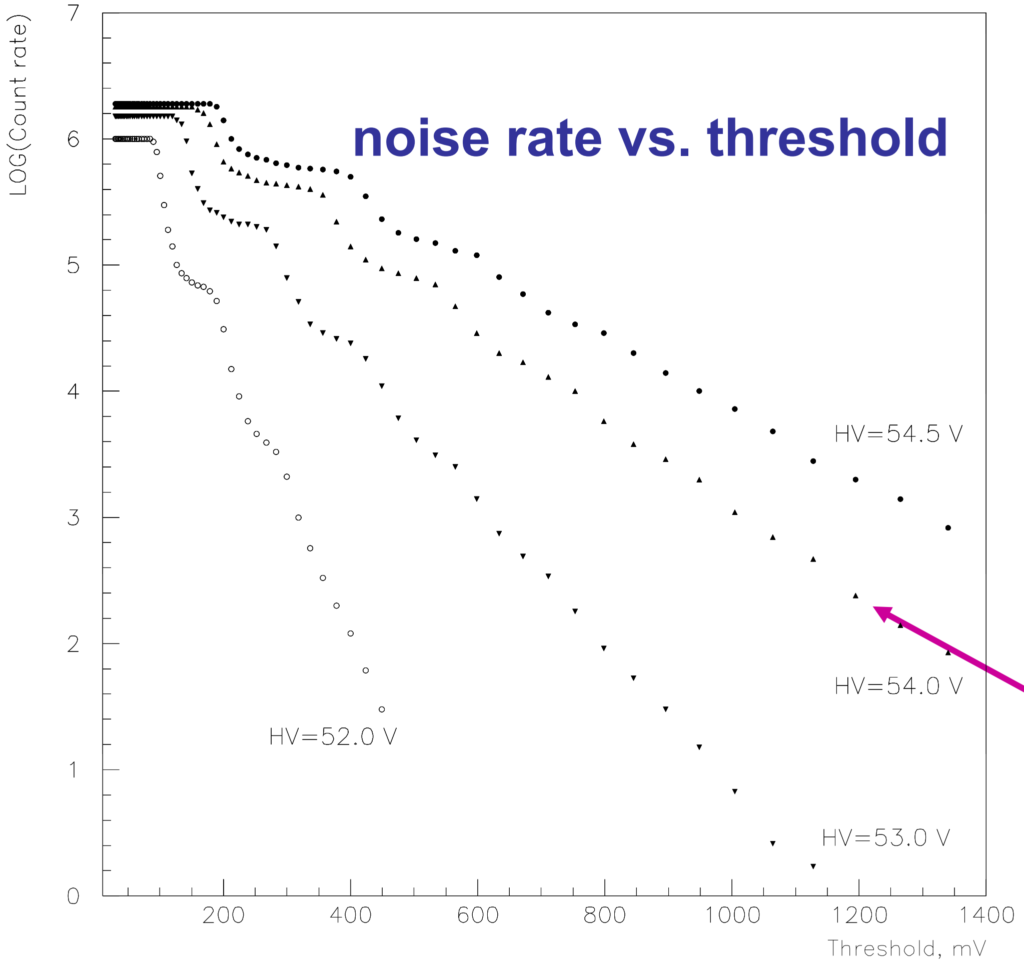
SiPM has excellent single photo-electron resolution (uniform response from all pixels)

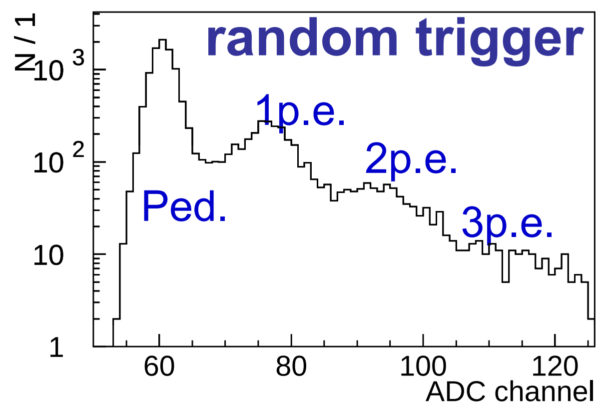


Fit of LED signal

$\sum$ Poiss$\oplus$Xtalk$\cdot G(x_0+i\cdot\Delta x, \sigma_0+\sigma_1\cdot\sqrt{i})$

SiPM Noise

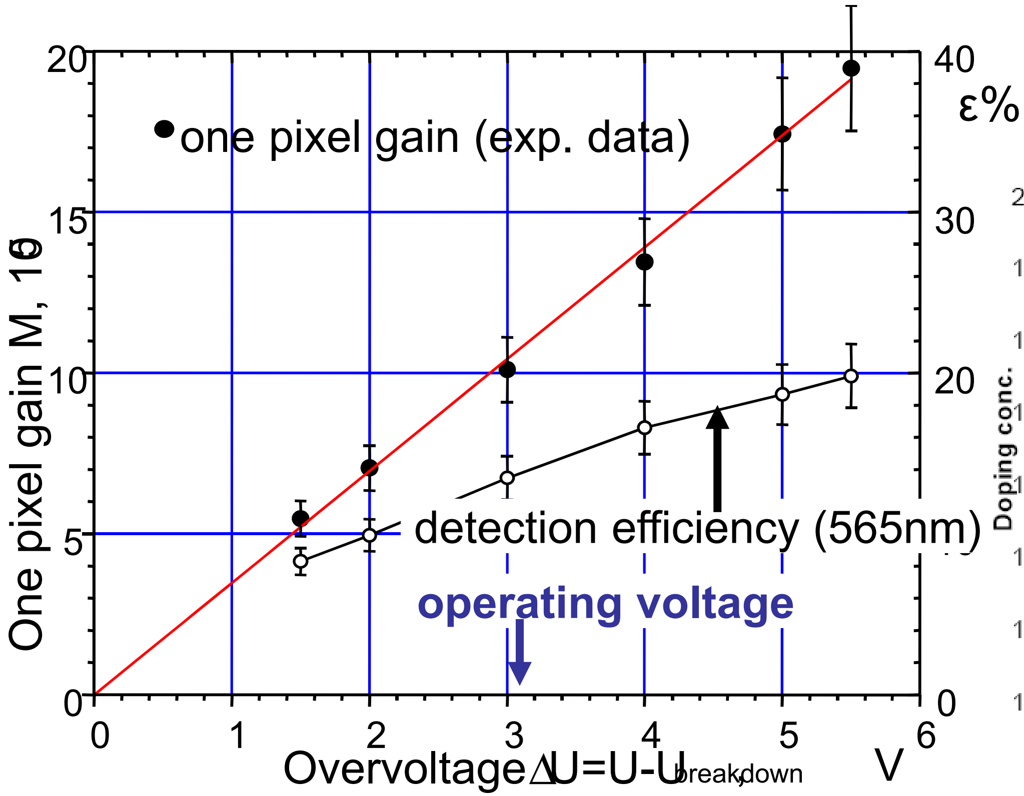


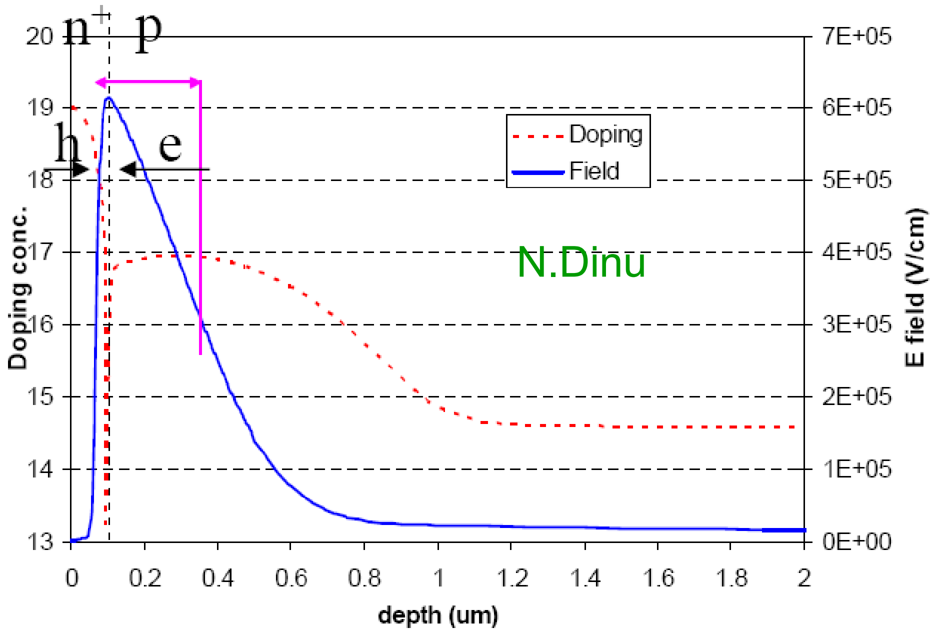


1p.e. noise rate ~2MHz.
threshold 3.5p.e. ~10kHz
threshold 6p.e. ~1kHz

Optimal operating voltage for this SiPM ~54V

Other SiPMs have similar properties
Hamamatsu MPPCs have considerably smaller noise





Photon detection efficiency (PDE)=

QE (~80%) * Geiger efficiency (~60%) *Geometrical efficiency (~35%)

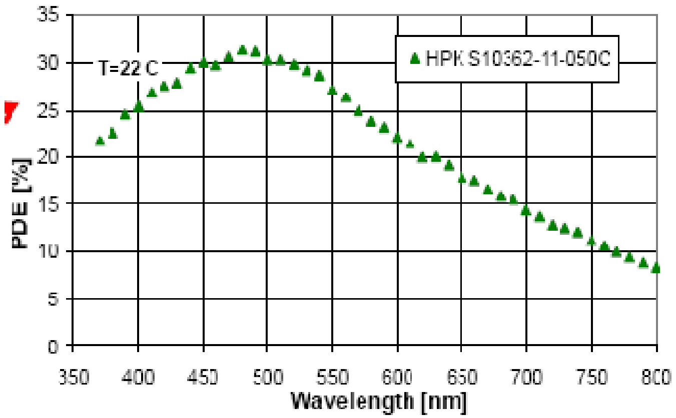
- highest efficiency for green light ➔ matches well with WLS fibers

- **X-talk increases with gain → optimal gain about 10^6**

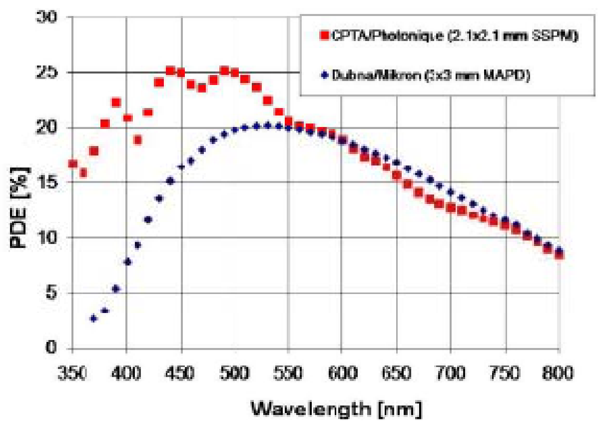
Temperature and voltage dependence

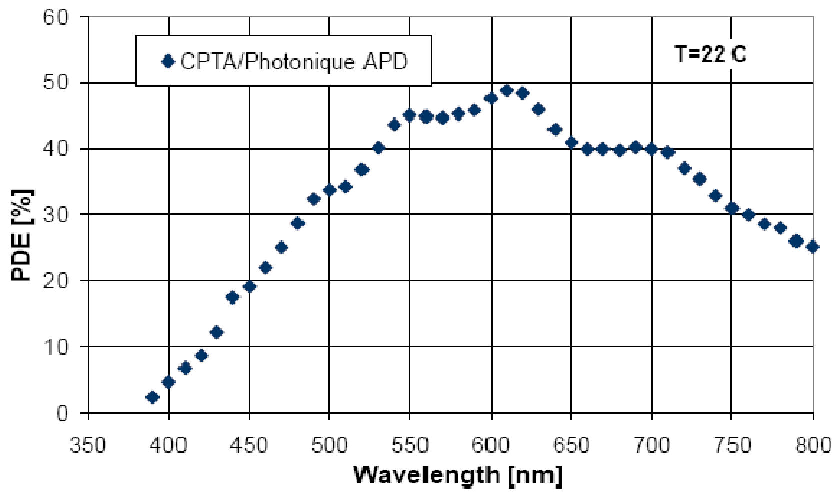
-1 °C ➔ +4.5% in Gain*PDE*Xtalk +0.1 V ➔ +6% in Gain*PDE*Xtalk

Typical SiPM PDE



(Y. Musienko, PD-07, Kobe)

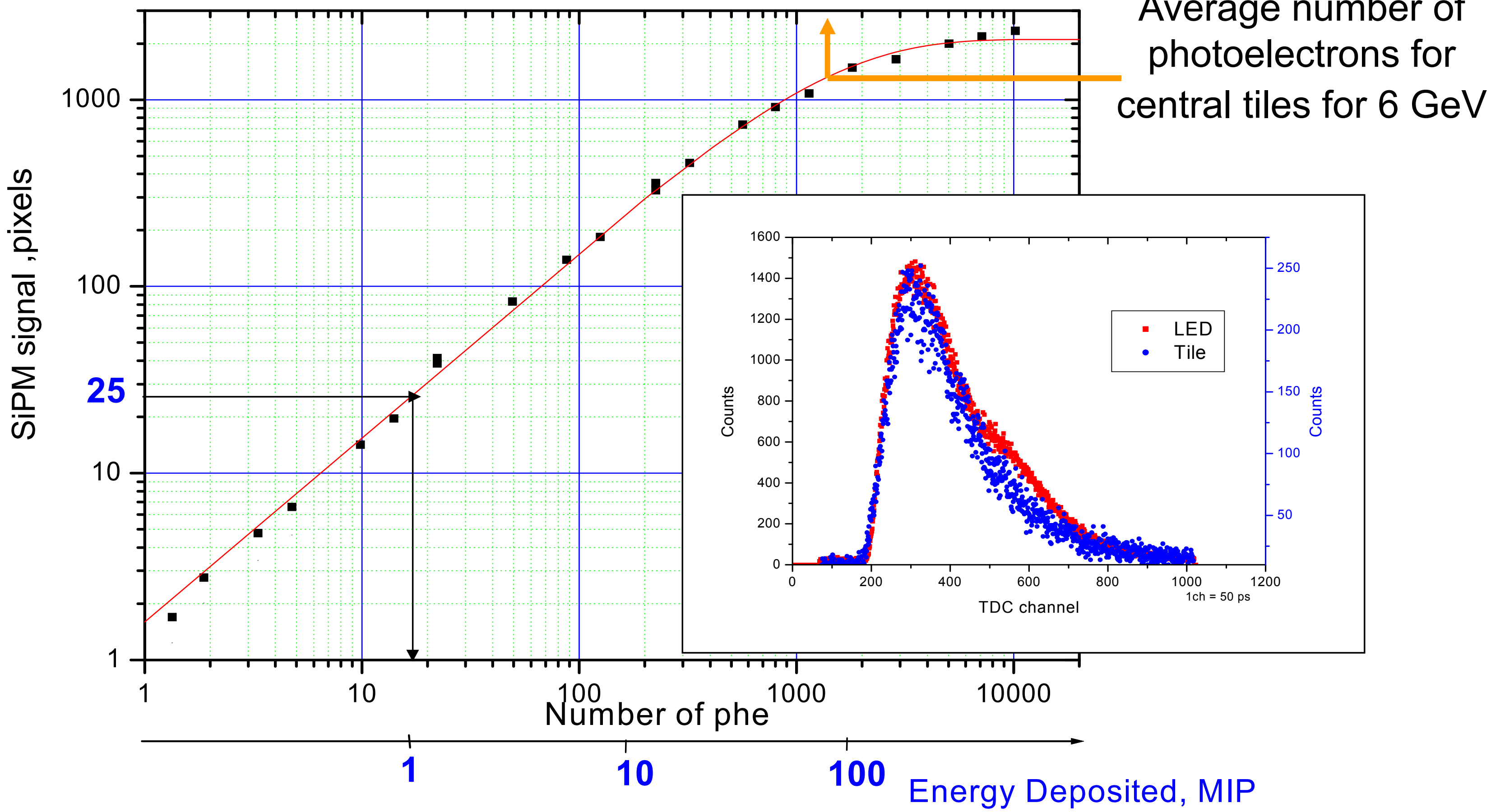




(Y. Musienko, PD-07, Kobe)

SiPM signal saturation due to finite number of SiPM pixels

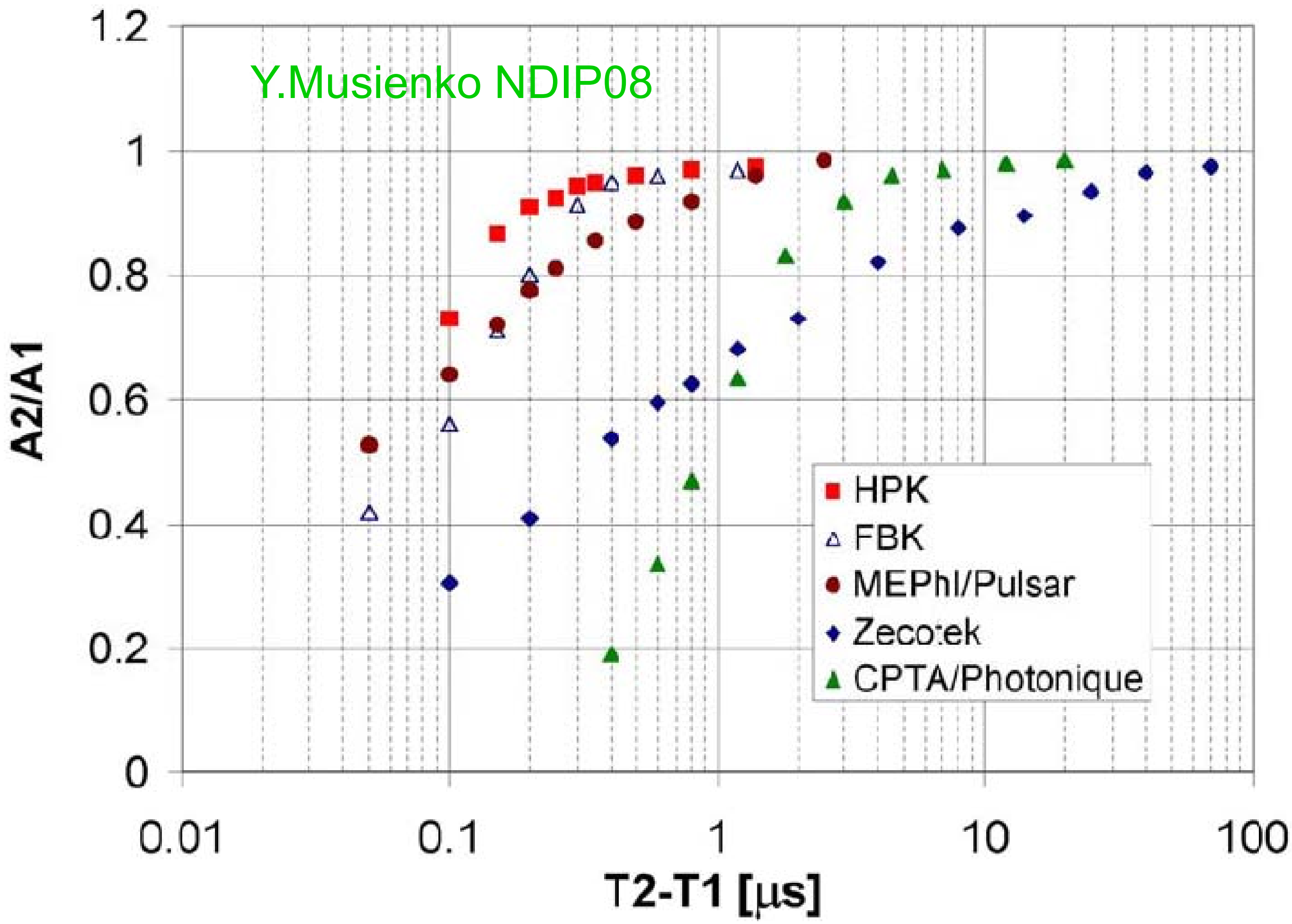
calibration curve: SiPM signal vs energy deposited:



Very fast pixel recovery time ~ 20ns

For large signals each pixel fires about 2 times during pulse from tile

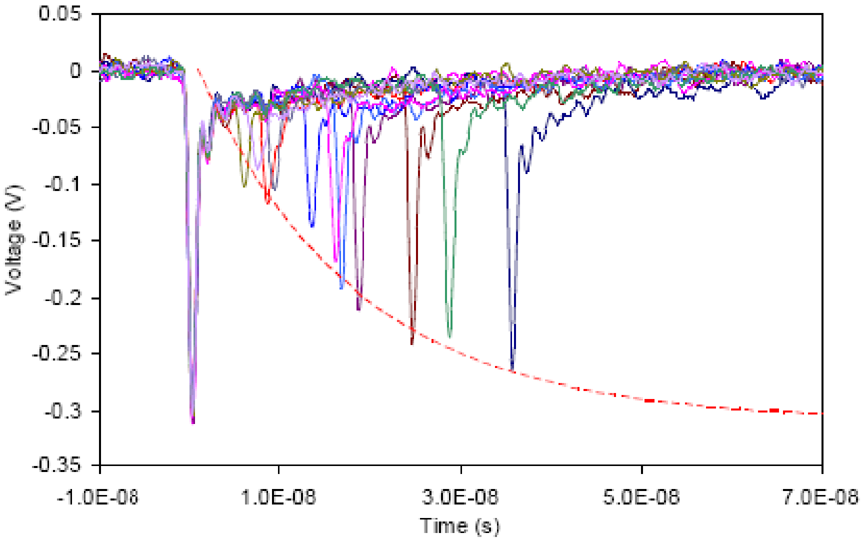
SiPM pixel recovery time depends on RC and can be quite fast

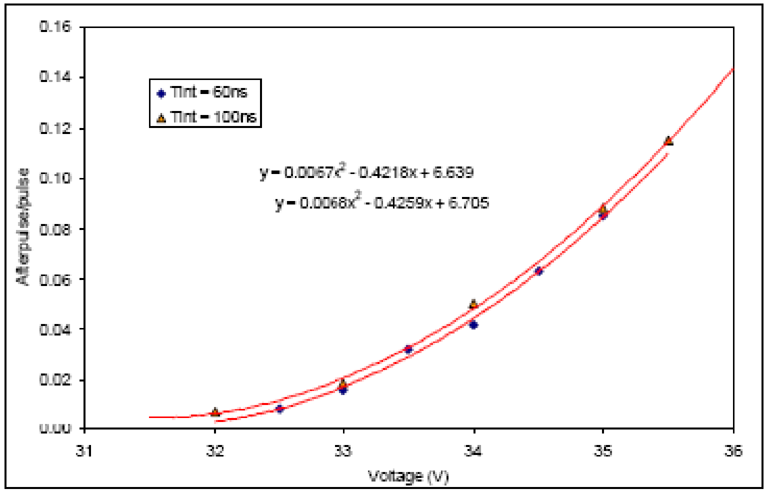


Since usually only small fraction of pixels is fired
SiPM dead time is much smaller than pixel recovery time

After-pulses are caused by trapped charge carriers

C. Piemonte: June 13th, 2007, Perugia





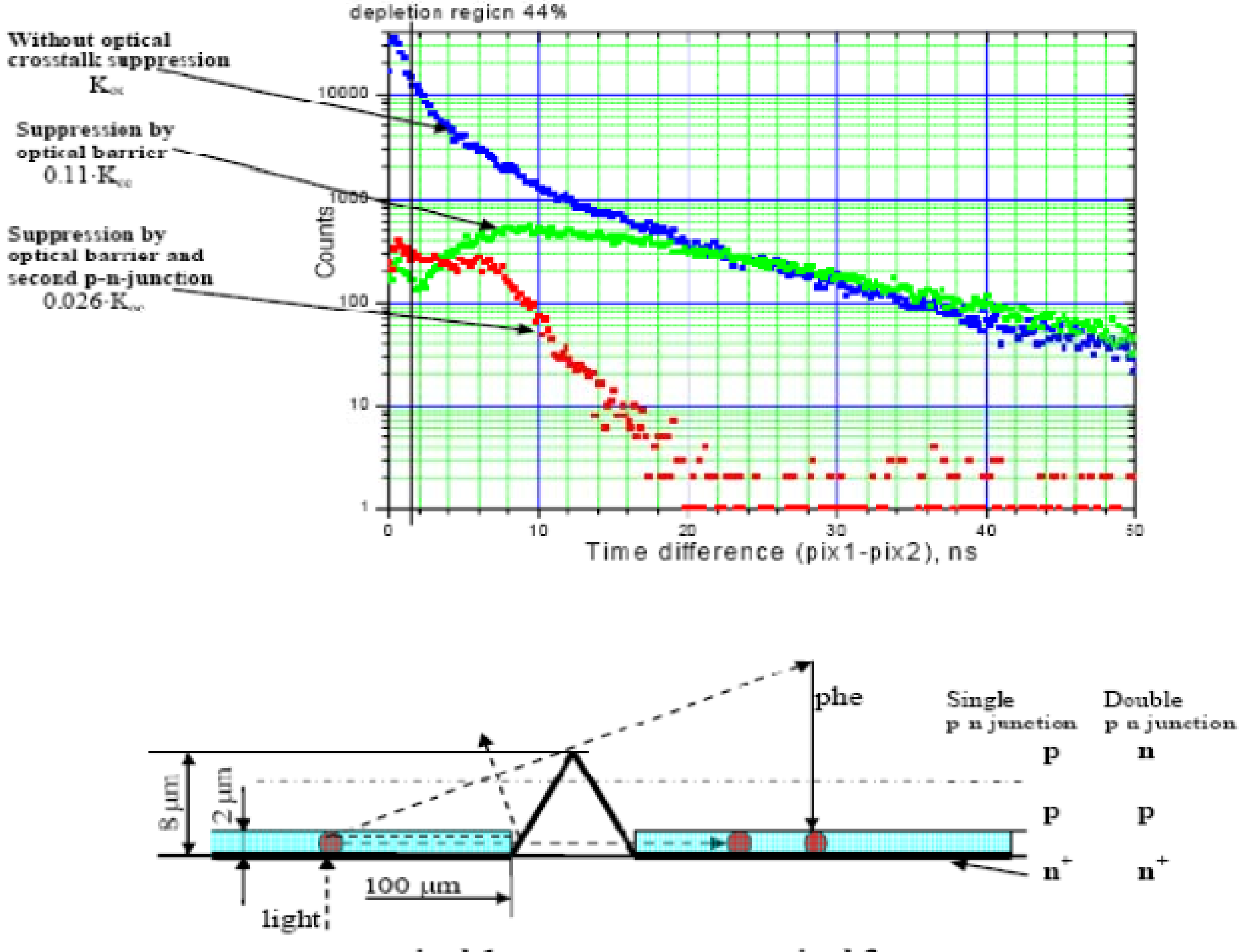
Events with after-pulse measured on a single micropixel.

After-pulse probability *vs* bias

Increase of after-pulse amplitude with time is due to pixel voltage recovery

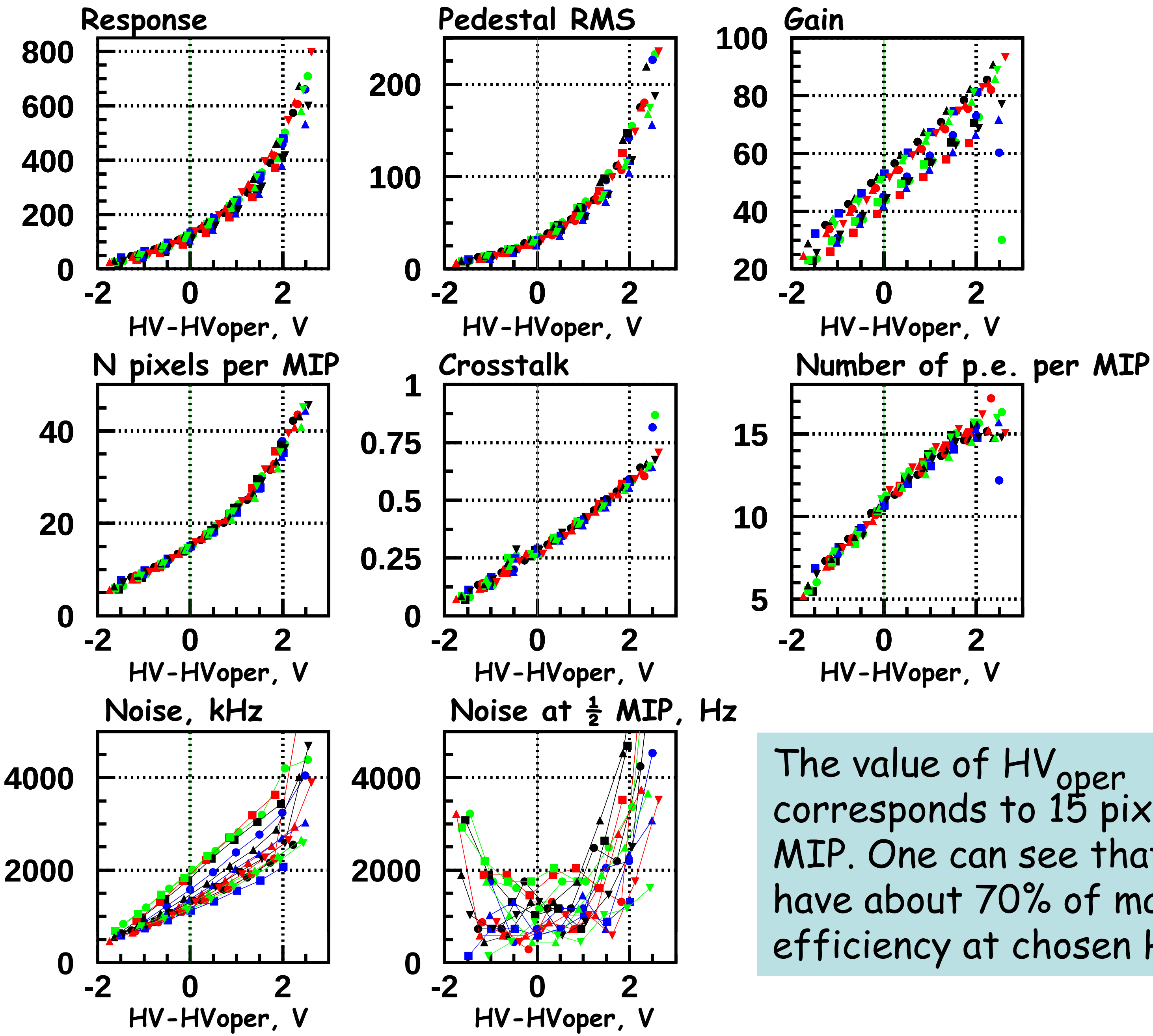
Main fraction of after-pulses appear soon after the initial signal (time constant ~20ns) however there is also after-pulse component with about 100ns time constant

Optical Crosstalk studies



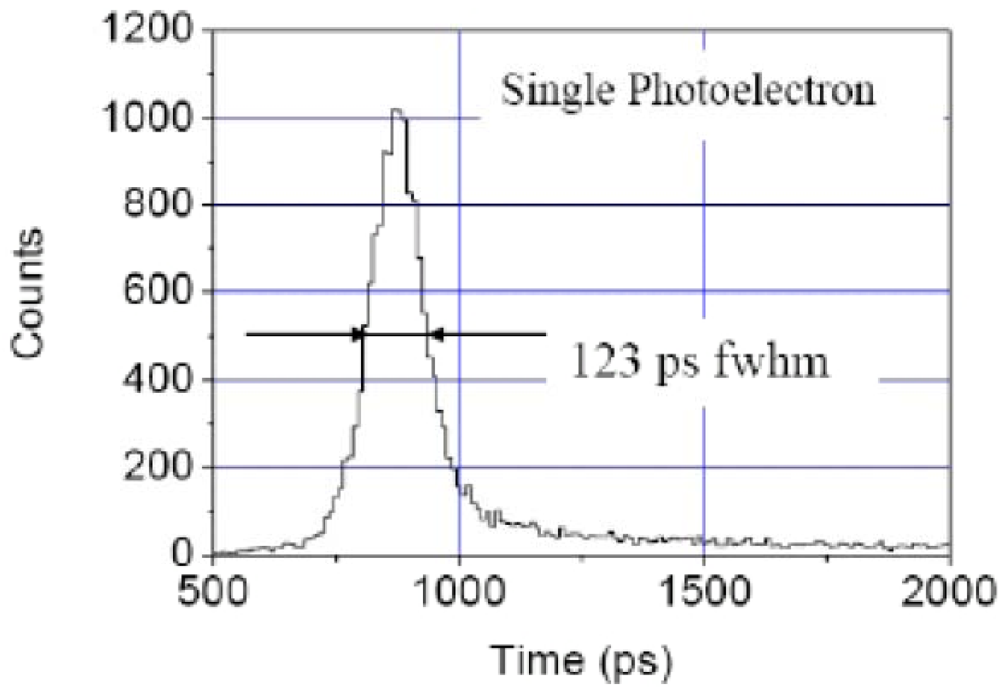
Optical crosstalk between two separate pixels

MEPhi-Pulsar SiPM parameter dependence on over-voltage



The value of HV_{oper} corresponds to 15 pixels per MIP. One can see that we have about 70% of maximal efficiency at chosen HV_{oper}.

SiPMs have excellent timing properties

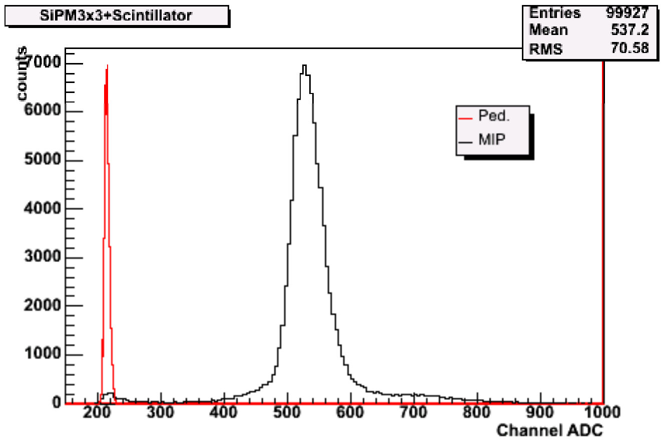


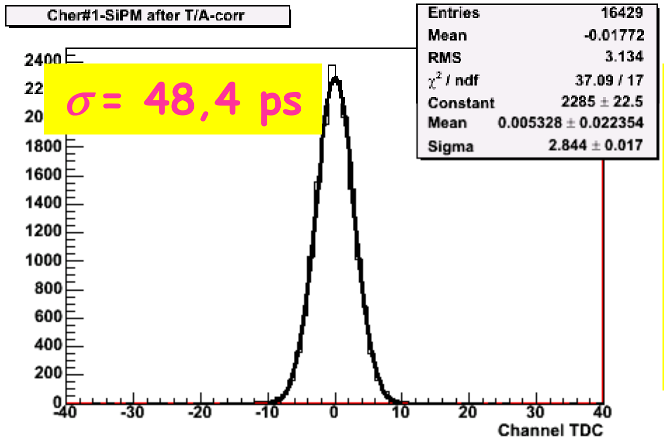
B.Dolgoshein Beaune-02

TOF with SiPM (MEPHI)

SiPM 3x3 mm^2 attached directly to BICRON - 418 scintillator 3x3x40 mm^3

Signal is readout directly from SiPM w/o preamp and shaper !

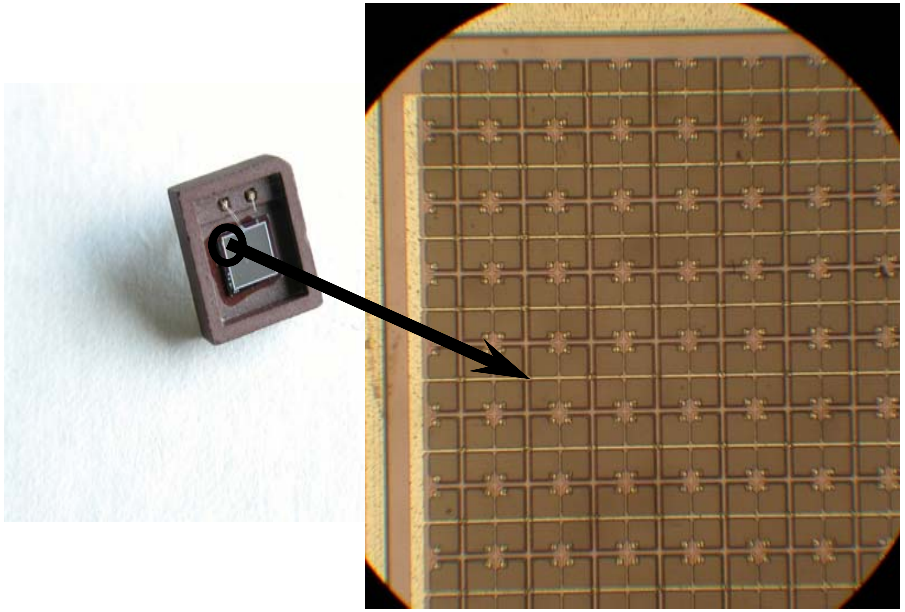




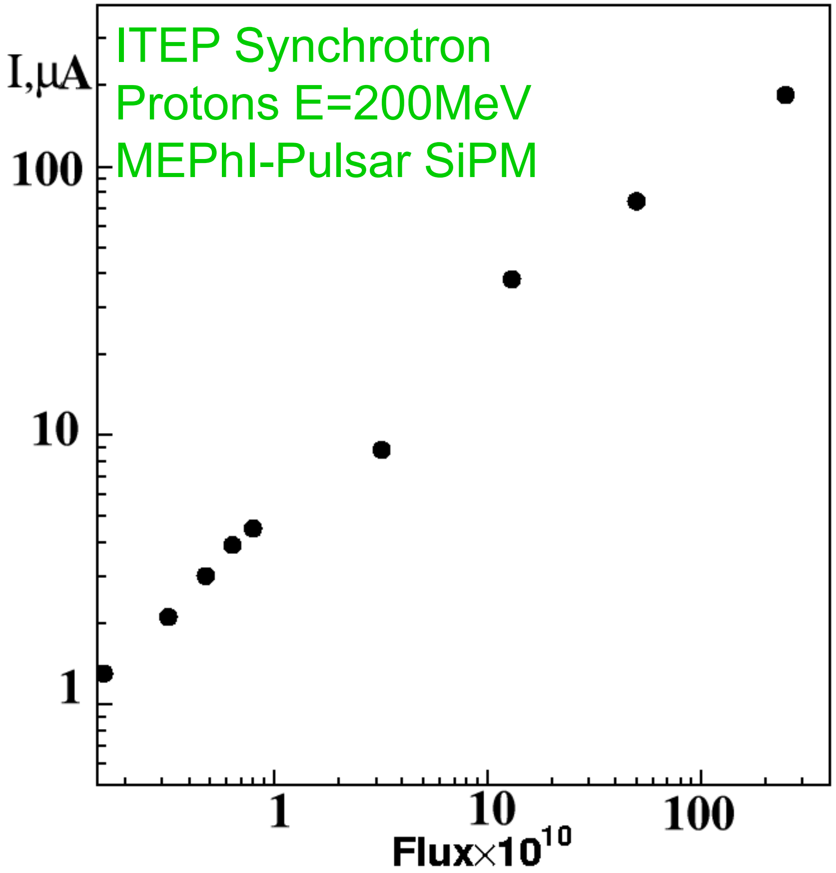
A ~ 2700 pix
Threshold~100pix
σ = 48,4 ps
σ_{elect} = 33 ps
(not subtracted)

SiPM Parameters

- Sensitive area : 3x3 mm2 # of pixels: 5625
- Depletion region: appr. 1 μm
- Pixel size: 30 μmx30 μm
- 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
  After pulsing probability: appr. 1%
- Optical crosstalk: appr. 30 - 50 %
  ENF: appr. 1.5-2.0(overvoltage dependent)



Radiation damage measurements



Dark current increases linearly with flux Φ as in other Si devices:

$\Delta I = \alpha \Phi V_{eff} P_G Gain$, $\alpha = 6\times10^{-17}$A /cm

(Radiation damage by 200MeV protons is similar to 1 MeV neutrons)

Veff ~ 0.004mm^3 determined from observed ΔI

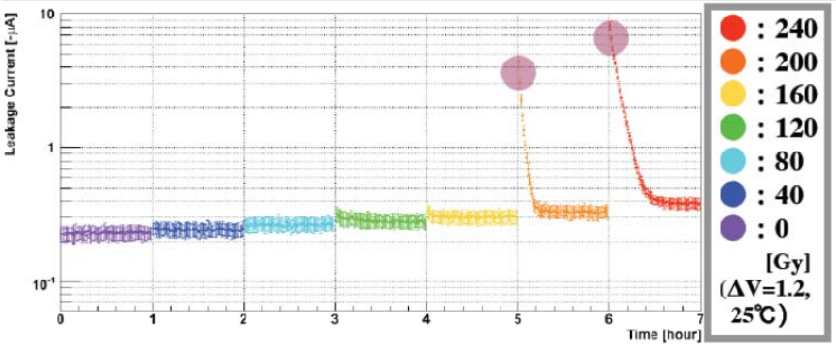
Since initial SiPM resolution of ~0.1 p.e. is much better than in other Si detectors it suffers sooner:
After $\Phi \sim 10^{10}$ individual p.e. signals are smeared out

However MIP signal are seen even after $\Phi \sim 10^{11}$/cm^2

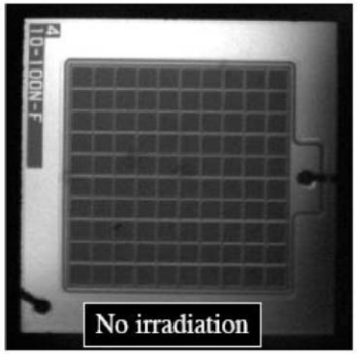
Other SiPM types show similar behavior

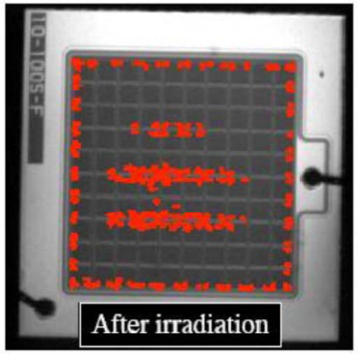
Radiation damage by photons and electrons is much smaller

Leakage current after each irradiation

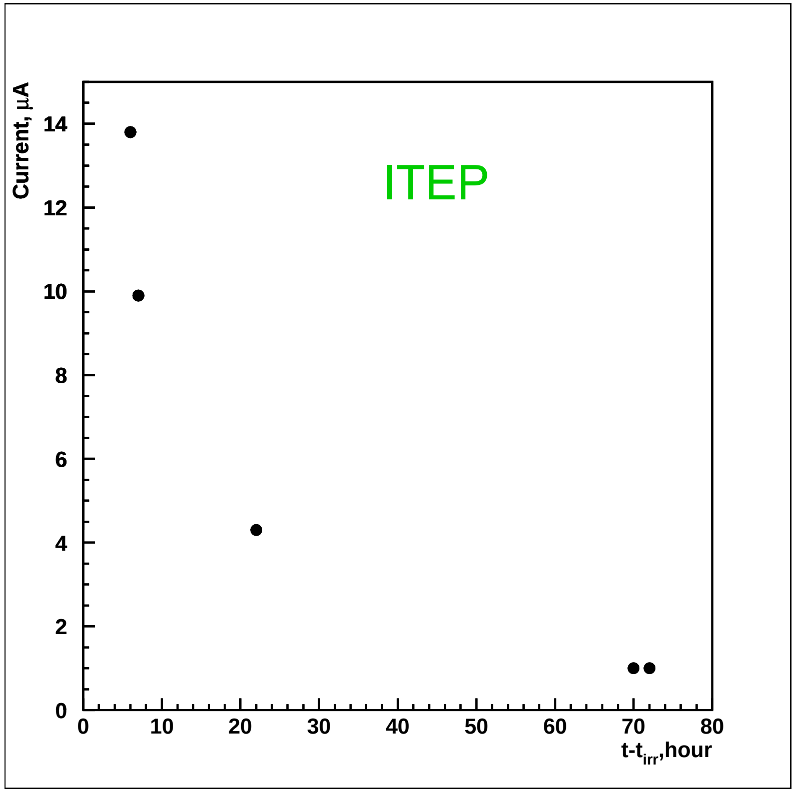


Matsubara PD-07



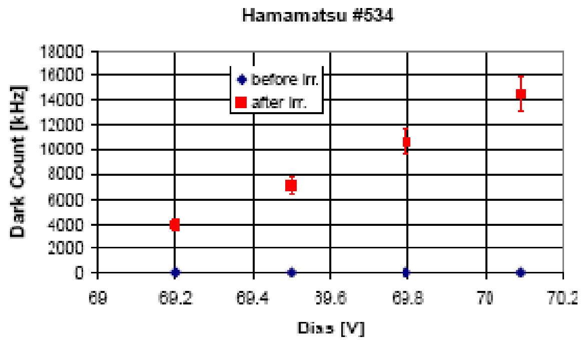


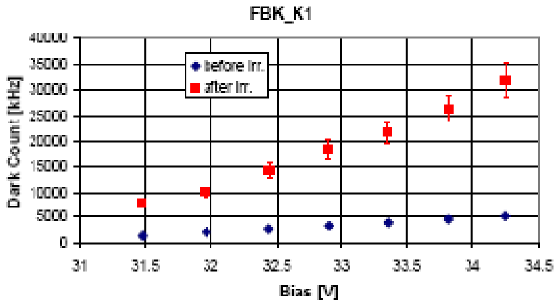
1600 pix MPPC after 200kRad Co60 irradiation

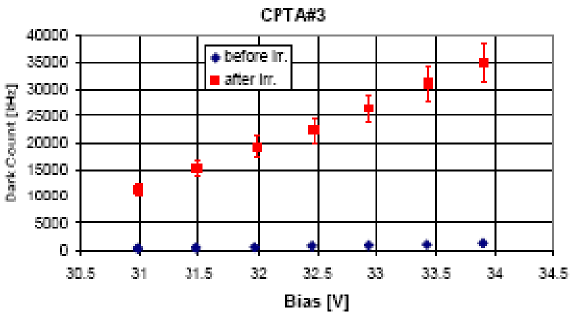


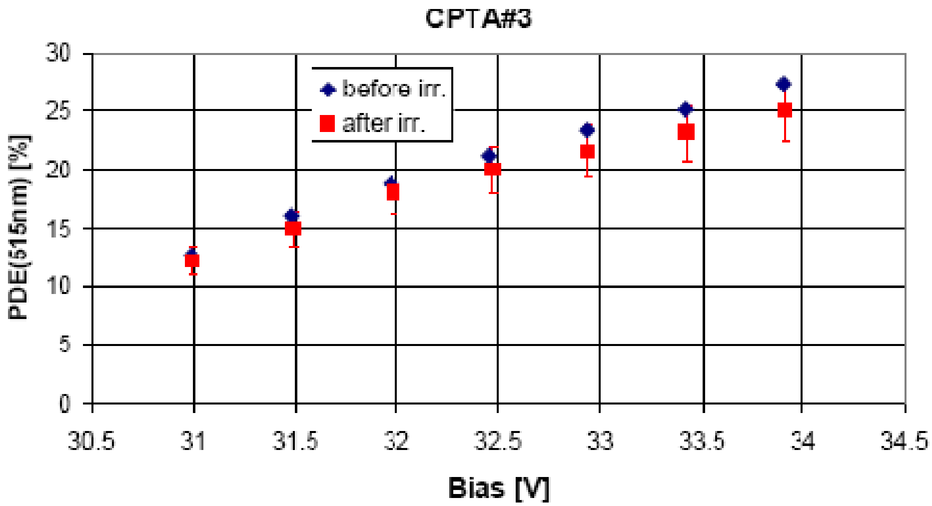
No change in PDE, VB, Rcell, after 10^{10} 82MeV protons/cm^2

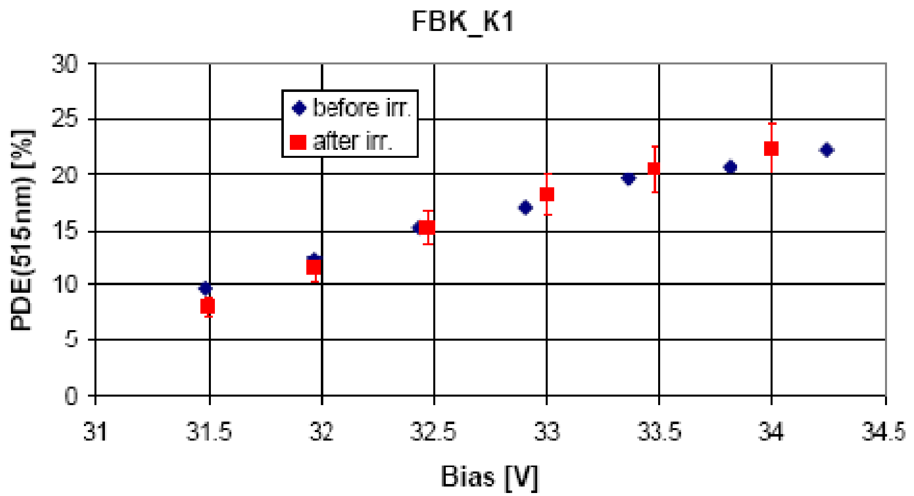
(Y.Musienko NDIP08)











(Y.Musienko NDIP08)

SiPM Applications

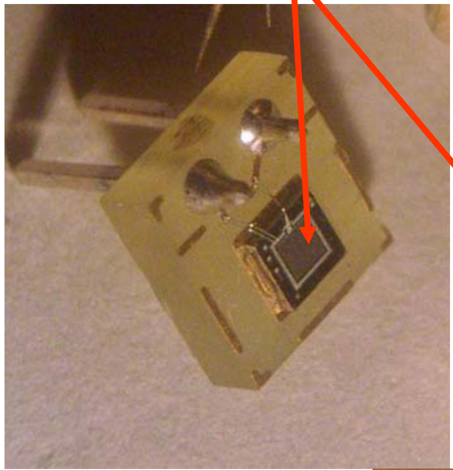
Scintillator tile analog or semi-digital HCAL (CALICE Collab.)

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

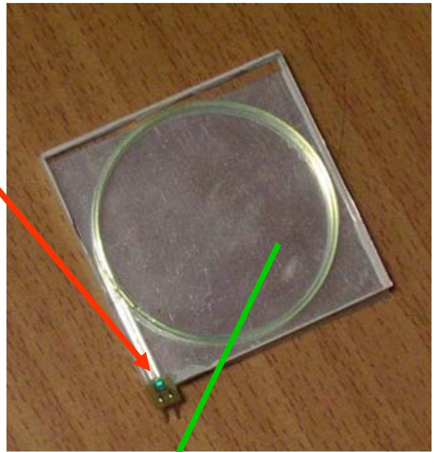
(the first "mass" application of SiPMs)

Moscow → Hamburg

MEPhI SiPM

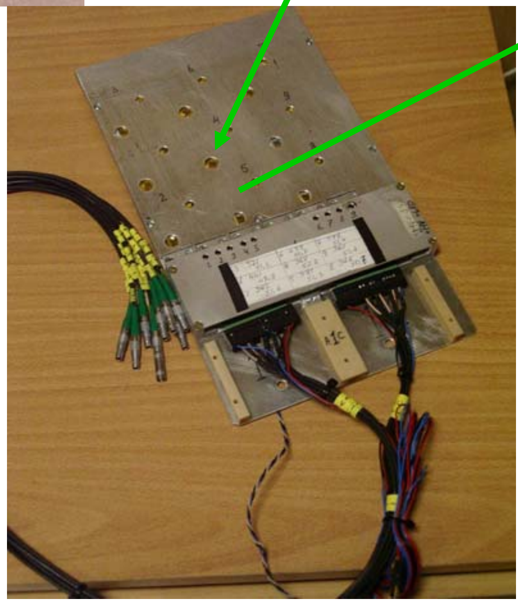


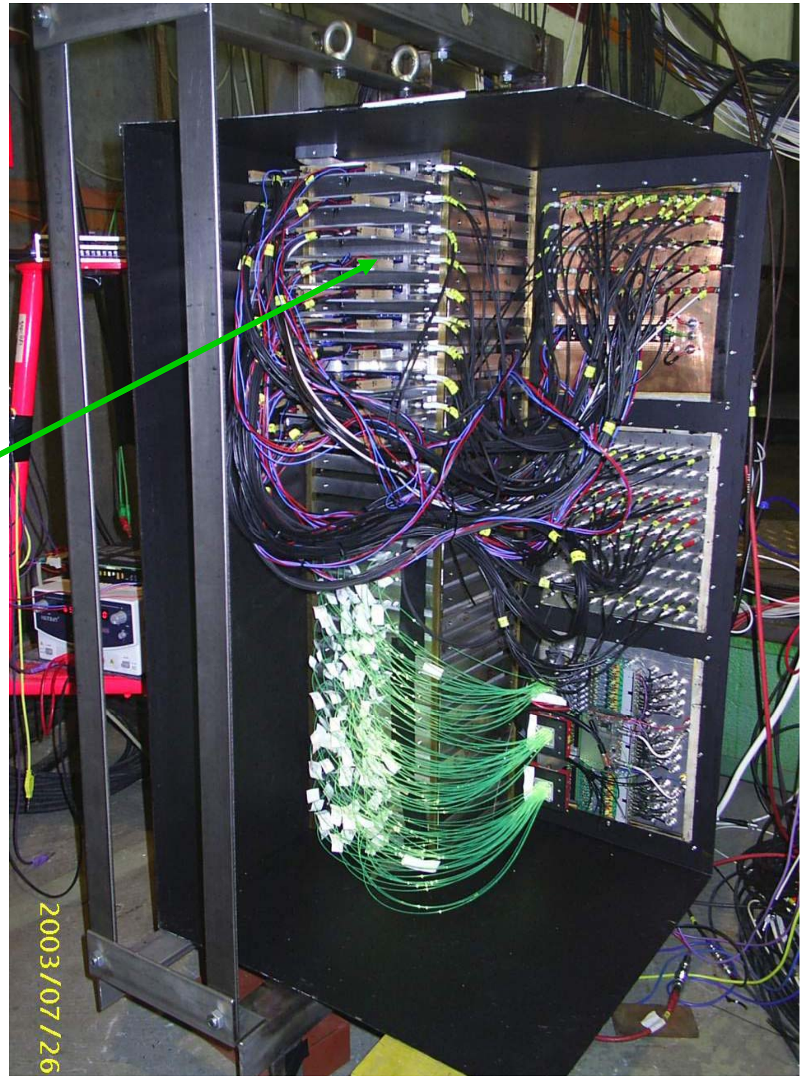
Tile 5x5x0.5cm^3



Cassette

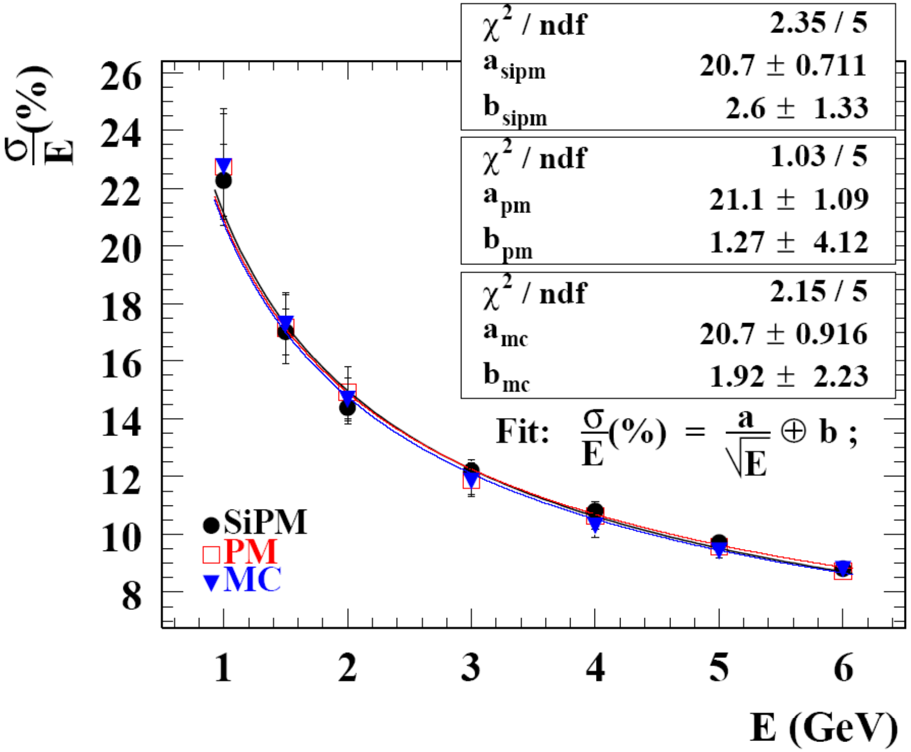
3x3 tiles

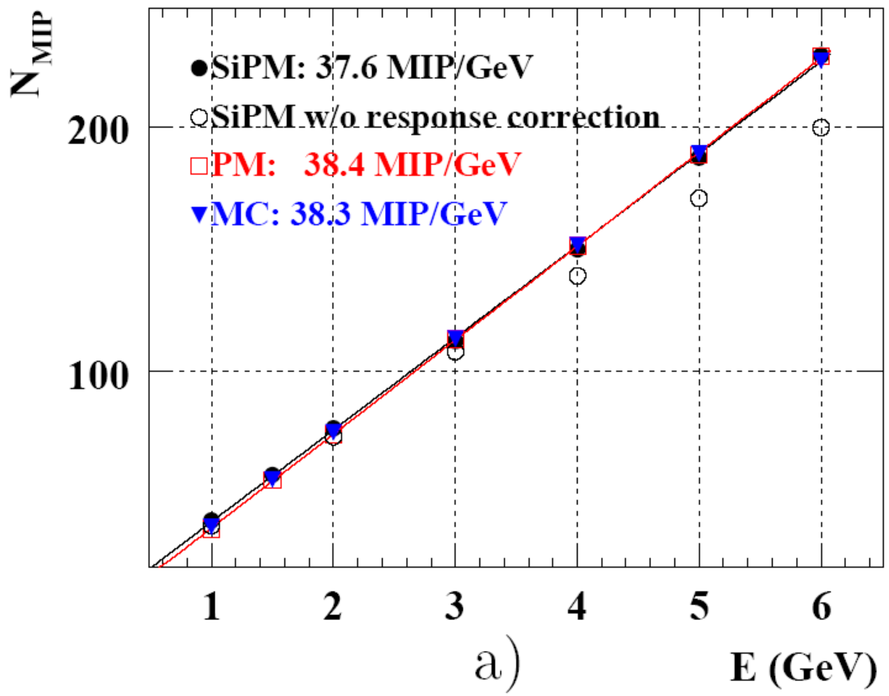




MINICAL tests with electron beam

Measurement of electron energy with HADRON CALORIMETER ⇒ resolution modest



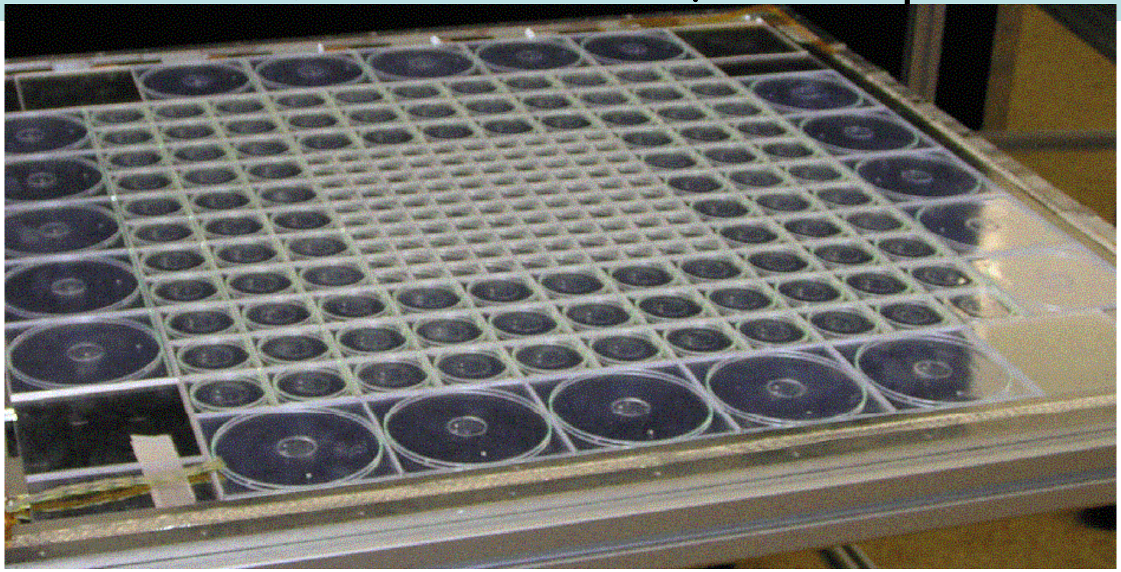


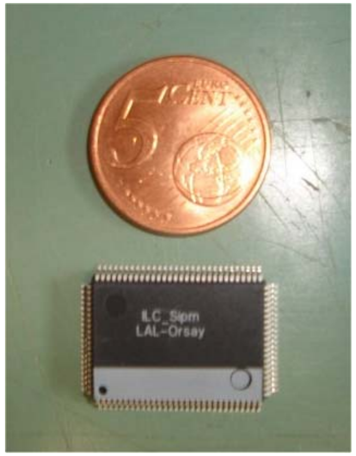
➔ Very good agreement between SiPM, MAPMT, APD(not shown) and MC in the whole range 1 - 6 GeV

➔ 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
Results with novel SiPM photodetectors were obtained **before** MAPMT results
It took much longer to solve calibration problems with APDs

The CALICE HCAL prototype comprises 38 planes of scintillating detectors with 216 tiles in first 30 planes and 145 tiles in 8 last ones.

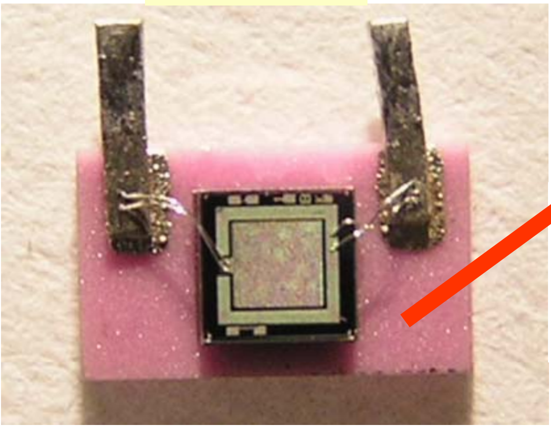




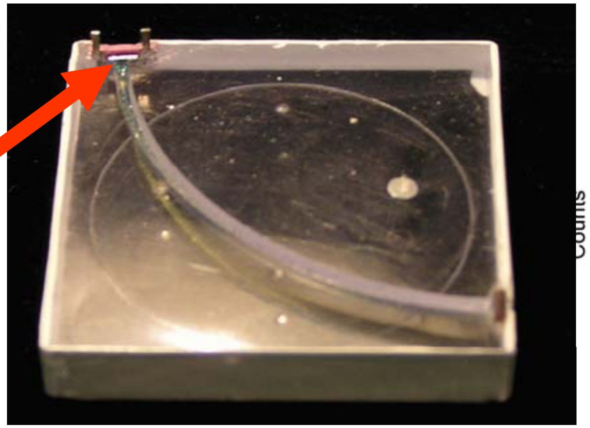
LAL 18 ch. SiPM FE chip

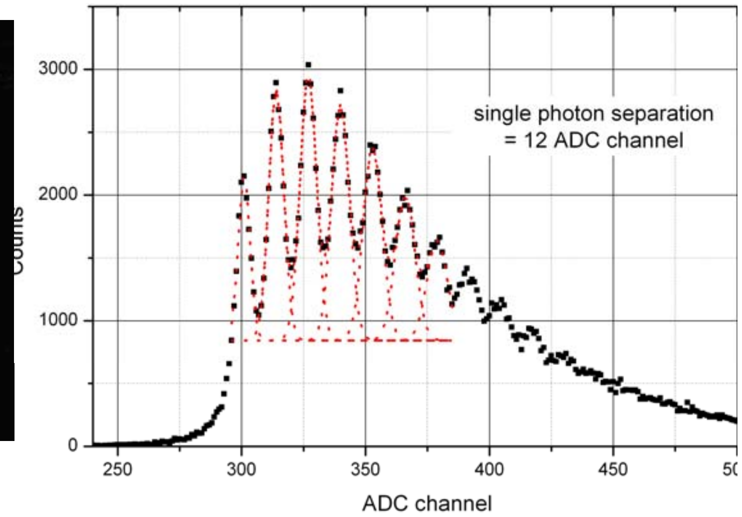
Light from a tile is read out via WLS fiber and SiPM

SiPM



3x3 cm^2 tile with SiPM



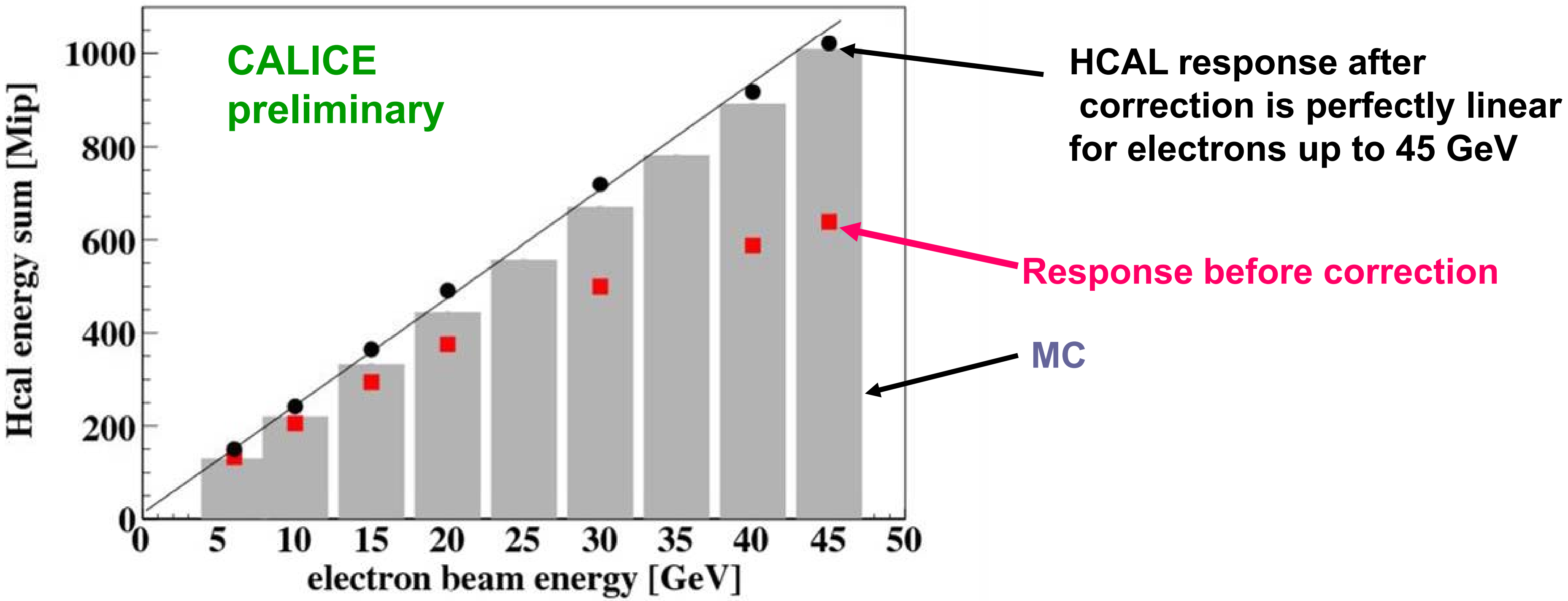


Operational experience with HCAL

HCAL was operated practically without problems at CERN during 2006-07 (7months) initially with 23 planes and then with 38 planes. In 2008 tested at FNAL

~98% of channels are good
~1% are dead (because of problems with SiPM soldering – improves with time)
~1% problems with SiPMs (SiPM selection procedure was not perfect initially)

Good channels were calibrated with muons and corrected for non linear SiPM response

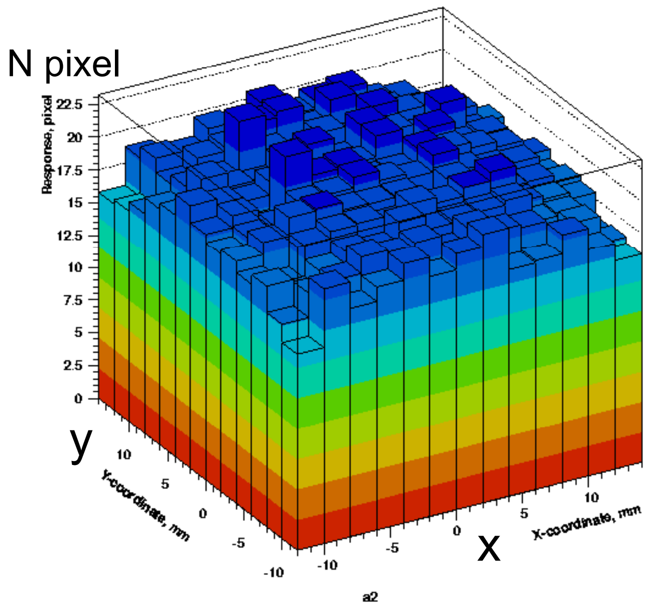


Tile thickness can be reduced to 3 mm (saves a lot of money)

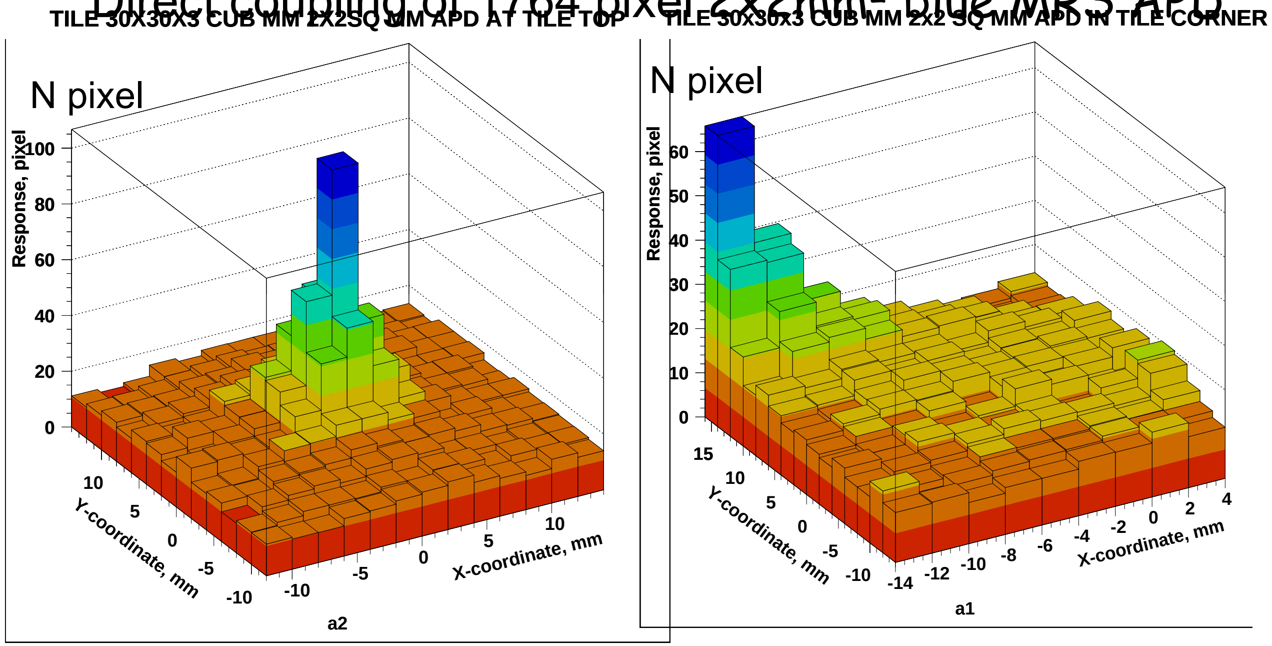
Response uniformity is good for tiles with WLS fibers even for thin tiles and problematic for direct SiPM coupling which is easier for fabrication

Uniformity measurements of 30x30x3mm^3 tiles at ITEP synchrotron

Arch fiber&SiPM 1.5MIP



Direct coupling of 1764 pixel 2x2mm^2 blue MRS APD

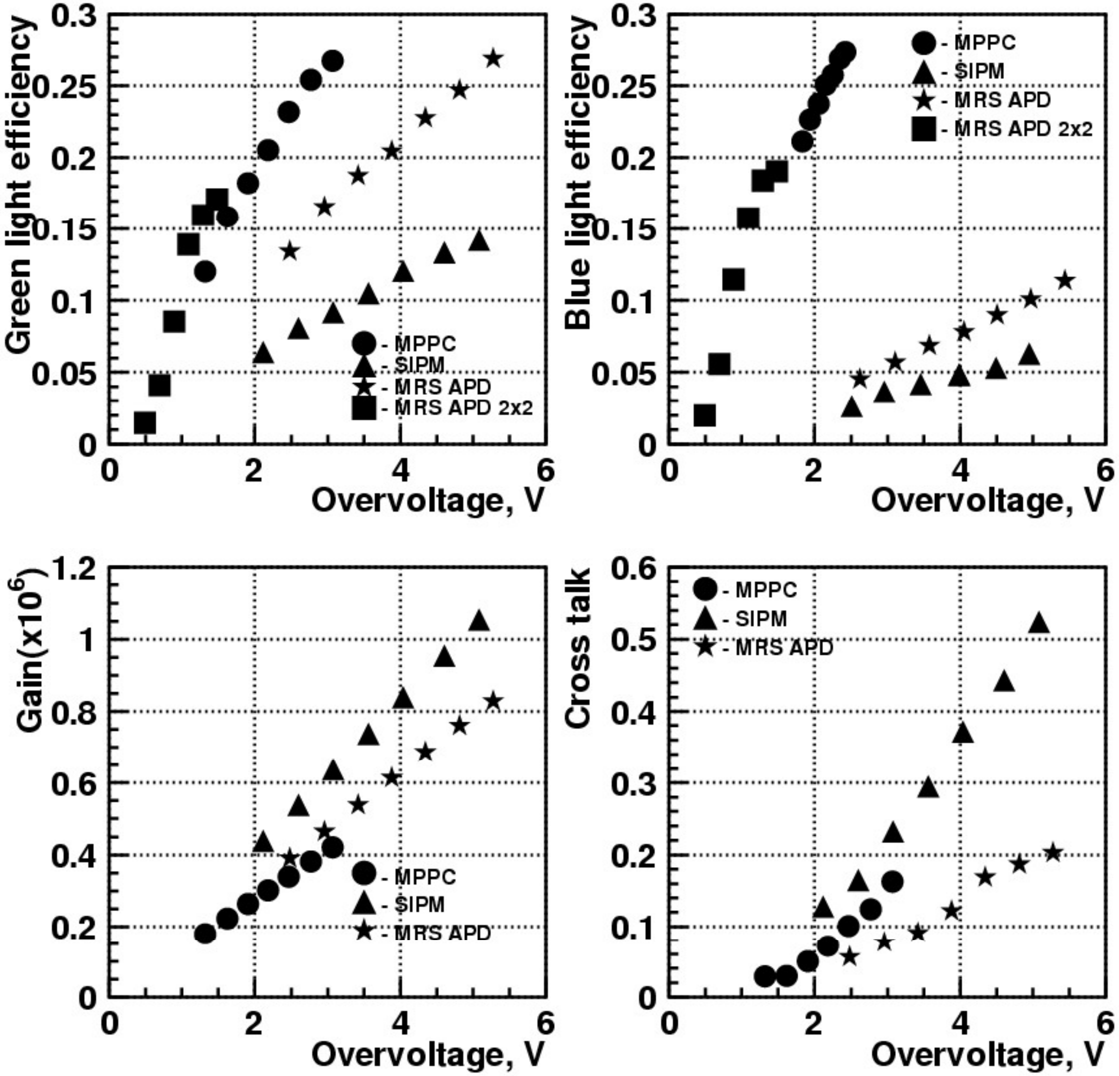


Problems with direct coupling will be more severe for larger size tiles

Light yield is sufficient for 3mm thick tiles with glued WLSF and SiPM (~14pix./MIP) and larger area SiPMs (3x3mm^2) or MRS APD (2x2mm^2 blue extended) but noise is too high in these detectors to resolve individual p.e. – bad for calibration

Comparison of SiPMs used in mass applications

MEPhI-Pulsar SiPM (1156pix) ~ 8000 channels (CALICE HCAL&TC)
CPTA MRS-APD (656pix) ~500 channels (ALICE TOF test)
Hamamatsu MPPC (1600pix) ~500 channels (CALICE ScECAL)



SiPMs were illuminated with Y11 (green) and scintillator (blue) light
Efficiency was normalized to MPPC one

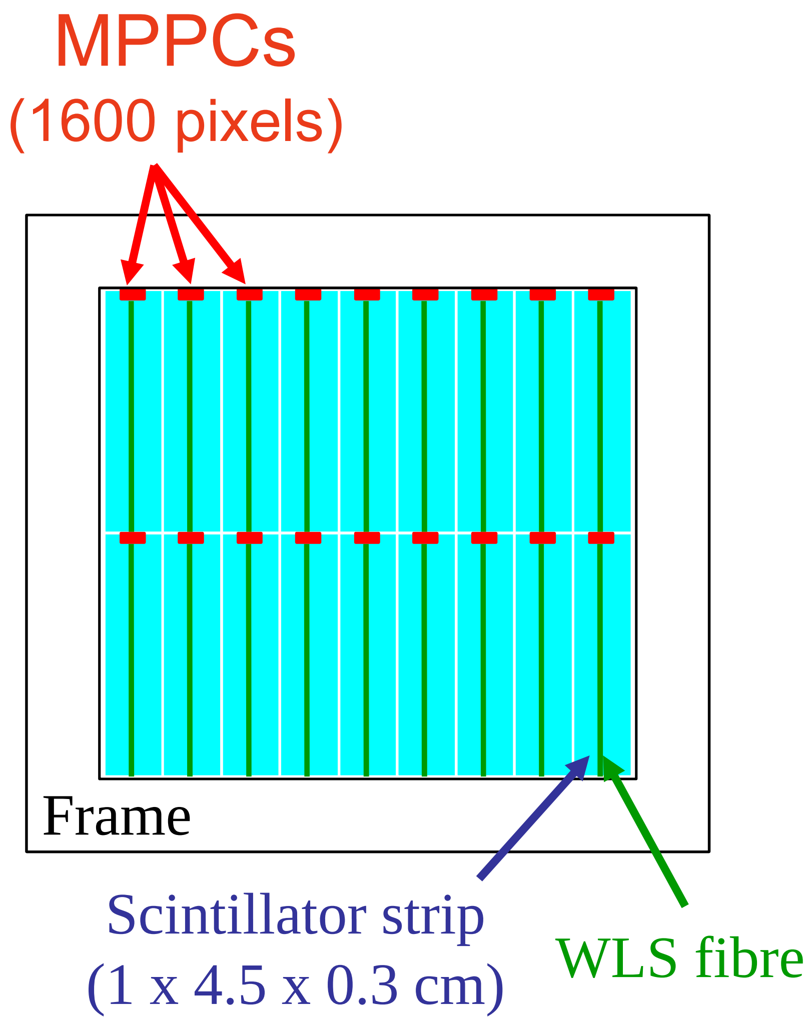
MRS-APD and MPPC have larger PDE and smaller X-talk than MEPhI SiPM

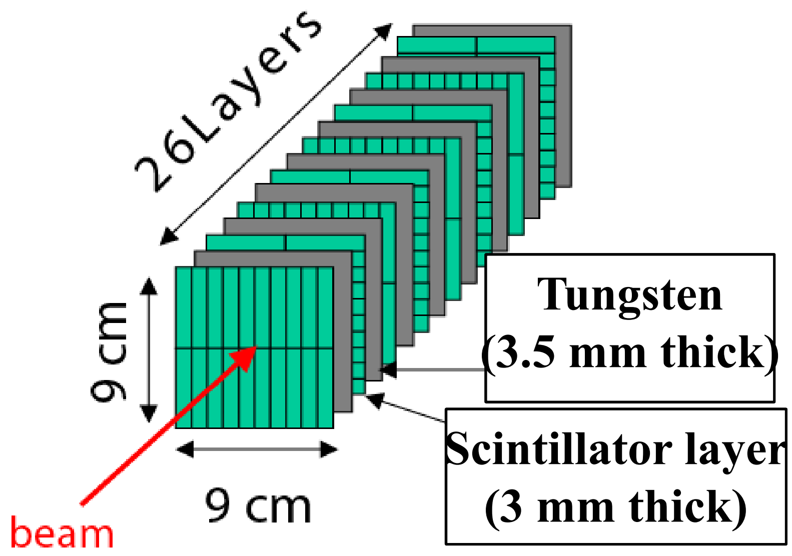
MPPC has ~4 times smaller noise

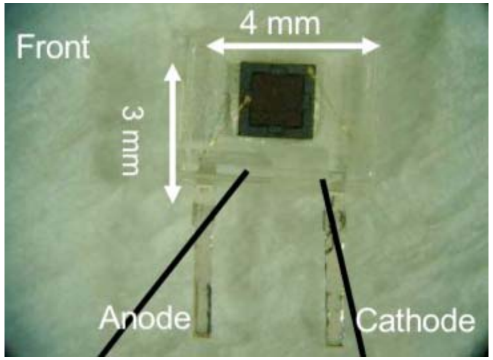
Blue extended MRS-APD has PDE comparable with MPPC

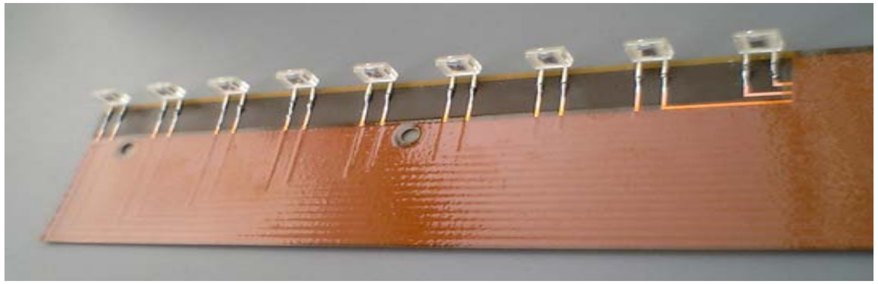
New MEPhI-MPI SiPMs with ultra-low X-talk and high PDE already available

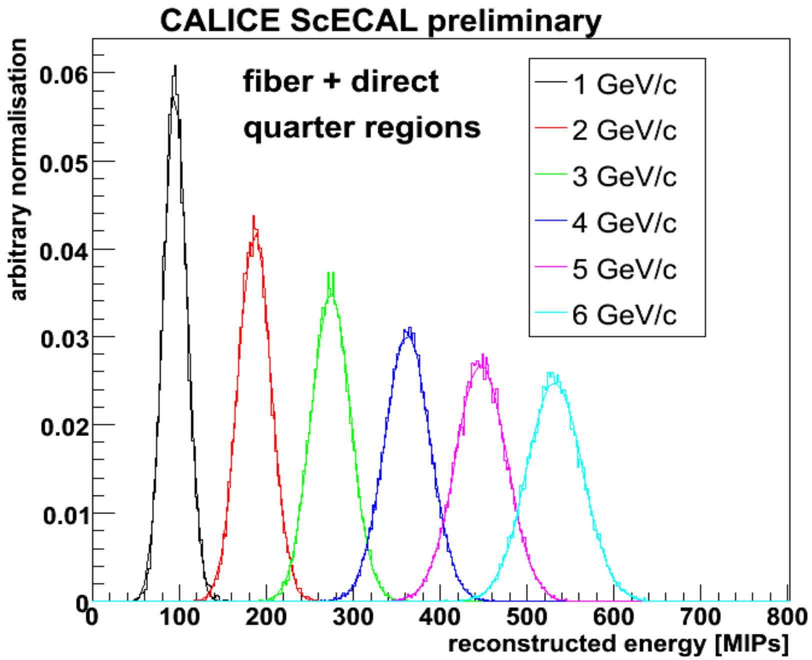
CALICE (Japan-Korean group) Scintillator e/m Calorimeter

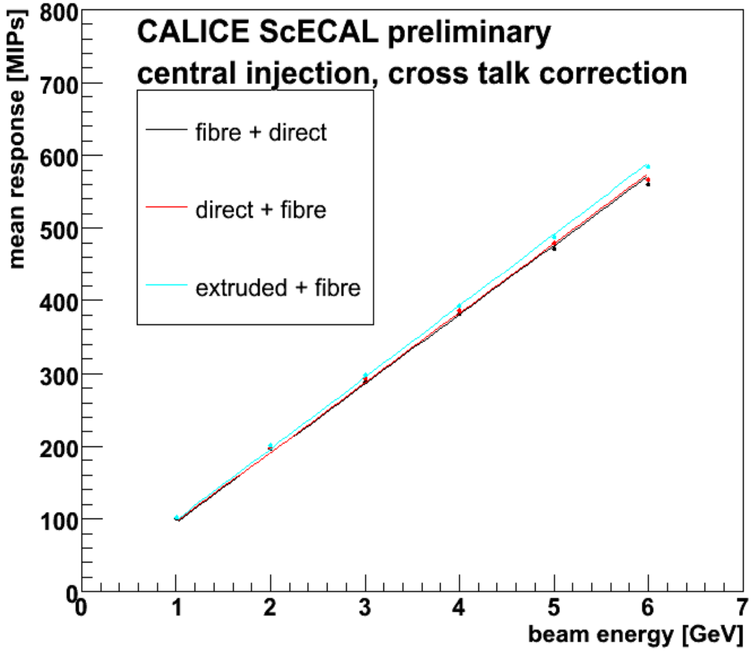












energy response

Linear response.

No strong effect of MPPC saturation has been seen

2000 channel e/m calorimeter with MPPC readout will be tested at FNAL this year

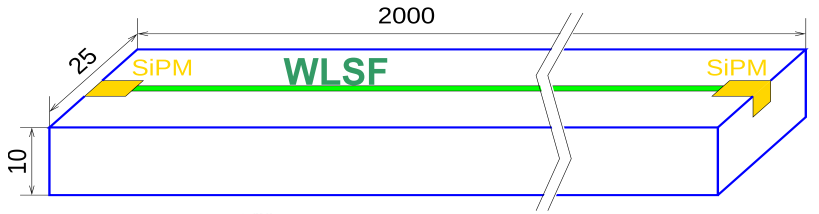
Scintillator based muon systems

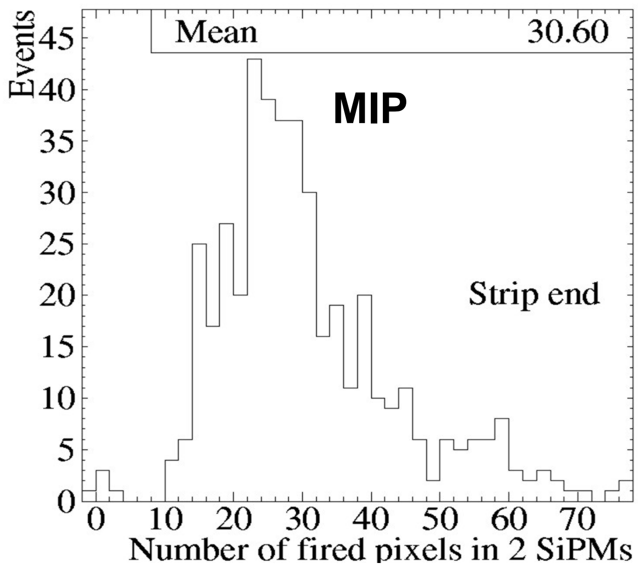
Si Photo Multiplier (SiPM) offers more elegant solution than traditional MAPMT :

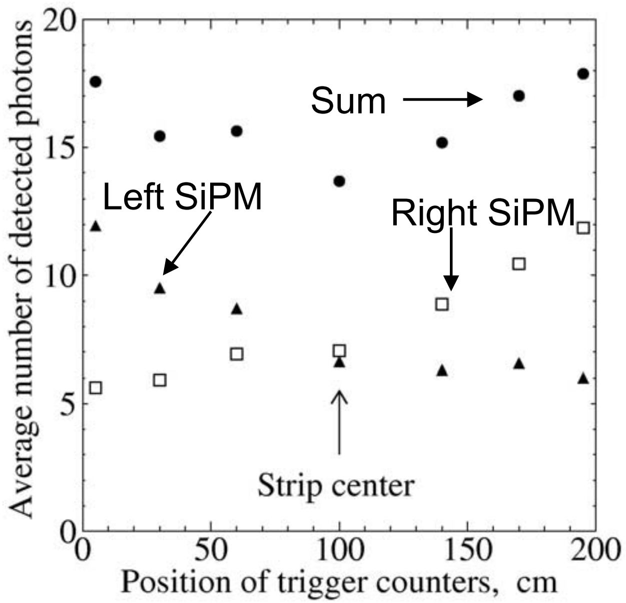
It works in magnetic field – no clear fibers for light transportation

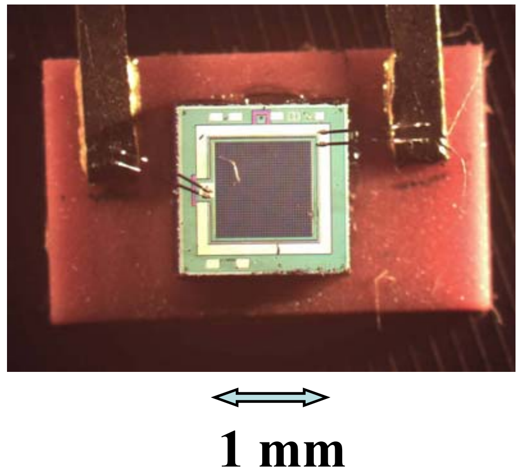
It is very small and can be installed directly in scintillator strip

ITEP tested a 200x2.5x1cm^3 strip with WLS fiber and SiPM at each end









MIP Landau distribution starts above 10 fired pixels!
(WLS fiber is not glued to strip)

More than 13 detected photons per MIP
ε>99%at rate >1kHz/cm^2

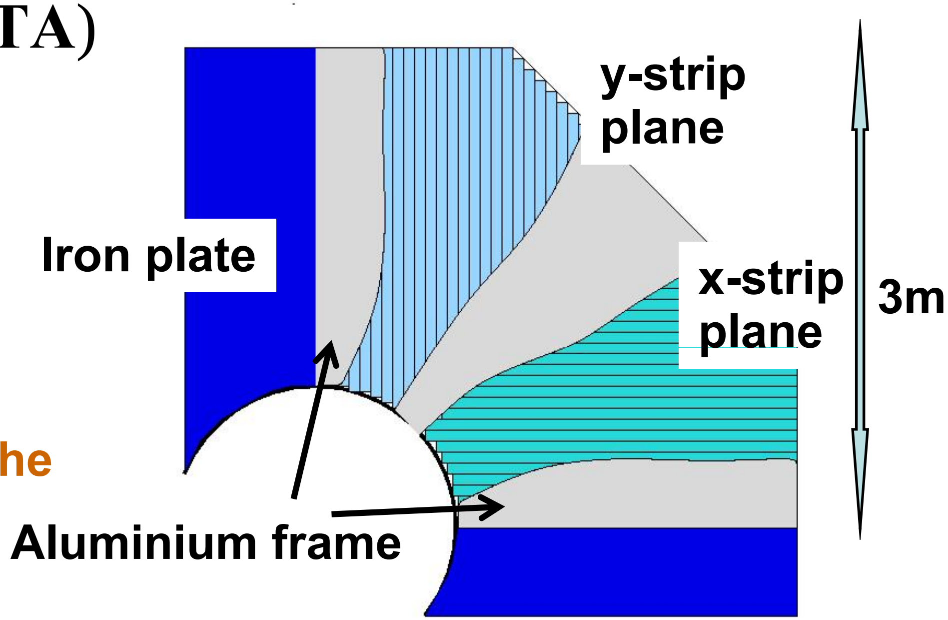
SiPM – matrix of 1024 photodiods in Geiger mode
Developed by MEPhI

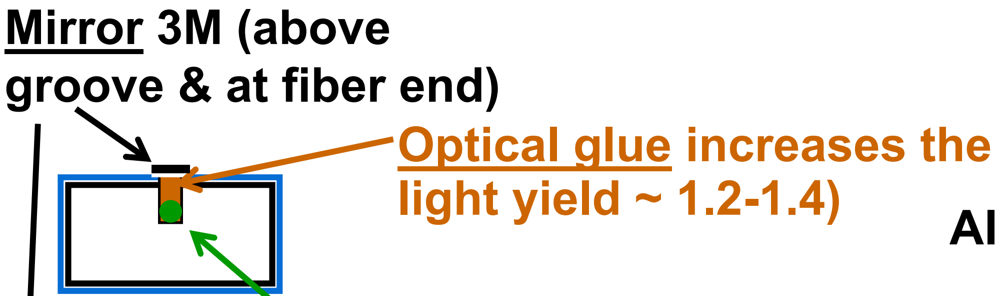
Scintillator KLM for BELLE

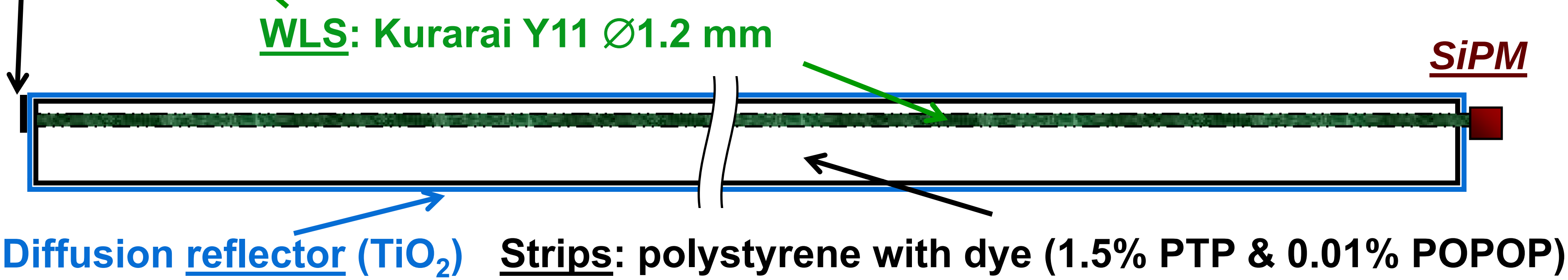
- **Two independent (x and y) layers in one superlayer made of orthogonal rectangular strips with WLS read out**

  (28,000 channels)

- **Photodetector - MRS APD (CPTA)**

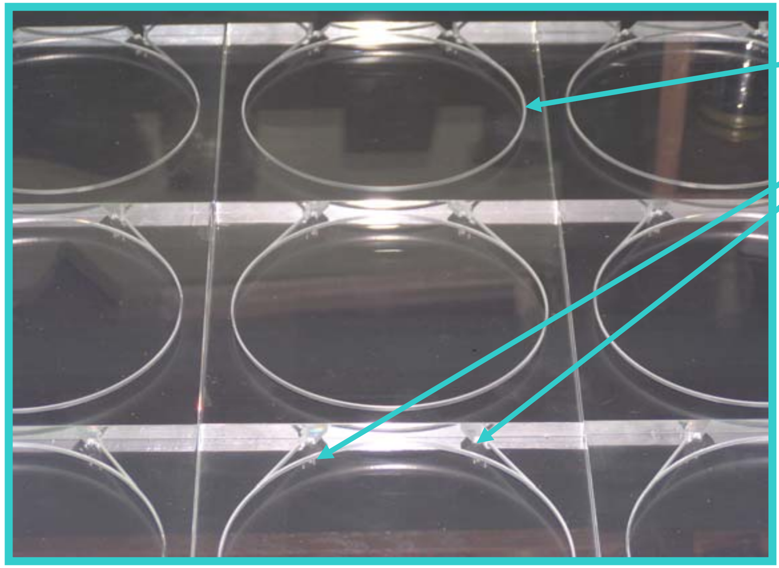






ALICE TOF Cosmic Test System with 500 MRS APD was built at ITEP

Mosaic stricture of the trigger detector

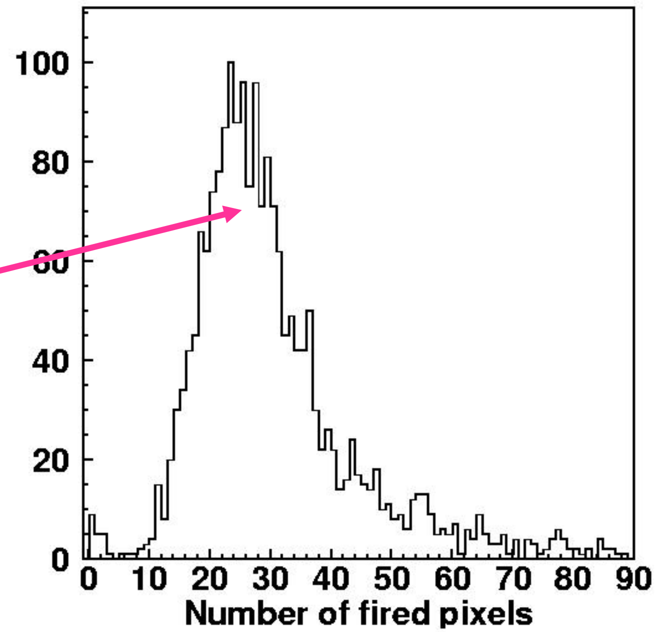


Light detection by

WLS Fiber and MRS APD

2 MRS APDs per 15x15x1 cm^3 tile

- **dense packing ensures the absence of 'dead' zones**
- **intrinsic noise of a single cell ~ 0.01 Hz**
- **rate capability up to ~ 10KHz/cm^2**
- **time resolution ~ 1.2 ns**



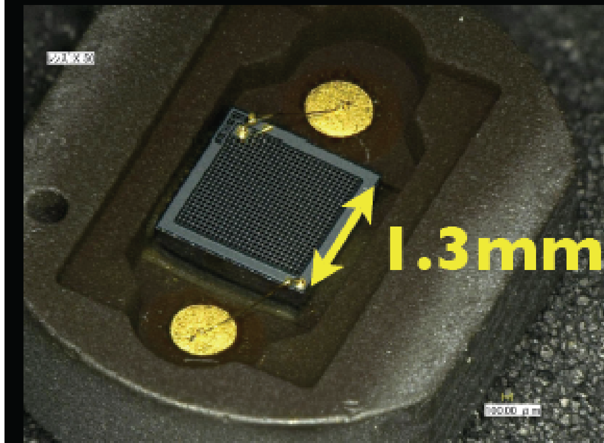
More than 20 photoelectrons per MIP are detected even without WLS fiber gluing to tile

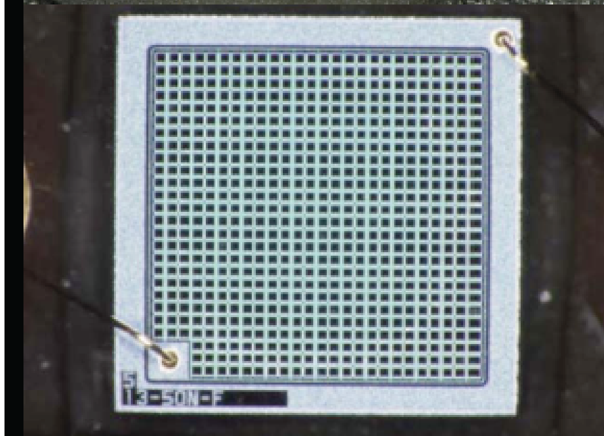
MPPC Spec for T2K

Item	Spec
Active area	1.3×1.3mm^2
Pixel size	50×50μm^2
Number of pixels	667
Operation voltage	70V (typ.)
Photon detection eff. @ 550nm	>15%
Dark count (gain=7.5×10^5)	<1.35Mcps(0.5pe) <0.135Mcps(1.5pe)
Number of device	~60,000

S10362-13-050C

Specially developed for T2K

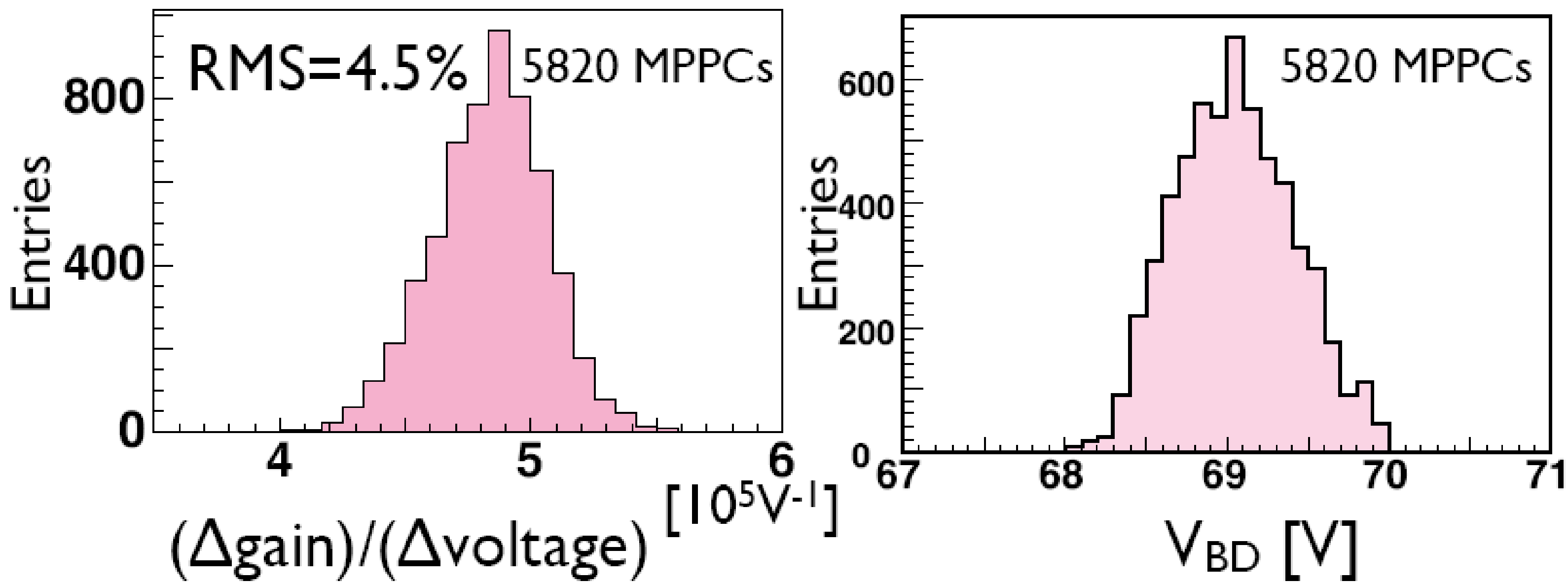




Gain/V_{BD} for T2K-MPPC

For 5820 MPPCs

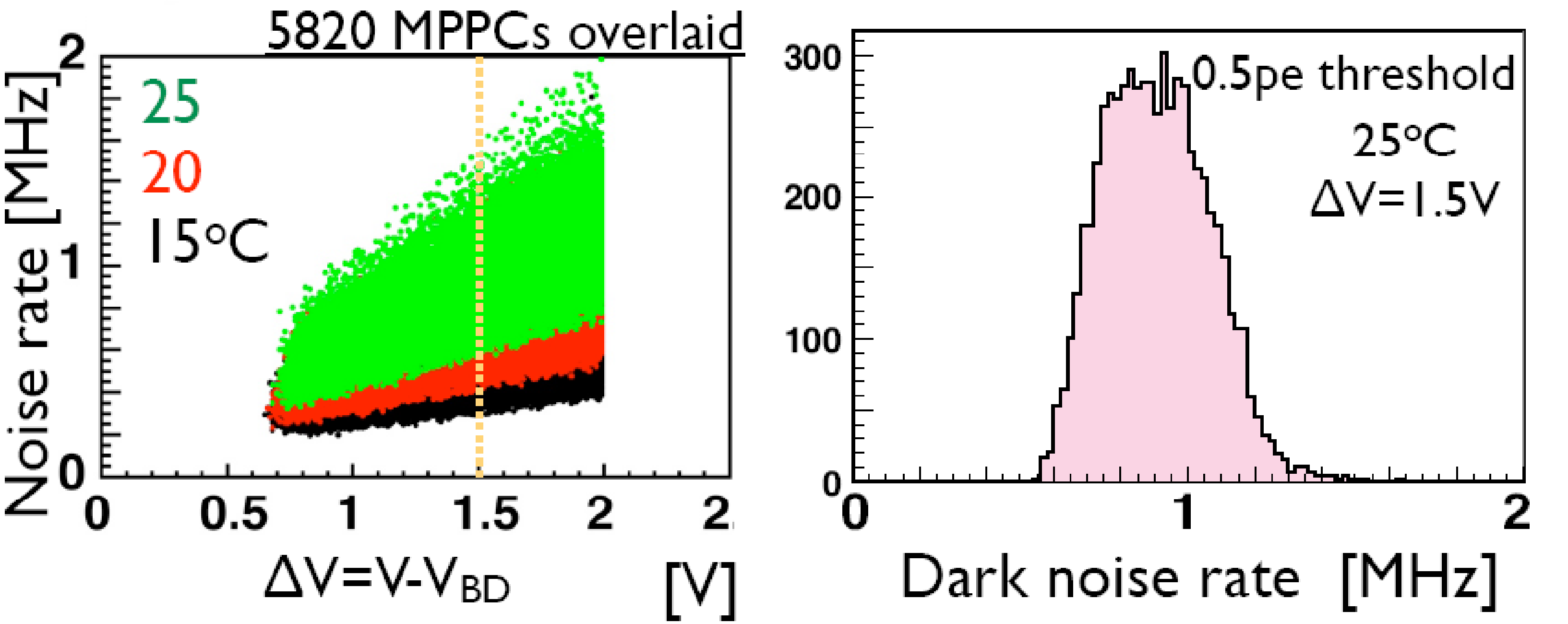
25°C



Excellent device uniformity.

Dark noise

For 5820 MPPCs



Device/temperature dependence seen

Satisfy our requirements

Positron-Electron Balloon-borne Spectrometer (PEBS)

Scintillation Fiber Tracker with 55000 channels (1700 SiPM arrays)
Scintillator strip – WLS fiber Electromagnetic Calorimeter with ~2000 SiPM

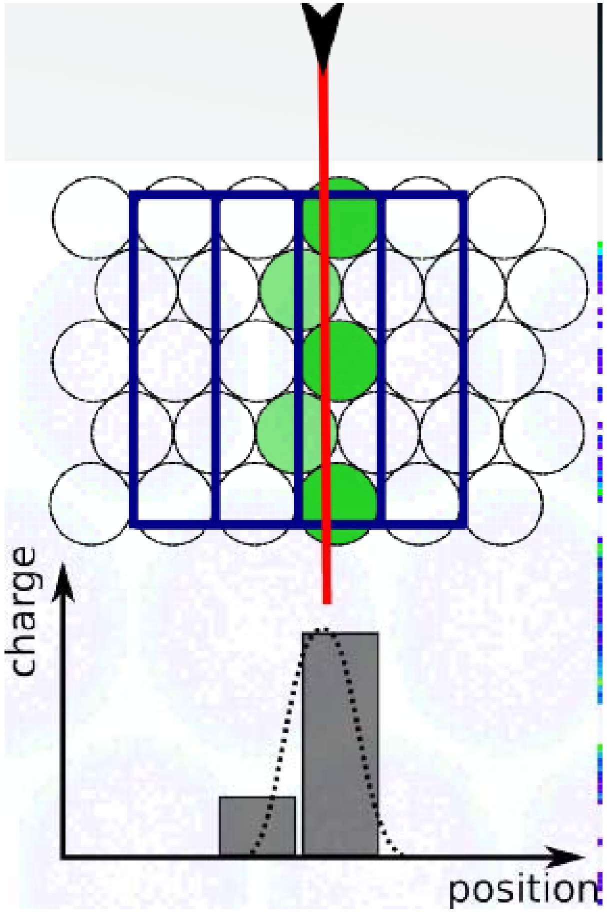
11

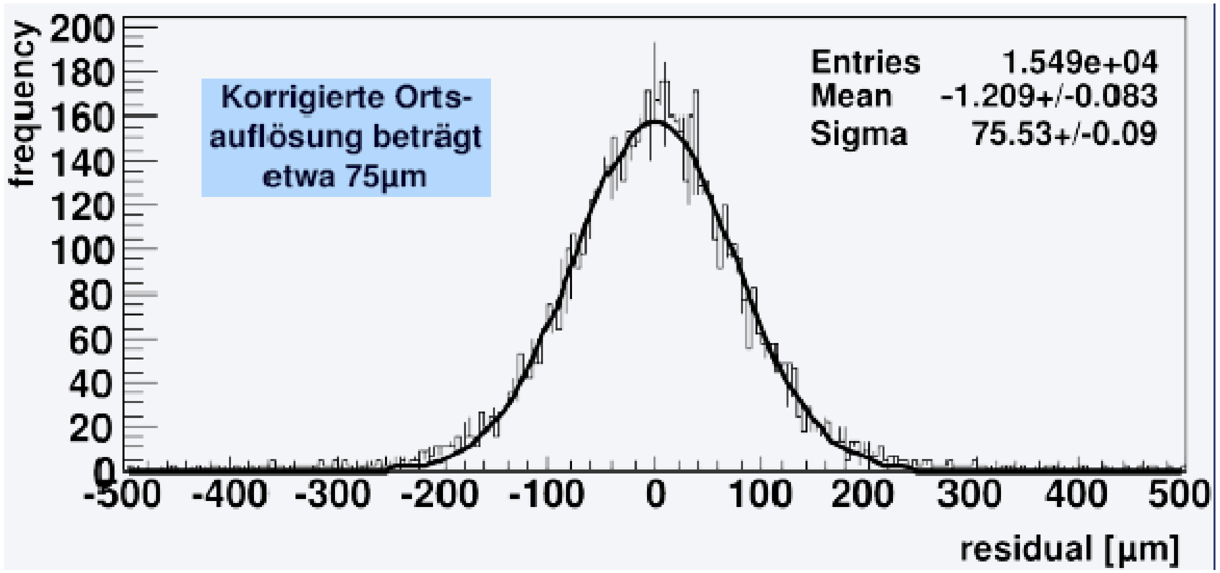
SiPM(-Arrays) im Test

Produzent	Hamamatsu	Hamamatsu	IRST-ITC
Typ	MPPC S10362-11-100C	MPPC 5883	
Kanäle	1	32	32
Pixel	100	32 x 80	32x110
Aktive Fläche	1mm x 1mm	32 x 0.22mm x 1.1mm	32 x 0.23mm x 1.1mm
Betriebsspannung	70V	70V	32V
Photoneffizienz	40% @ 500nm; 60% @ 430nm	?	20% @ 500nm
1-Photon-equivalen-tes Rauschen	600kHz	300kHz	1MHz
Pixelcrosstalk Wahrscheinlichkeit	0,58	0,3	0,1

~10p.e./MIP obtained with 0.25mm Kuraray fiber & Hamamatsu SiPM array

Position resolution of 75 micron achieved (S.Schael)

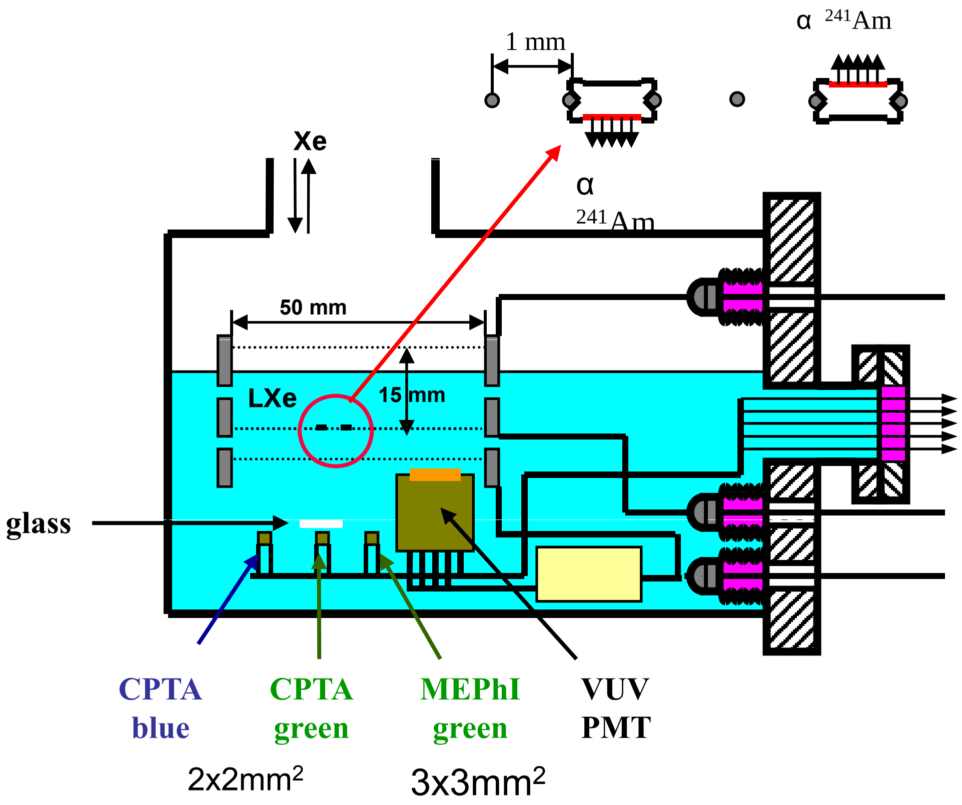


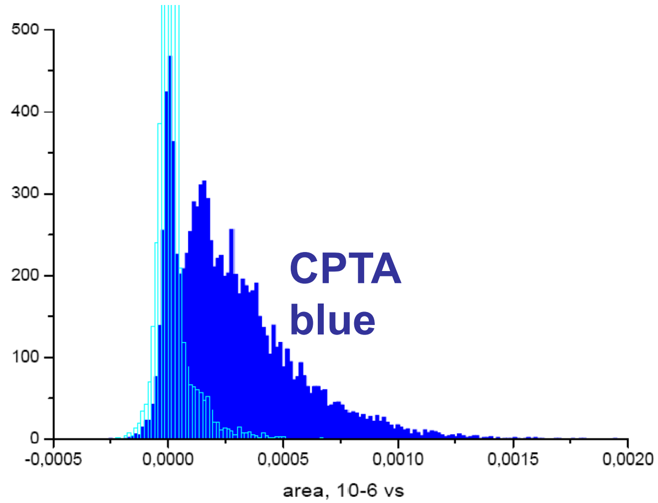


SiPM test in LXe

E. Aprile et al.,NIM **A556** (2006), p. 215
have shown unexpectedly high PDE (**5.5%)** for MEPhI-PULSAR SiPM
Would be great for Dark Matter searches

Our test of SiPM in LXe:
- *^{241}Am – α-source*
- *(!) triggering by UV sensitive PMT*
- *one of the SiPMs was screened by glass*



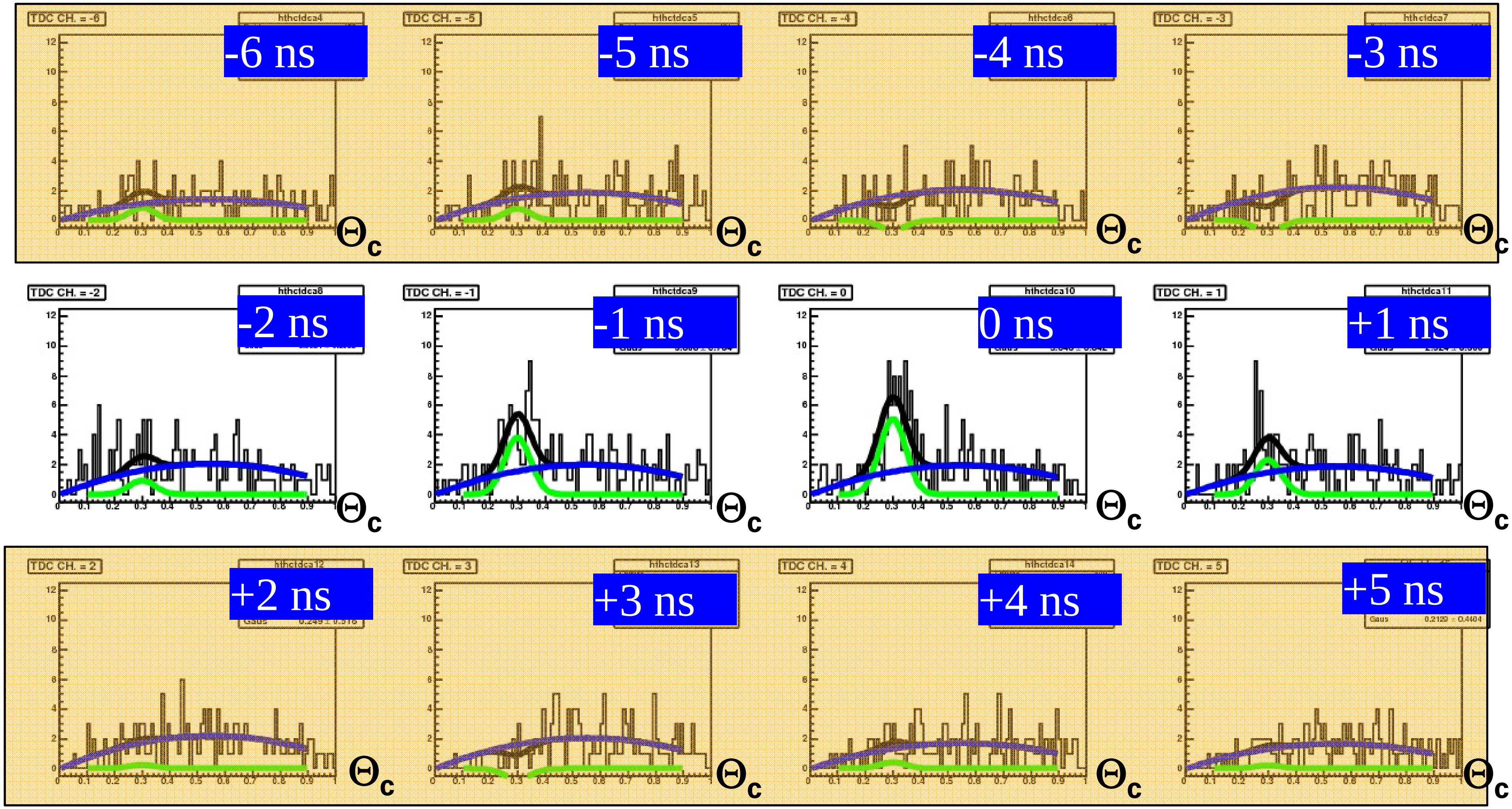


CPTA blue **PDE = 0.75%**
MEPhI green **PDE = 0.45%**
CPTA green with glass **no signal**

WLS is required
Preparing to test *p*-terphenyl:
- **deposited between two sapphire windows**
- **p-terphenyl doped poly-*n*-xylene film**

SiPM: Cherenkov angle distributions for 1ns time windows

P.Krizan (Novosibirsk 08)



Cherenkov photons appear in the expected time windows →
First Cherenkov photons observed with SiPMs!

There are other SiPM applications in particular for PET and Astrophysics

There are many new developments

I selected just 2 examples

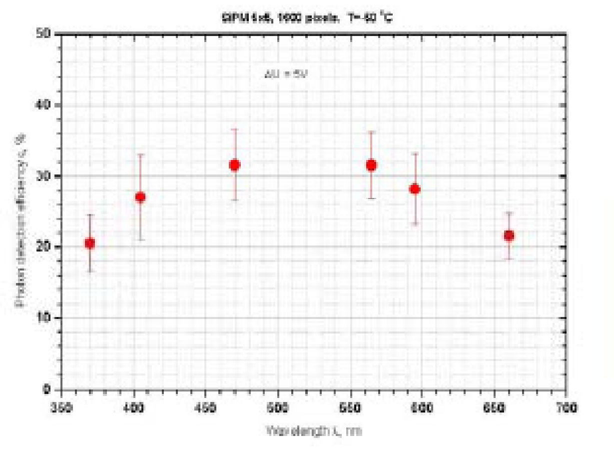
New MEPhI-MPI SiPM with strong X-talk suppression

(Mirzoyan NDIP 08)

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



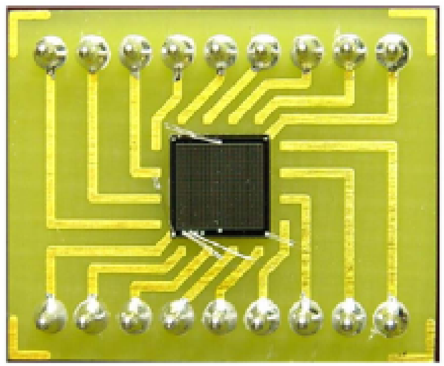
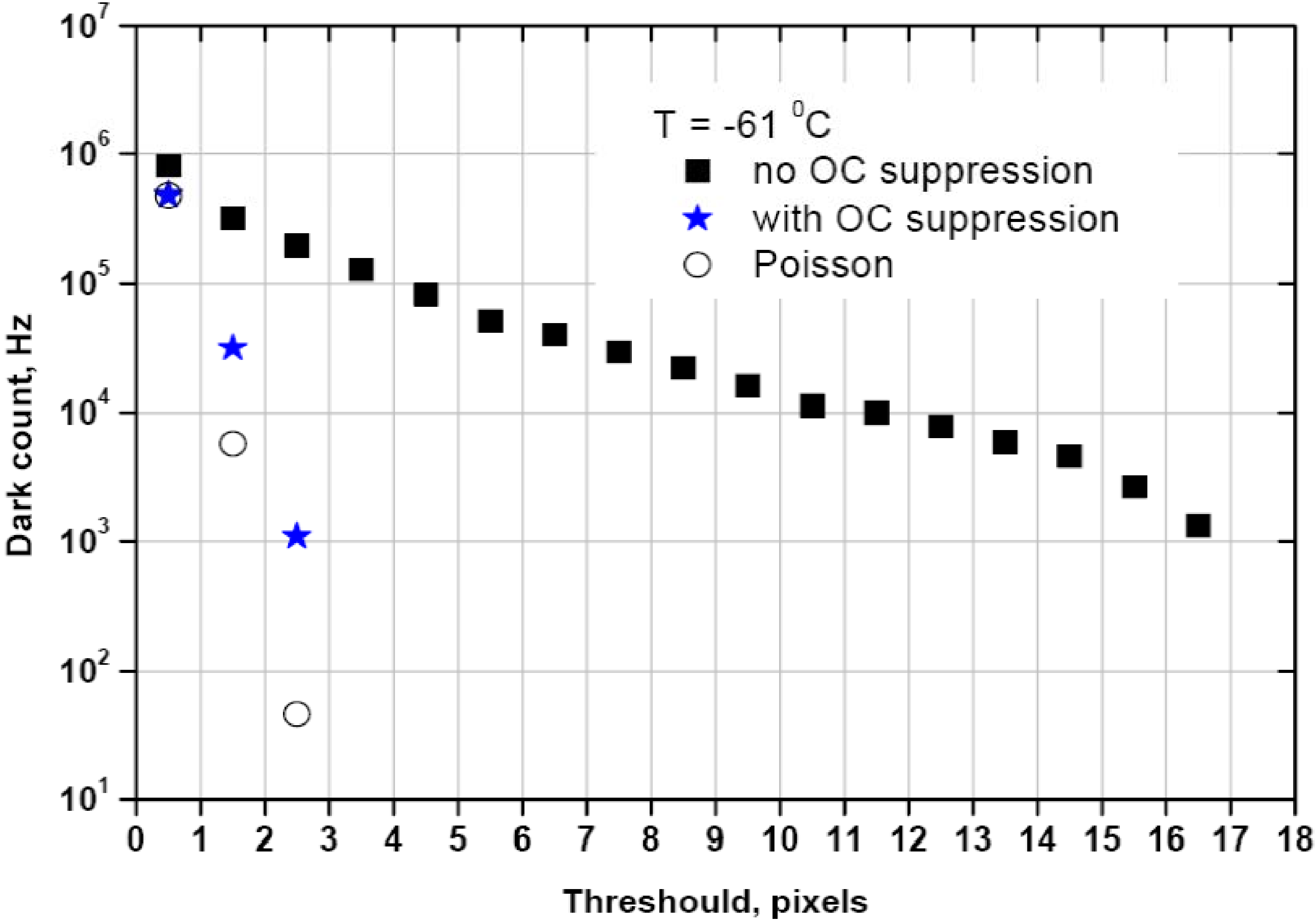
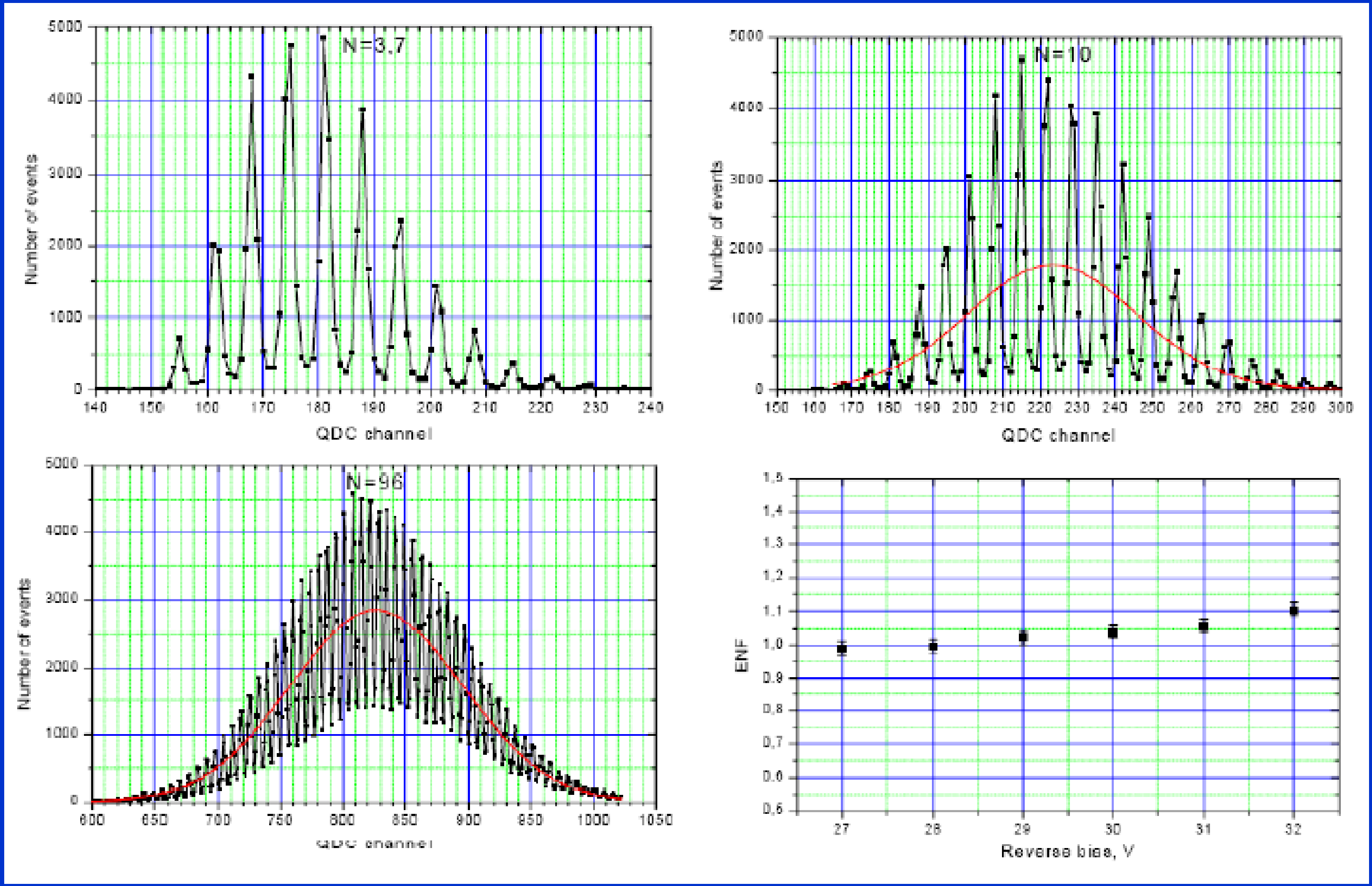


Figure 3: $25(5 \times 5)mm^2$ SiPM. It consists of the array of $1600(40 \times 40)$ micropixels with $100 \times 100\mu m^2$ size.

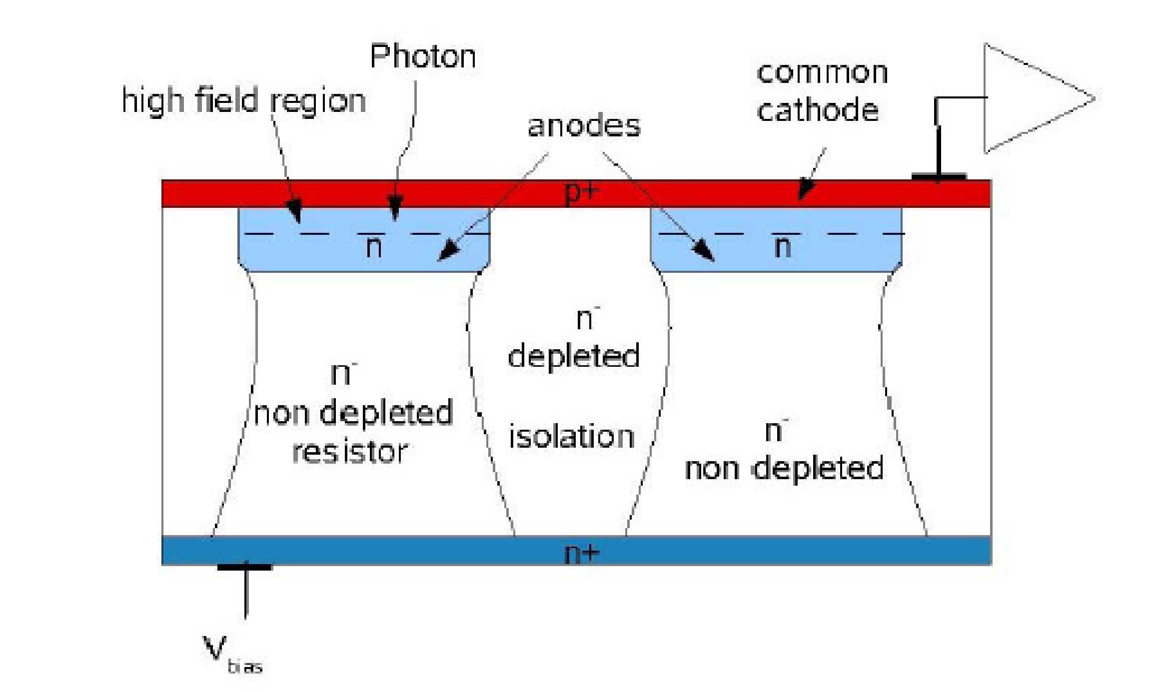


5x5mm ^{2} Mirzoyan NDIP08

SiPM with cross-talk suppression: World record of ultra-fast light sensors in amplitude resolution



New type of SiPM - Why not ?



Front side cathode and backside n+ region are common for the entire array

Anode region becomes an internal node within silicon

Bulk region beneath the anode acts as vertical resistor shielded by the anode from depletion

Gap regions are depleted and isolate the individual resistors

But resistor matching does not work with a wafer of usual thickness ! ☹

Conclusions

SiPM is a novel and very promising photo-detector

Fast going R&D already resulted in SiPMs with

Larger PDE
Larger size
Larger dynamic range
Smaller noise
Smaller X-talk

Radiation damage and other properties are better understood now

~ 10 thousand SiPMs have already been used in experiments

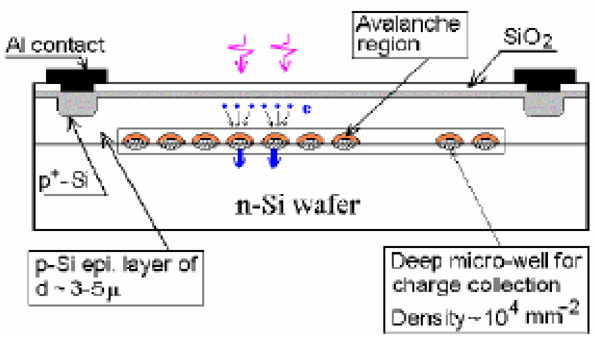
Several projects with 30-60 thousand SiPMs are in preparation

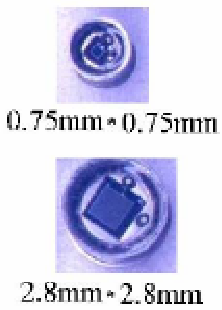
SiPMs are still quite expensive especially for large area applications

Backup Slides

Micro-pixel APDs with large dynamic range

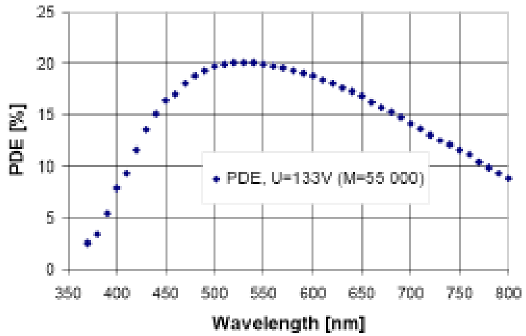
An AMPD with deep micro-wells. Version # 3.

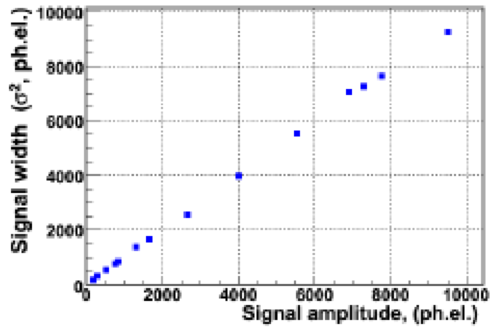




Z. Sadygov, Beaune-05

Micro-well structure with multiplication regions located in front of wells at 2-3 μm depth was developed by Z. Sadygov. MAPDs with 10 000 – 15 000 pixels/mm² were produced. Such devices are good for calorimetry applications.

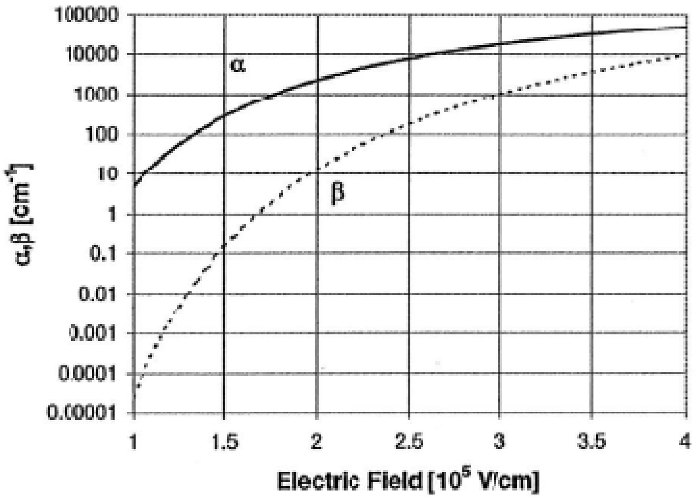




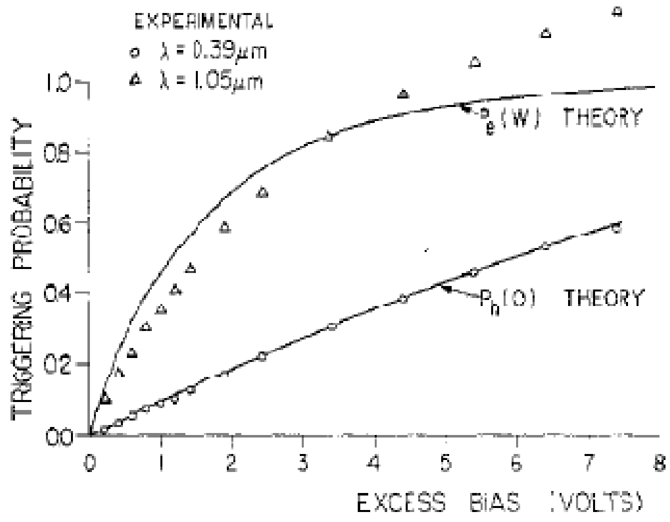
M.Golubeva et.al. LONGITUDINALLY SEGMENTED LEAD/SCINTILLATOR HADRON CALORIMETER WITH MICROPIXEL APD READOUT (this conference)

Breakdown initiation probability

Because of the higher ionization coefficient, the electron triggering probability is always higher than that of holes



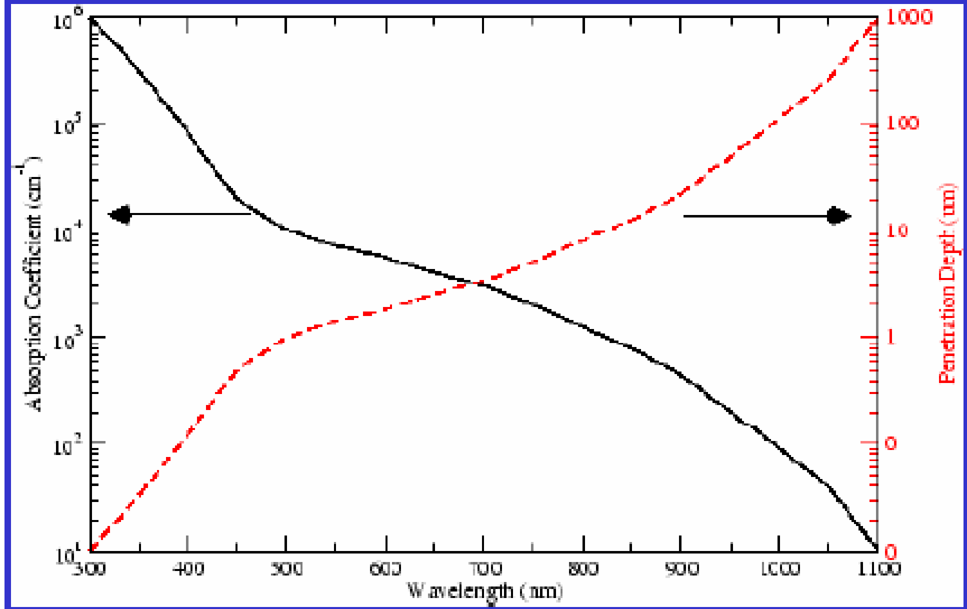
Ionization coefficients for electrons and holes in silicon



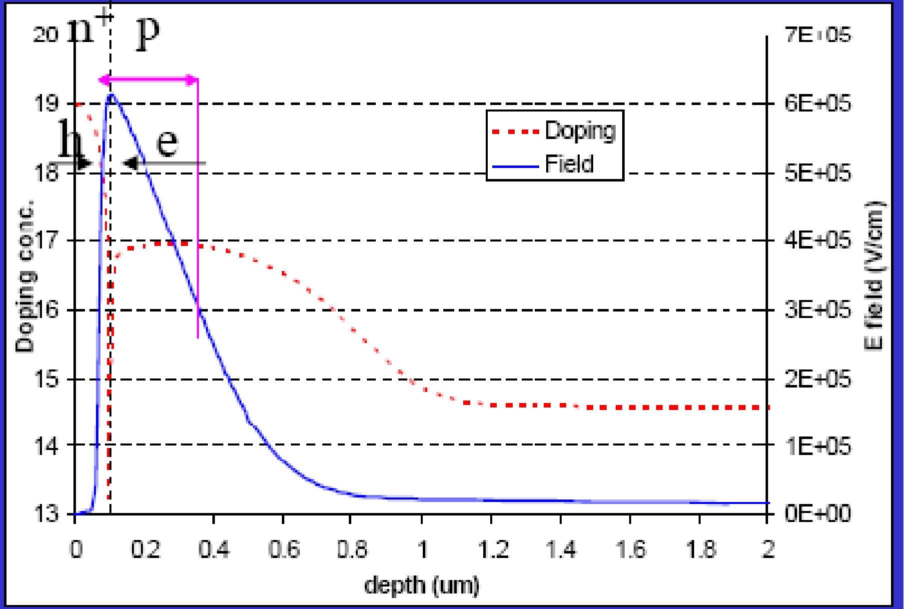
Triggering Phenomena in Avalanche Diodes

[illegible] PAOLO ANTOGNETTI, [illegible]

Light absorption

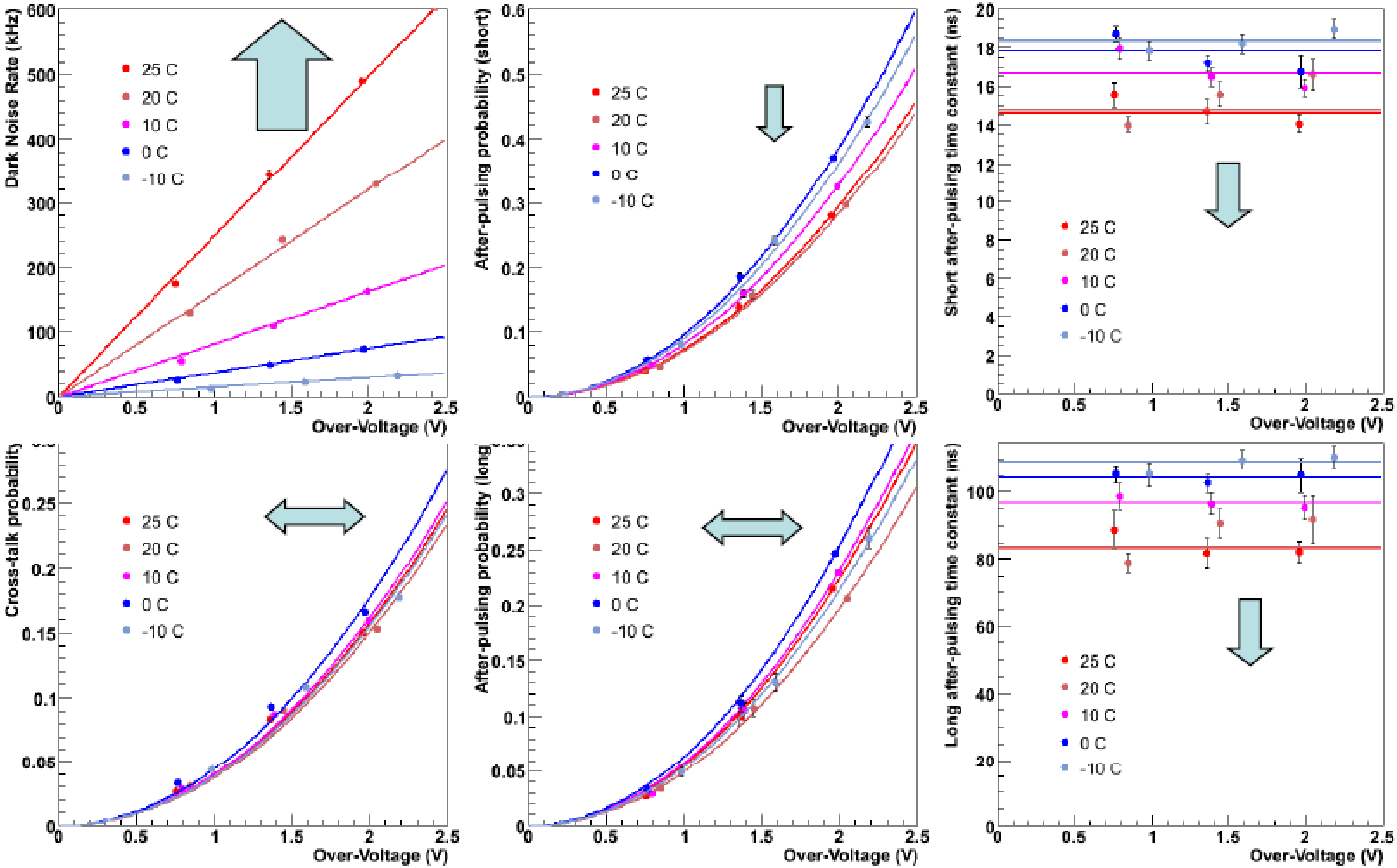


Attenuation of the light intensity in silicon (Beer-Lambert law)



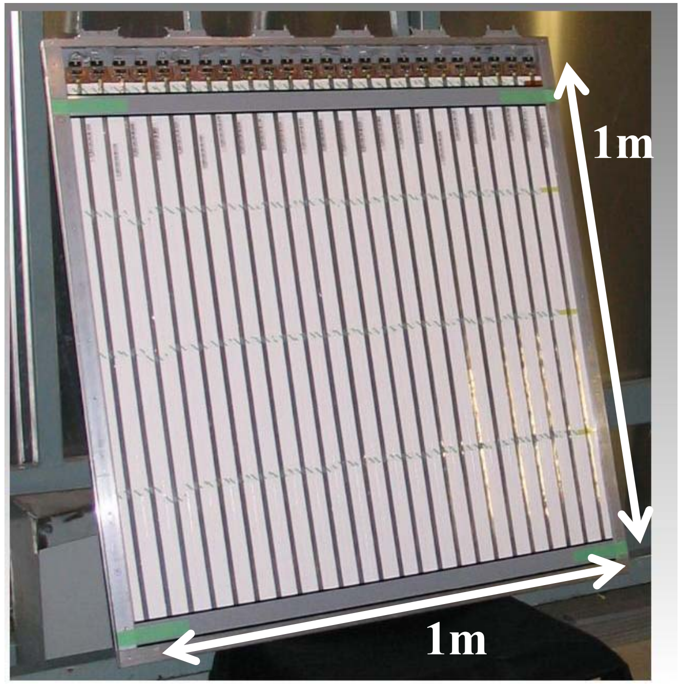
Simulated doping profile and electric field of the SiPM

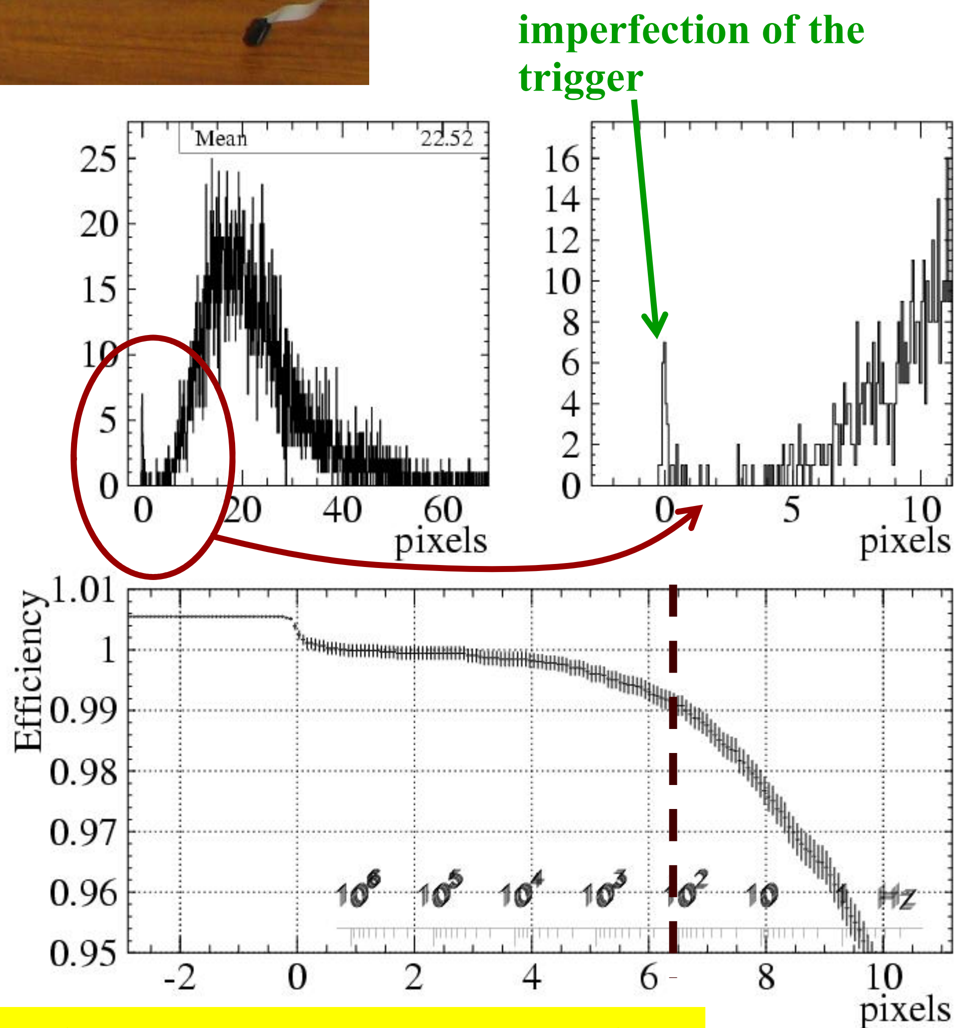
- At low wavelengths only the holes cross the high field region & trigger the avalanche
  - ⇒ triggering probability @ low λ (e.g. 385, 390, 395nm) = hole triggering probability
- At high wavelengths only the electrons cross the high field region & trigger the avalanche
  - ⇒ triggering probability @ high λ (e.g. 700nm) = electron triggering probability


Dark Noise Rate (kHz)
Over-Voltage (V)
25 C
20 C
10 C
0 C
-10 C
After-pulsing probability (short)
Over-Voltage (V)
25 C
20 C
10 C
0 C
-10 C
Short after-pulsing time constant (ns)
Over-Voltage (V)
25 C
20 C
10 C
0 C
-10 C
Cross-talk probability
Over-Voltage (V)
25 C
20 C
10 C
0 C
-10 C
After-pulsing probability (long
Over-Voltage (V)
25 C
20 C
10 C
0 C
-10 C
Long after-pulsing time constant (ns)
Over-Voltage (V)
25 C
20 C
10 C
0 C
-10 C

Four 1mx1m scintillator planes have been built at ITEP and tested at KEK

1 m × 40 mm × 10 mm strip



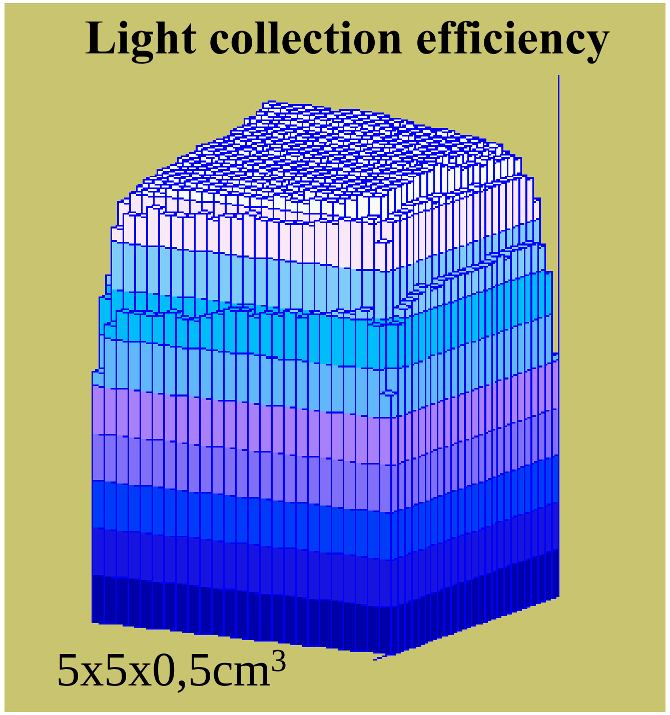


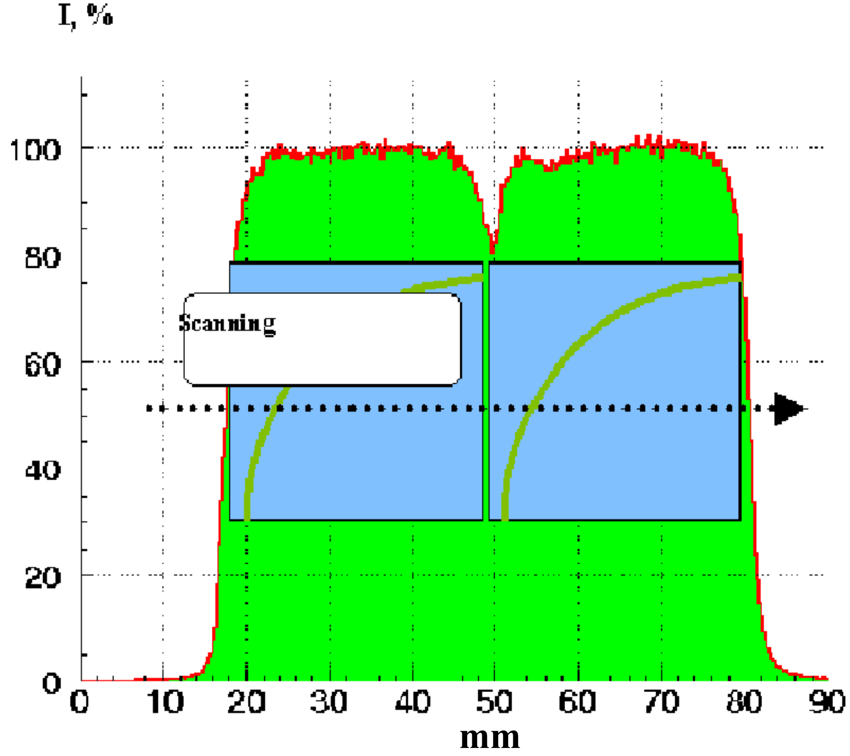
Internal SiPM noise is not a problem (suppressed by threshold), and is much smaller than expected physical background rate

Light Collection Uniformity,

Y11 MC 1mm fiber, Vladimir Scintillator, mated sides, 3M foil on top and bottom
Reduction in light yield near tile edges is due to finite size of a β source

Light yield drop between tiles acceptable (Calorimeter geometry is not projective)
Cross-talk between tiles ~2% - acceptable

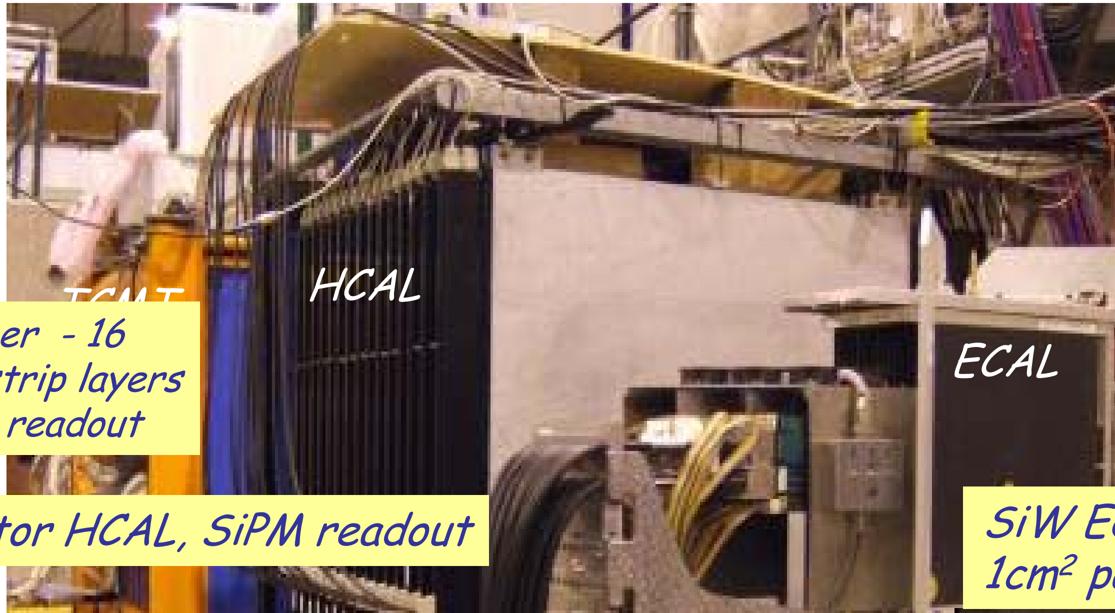




Sufficient uniformity for a hadron calorimeter even for large tiles
Acceptable cross-talk between tiles of ~2% per side
Sufficient light yield of 17, 28, 21 pixels/mip for 12x12, 6x6, and 3x3 cm^2 tiles (quarter of a circle fiber in case of 3x3 cm^2 tile)

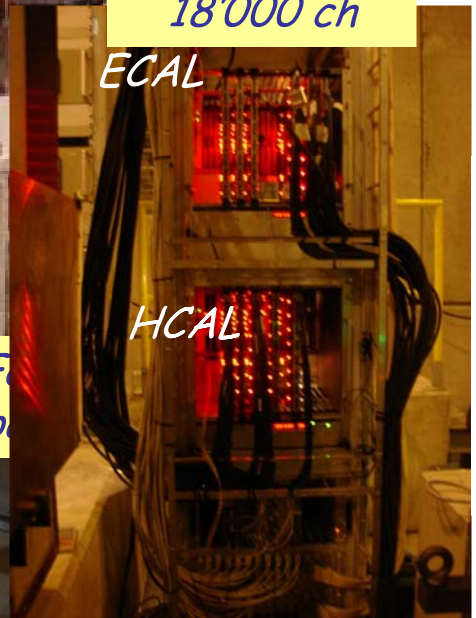
HCAL, ECAL, and TC have been tested last year at CERN

Set-up at SPS H6b

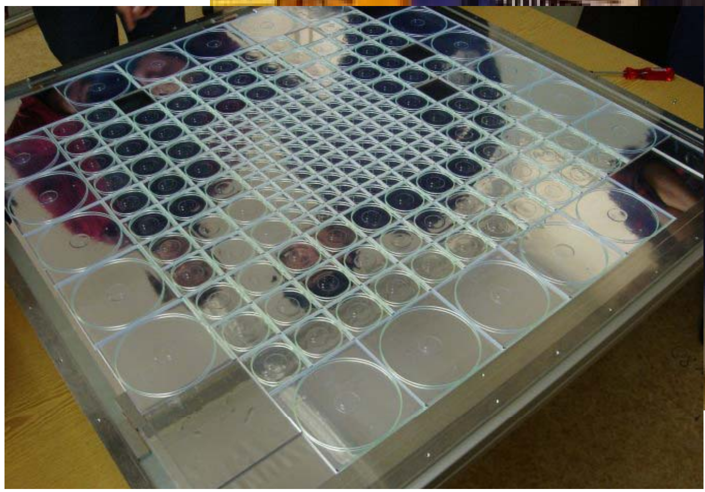


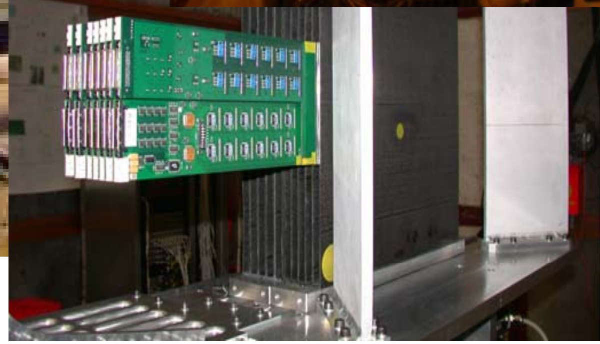
Tail catcher - 16 scintillator strip layers with SiPM readout

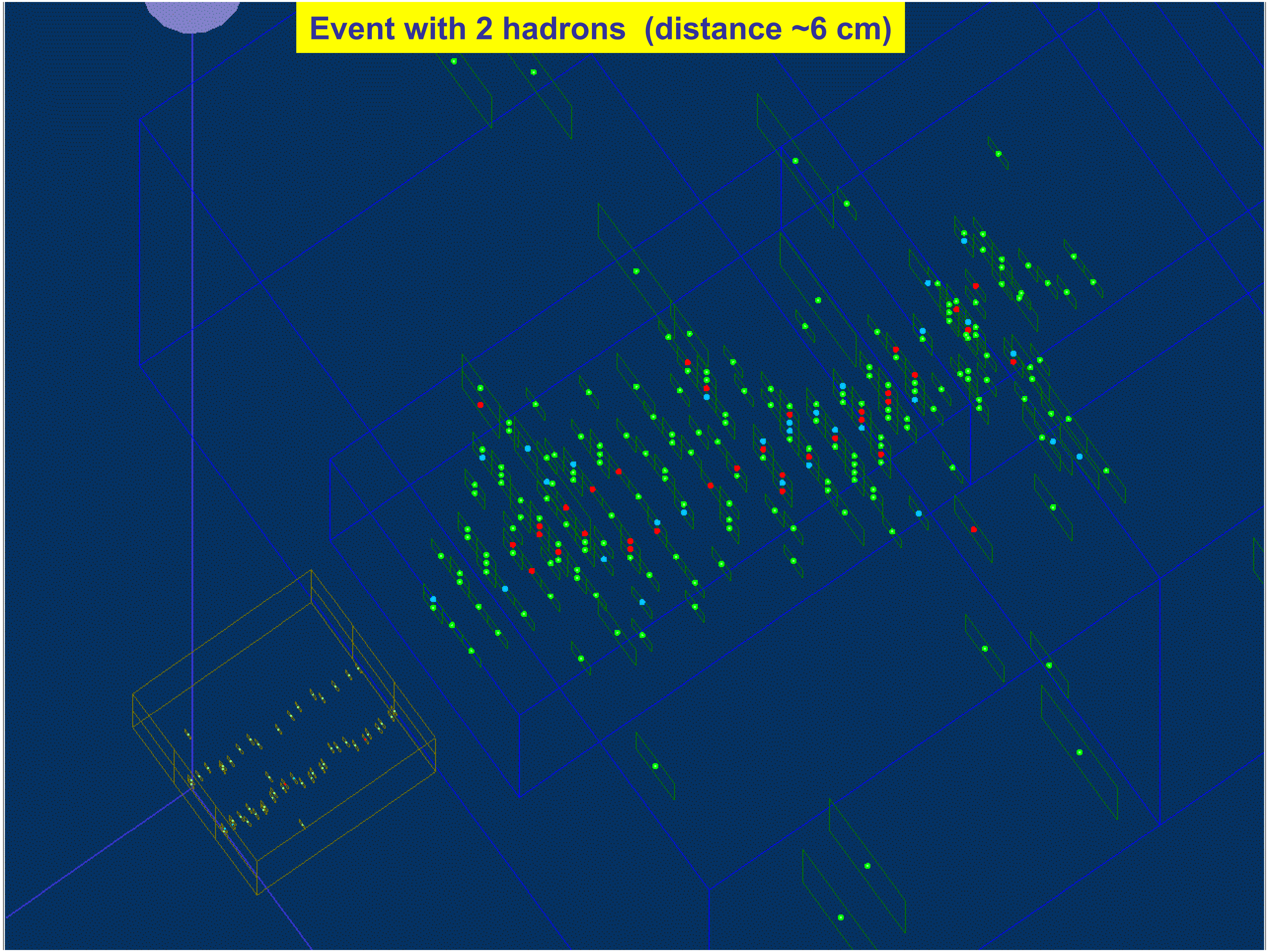
Sintillator HCAL, SiPM readout



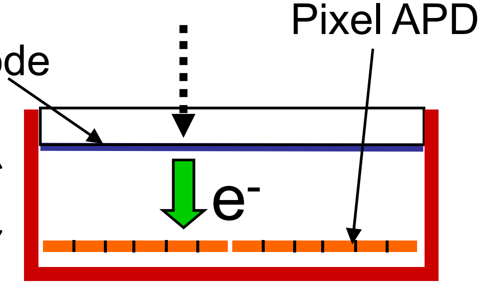
Common DAQ 18'000 ch



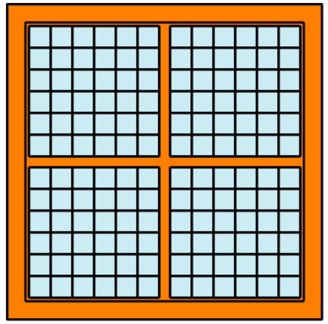



Event with 2 hadrons (distance ~6 cm)

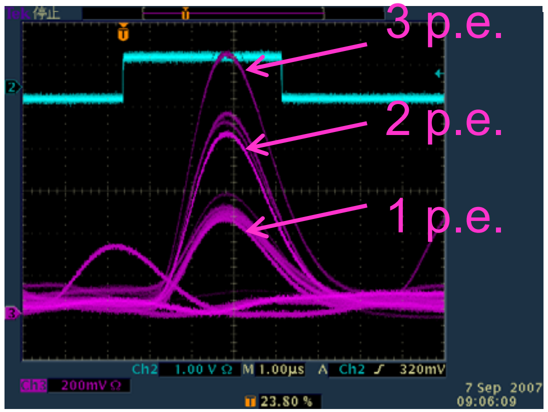
144ch HAPD

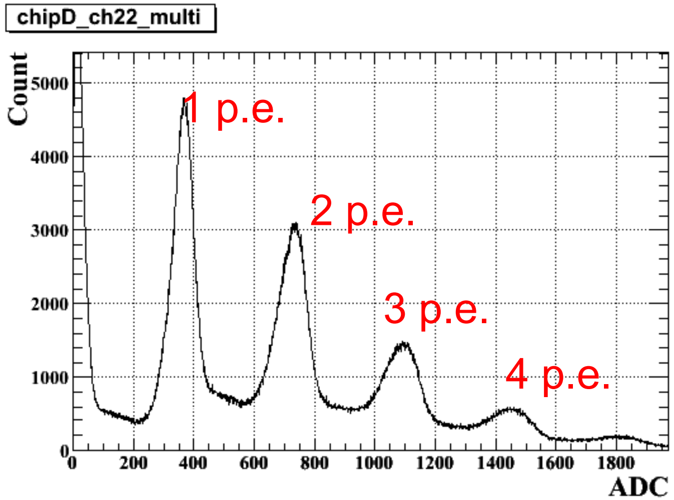


- Newly developed under collaboration with Hamamatsu Photonic
- 4 APD chips (6x6pixel/chip)
- 5x5mm2 pixel



Test at bench

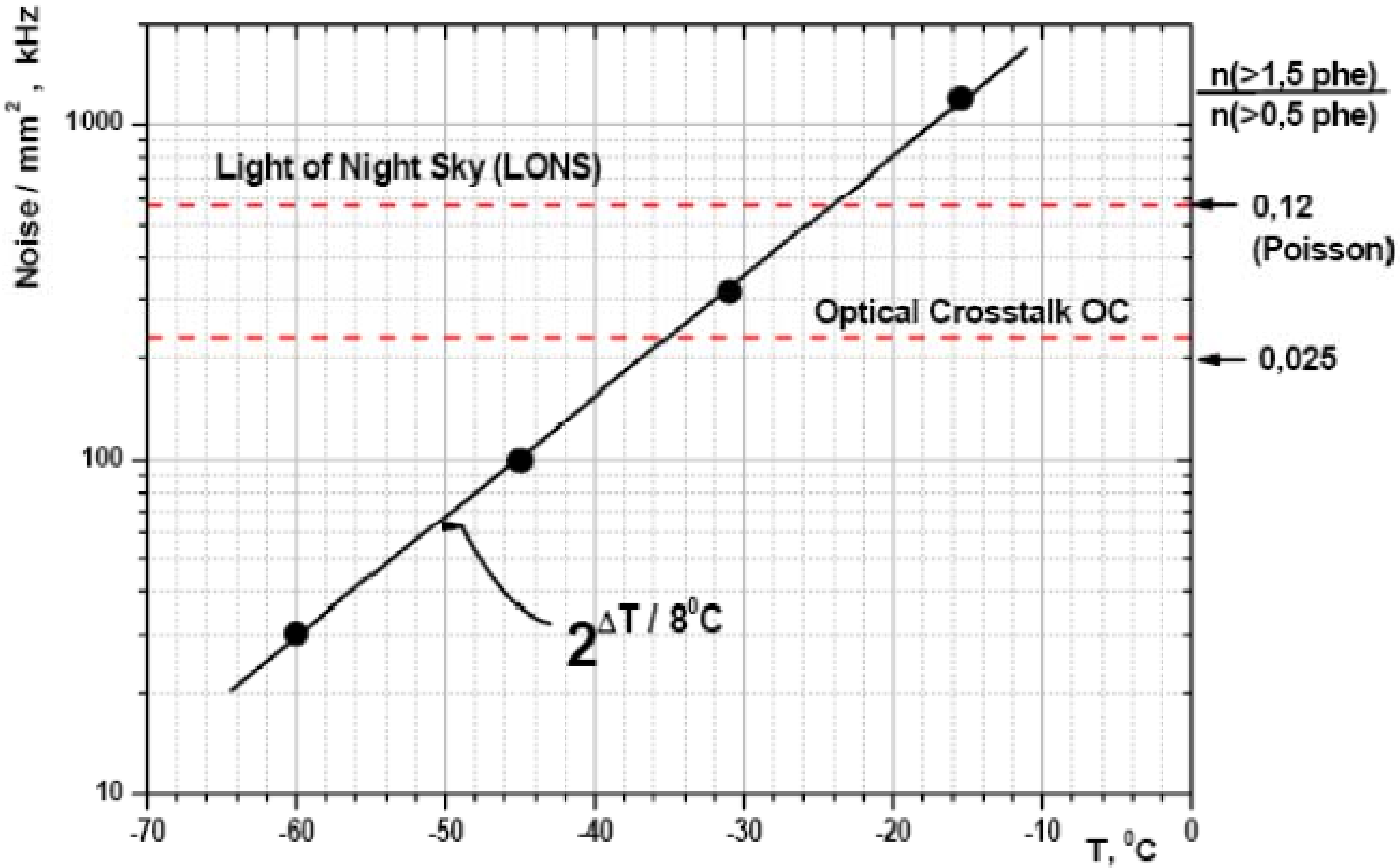


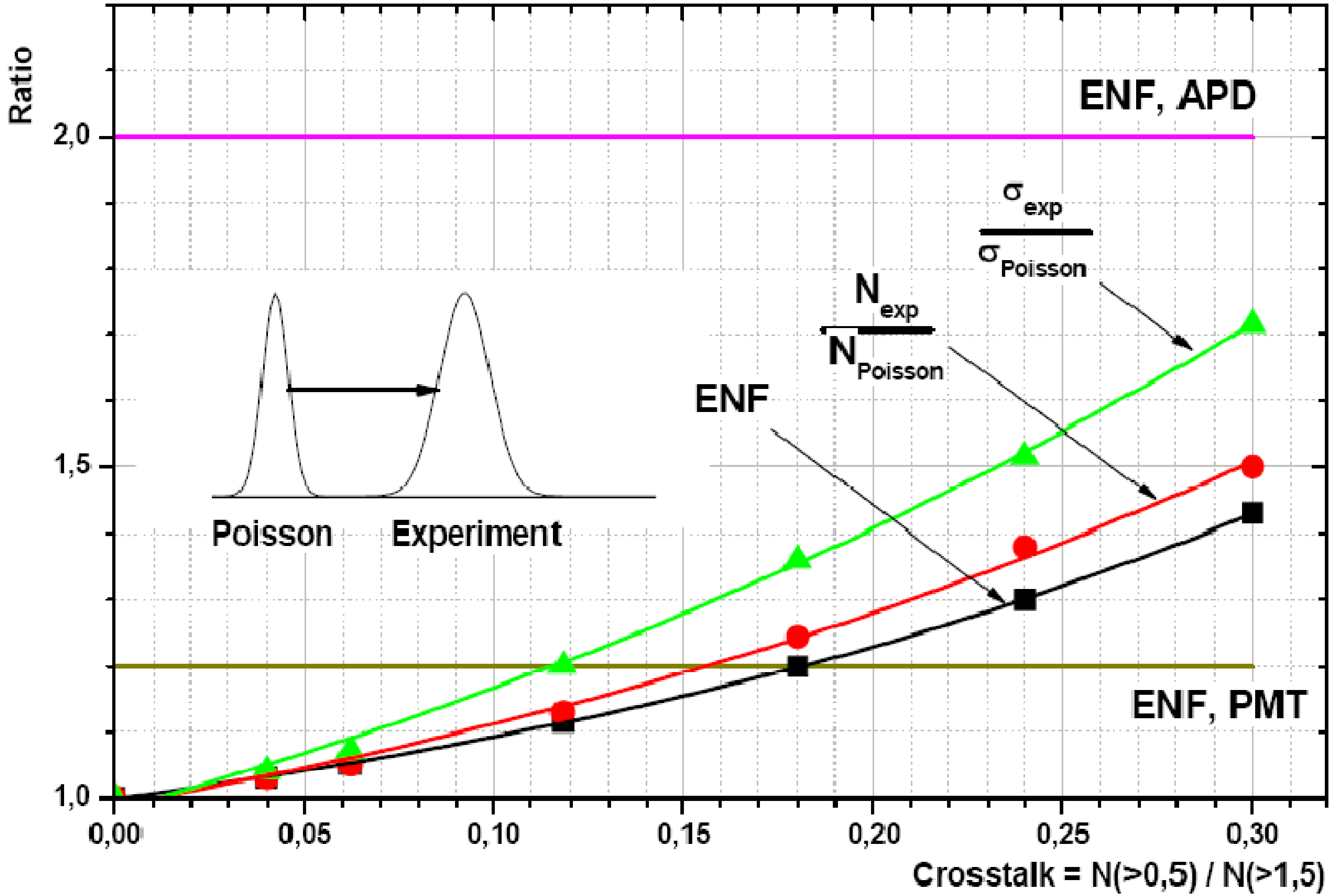


Total gain ~ 5×10^4

S/N = 8-15 for single p.e.

Dark Rate vs temperature ➔ acceptable temperature



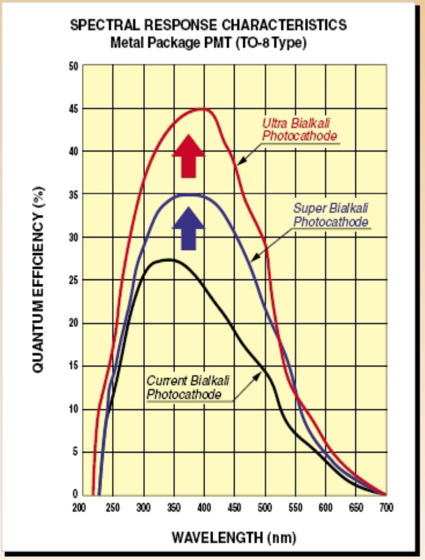


Ratio
2,0
1,5
1,0
0,00
0,05
0,10
0,15
0,20
0,25
0,30
Crosstalk = N(>0,5) / N(>1,5)
ENF, APD
ENF, PMT
ENF
$\frac{N_{exp}}{N_{Poisson}}$
$\frac{\sigma_{exp}}{\sigma_{Poisson}}$
Poisson
Experiment

Recent surprises

High QE achieved with high purity photocathode materials (99.9999) and process tuning

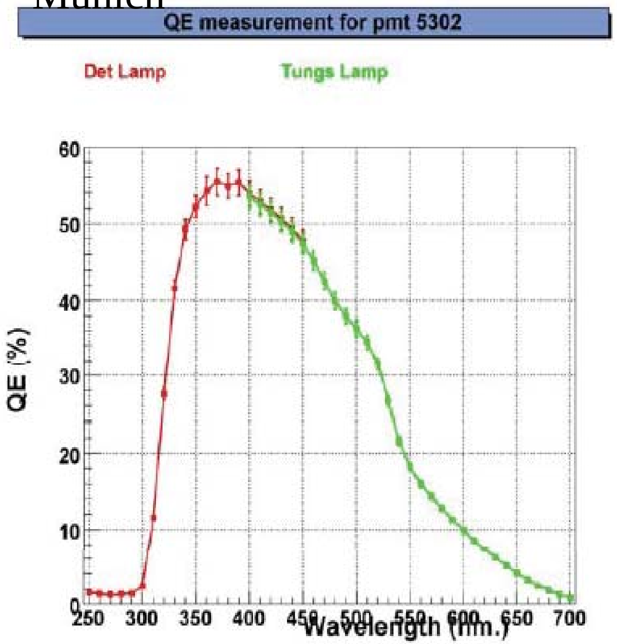
Ultra Bialkali Photocathode (UBA): QE 43% typ.
Super Bialkali Photocathode (SBA): QE 35% typ.



Photocathode	QE at peak wavelength		Type Availability
	Min.	Typ.	
Ultra Bialkali (UBA)	38 %	43 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT)
Super Bialkali (SBA)	32 %	35 %	Metal Package PMT (TO-8 Type, □28 mm Type PMT) φ28 mm to φ76 mm Head-on PMT (Glass Bulb Type)

Photonis PMT 5302

Measurements done at MPI Munich

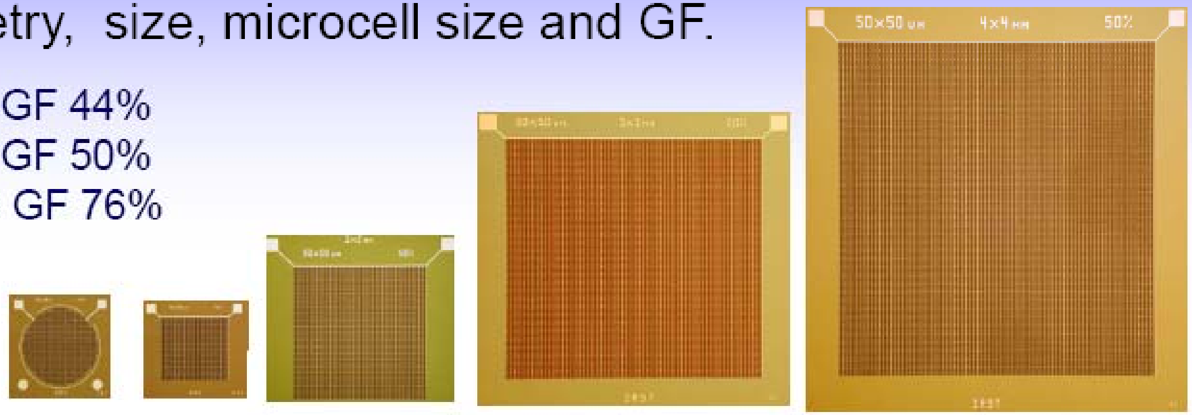


New detectors

N41-2: C. Piemonte. *Recent Progress in the Performance of Silicon Photomultipliers produced at FBK-irst.*

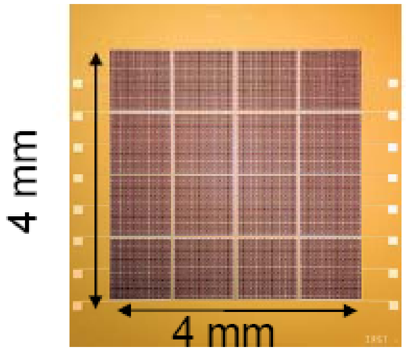
- Different geometry, size, microcell size and GF.

40x40❍m => GF 44%
50x50❍m => GF 50%
100x100❍m => GF 76%

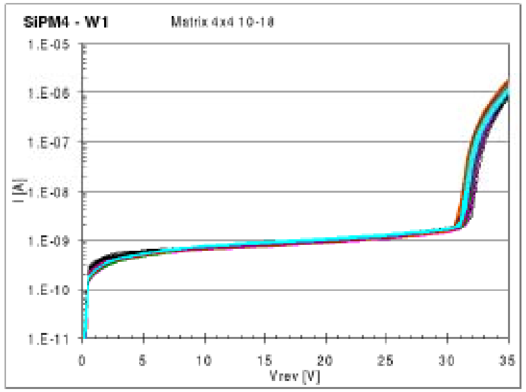


circular (1mm diam) 1x1mm 2x2mm 3x3mm (3600 cells) 4x4mm (6400 cells)

- Matrices 16 elements (4x4)

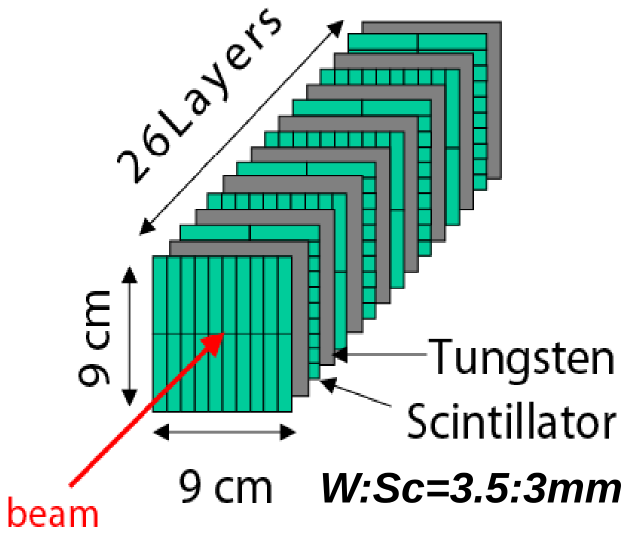


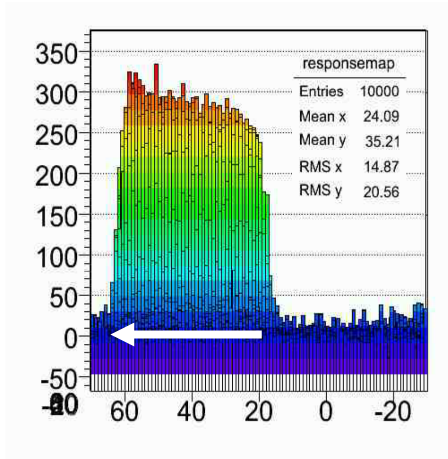
IV CURVES OF 9 MATRICES. VERY UNIFORM BREAKDOWN POINT

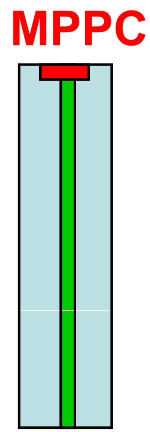


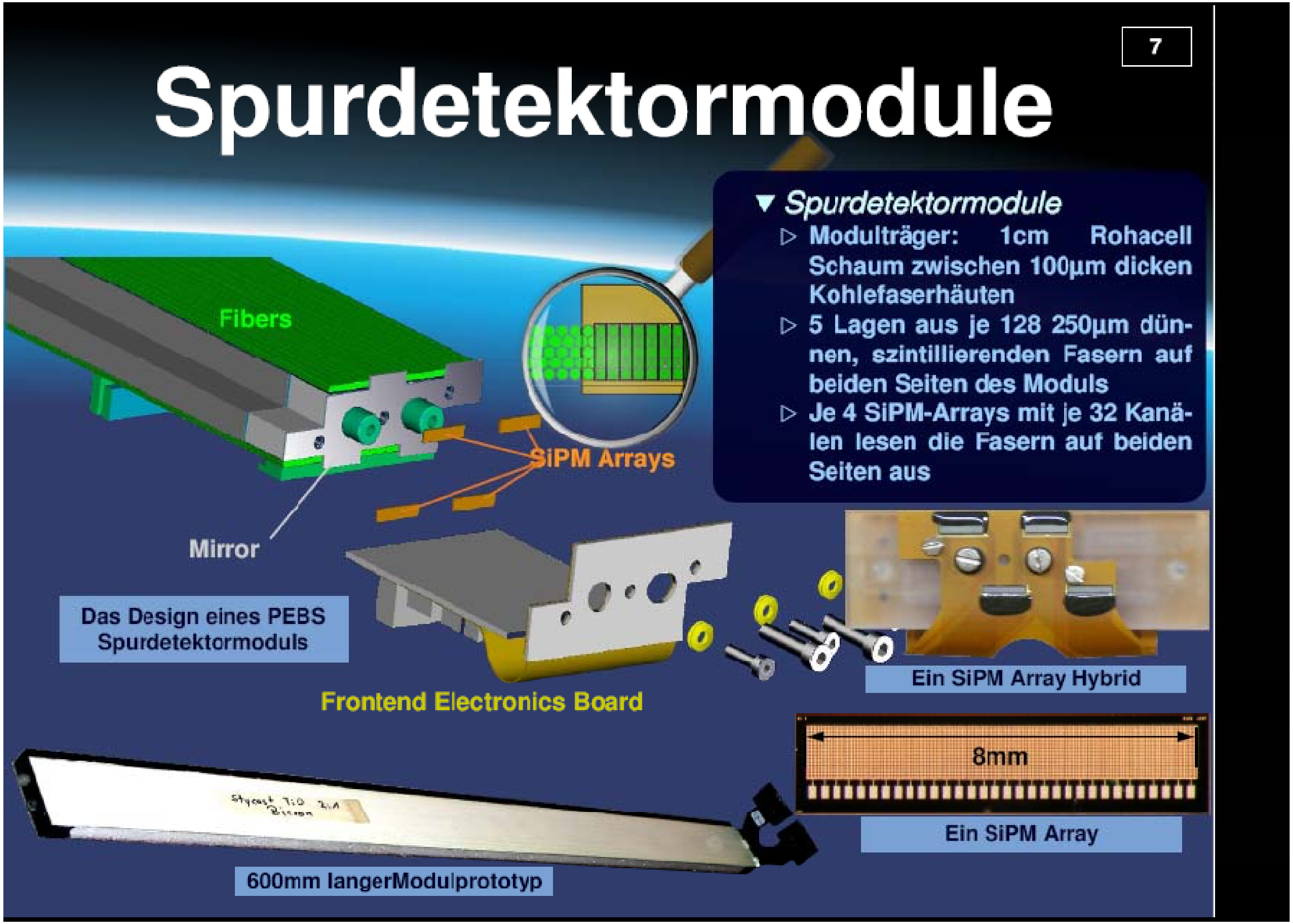
Result of the beam test demonstrates that the MPPC is feasible for the GLD calorimeter readout.

	Photomultiplier	MPPC
Gain	~10^6	10^5~10^6
Photon Detection Eff.	0.1 ~ 0.2	~0.2 for 1600 pix. MPPC
Response	fast	fast
Photon counting	Yes	Great
Bias voltage	~ 1000 V	~ 70 V
Size	Small	Compact
B field	Sensitive	Insensitive
Cost	Very expensive !	Not very expensive
Dynamic range	Good	Determined by # of pixels
Long-term Stability	Good	Unknown
Robustness	decent	**Unknown, presumably good**
Noise (fake signal by thermions)	Quiet	Noisy (order of 100 kHz)









7
Spurdetektormodule
Spurdetektormodule
Modulträger: 1cm Rohacell Schaum zwischen 100µm dicken Kohlefaserhäuten
5 Lagen aus je 128 250µm dünnen, szintillierenden Fasern auf beiden Seiten des Moduls
Je 4 SiPM-Arrays mit je 32 Kanälen lesen die Fasern auf beiden Seiten aus
Fibers
SiPM Arrays
Mirror
Das Design eines PEBS Spurdetektormoduls
Frontend Electronics Board
Ein SiPM Array Hybrid
8mm
Ein SiPM Array
600mm langerModulprototyp

Selection of SiPMs

1. Long term stability test: ~48 hours at elevated HV (~+3V->5 μA)

Selection criteria: SiPM current < 5 μA

2. Tune of operation HV and saturation curve measurement with LED

Tune HV till number of pixels per MIP 14.25 < ***Npix*** < 15.75

Selection criteria:

SiPM gain ***G*** > $4 \cdot 10^5$

Noise frequency at zero level F_0 < 3 MHz

Noise frequency at ½ MIP level $F_{1/2}$ < 3000 Hz

Crosstalk < 0.35

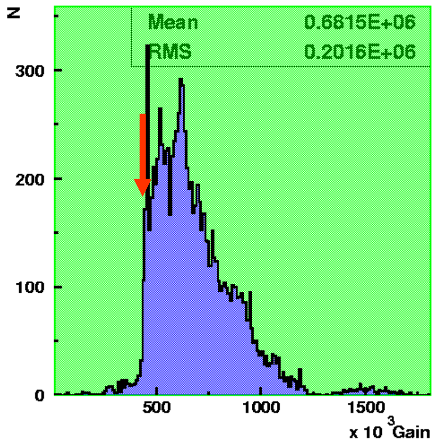
SiPM current ***I*** < 2 μA

RMS of multiple SiPM current measurements RMS_I < 20 nA

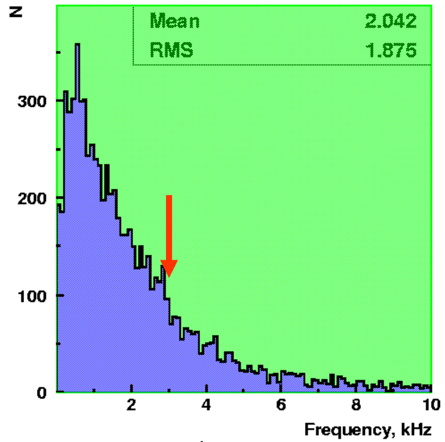
Number of pixels at maximal light (~200MIP) during measurement of saturation curve $N_{pix\ max}$ > 900

3. Check Tile-WLS Fiber-SiPM system with Sr source

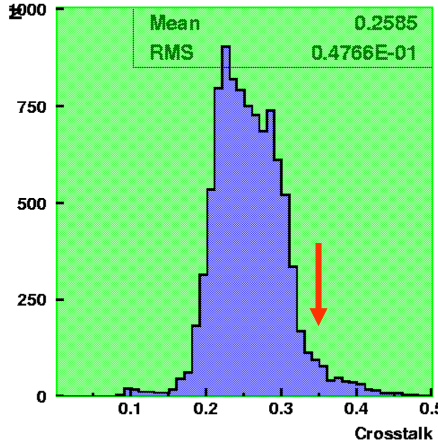
Parameters of ~ 10000 tested SiPM's



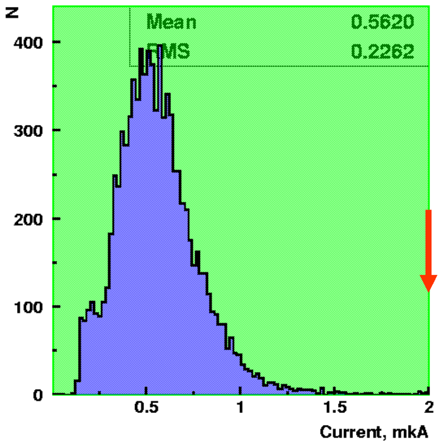
GAIN



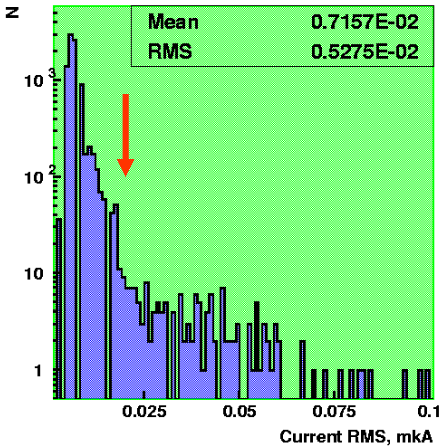
NOISE AT ½ MIP(7.5 pixels)



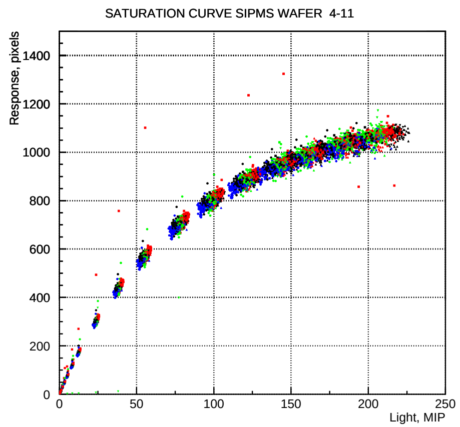
CROSS TALK



SIPM CURRENT

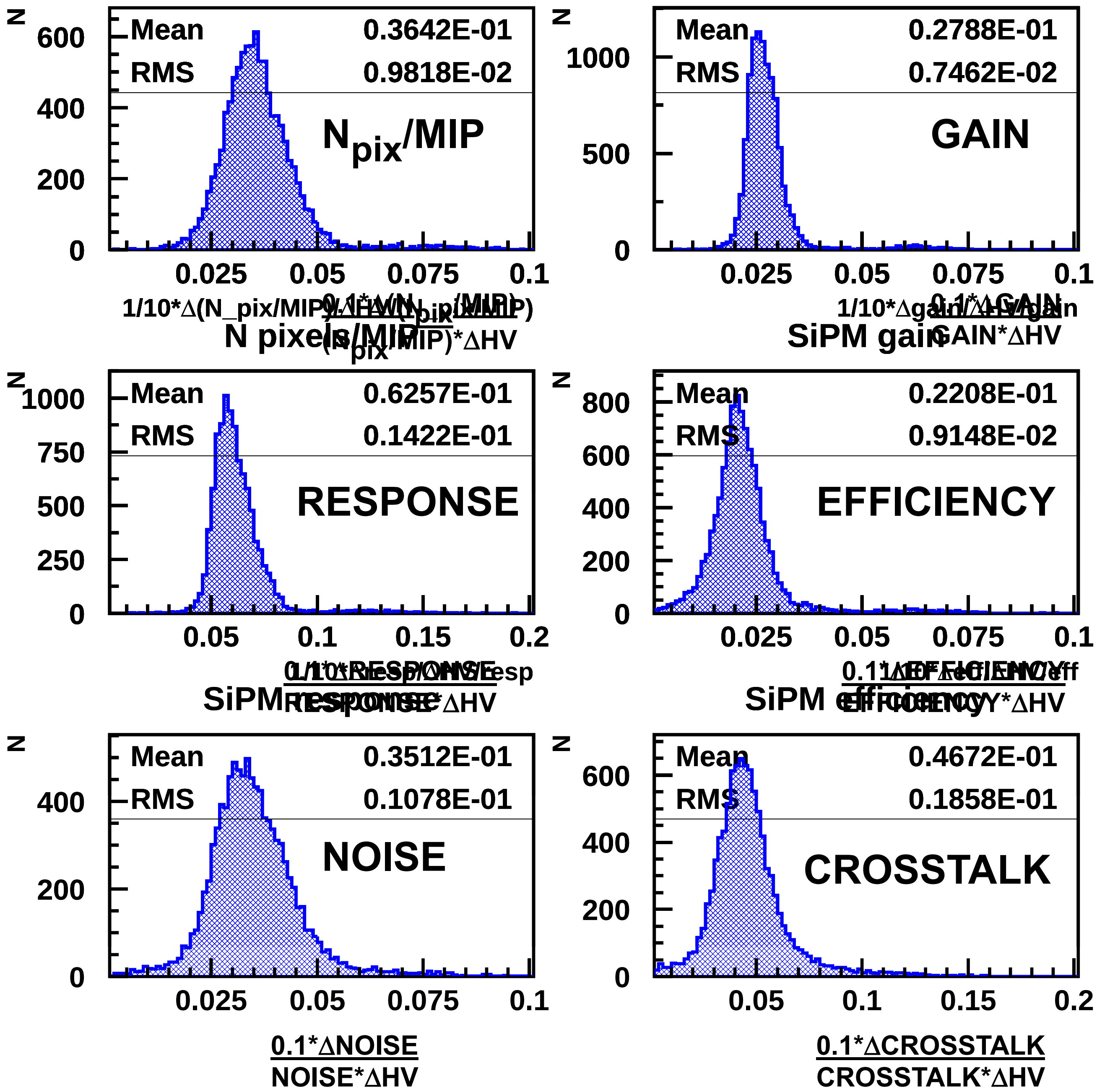


CURRENT STABILITY

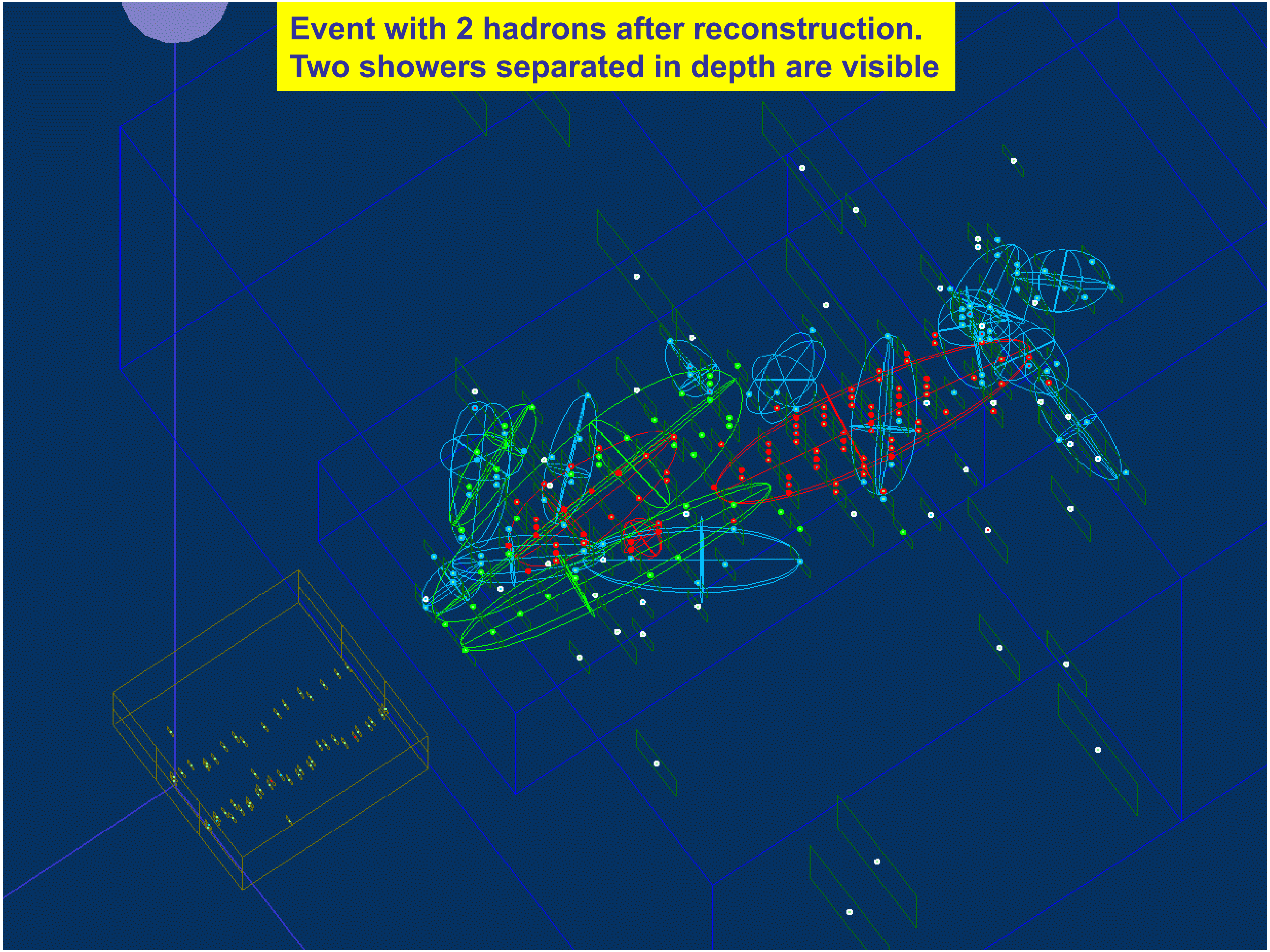


SATURATION CURVE

SIPM PARAMETER VARIATION AT 0.1 V HV VARIATION

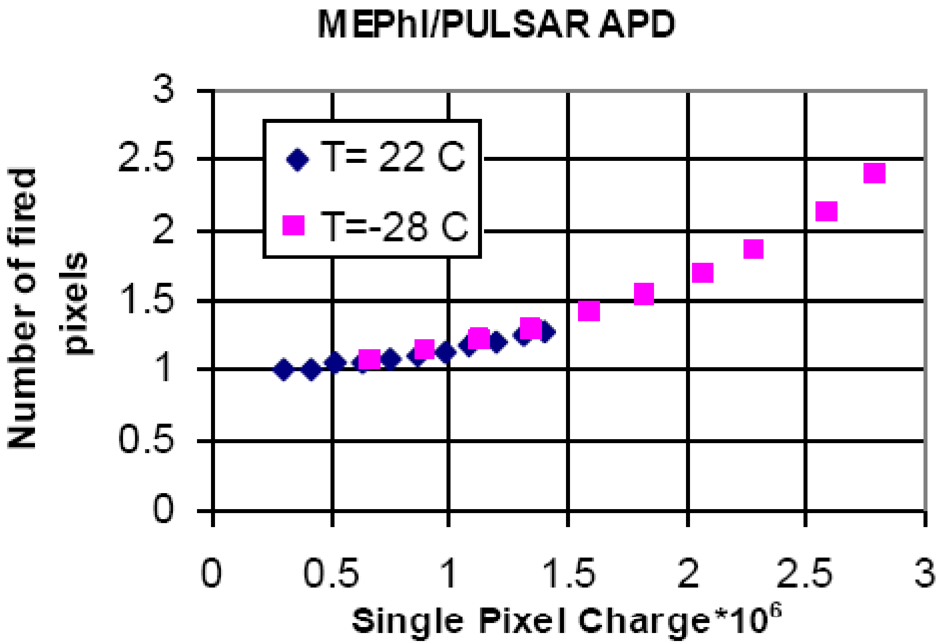


Event with 2 hadrons after reconstruction.
Two showers separated in depth are visible



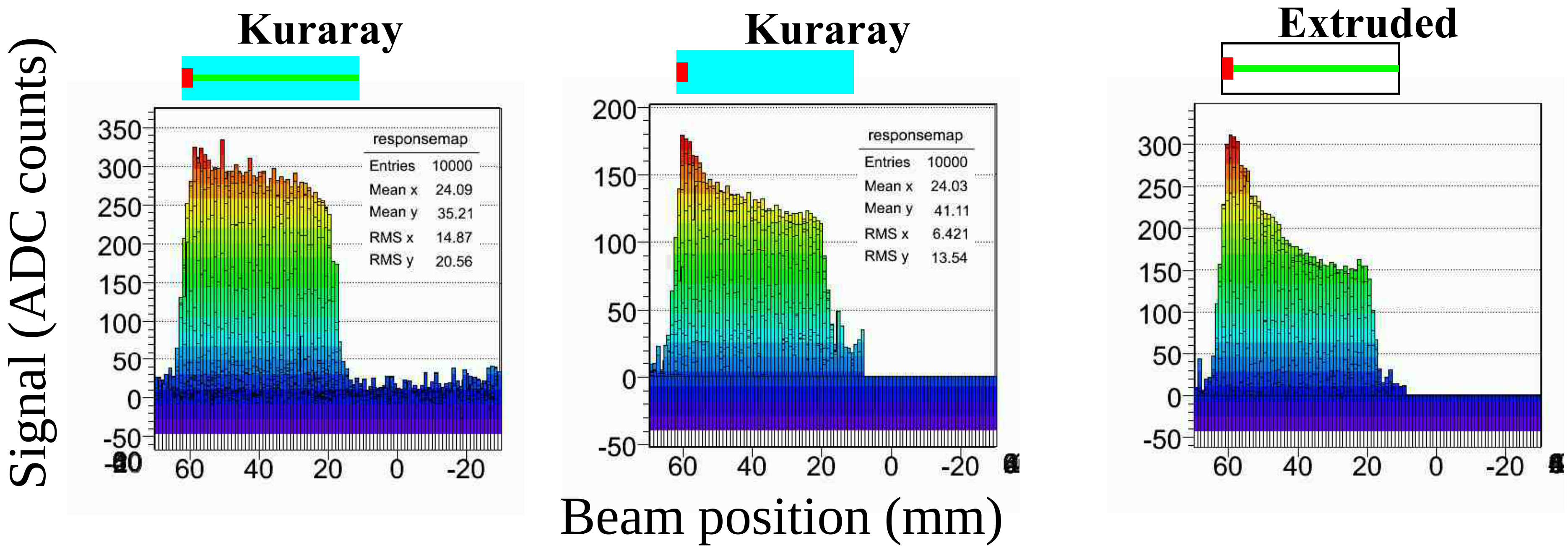
Excess Noise Factor

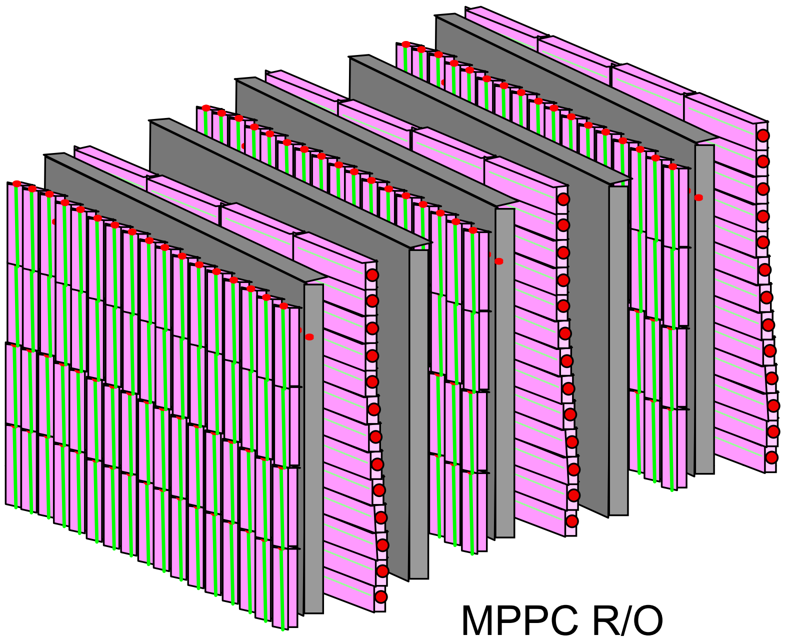
… and in an increase of the SiPM excess noise factor



$$F = 1 + \frac{\sigma_M^2}{M^2}$$

Uniformity of 3 different types of scintillators





- The 2[nd] prototype will be 4 times larger than the DESY BT module.
  (20 x 20 cm, ~30 layers)
- Fully adopt the extruded scintillators.
- Expect > 2000 readout channels.

	PMT	**MCP-PMT**	**HPD / HAPD**	**Geigermode-APD**
Gain	$>10^6$	$\sim 10^6$	$\sim 10^3$ X10～100 w/ APD	$\sim 10^6$
Quantum Eff.	～20%, ～400nm (bialkali)			**> 50%, ～** 600nm
Collection Eff.	70%	60%	**100%**	50%
Time resolution	～300ps	**～30ps**	～150ps Depends on readout	<100ps To be checked
B-field immunity	×	△ Depends on angle		○
Problems		lifetime		Noise, size

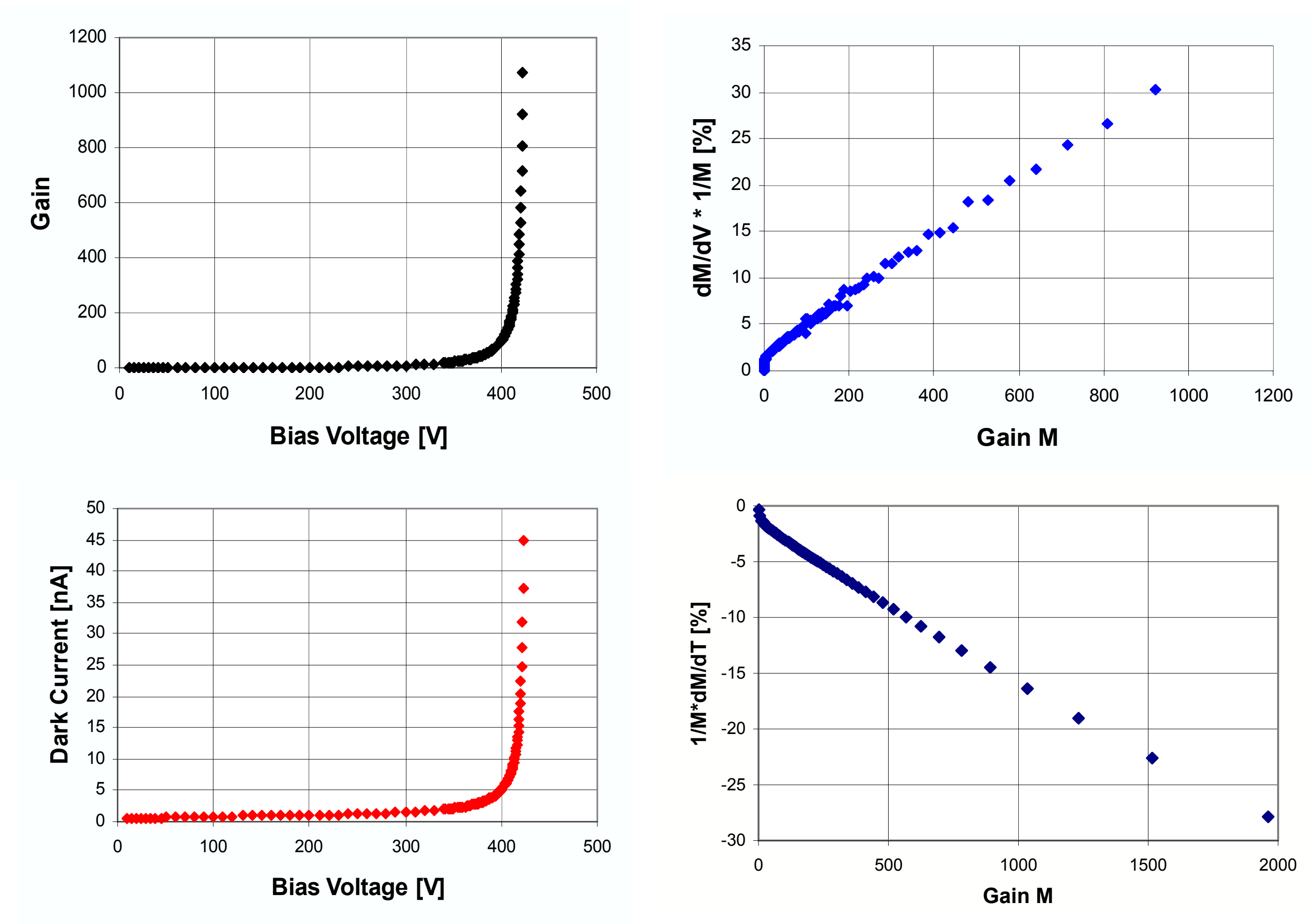
Since 1989 many GM APD structures were developed by different developers:

- CPTA/Photnique (Moscow/Geneva)
- Zecotek (Singapur)
- MEPhI/Pulsar (Moscow)
- Hamamatsu Photonics (Hamamatsu, Japan)
- SensL (Cork, Ireland)
- RMD (Boston)
- MPI Semiconductor Laboratory (Munich, Germany)
- FBK-irst (Trento, Italy)
- ……

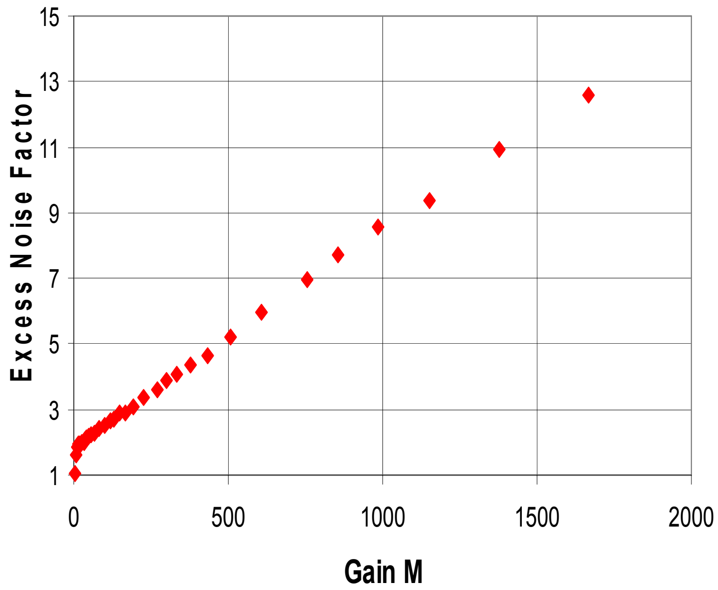
Every producer invented their own name for this device:

MRS APD, MAPD, SiPM, SSPM, SPM, G-APD , MPPC

Stability of a 5x5 mm^2 APD from Hamamatsu



Excess Noise Factor



$F(\langle M \rangle) = \langle M^2 \rangle / \langle M \rangle^2$

$F = k_{eff} \cdot M + (2-1/M) \cdot (1-k_{eff})$

for $M > 10$: $F = 2 + k_{eff} \cdot M$

$k_{eff} \approx k = \beta/\alpha$

α and β are the ionization coefficients for electrons and holes

$\alpha >> \beta$

Emission Spectrum of Y11 WLS Fiber

Measured at distances 10cm, 30cm, 100cm and 300cm from source.