# Large area UV SiPMs with very high PDE & extremely low cross-talk

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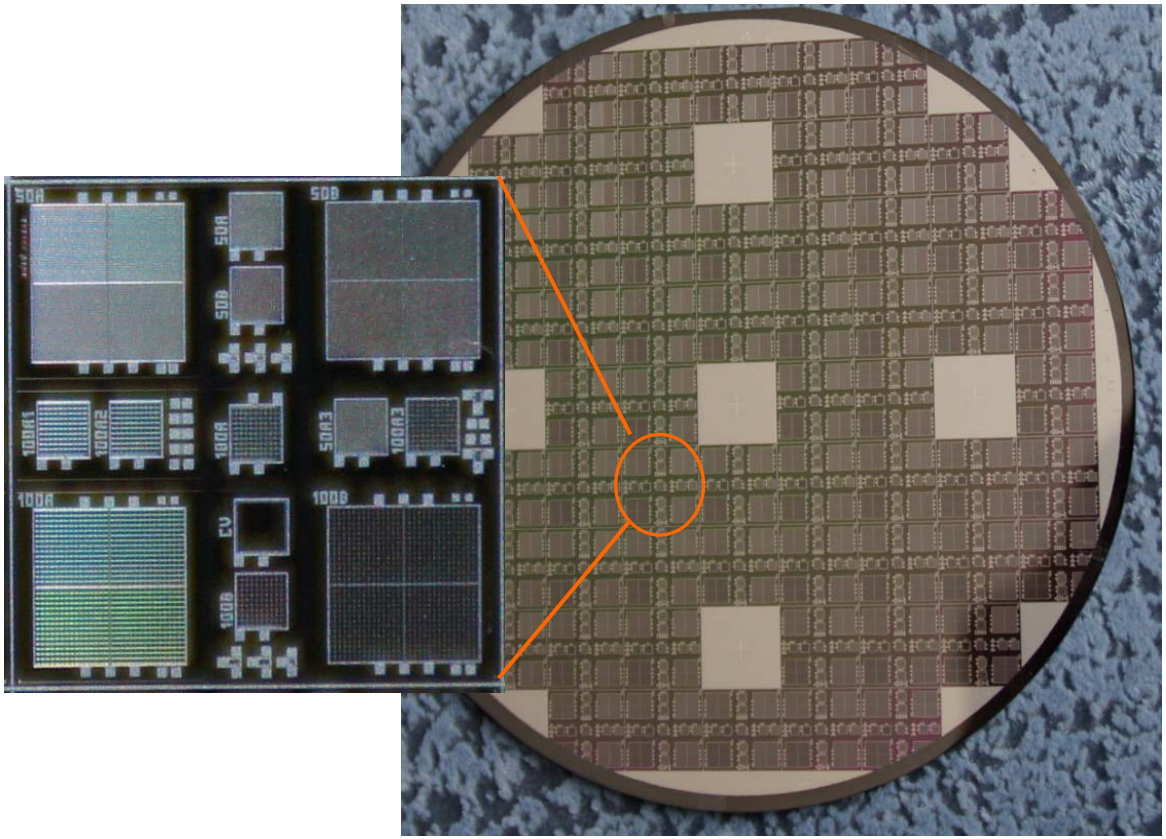
# Homage to Boris Dolgoshein (1930-2010)

- Professor, head of the particle-physics department in MEPHI
- Inventor of streamer chamber (1962)
- Developer and pioneer of Transition Radiation Detector (TRD)
- Since 1993 developing a new photon detector which he gave the name Silicon Photo-Multiplier (SiPM). Collaborating with DESY and then with Max-Planck Institute for Physics in Munich on SiPM
- 1st in the world large-scale SiPM application in Hadron Calorimeter prototype (~$10^4$ SiPM channels)

Developing UV sensitive SiPM with extremely low X-talk and very high PDE for MAGIC and EUSO experiments, 2002-2010

# MEPhI - MPI for Physics R&D collaboration and cooperation with EXCELITAS (former PerkinElmer)

A test batch produced in December 2010



- SiPM Sizes

1x1 and 3x3 mm²

- µ-cell pitch

50 and 100 µm

- Geom. Eff.

40-80%

18 different modifications

# Special features

**3+ -fold X-talk suppression**

A known way to suppress X-talk:
1. Isolating trenches

**New ways:**
2. 2nd p-n junction for isolating the bulk from the active region
(patented)

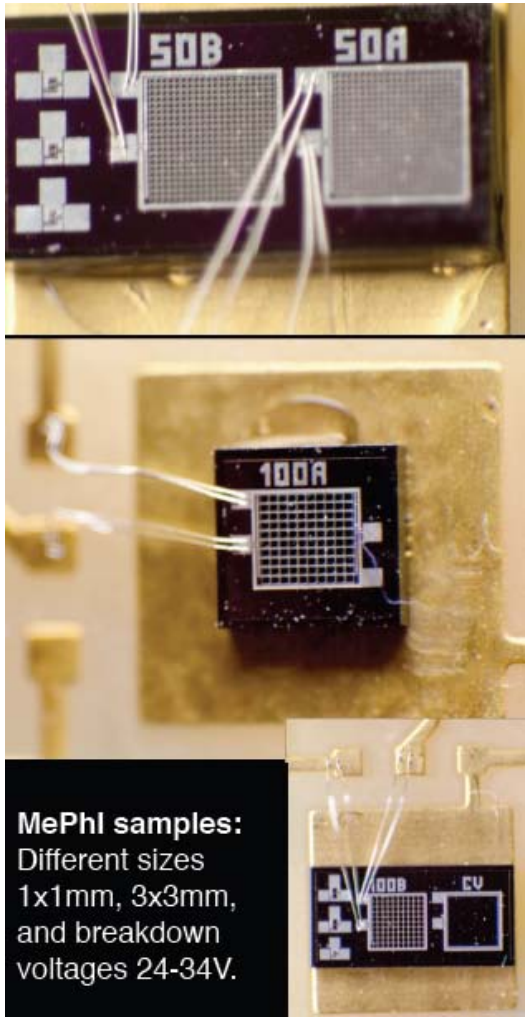
3. OC suppression by ion implantation
(patent pending)

**Very high UV sensitivity**

**Record high PDE**

**Geometrical efficiency 80%**

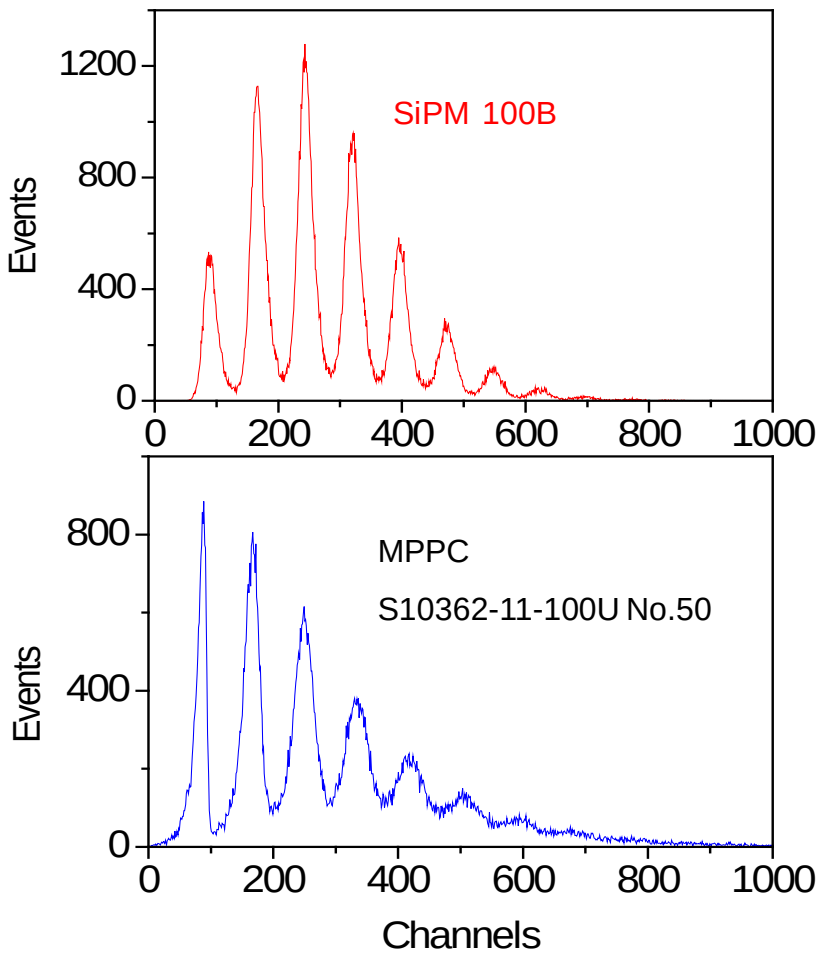
**Very low temperature dependence**

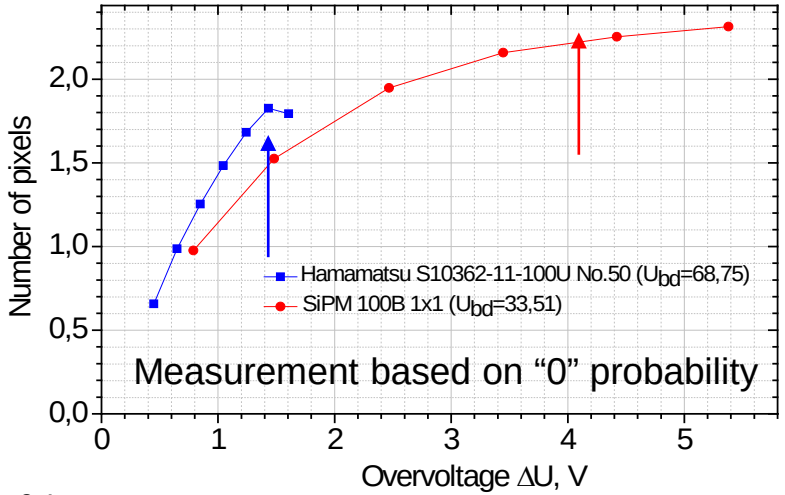


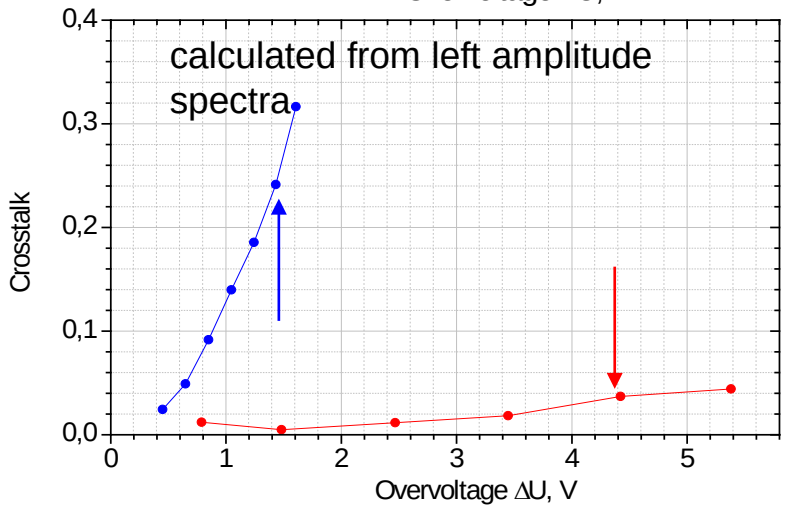
# SiPM vs. MPPC

SiPM: 1x1 mm$^2$, 100x100 μm$^2$, Geometrical Efficiency ~80%, T=+25°C, λ = 435 nm

Same light impinging on both sensors

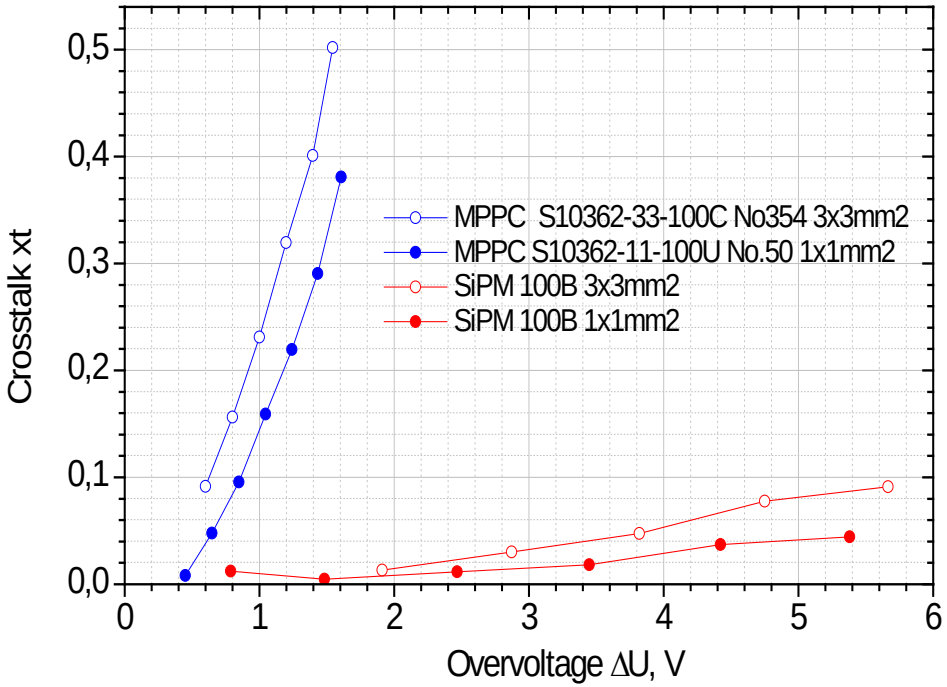


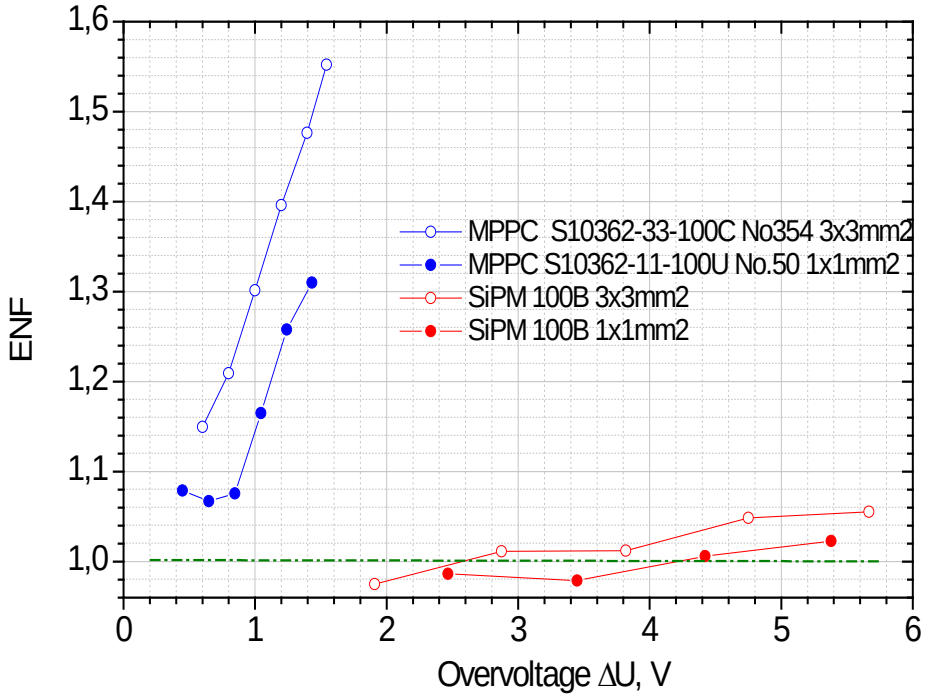



# X-talk and Excess Noise Factor

Light source variation according Poisson law



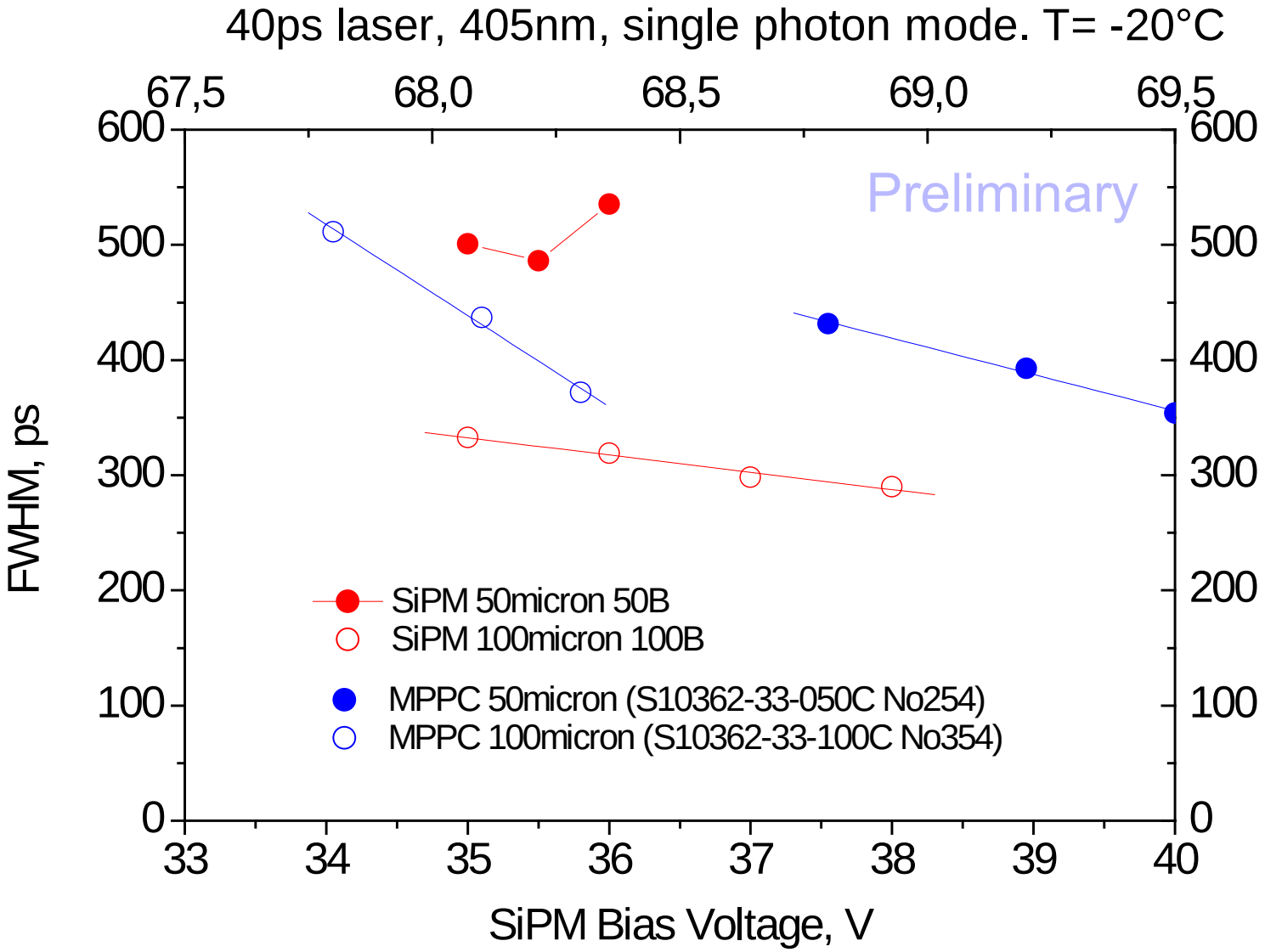

$$N_{fired\_pixels} = \frac{< Mean >}{A_{1e}} \qquad N_{fired\_pixels} = \frac{N_0}{1 - Xt} \qquad (\frac{\sigma}{< Mean >})^2_{\exp} = \frac{ENF}{N_0}$$

$N_0$: number of fired pixels calculated from "0" probability

$Xt$: crosstalk

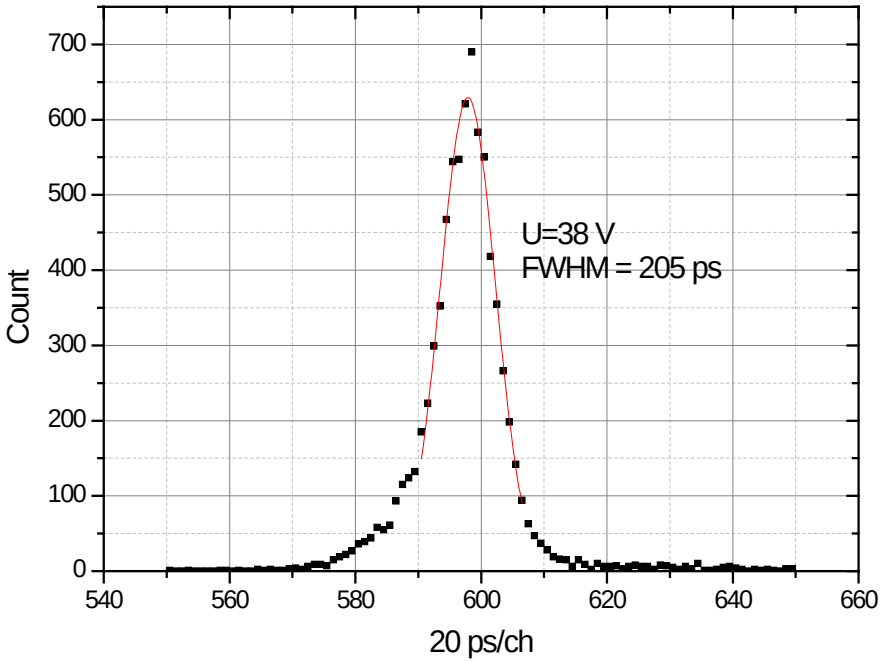
$A_{1e}$: single cell amplitude

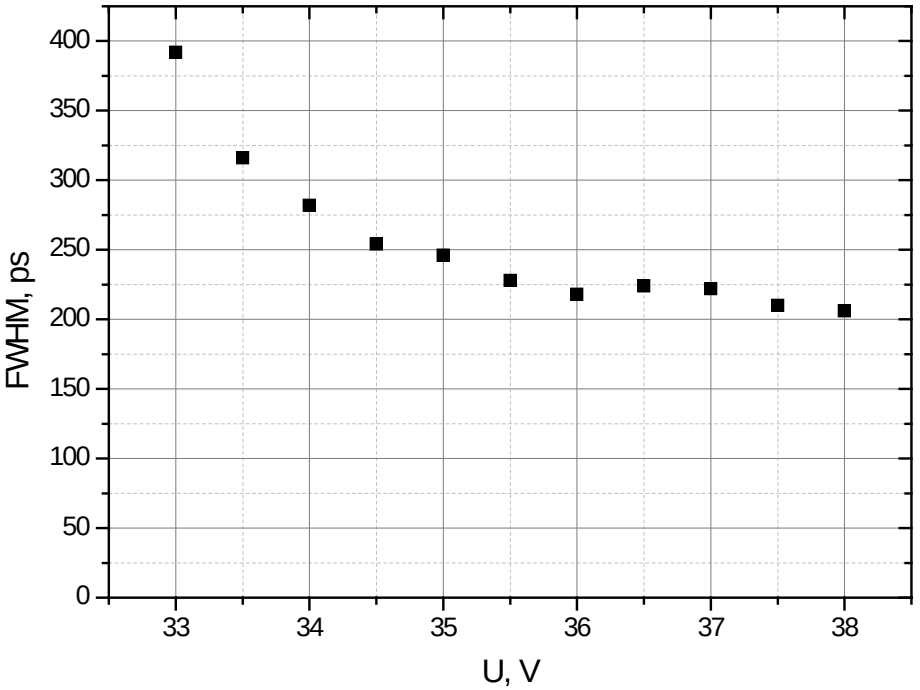
# Timing for 3x3 mm$^2$ SiPM and MPPC



# Timing with 3x3mm$^2$, type 100B SiPM

40ps laser, 405nm, single photon mode, T= -40°C

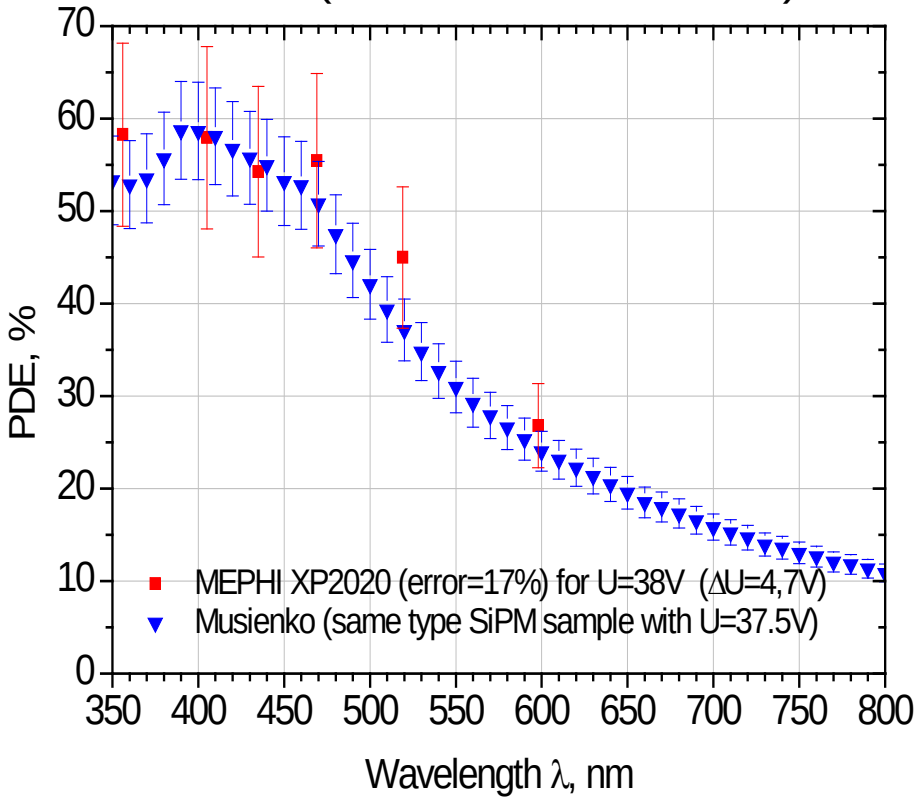


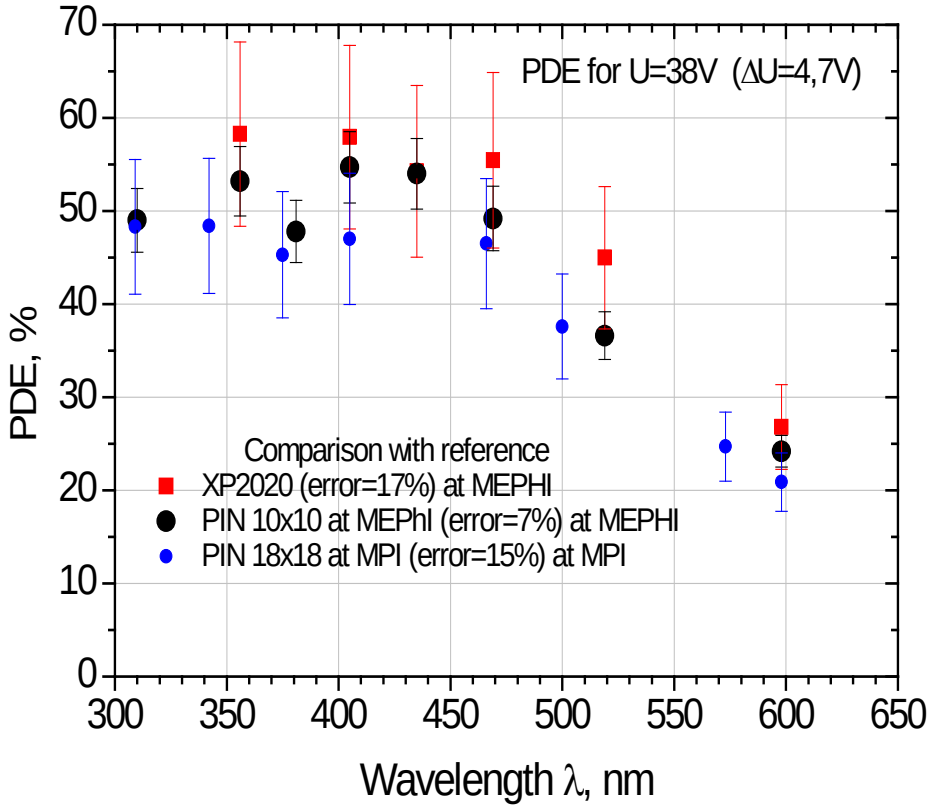

Best value measured for 3x3 mm$^2$ 100B SiPM is **205 ps**

# Record high PDE (pulsed mode LED, 100B type SiPM, 1x1 mm$^2$)

Measurements at MEPHI and at CERN (thanks to Y.Musienko)

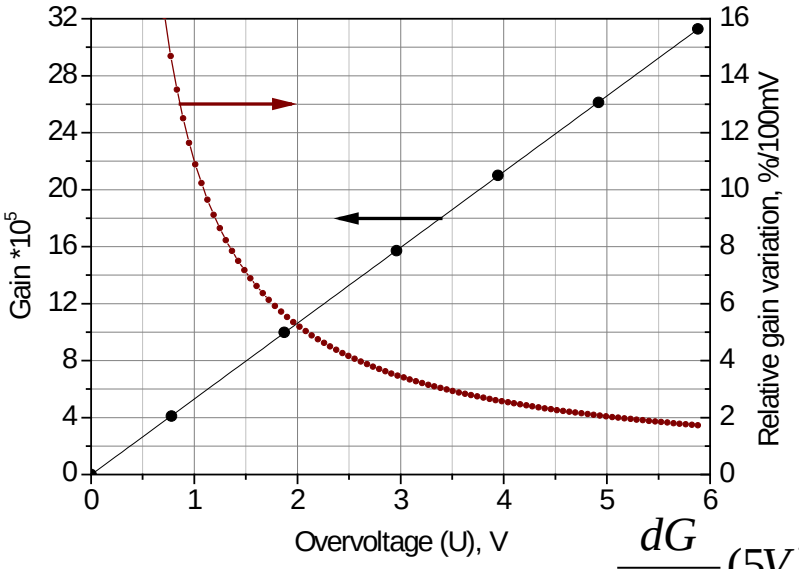



Measurements at MEPHI and at MPI

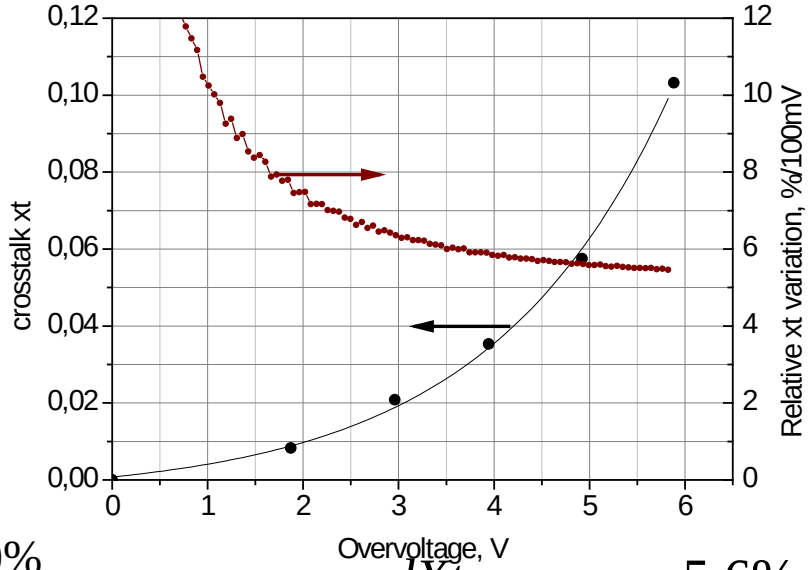



- The PDE measured with reference calibrated PIN-diodes is slightly lower than with the reference calibrated PMT
- All results are consistent within experimental errors

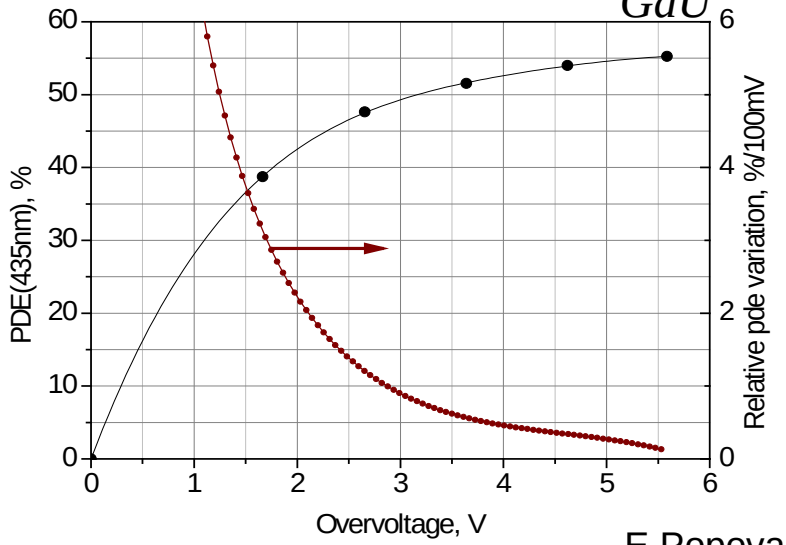
# Voltage stability SiPM 100B for 5V (15%) overvoltage




$$\frac{dG}{GdU}(5V) = \frac{2.0\%}{100mV}$$

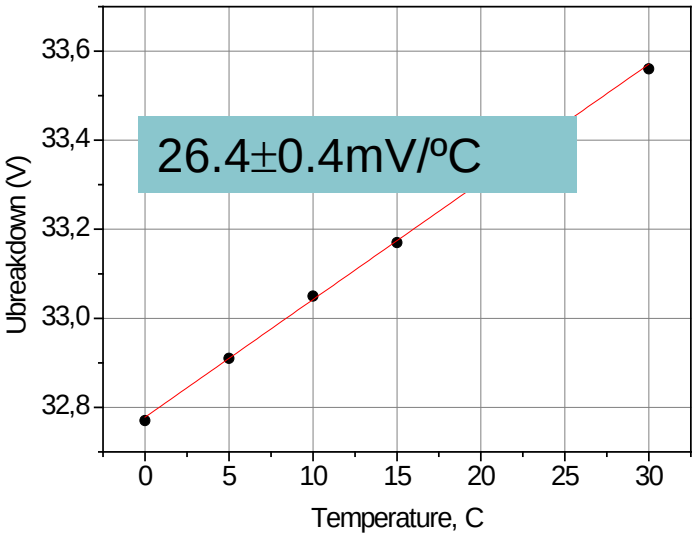


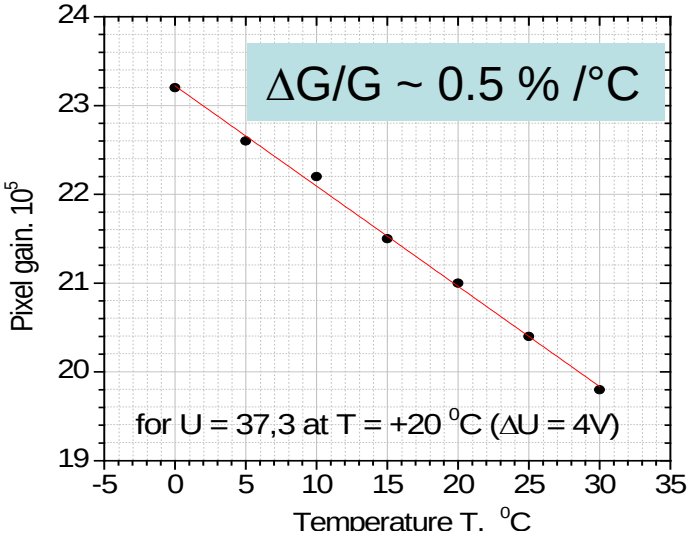

$$\frac{dXt}{XtdU}(5V) = \frac{5.6\%}{100mV}$$

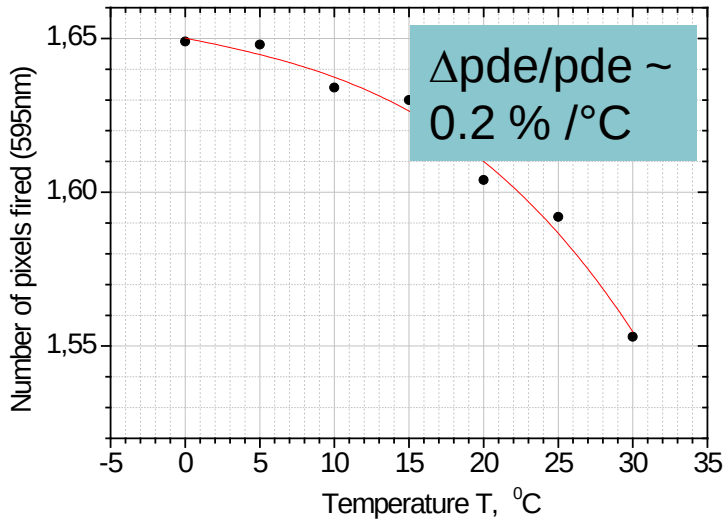


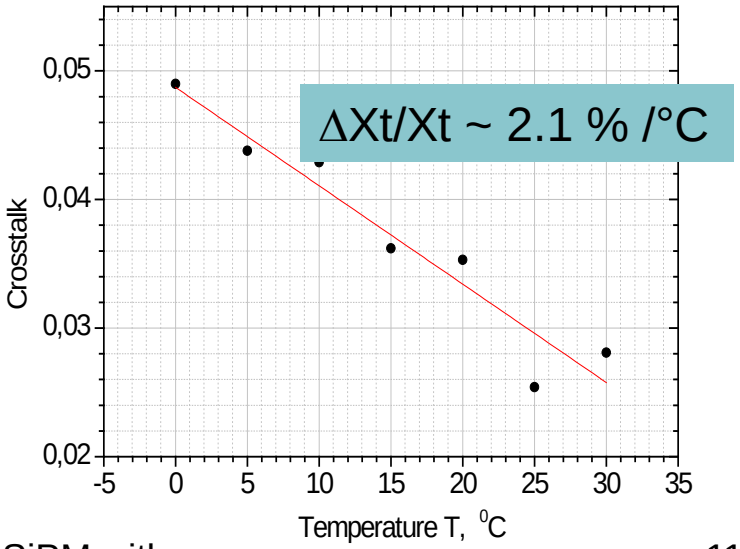

$$\frac{d\varepsilon}{\varepsilon dU}(5V) = \frac{0.25\%}{100mV}$$

# Temperature dependence type 100B SiPM



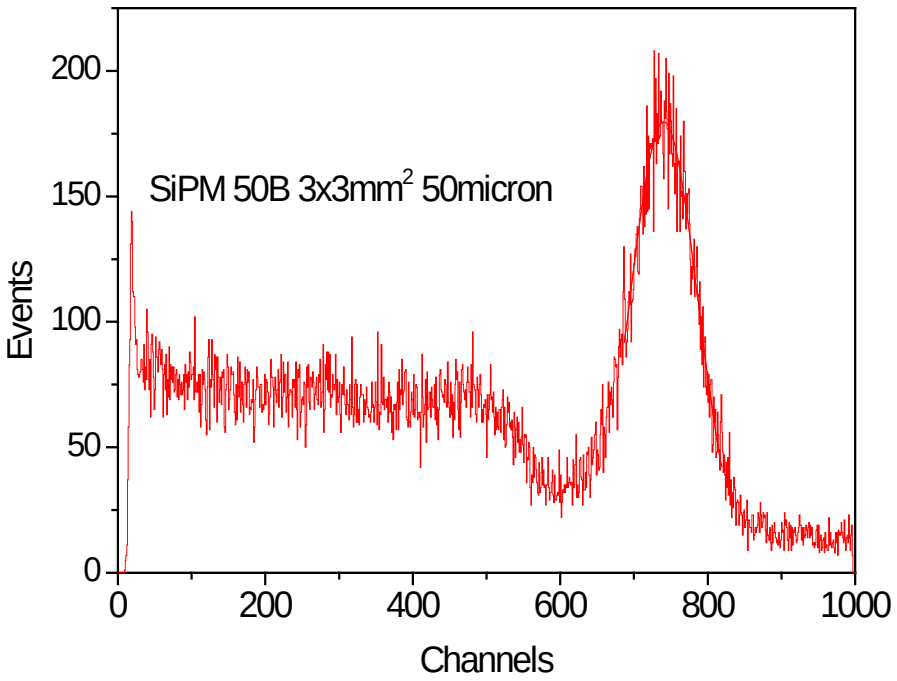



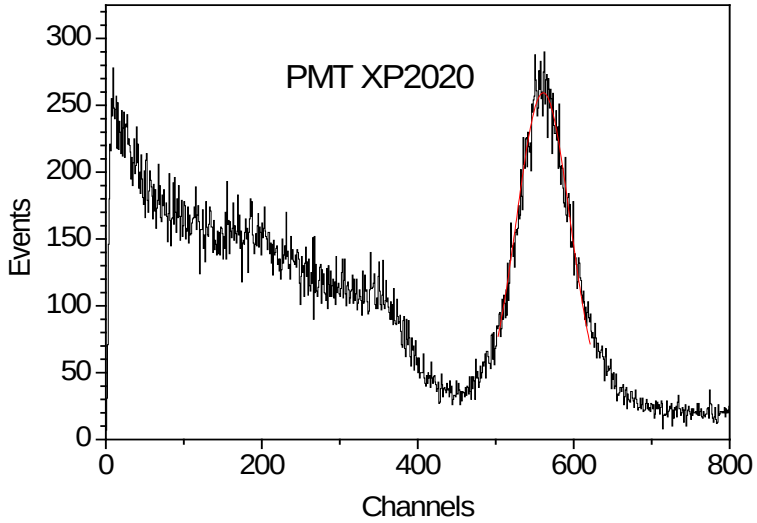
# PET Spectrometry with LYSO and $Na^{22}$

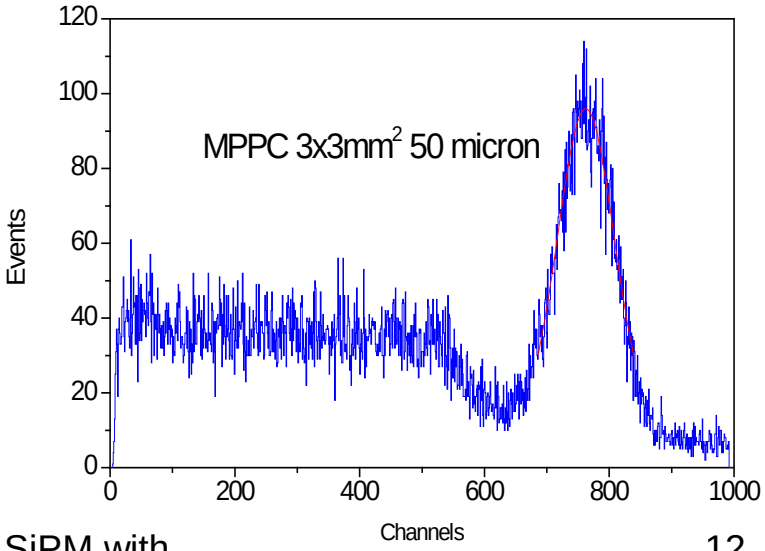
Preliminary. Setup is not yet optimized

Self triggering mode
Amplitude spectra Integration time 1μs
LYSO 3x3x5 $mm^3$
Without collimator




Energy Resolution (FWHM) ~14%

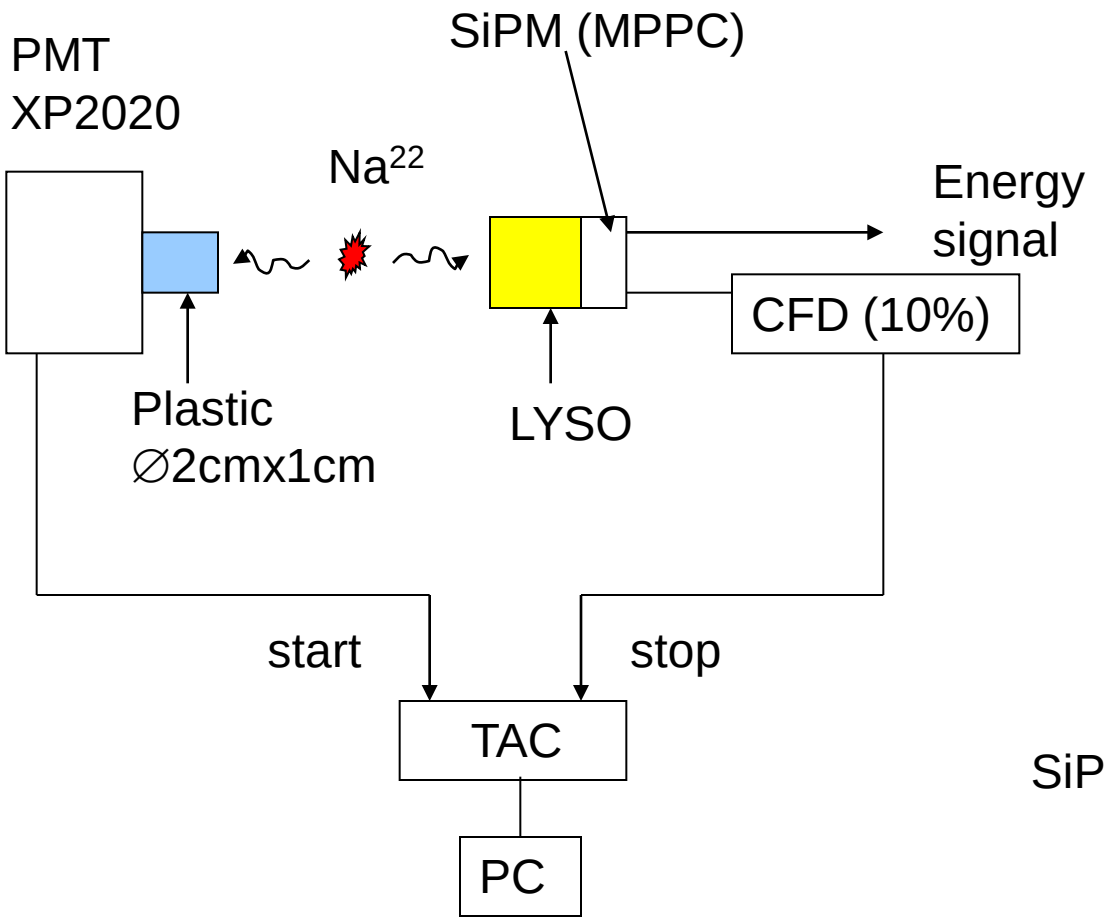


# Timing for PET with LYSO and $Na^{22}$

LYSO 3x3x5mm3
Without collimator

Preliminary. Setup is not yet optimized




FWHM (PMT resolution is Not substructed)

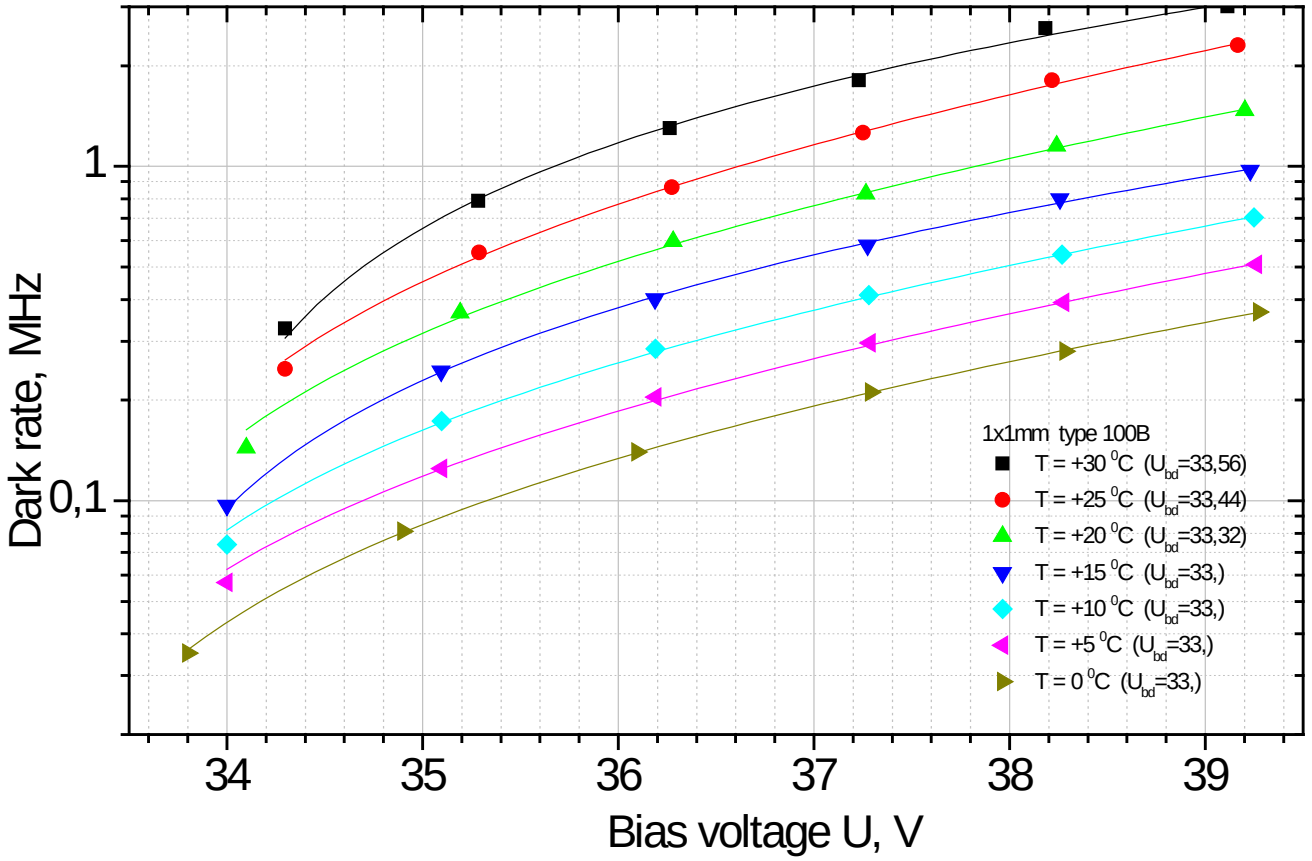
| | |
|---|---|
| SiPM 100B | 340ps |
| SiPM 50B | 375ps |
| MPPC-50 | 520ps |

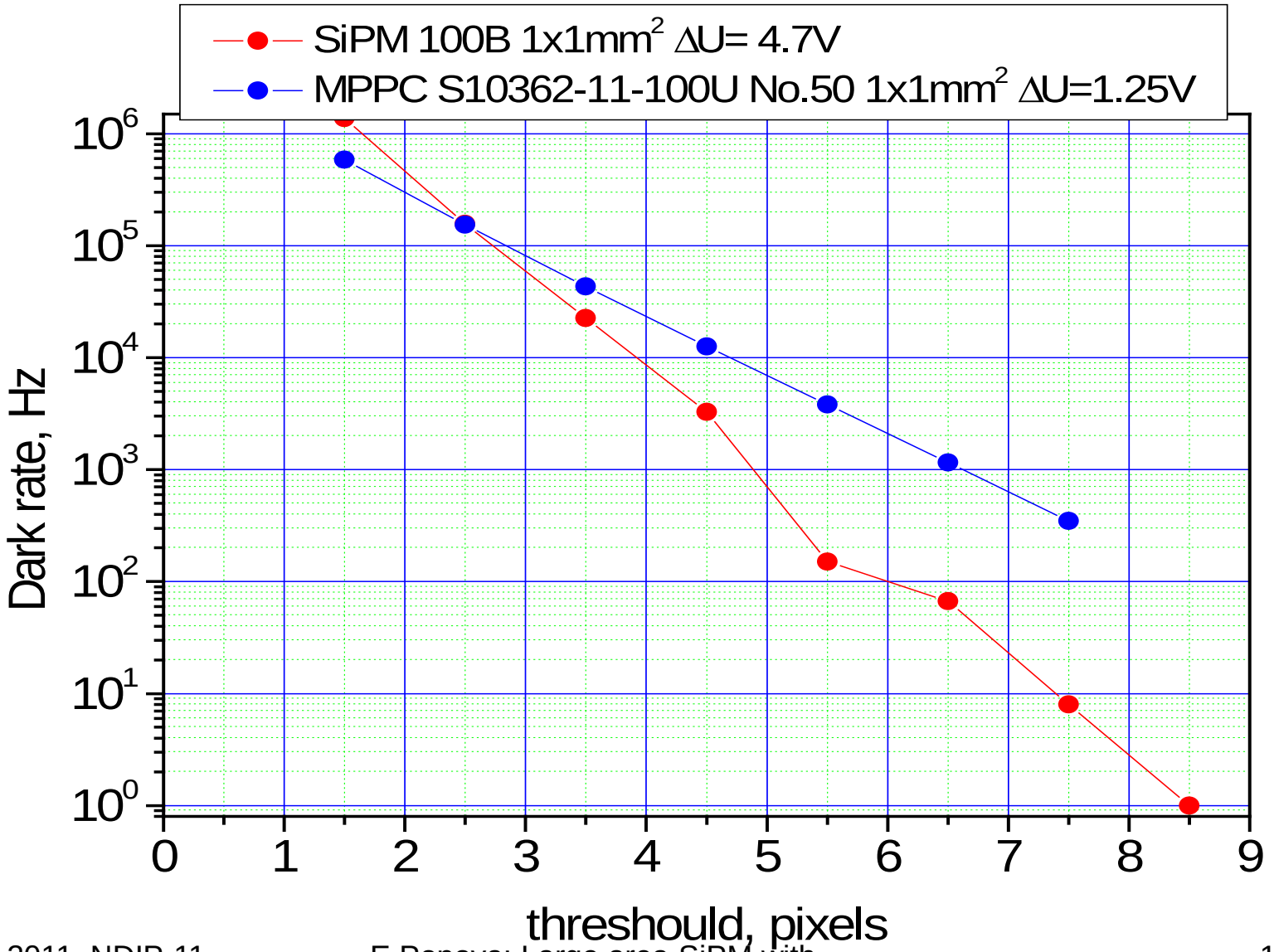
SiPMs and MPPC are 3x3mm$^2$

# Summary

- MEPHI & MPI, with strong support of Excelitas, have produced SiPMs of 1x1 and 3x3 $mm^2$ sizes with extremely high PDE ( ≥ 50%) in the UV-blue region
- The X-talk is ~ 3-5 % for saturated PDE ($\Delta U/U$ ~12-15 %)
- ENF is ~ 1.02 (due to 4-fold X-talk suppression)
- T° sensitivity: PDE ~0.2 %/°C; Gain ~0.5 %/°C
- Time jitter (FWHM) for 3x3 $mm^2$ SiPM (100 μm pitch) is ~ 200-300 ps; further improvements are possible
- Dark rate ~ 1MHz/$mm^2$
- On the way of becoming commercial product of Excelitas

# SiPM Noise

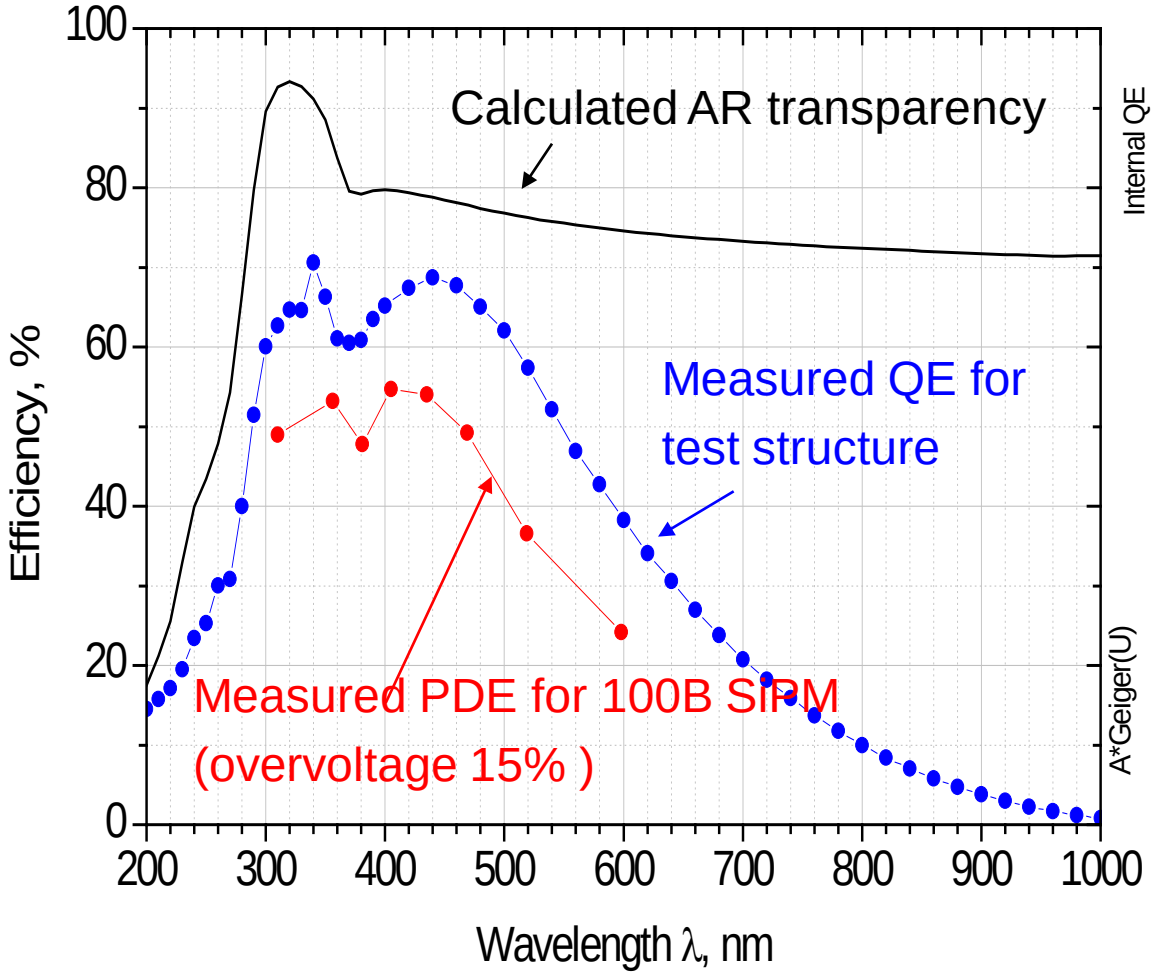

Dark rate, MHz
1
0,1
34
35
36
37
38
39
Bias voltage U, V
1x1mm type 100B
T = +30 °C (U_bd=33,56)
T = +25 °C (U_bd=33,44)
T = +20 °C (U_bd=33,32)
T = +15 °C (U_bd=33,)
T = +10 °C (U_bd=33,)
T = +5 °C (U_bd=33,)
T = 0 °C (U_bd=33,)

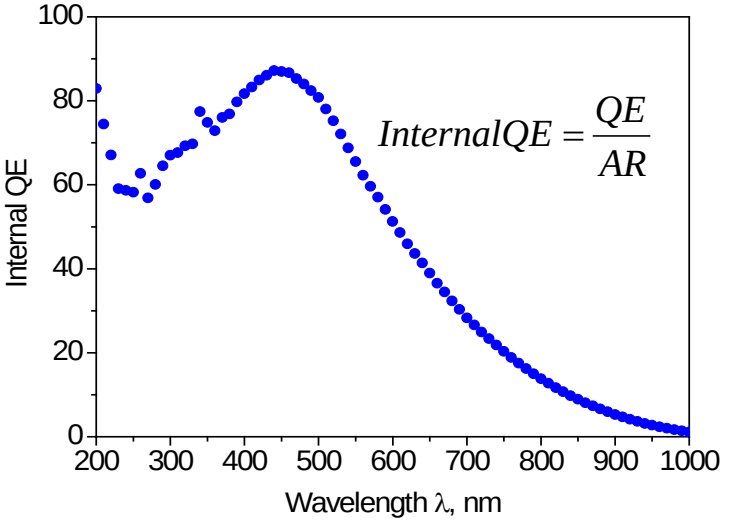

SiPM 100B 1x1mm$^2$ ΔU= 4.7V
MPPC S10362-11-100U No.50 1x1mm$^2$ ΔU=1.25V
Dark rate, Hz
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
0
1
2
3
4
5
6
7
8
9
threshould, pixels

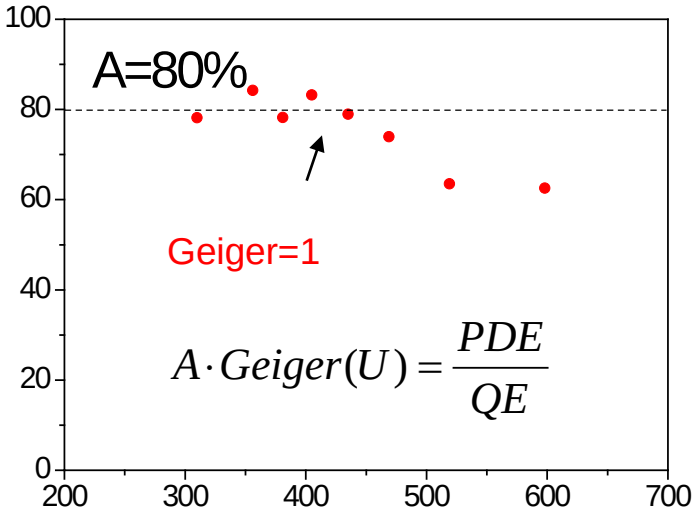
# Efficiency measurements

reference: a calibrated PIN diode Hamamatsu S1337-1010BQ

$$PDE = AR \cdot InternalQE \cdot A \cdot Geiger(U)$$



# Spectral PDE comparison