SiPM characterization at LAL

XI SuperB Workshop
Frascati, December 1-5 2009

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On behalf of the Instrumentation Group :

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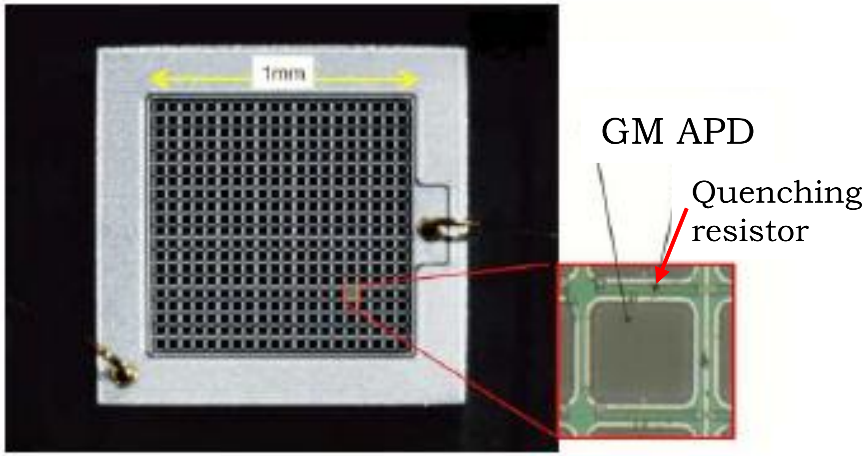
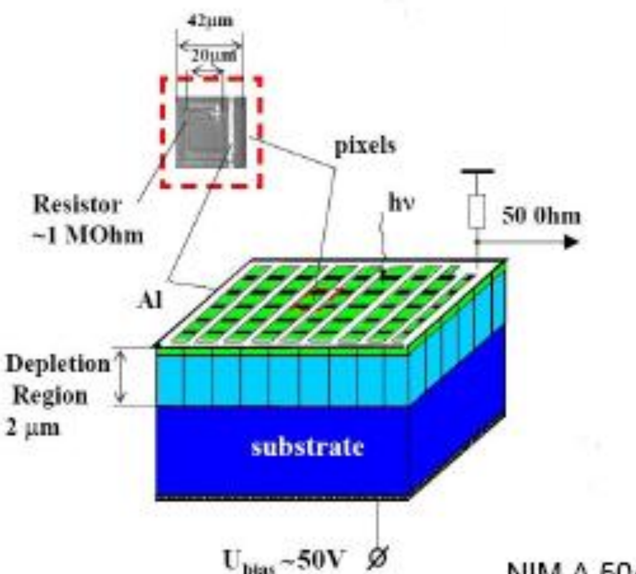
D.W. Kim (from December)

The Silicon Photomultiplier (SiPM)

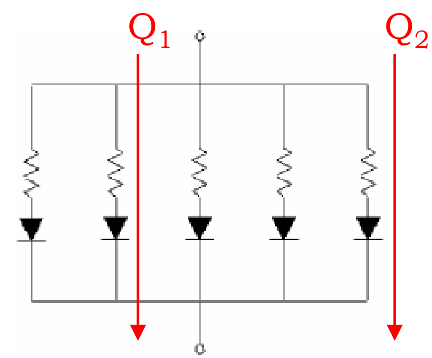
HAMAMATSU MPPC





NIM A 504 (2003) 48

- Single SiPM segmented in micro GM-APD cells (pixels)
- Each pixel has one passive quenching resistor
- All pixels connected in parallel.



$Q = Q_1 + Q_2 = 2 \times Q_1$

Output charge α nb of triggered pixels

α nb of incident photons

Characterization of SiPM at LAL

❖ Active area : geometrical parameters (fill factor)

DTM Test Bench

❖ Operational voltage range
- Breakdown voltage (V_{BD})
- Dark noise (DCR)

❖ Noise : DCR + after-pulse + cross-talk

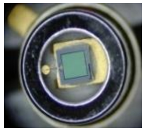
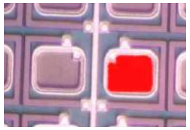
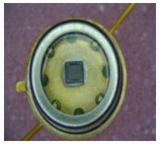
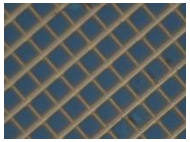
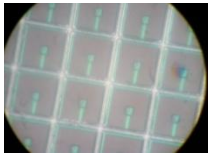
❖ Gain

Optical Test Bench

❖ Dynamic range
- saturation
- τ recovery

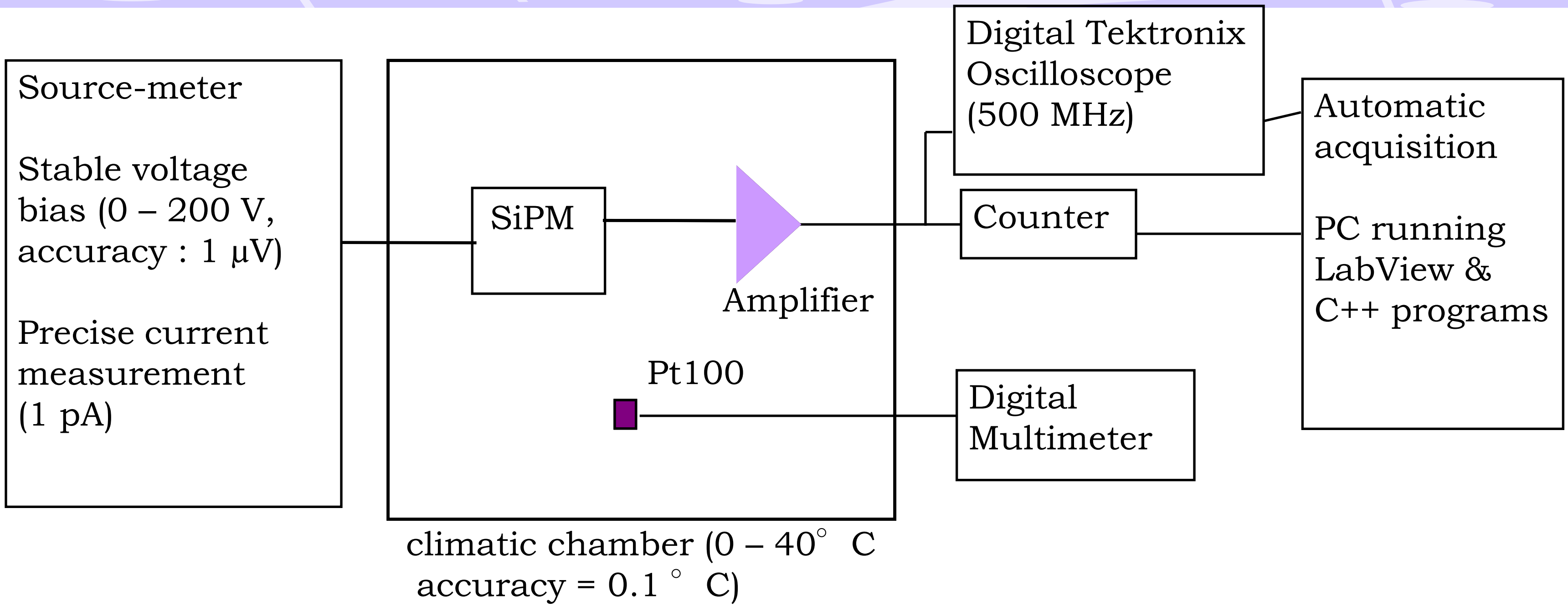
❖ Photon Detection Efficiency (PDE)

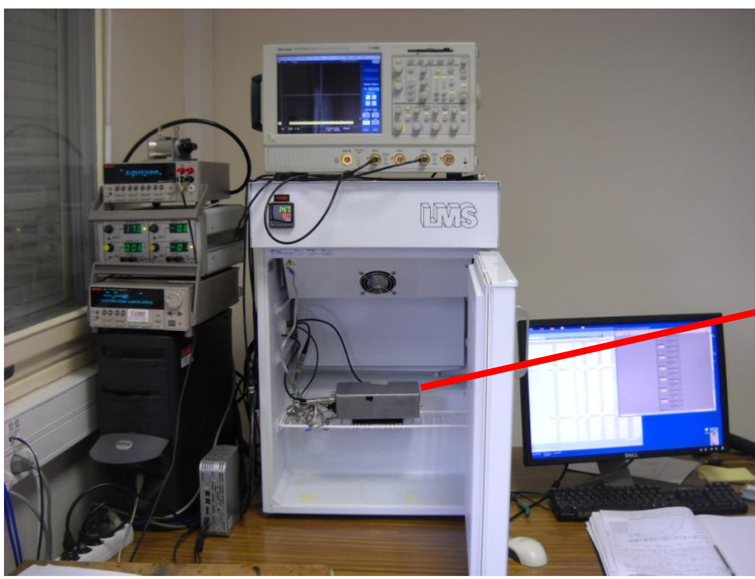
SiPMs (1 mm^2) studied at LAL

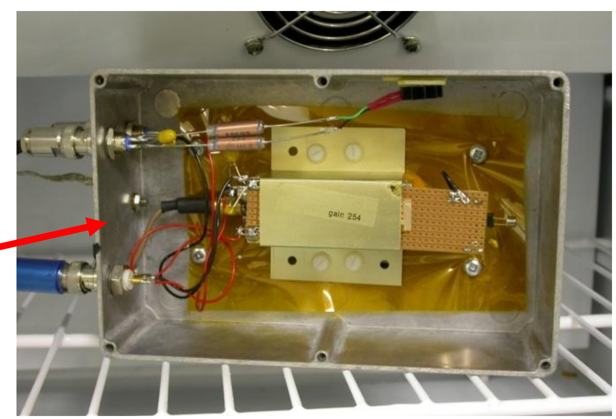
	Reference	Pixel nb	Pixel size (µm)	Fill factor (%)
F.B.K W  	**W20-B10-T3V2PD**	**625**	**40 x 40**	**20**
	W3-B3-T6V1PD	**625**	**40 x 40**	**16**
Hamamatsu MPPC  	**S10362-11-25**	**1600**	**25 x 25**	**31**
	S10362-11-50	**400**	**50 x 50**	**61.6**
	S10362-11-100	**100**	**100x 100**	**78.5**
SensL SPM  	**SPM-20**	**848**	**29 x 32**	**43**
	SPM-35	**400**	**44 x 47**	**59**
	SPM-50	**216**	**59x 62**	**68**
Photonique SSPM  	**SSPM-0701-BG**	**556**	**43 x 43**	**70**

V. Puill, XIth SuperB Project Meeting, Frascati, Dec 1-5 2009

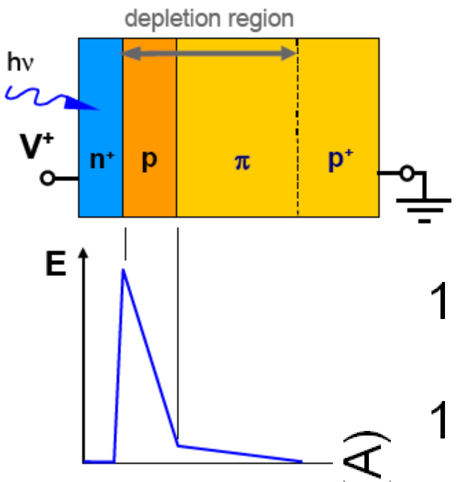
Facility 1 : The Dark Monitored Temperature (DMT) Test Bench

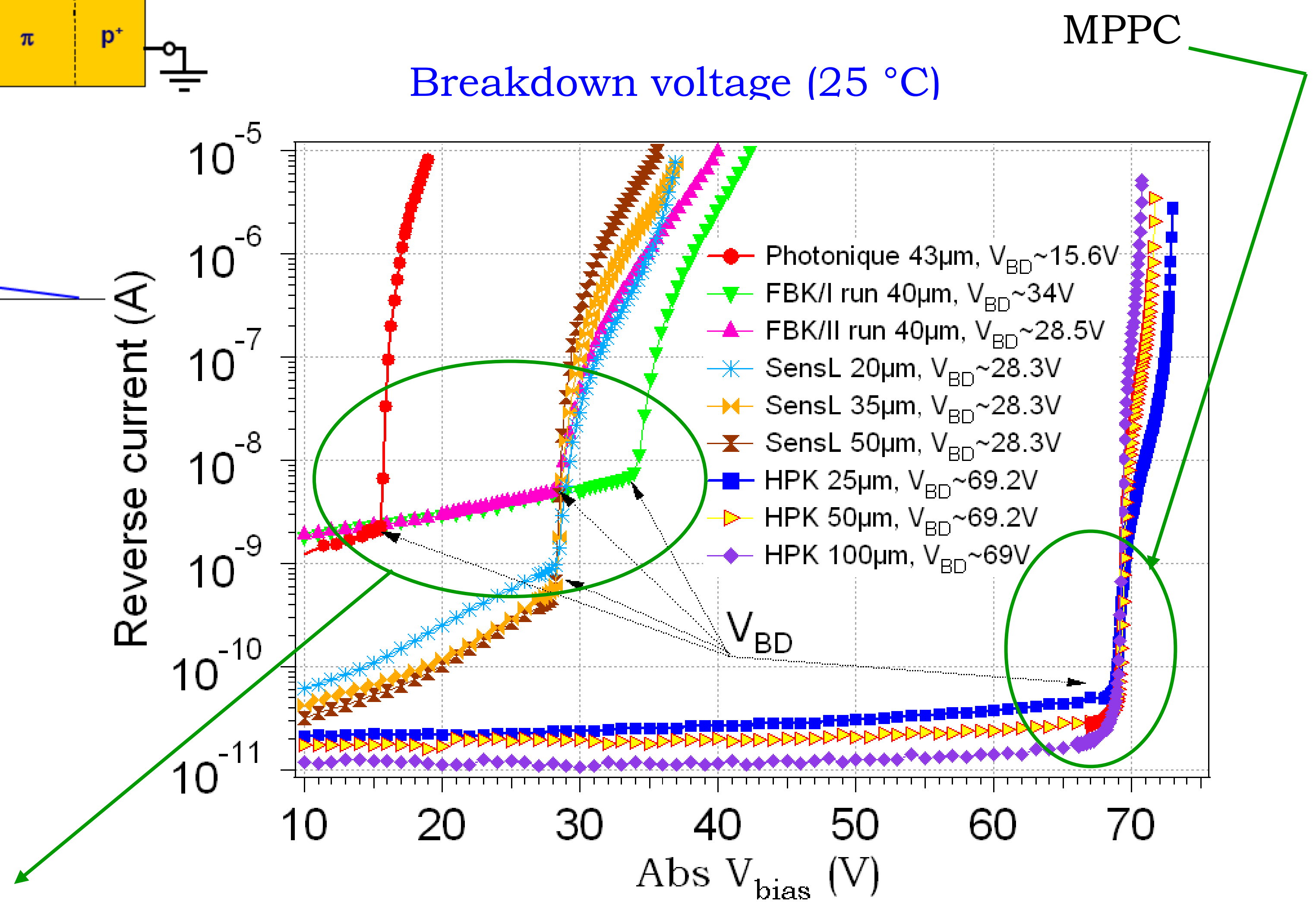






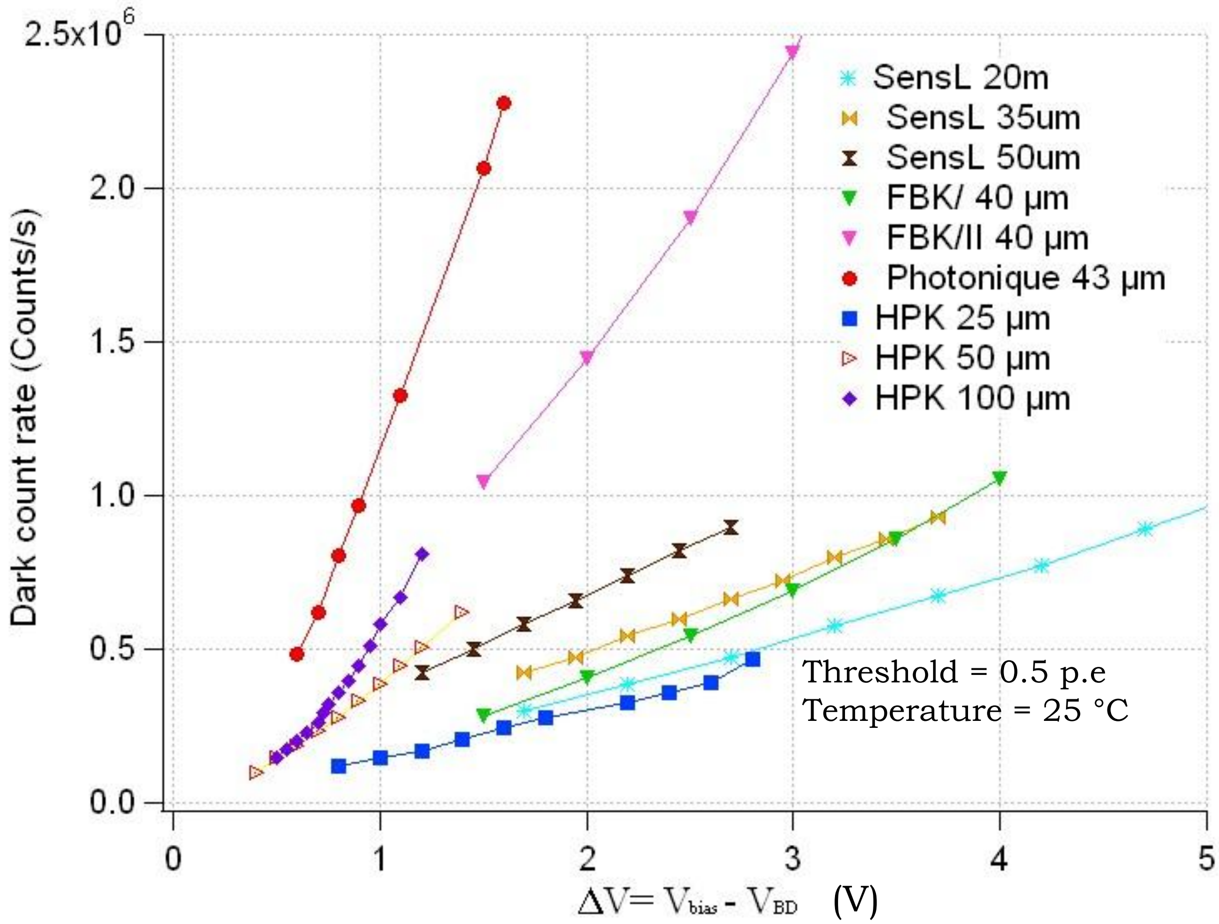
Determination of the operational voltage range : phase 1 : V_{BD}





Determination of the operational voltage range : phase 2 : DCR

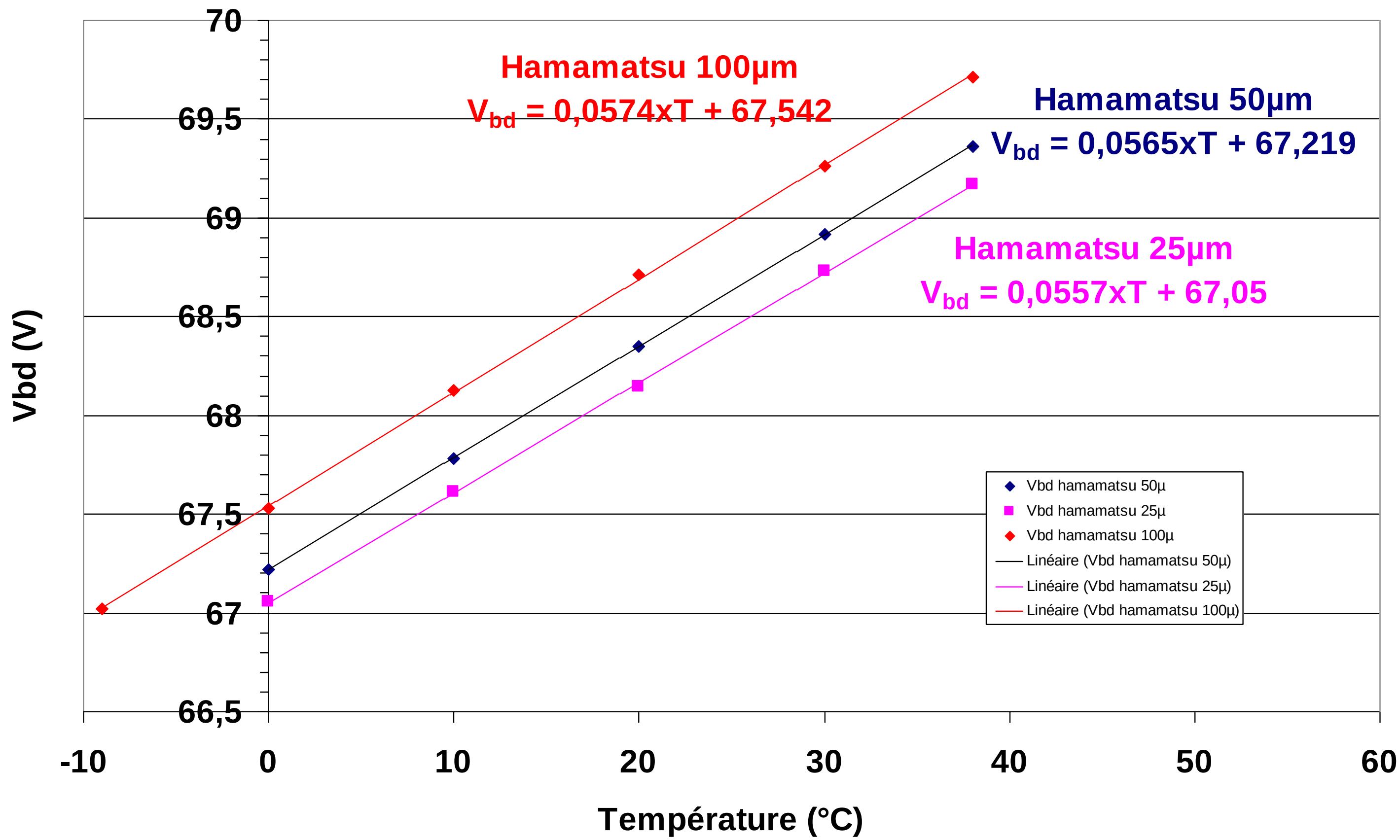
Dark noise : thermally produced avalanches. Look the same as pulses from photon



Operational voltage range :

$\Delta V/V_{BD}$~ 10-13% for Photonique, FBK, SensL SiPM
$\Delta V/V_{BD}$ ~ 2-5% for HAMAMATSU MPPC

Evolution of V_{BD} with temperature

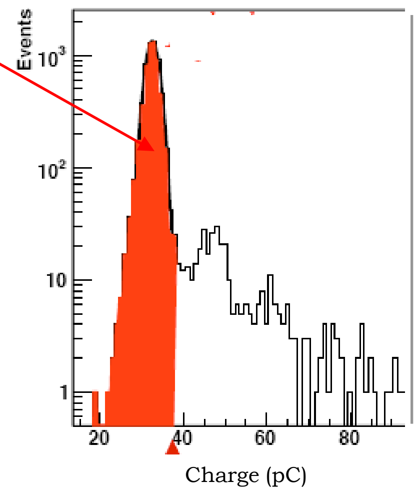


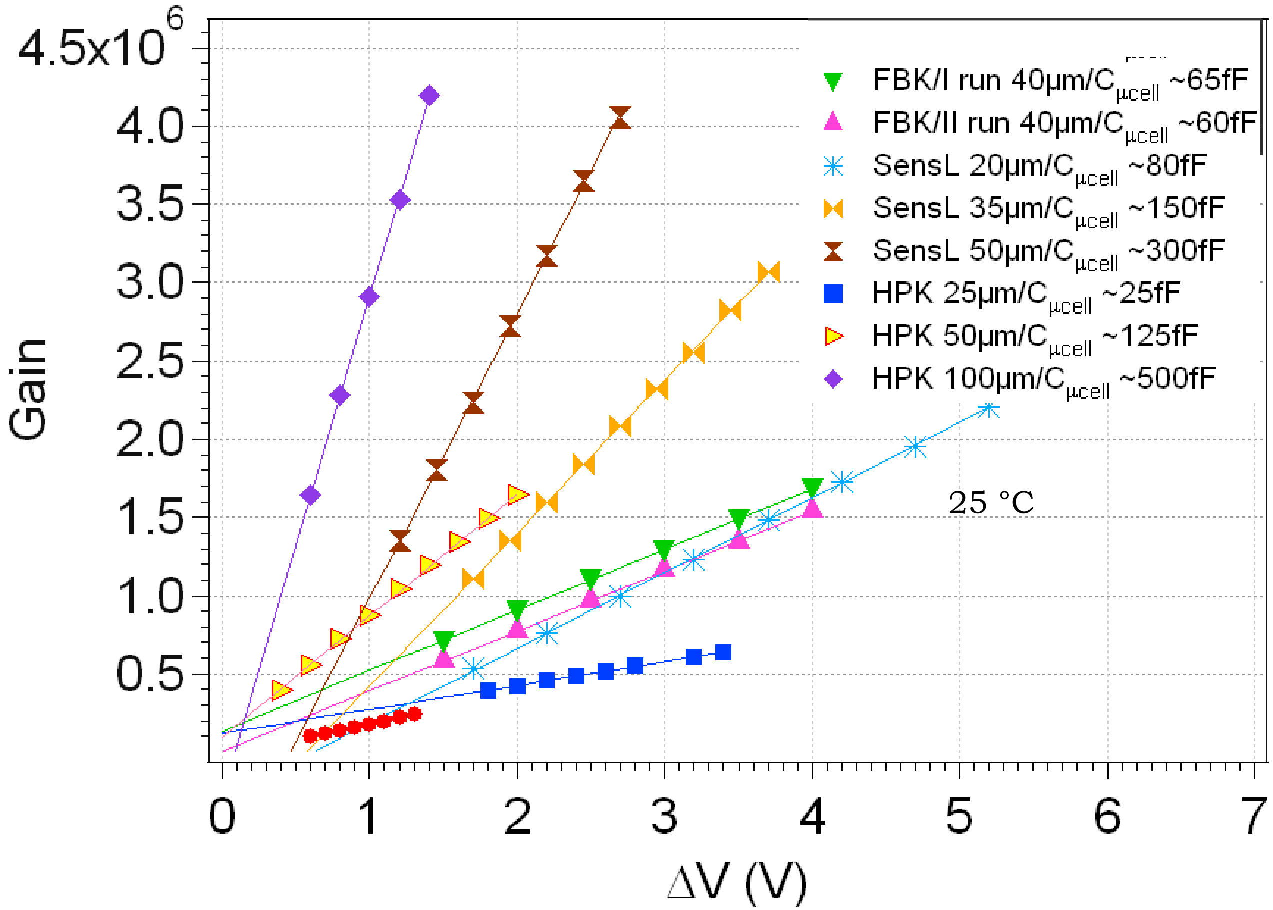
Breakdown voltage increases with the temperature

$dV_{BD}/dT \sim 56$ mV/°C

Defined as the charge developed in one pixel by a primary carrier

$$Gain = \frac{Q_{pixel}}{e} = \frac{C_{pixel} \times (Vbias - VBD)}{e}$$

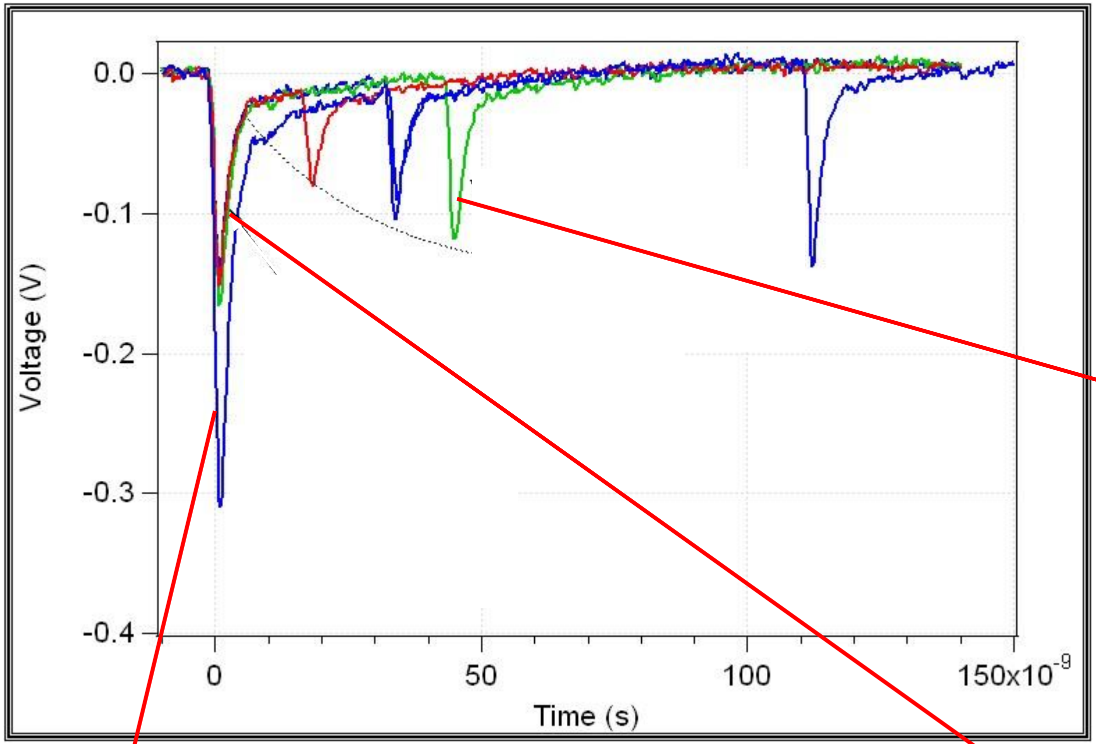




5×10^4 < Gain < 4×10^6

Other noise sources

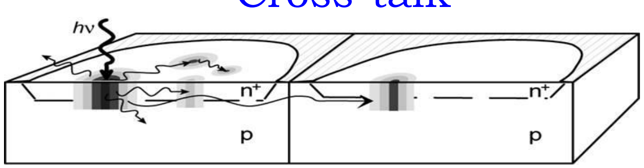
Noise : pulses triggered by non-photo-generated carriers



After-pulses

carriers trapped during the avalanche can produce delayed secondary pulses

Cross-talk



An avalanche in one pixel may produce an optical photon wich can trigger another avalanche in a neighboring pixel without delay

Dark noise

Thermally produced avalanche.
Looks the same as pulse from photon

Ongoing studies on secondary effects and temperature dependence of SiPM

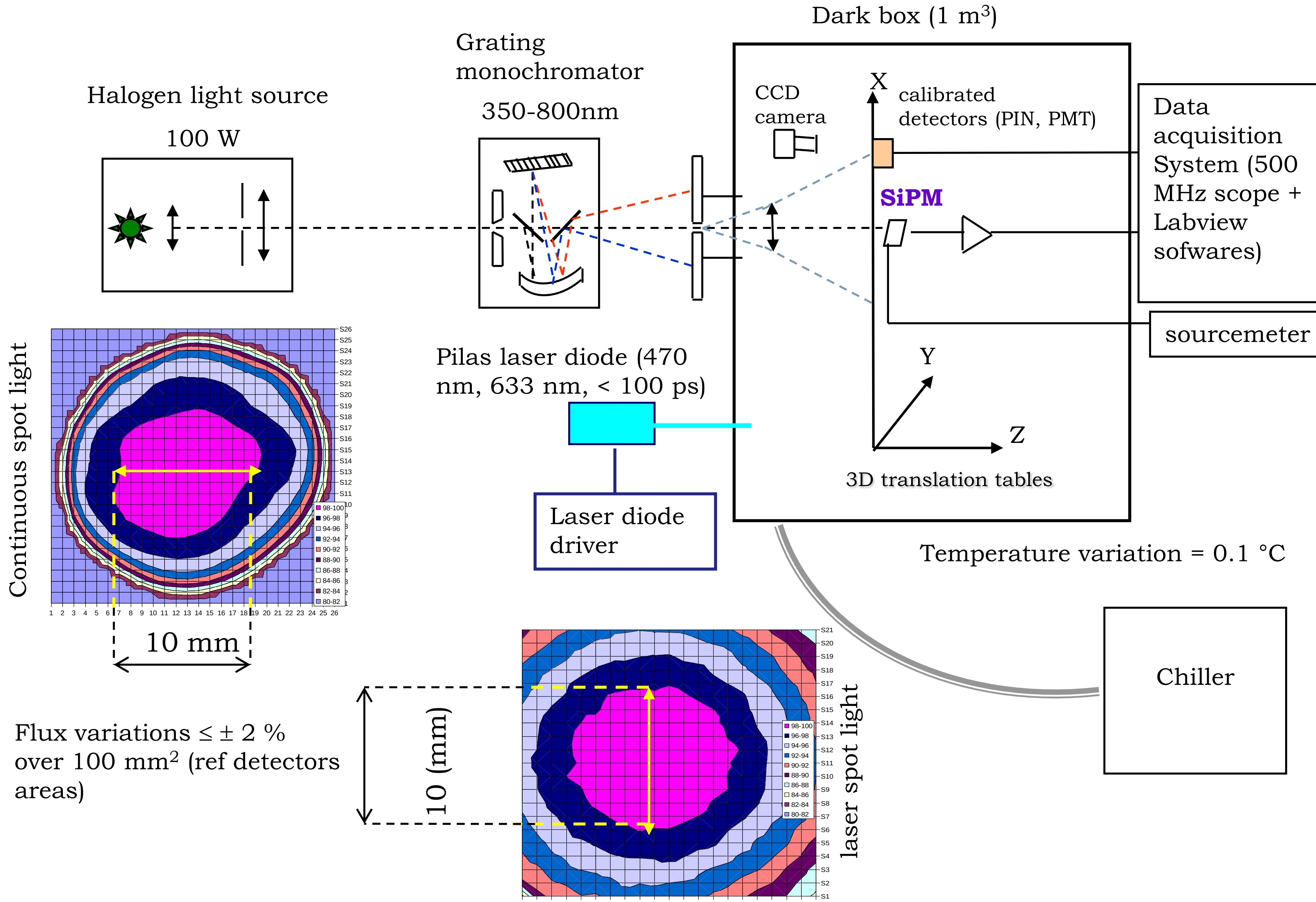
- ❖ After-pulses
- ❖ Cross-talk

Off-line waveform analysis (collaboration with FERMILAB)
→ calculation of the total gain

- ❖ Temperature dependence of the V_{BD}, gains, DCR, pulse shape

To be published soon

Facility 2 : The Optical Test Bench



Flux variations ≤ ± 2 % over 100 mm² (ref detectors areas)

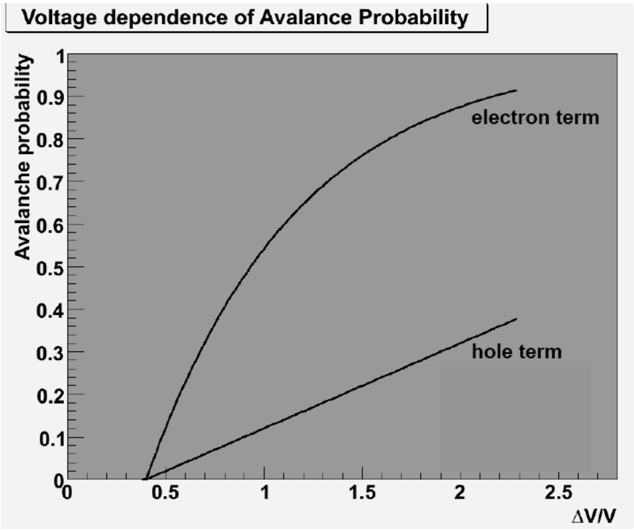
Photon Detection Efficiency

$$PDE = Q_{\varepsilon} \times P_{trigg} \times \varepsilon_{geo}$$

Quantum efficiency
→function of incident
photon wavelength

Avalanche triggering probability
probability of photoelectron creating
an avalanche → function of over-voltage

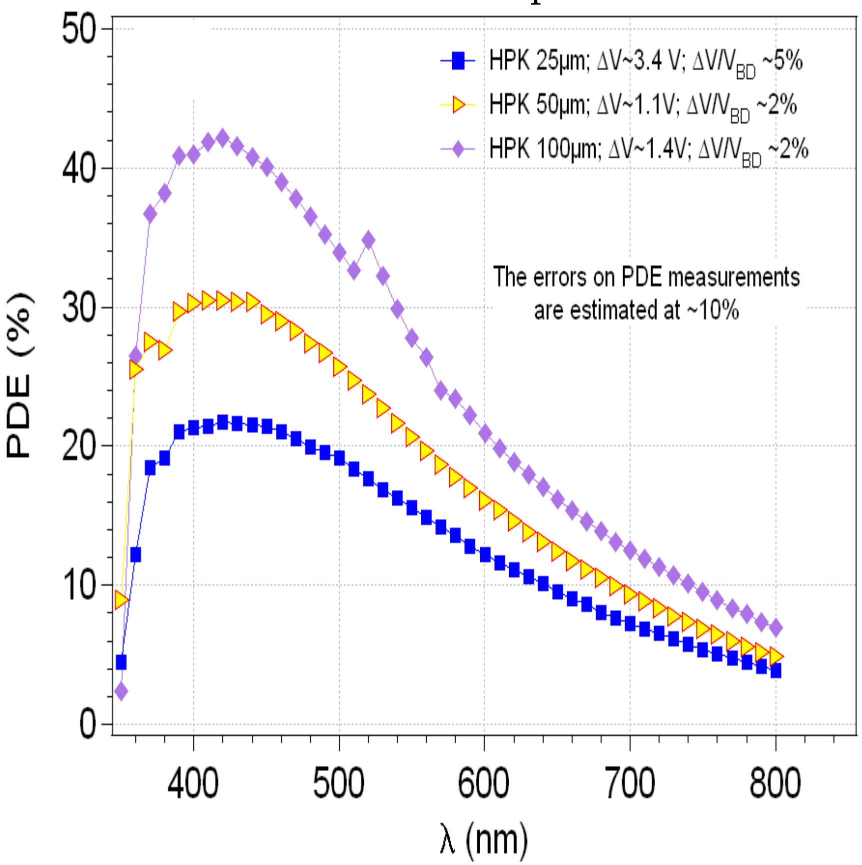
Geometrical fill factor :
Sensitive/total area

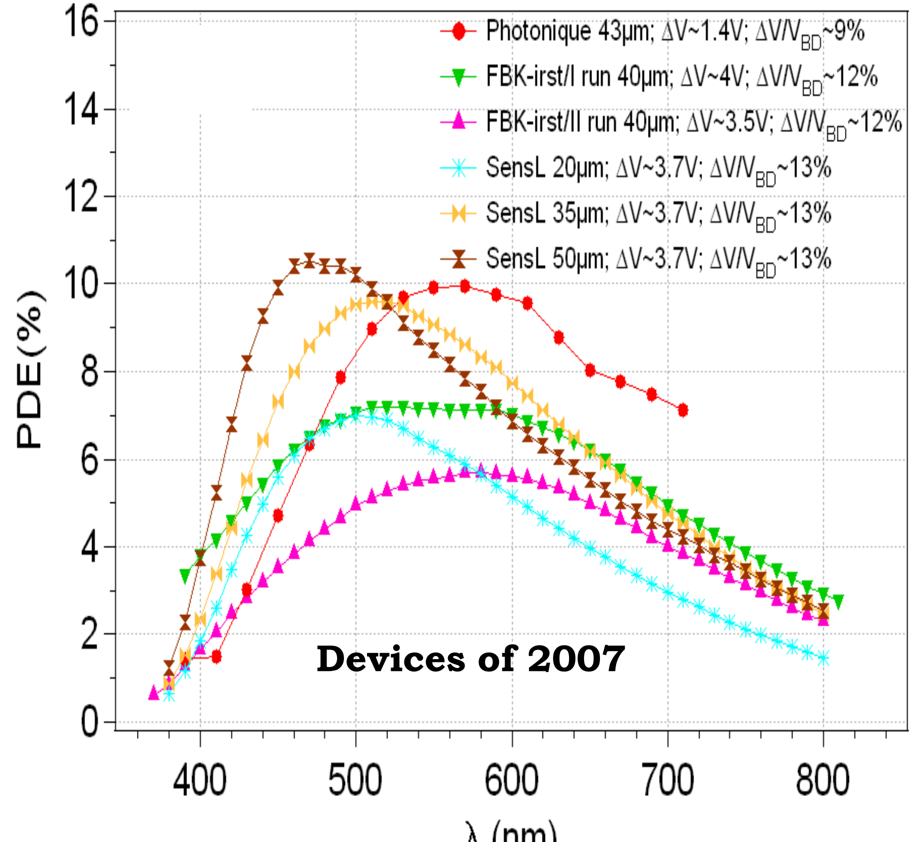


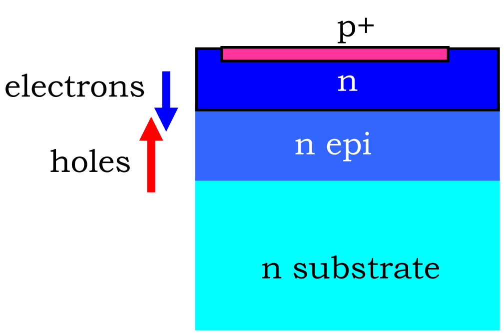
D.Orme, PD09

Measurement of the Photon Detection Efficiency with continuous light at 25 °C (errors +/- 10 %)

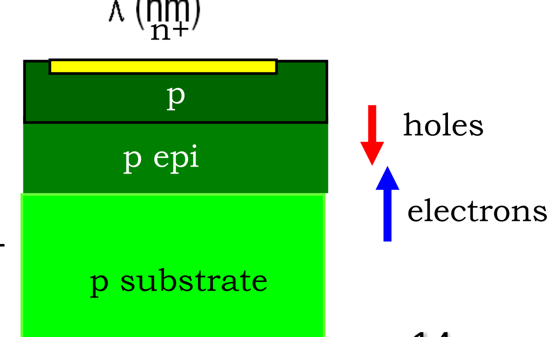
After-pulses and cross-talk taken into account.





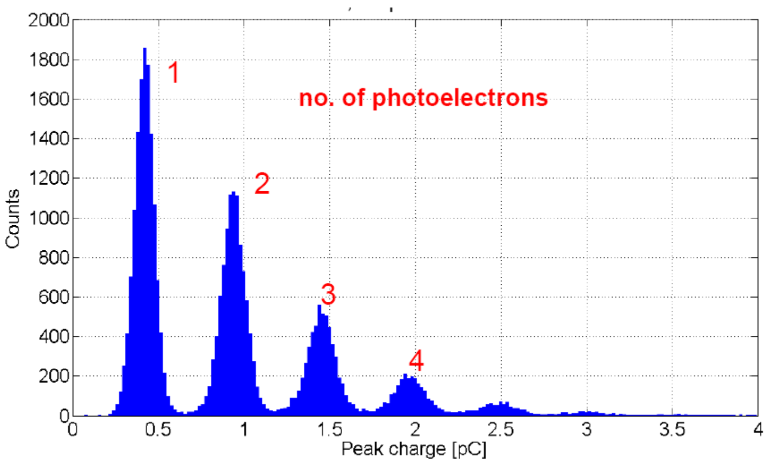


PDE shape is dependent of the structure:
p-on-n is more blue sensitive than n-on-p(e- trigger avalanches at short λ)



Counting method : measurement with pulsed light

$$PDE_{counting} = \frac{(N_{light} - N_{dark})_{SiPM} \, x A_{SiPM}}{\dfrac{(I_{light} - I_{dark})_{PMT}}{G_{PMT} x \varepsilon_{QPMT} x A_{PMT} x q_e}}$$



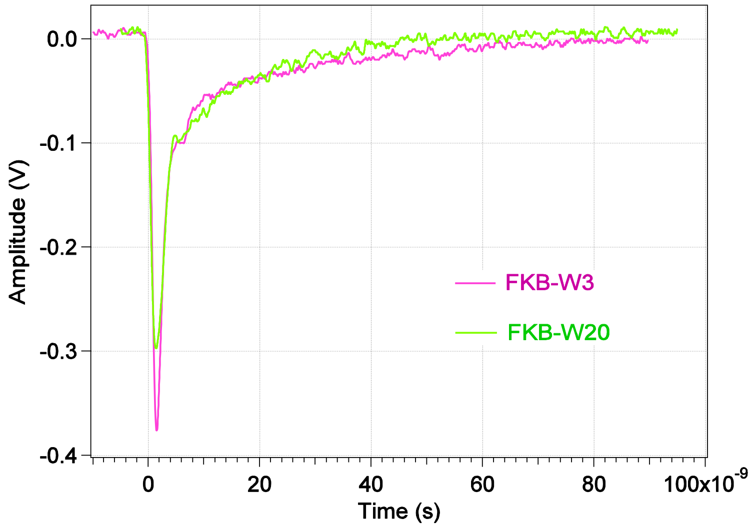
→ no need to calculate the gain

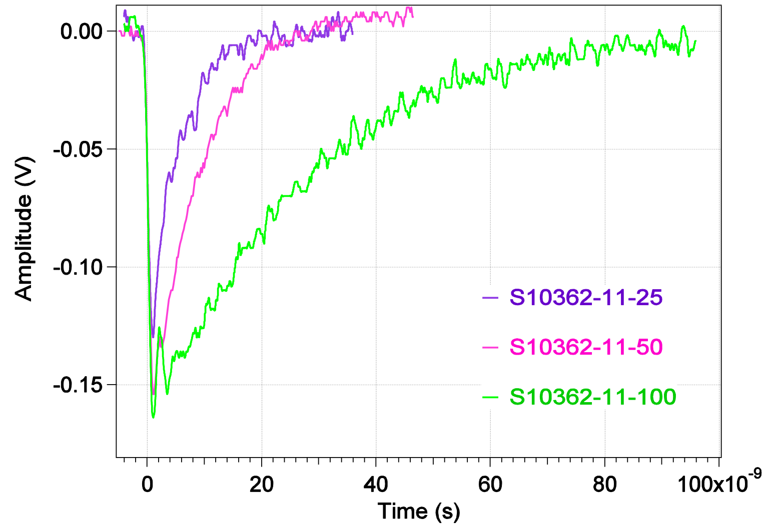
→ decrease of the errors on PDE

Comparison of the 2 methods → results to be published soon (maybe a poster at VCI 2010)

SiPMs Timing Resolution measurements

Pulse shapes of FBK SiPMs and HAMAMATSU MPPCs

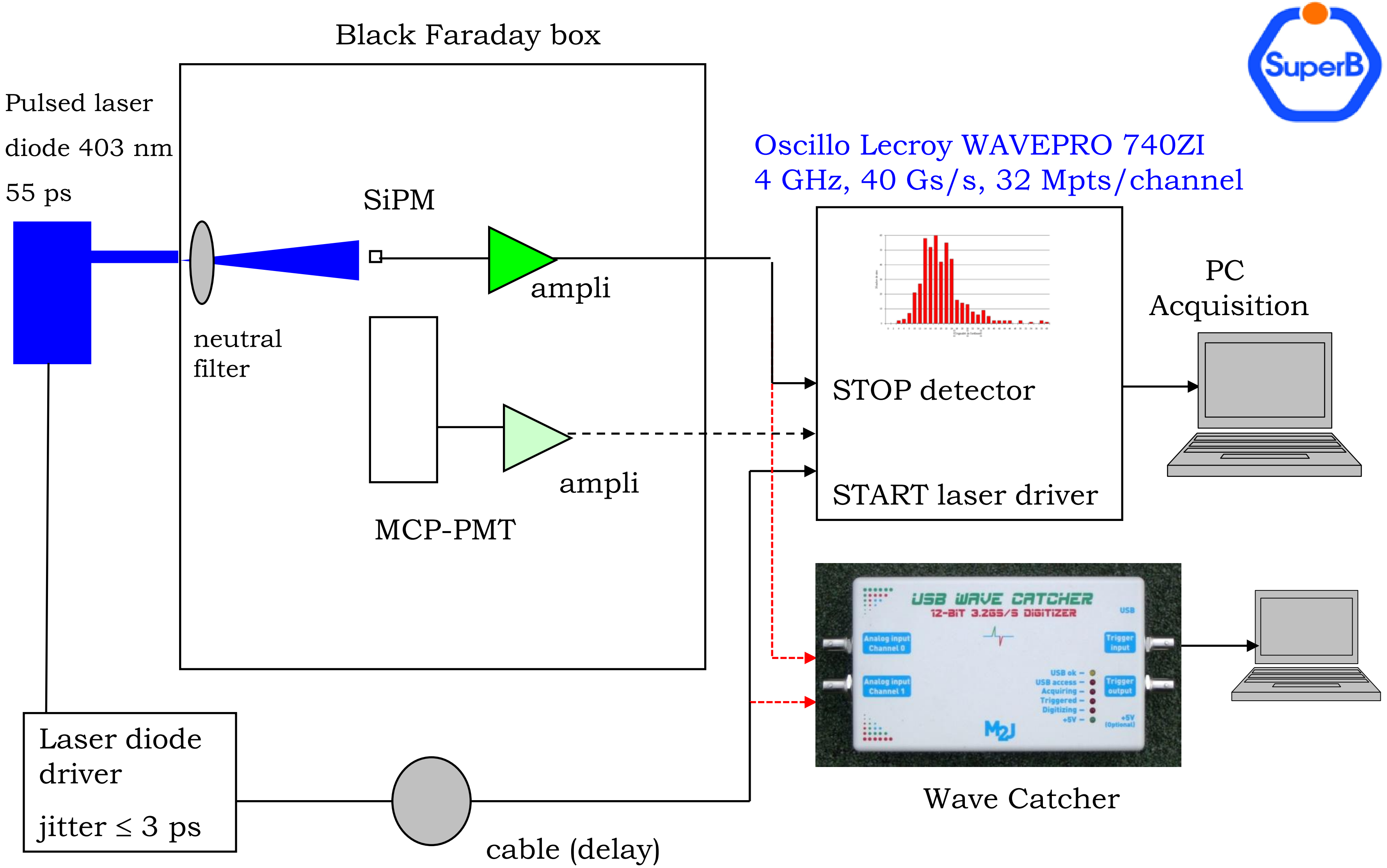




Goals of the study :

- Complete our characterization of SiPM with its timing properties
- Study the SiPM as a candidate for the TOF of the forward PID
- Give inputs for the whole detection chain simulation (LAL SuperB Physics group)
- Compare it with MCP-PMT
- Give “real” conditions for the tests of Wave Catcher (LAL electronics group)

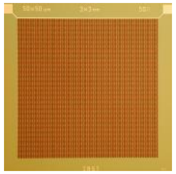
Timing Resolution test bench (to be built)



INFN financing (2009) : 20 k€
+ IN2P3 financing 2009) : 50 k€

New Photo-detectors to test (delivery in January)

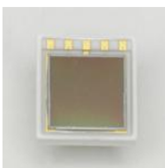
F.B.K



1 mm^2 400 pixels (50 µm)
9 mm^2 3600 pixels (50 µm)

Samples given for evaluation

HAMAMATSU



S10362-33 9 mm^2
14400 pixels (25 µm)
3600 pixels (50 µm)
900 pixels (100 µm)

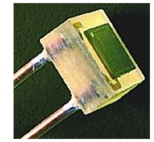
S10985-025C
2 x 2 array (9 mm^2)→ 36 mm^2

10-100S-FS
10-50S-B-4KS

New development « Wide trace » for a better timing resolution

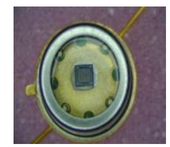
Samples given for evaluation

Photonique



SSPM-0710G9mm
9 mm^2 8100 pixels

Sensl



SPMMicro 9 mm^2

8640 pixels (20 µm)
848 (35 µm)
216 (50 µm)

BURLE MCP-PMT 8512

25 µm pore, 8×8 array,
53×53 mm active area

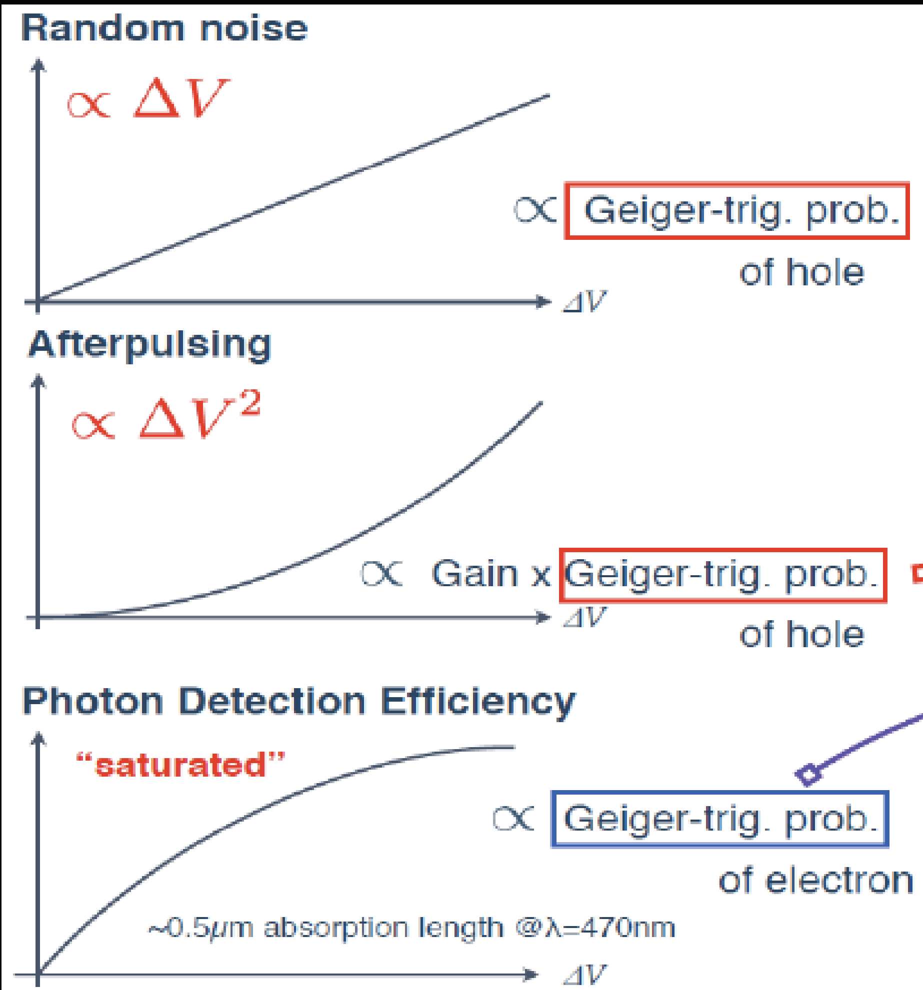
Measurement of the SiPM timing resolution in function of the :

- over-voltage
- wavelength (403 nm and 633 nm)
- simultaneous incident number of photons
- light spot size and position
- temperature

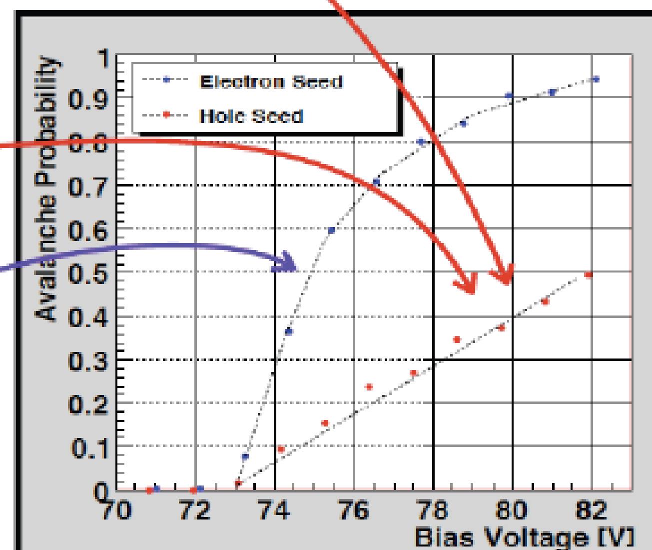
Comparison with Burle MCP-PMT

Additional slides

T. Murase, PD09



With considering the electric field structure and difference of impact ionization probability of e/h, we can explain the voltage dependence of random noise, afterpulse, and PDE.



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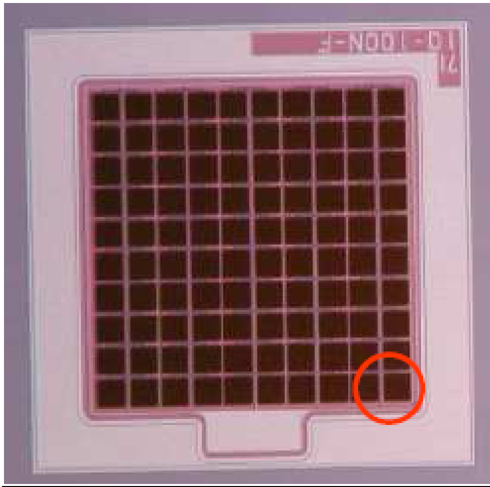
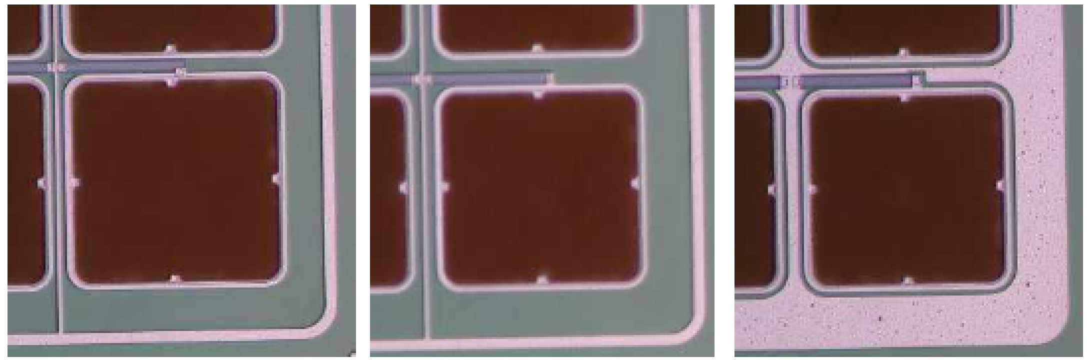
100um pitch Samples



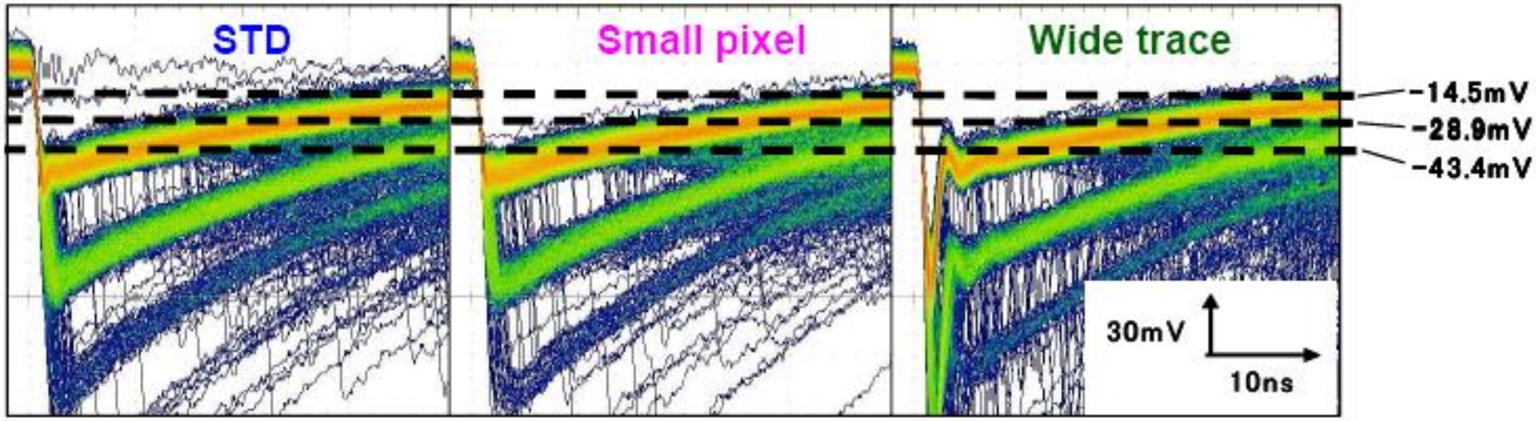
Quenching resistance = 115KΩ by forward IV curve

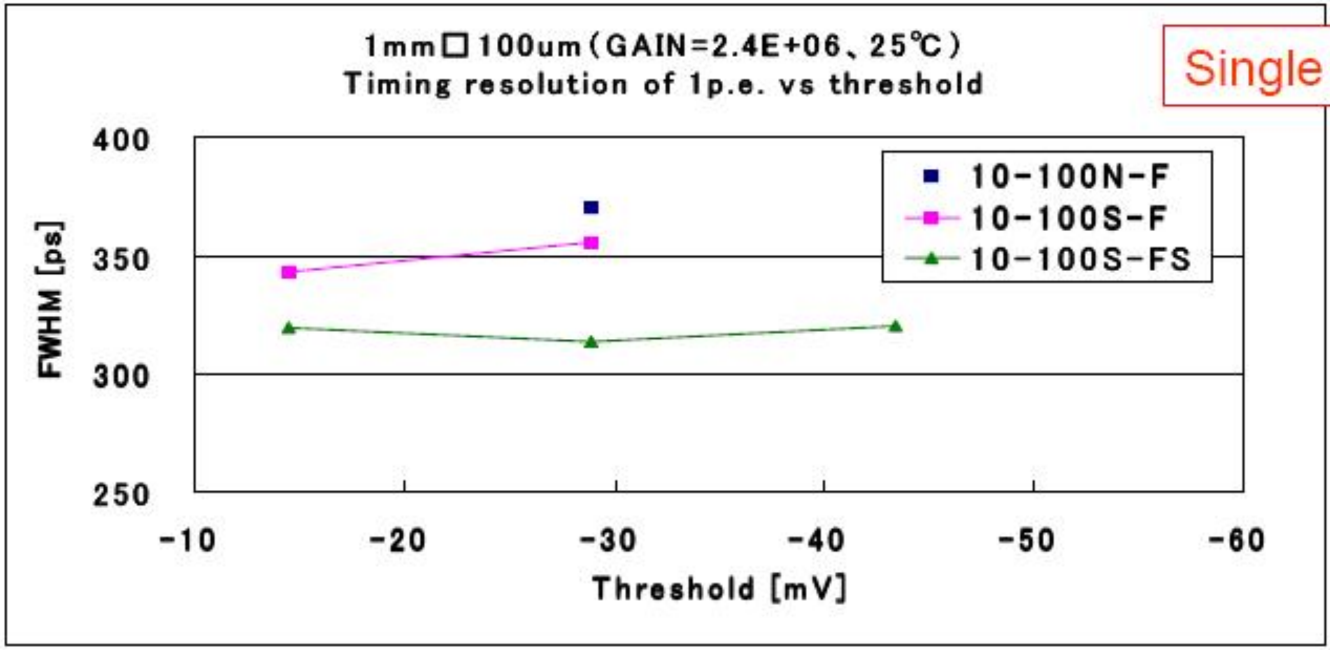


Sample name	10-100N-F (STD)	10-100S-F (Small pixel)	10-100S-FS (Wide trace)
Fill factor	78 %	72 %	72 %
ΔV(Vop−Vbr) #1	1.02 V	1.18 V	1.18 V
Dark count at Vop	1075 Kcps	1089 Kcps	1243 Kcps
Pixel capacitance (Cd) #2	373 fF	323 fF	325 fF
Stray capacitance / pixel #3	17 fF	37 fF	61 fF
PDE at Vop , 440nm	79.7 %	76.2 %	77.6 %

#1 : Vop is at 2.4E06 #2 : by GAIN vs VR curve #3 : Ctotal / 100 – Cd at 25℃

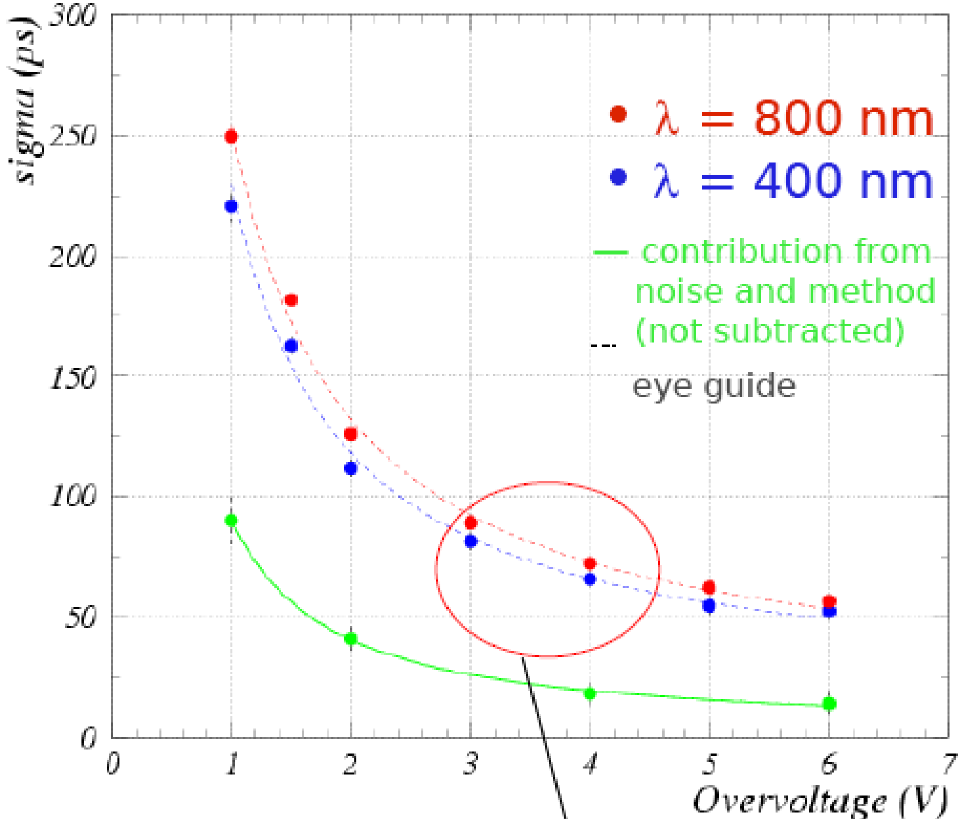
Timing resolution of 100um pitch MPPCs



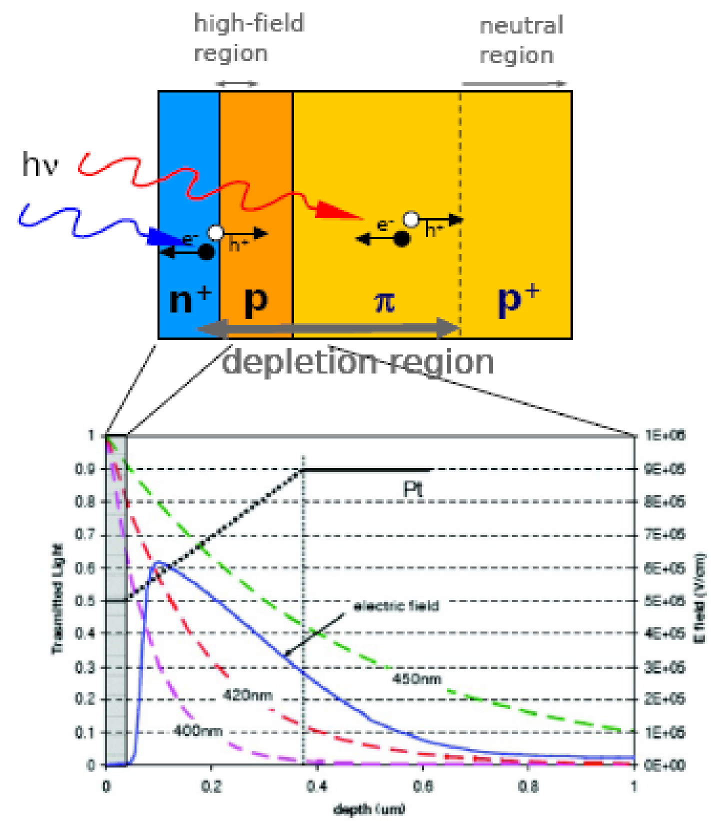


Single p.e.

Single photon timing (FBK-IRST)

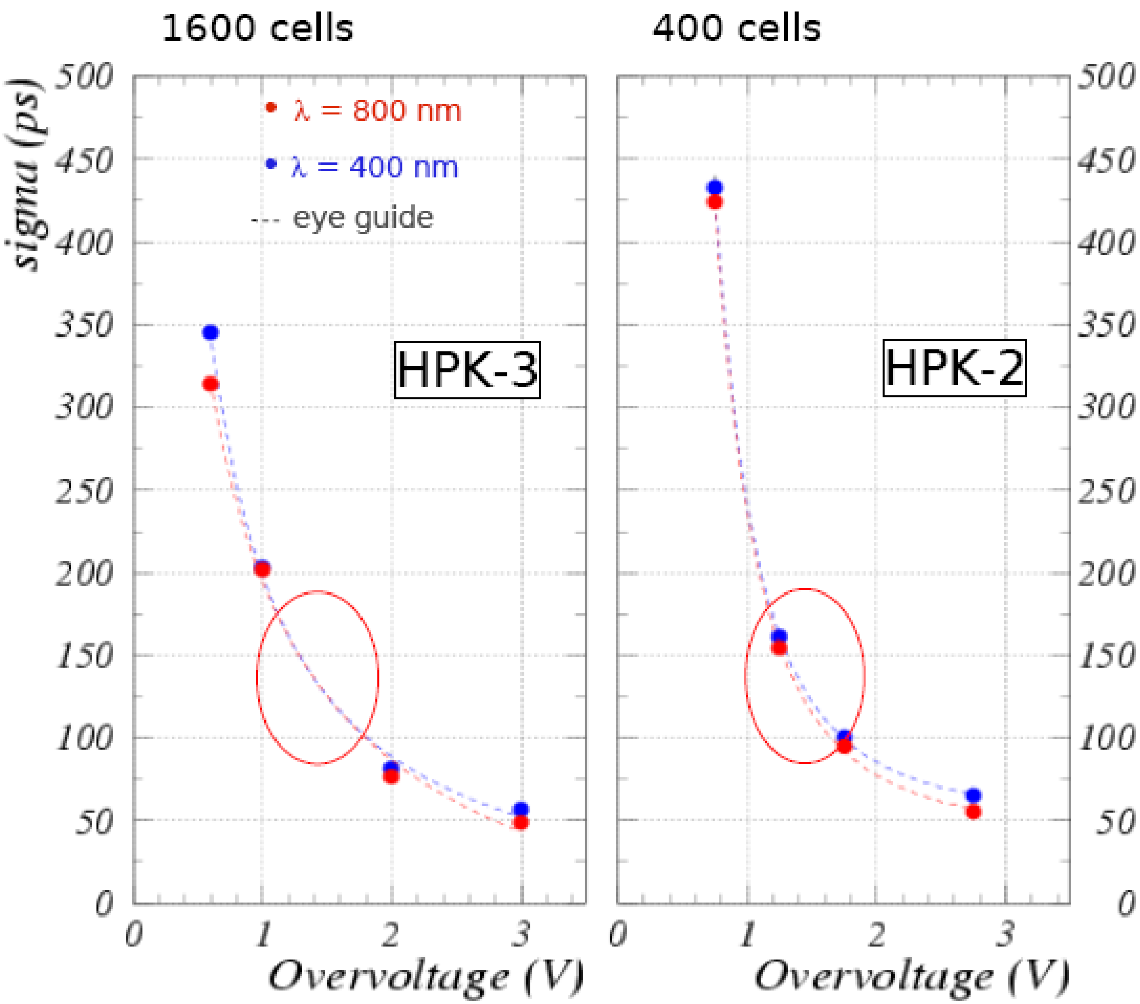


Typical working range



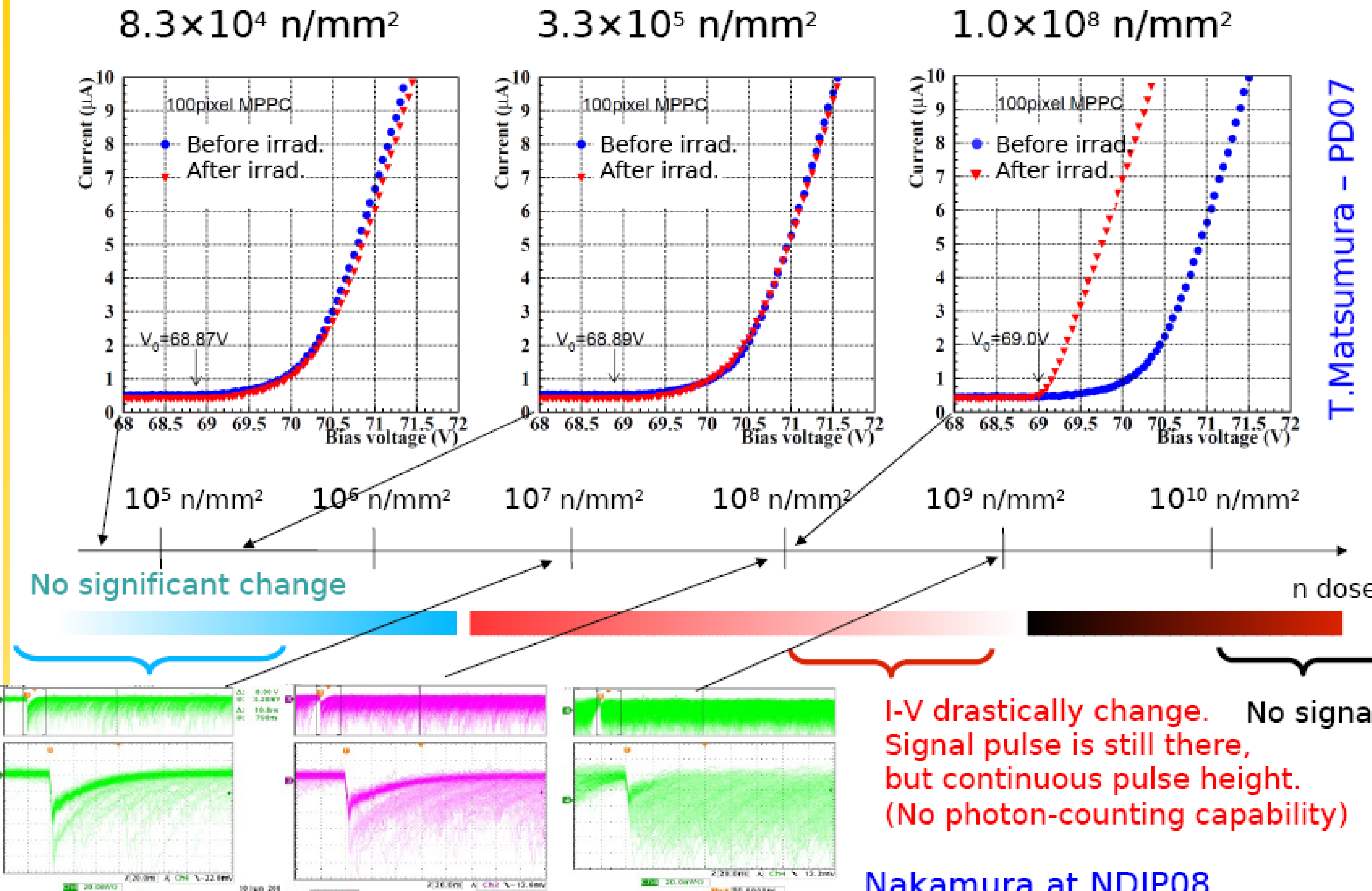
G.Collazuol et al.

Single photon timing (Hamamatsu)



G.Collazuol (unpublished)

Radiation damage: neutrons (0.1 -1 MeV)



I-V drastically change.
Signal pulse is still there,
but continuous pulse height.
(No photon-counting capability)

Nakamura at NDIP08