Research & Study
Detector Group

# Single Photoelectron timing resolution of SiPM

XVII SuperB Workshop - Kick Off meeting

May 29th - June 1st 2011 – Isola d'Elba

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# Plan

❖ List of the SiPMs studied at LAL

❖ Basic characterization of SiPM : operational voltage range, gain, dark noise, variation with temperature ….

❖ Test bench for timing measurement

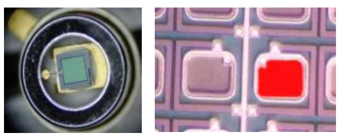
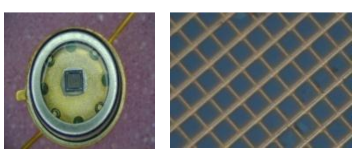
❖ Timing resolution measurement principle

❖ SPTR in function of the bias voltage

❖ SPTR in function of the wavelength

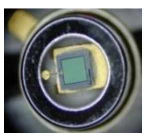
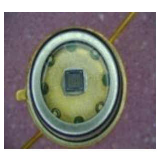
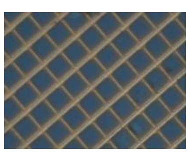
❖ SPTR in function of the temperature

# 1 $mm^2$ SiPMs characterized at LAL

| | Reference | Pixel nb | Pixel size (µm) | $V_{BD}$ (V) |
|---|---|---|---|---|
| **AdvanSiD (F.B.K)**  | **ASD-SiPM1S-M-50** | **400** | **50 x 50** | **29** |
| **Hamamatsu MPPC**  | **S10362-11-25** | **1600** | **25 x 25** | **69.2** |
| | **S10362-11-50** | **400** | **50 x 50** | **68.3** |
| | **S10362-11-100** | **100** | **100 x 100** | **68.7** |
| | **10-50S-BK 4S** | **400** | **50 x 50** | **69.1** |
| | **10-100S-FS** | **100** | **100 x 100** | **69.1** |
| **SensL SPM**  | **SPM1020X13** | **848** | **20 x 20** | **27** |
| | **SPM1035X13** | **400** | **35 x 35** | **27.5** |

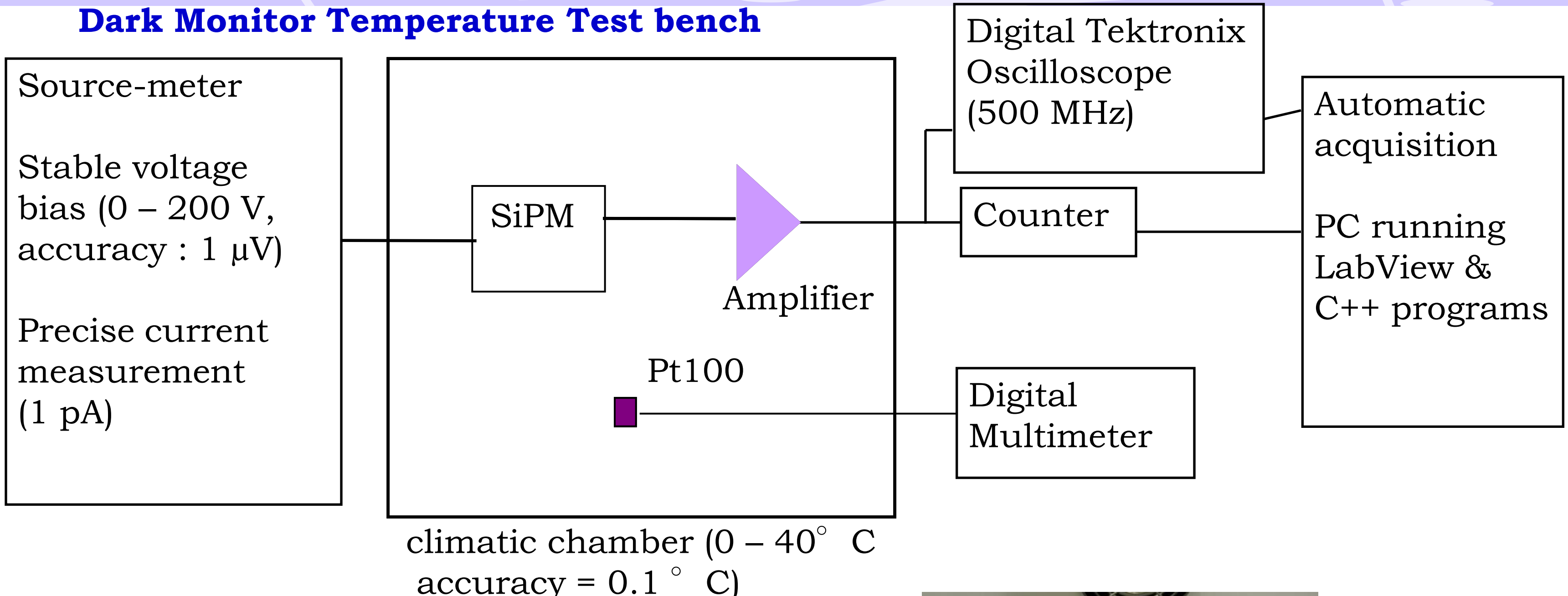
● Non commercial products

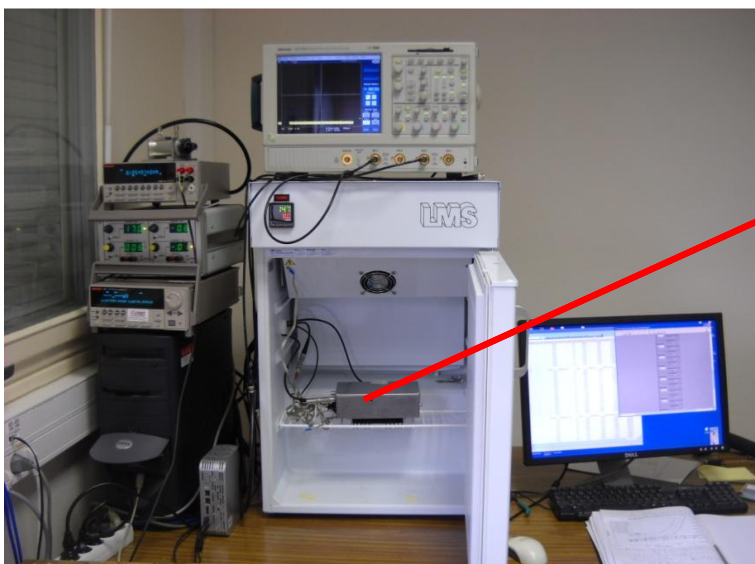
# 9 mm$^2$ SiPMs characterized at LAL

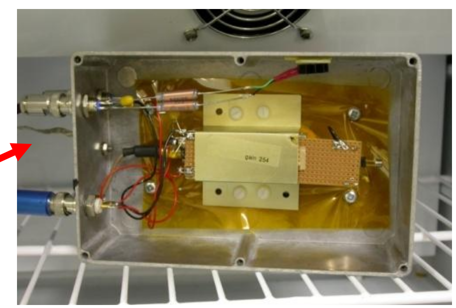
| | Reference | Pixel nb | Pixel size (µm) | $V_{BD}$ (V) |
|---|---|---|---|---|
| **AdvanSiD (F.B.K (3 x 3 mm²)**   | **ASD-SiPM3S-M-50** | **400** | **50 x 50** | **31** |
| **Hamamatsu MPPC (3 x 3 mm²)**   | **S10362-33-25** | **14400** | **25 x 25** | **69.5** |
| | **S10362-33-50** | **3600** | **50 x 50** | **69.5** |
| | **S10362-33-100** | **900** | **100 x 100** | **69.2** |
| **SensL SPM (2,85 x 2,85 mm²)**   | **SPM-3035X13** | **3640** | **35x 35** | **27** |

Non commercial products

**Dark Monitor Temperature Test bench**



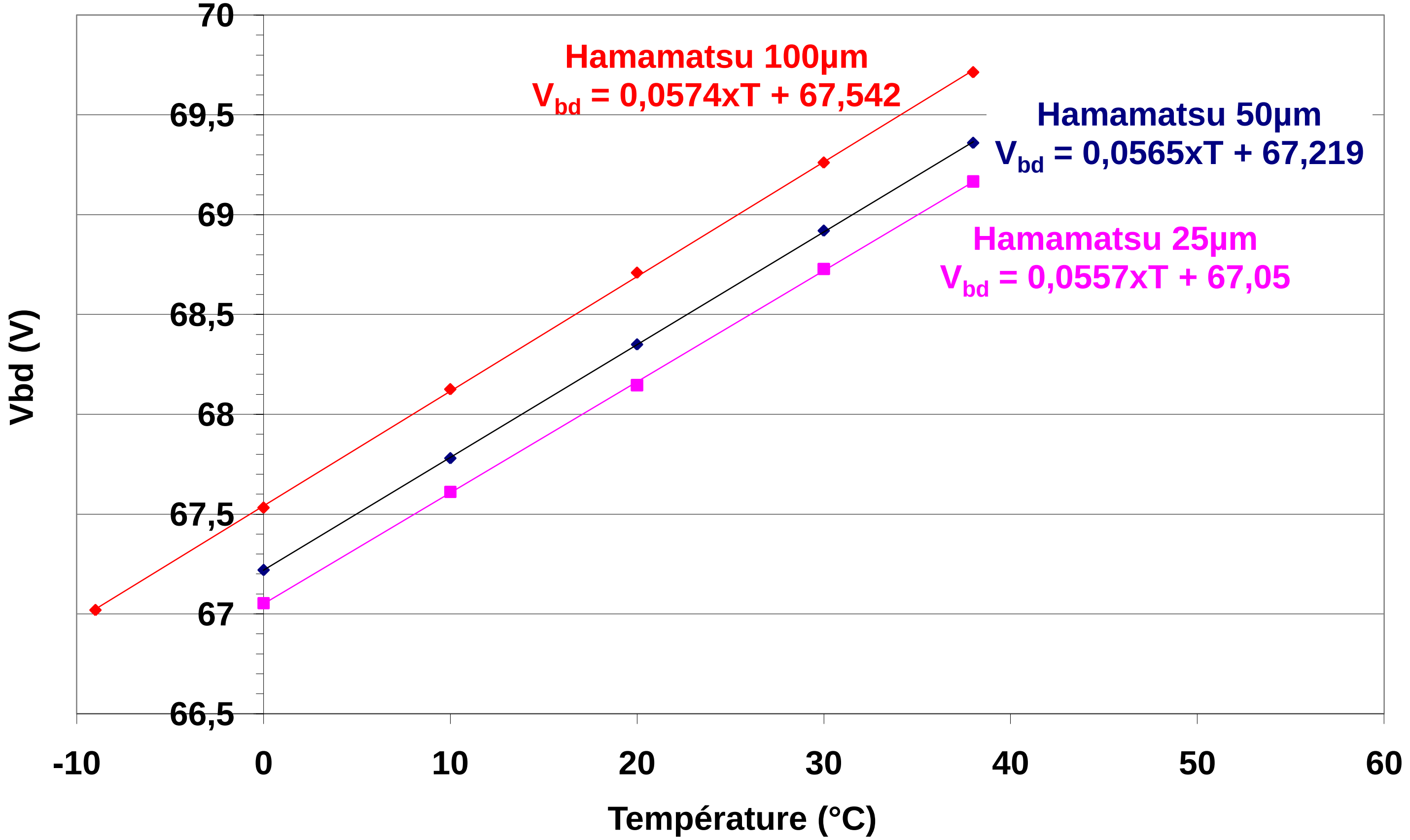





**Measurements of $V_{BD}$, gain, DCR**

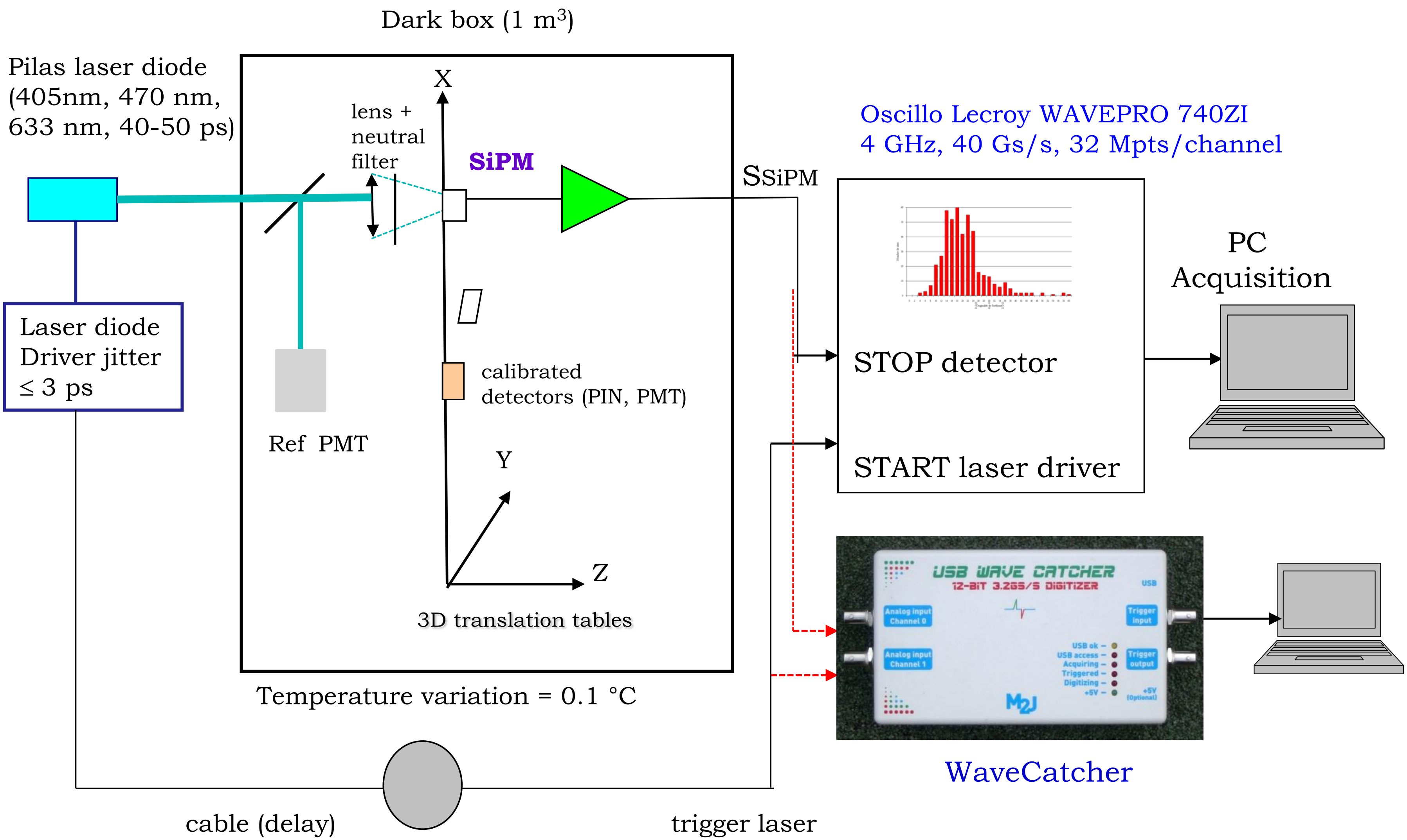
# Evolution of $V_{BD}$ with temperature

MPPC 1 mm²



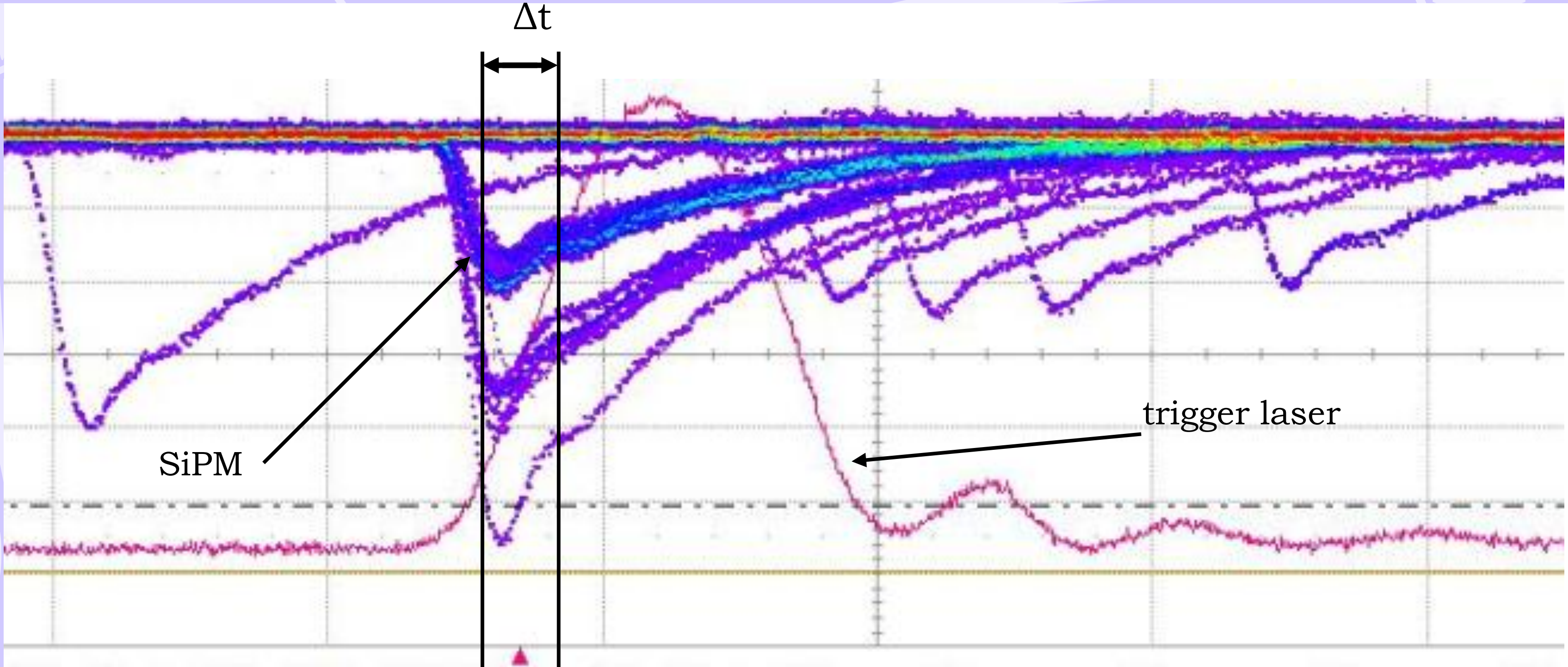

Breakdown voltage increases with the temperature

$dV_{BD}/dT$ ~ 56 mV/°C




V. Puill, SuperB Kick-off meeting, Elba, May 31 – June 1 2011

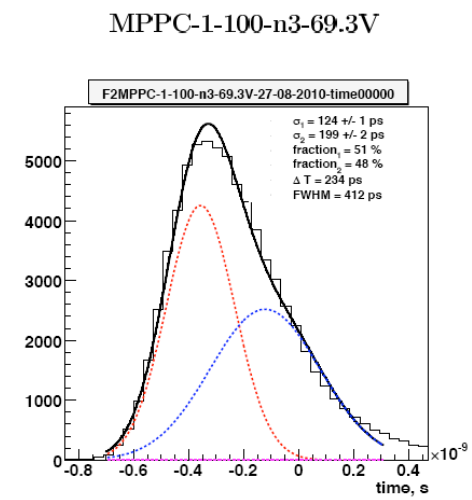
# Measurement principle of the SiPM timing resolution



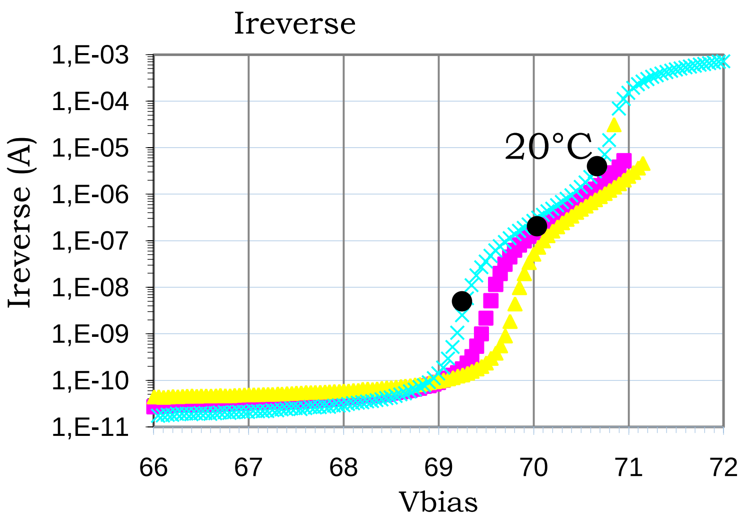

threshold for the laser = 50 %

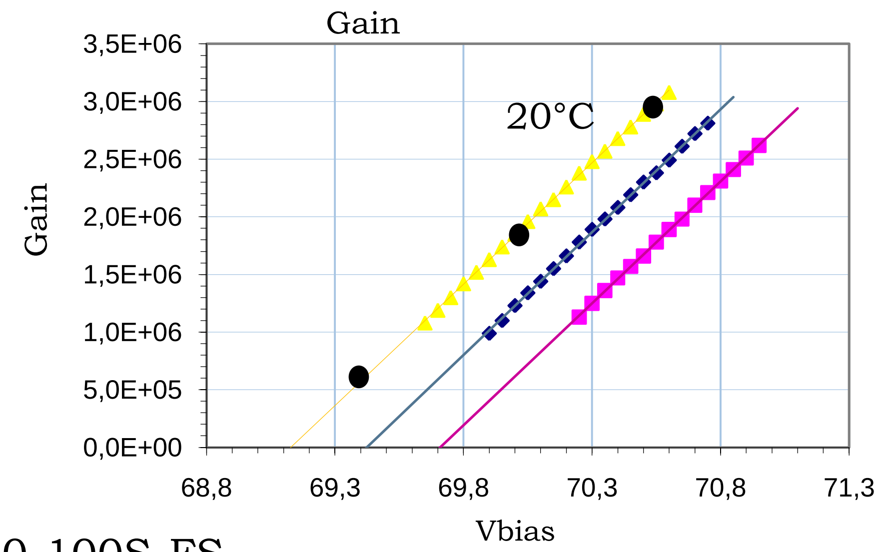
threshold = 50 % SSiPM

Measurement of the time between the laser and the SiPM signals → distribution of the Δt

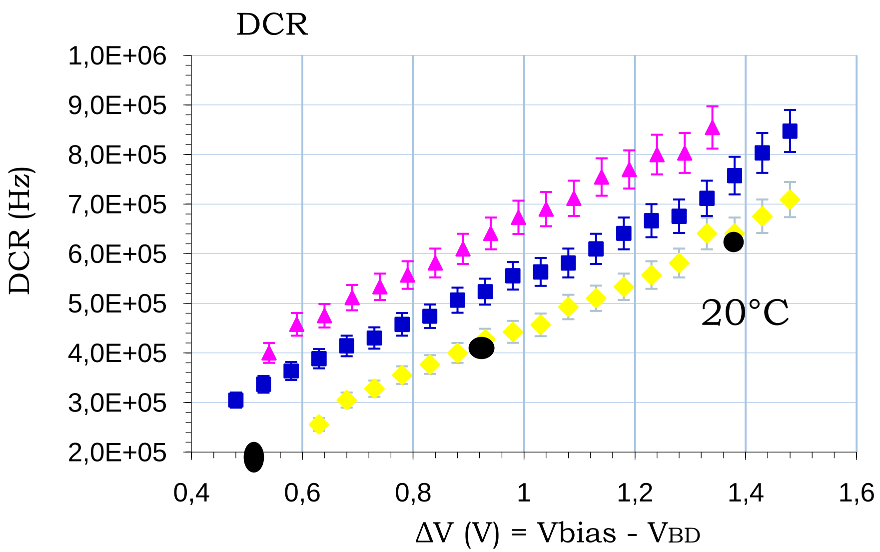


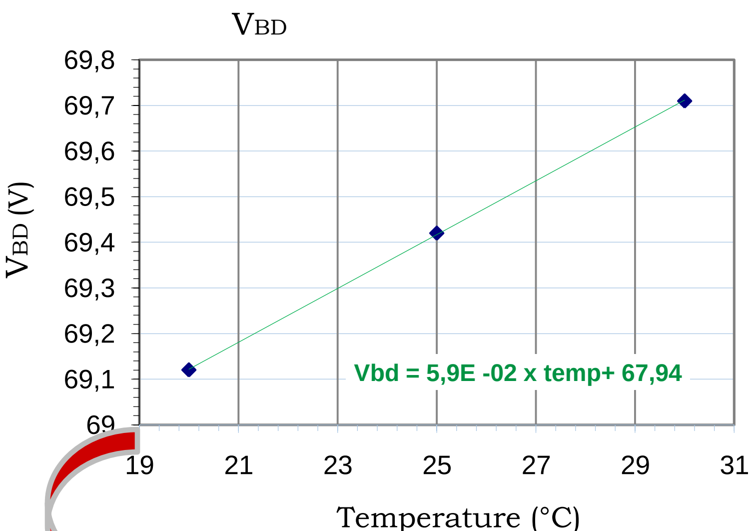
# Choice of the SPTR measurement points




e.g : MPPC 10-100S-FS




Correction of the bias voltage if the temperature changes inside the test bench to maintain a constant gain

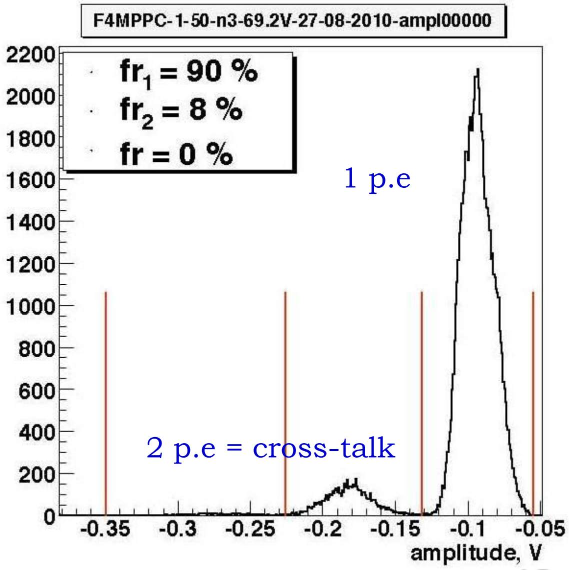
High power of the laser diode → pulse width ~40 ps-50 ps depending on the laser head

neutral filters

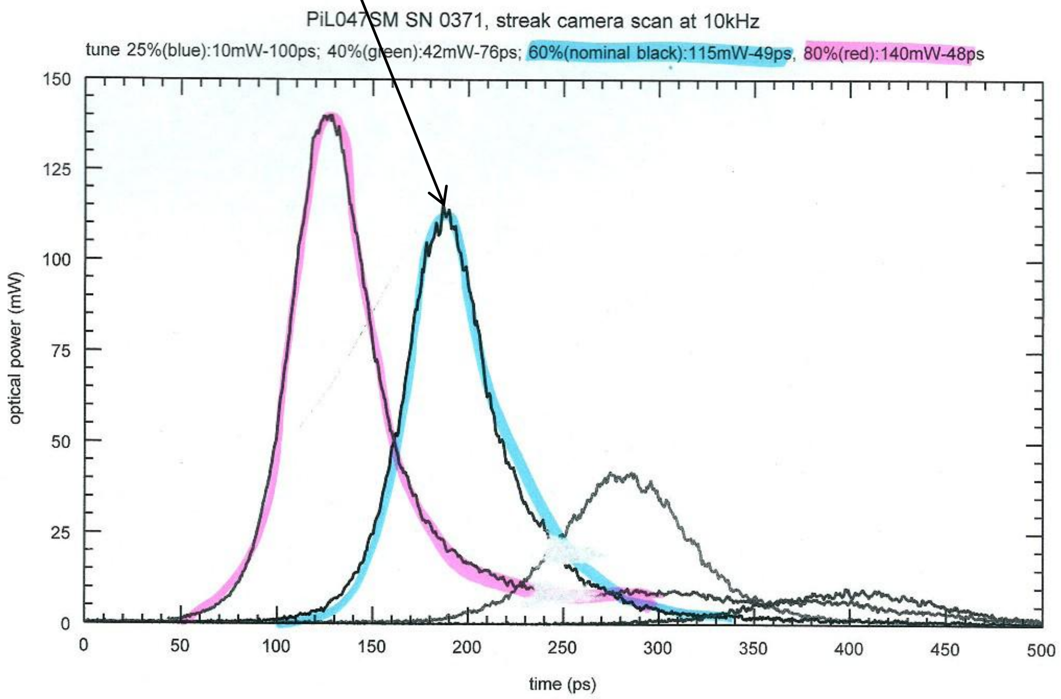
~ 1 photon/pulse/mm²

at the SiPM output : majority of 0, few 1 photo-electron

+ small quantity of signal α 2 p.e due to cross-talk



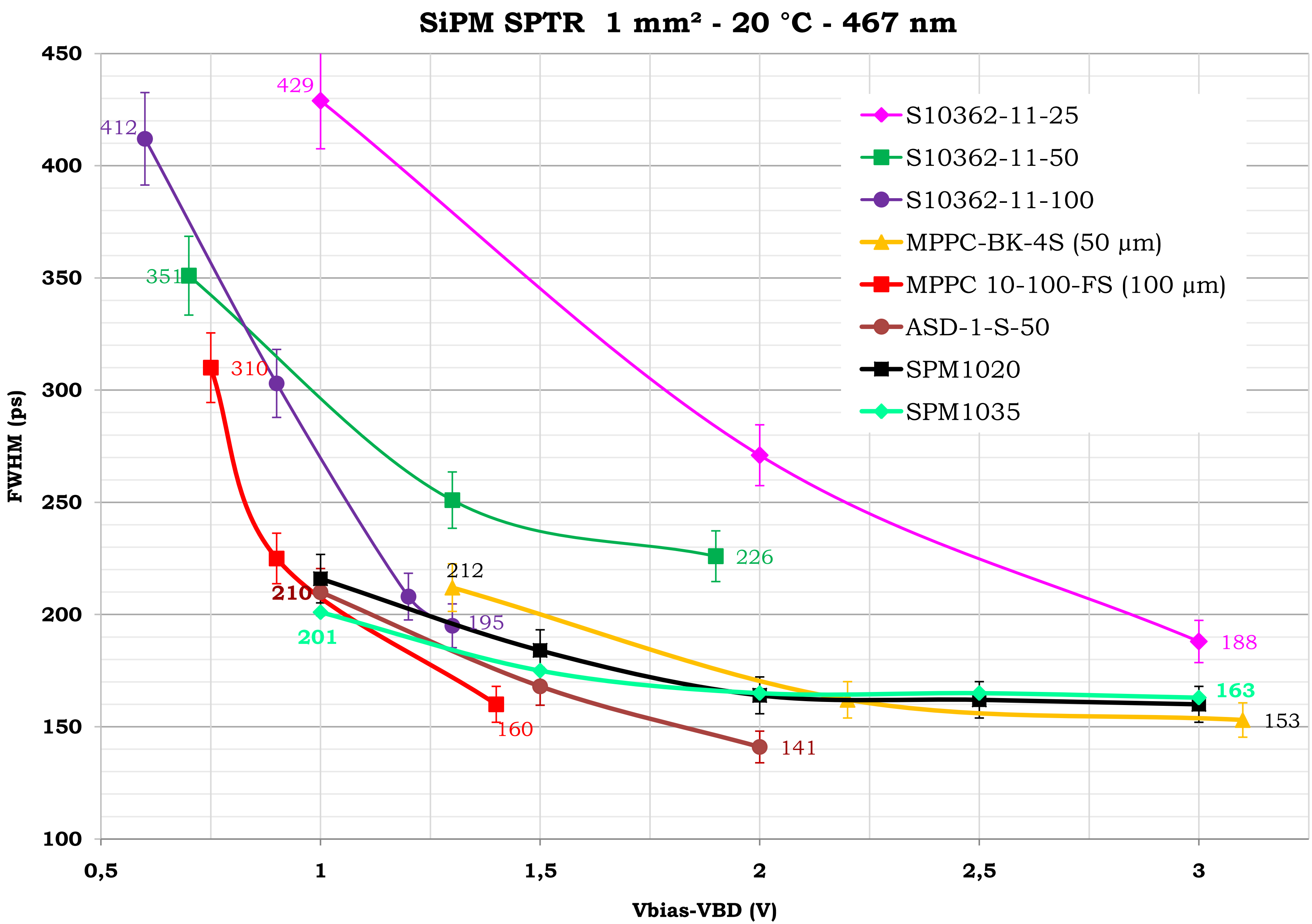
- Pilas pulsed laser diode




| λ (nm) | 405 | 467 | 635 |
|---|---|---|---|
| Pulse laser width (ps) | 38 | 50 | 40 |

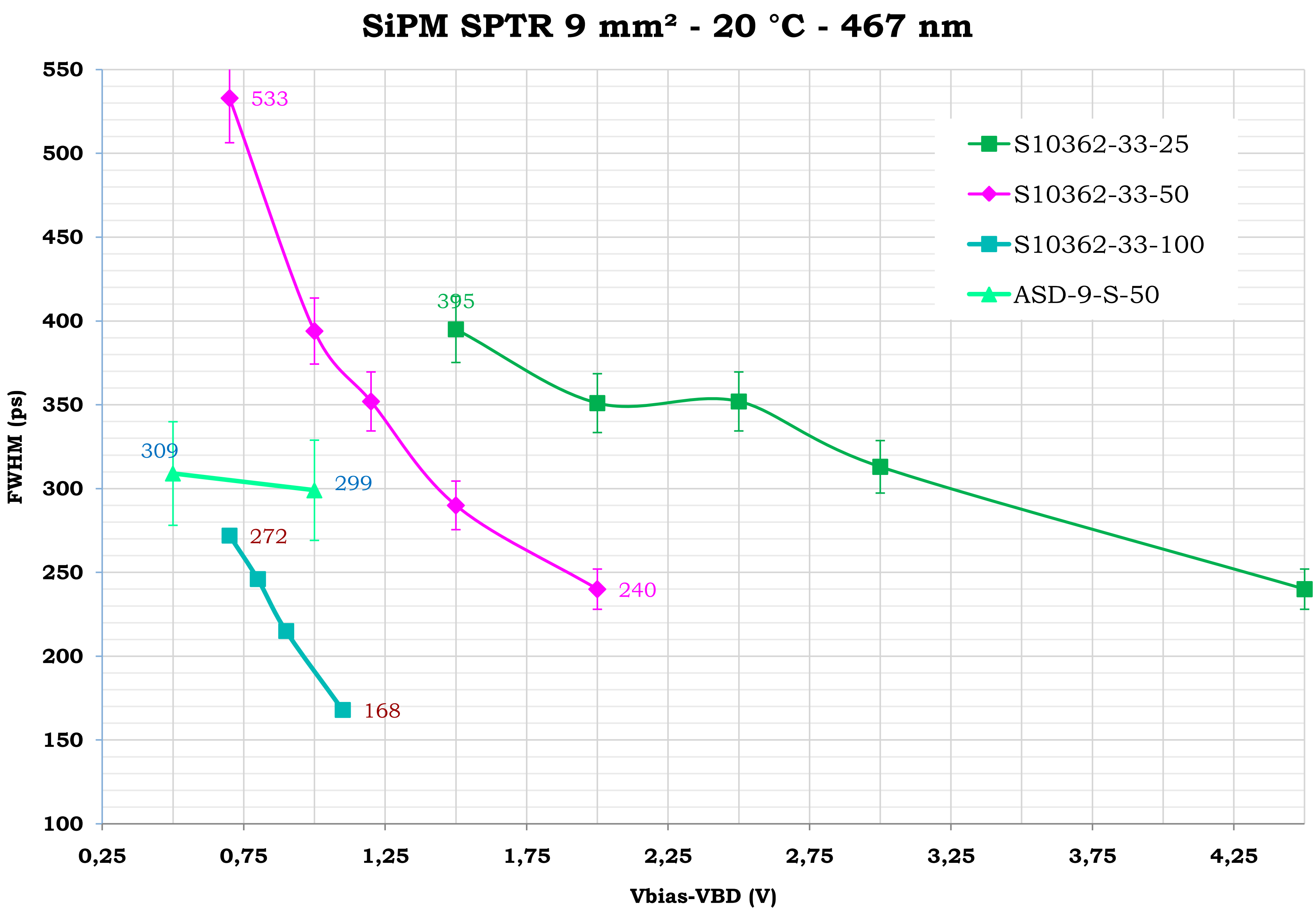
- Pilas driver : jitter ≈ 3 ps
- Timing resolution of the LECROY scope ≈ 1 ps
- Timing resolution of the Wavecatcher ≈ 8 ps

# 1 mm² SiPM SPTR in function of the applied voltage



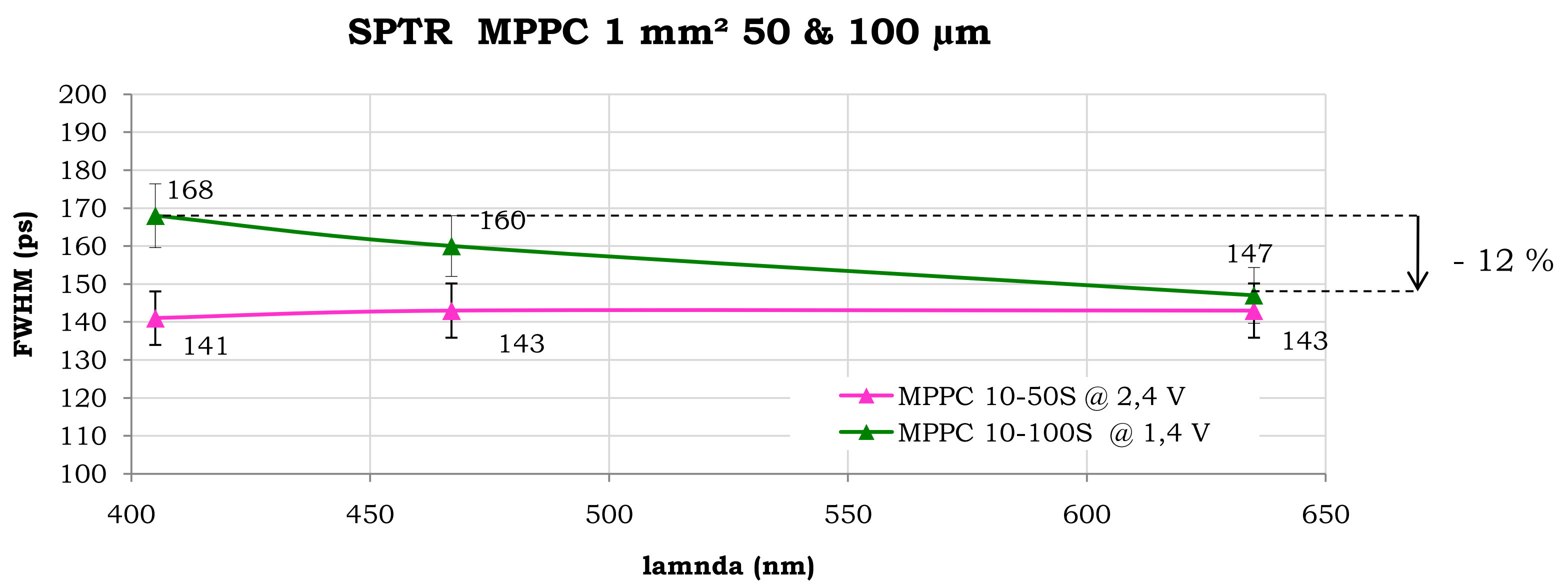

VDB : breakdown voltage

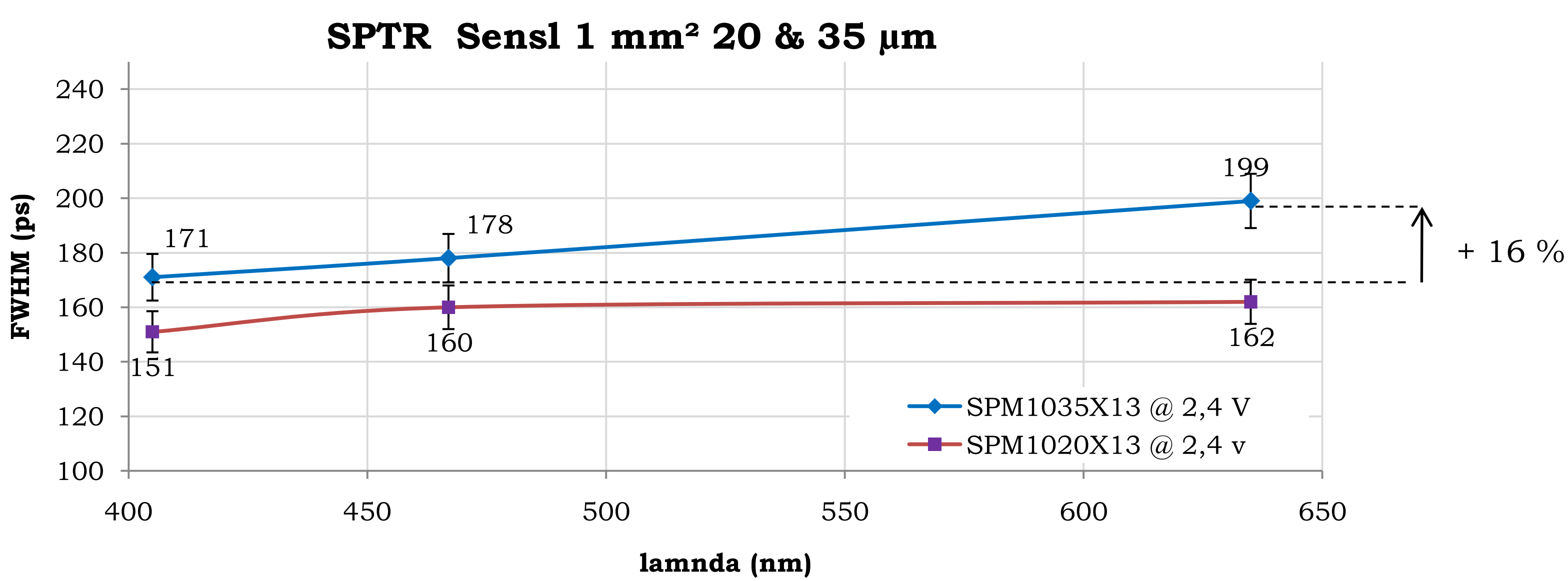
# 9 mm² SiPM SPTR in function of the applied voltage

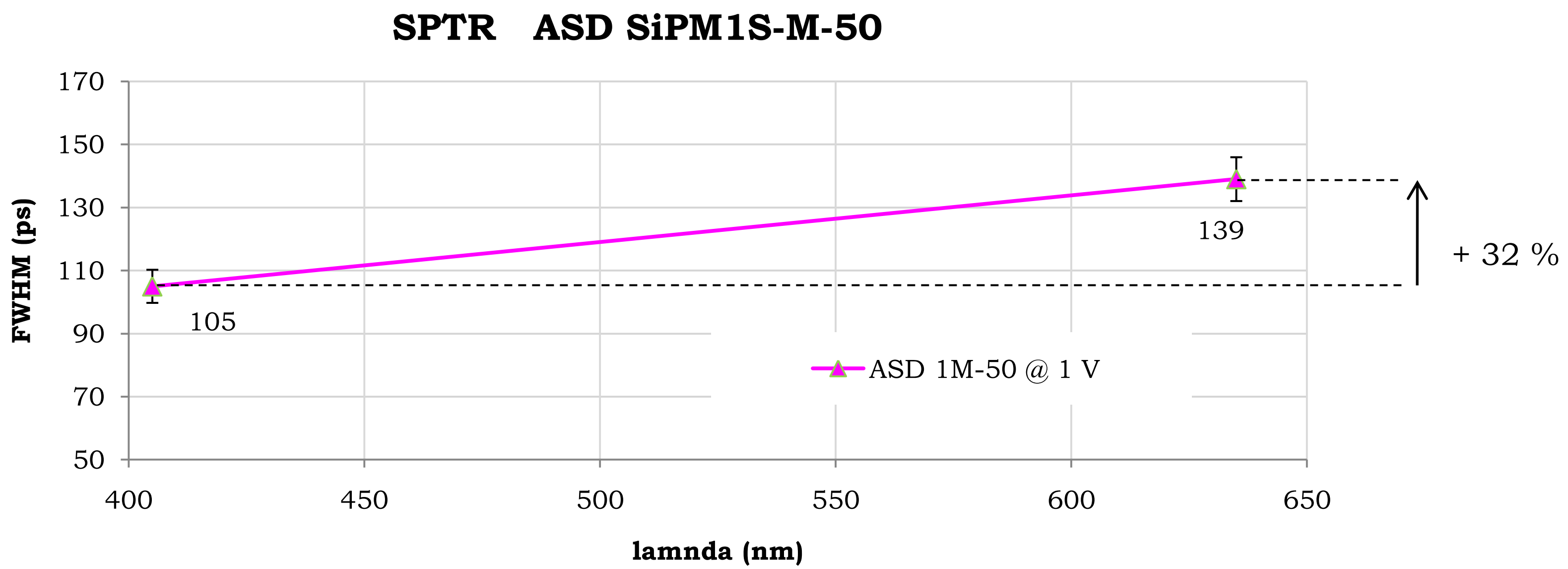


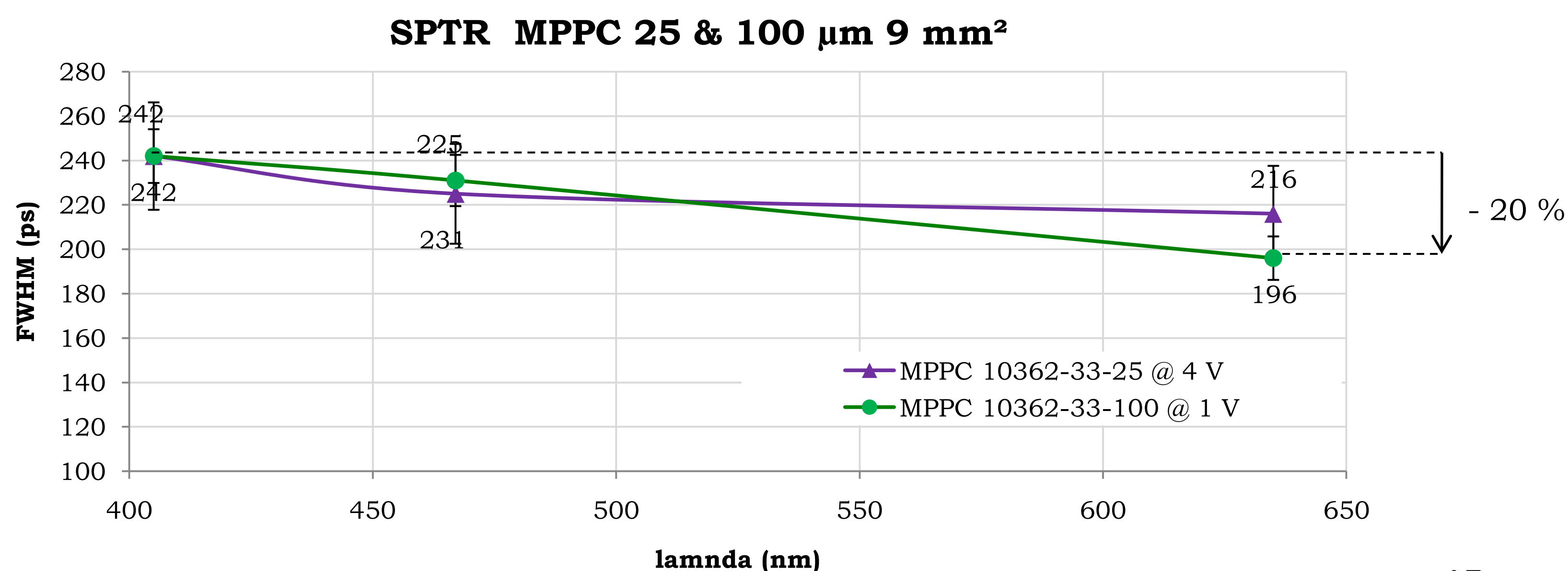

- SPM-3035X13 too noisy to measure the SPTR

# SiPM SPTR = f(λ) @ 20 °C and Vbias max

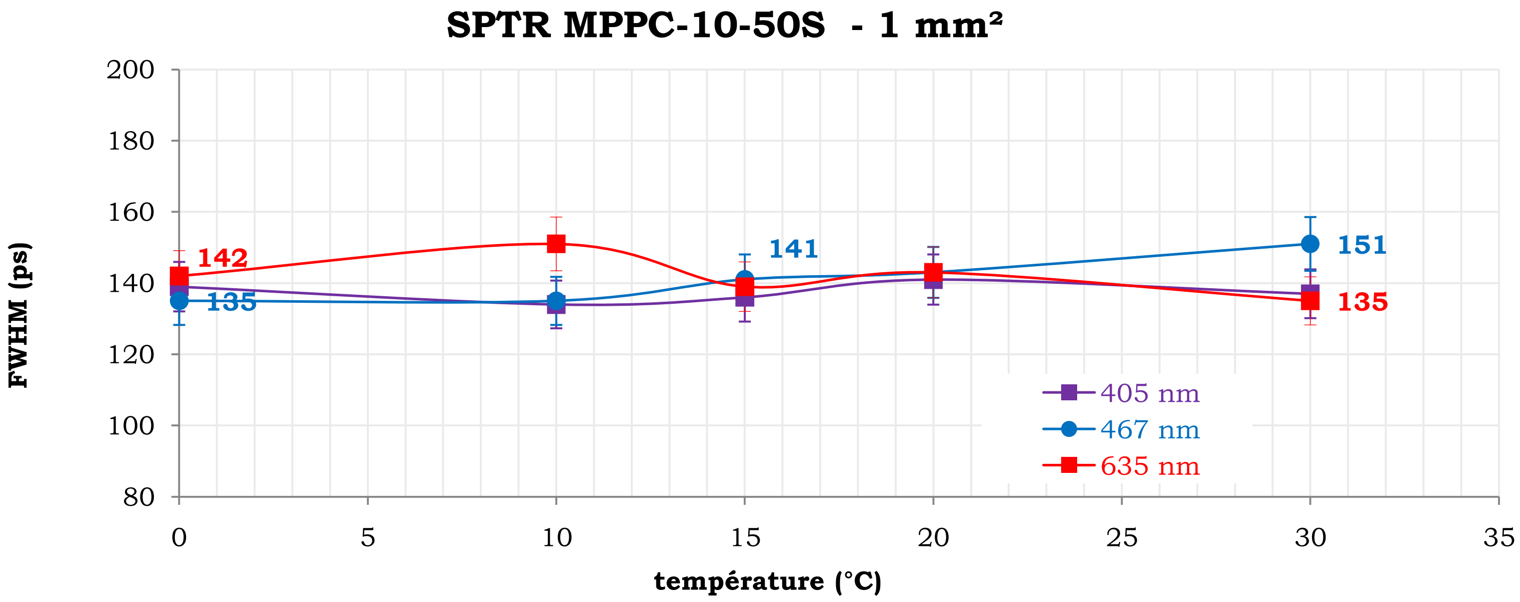


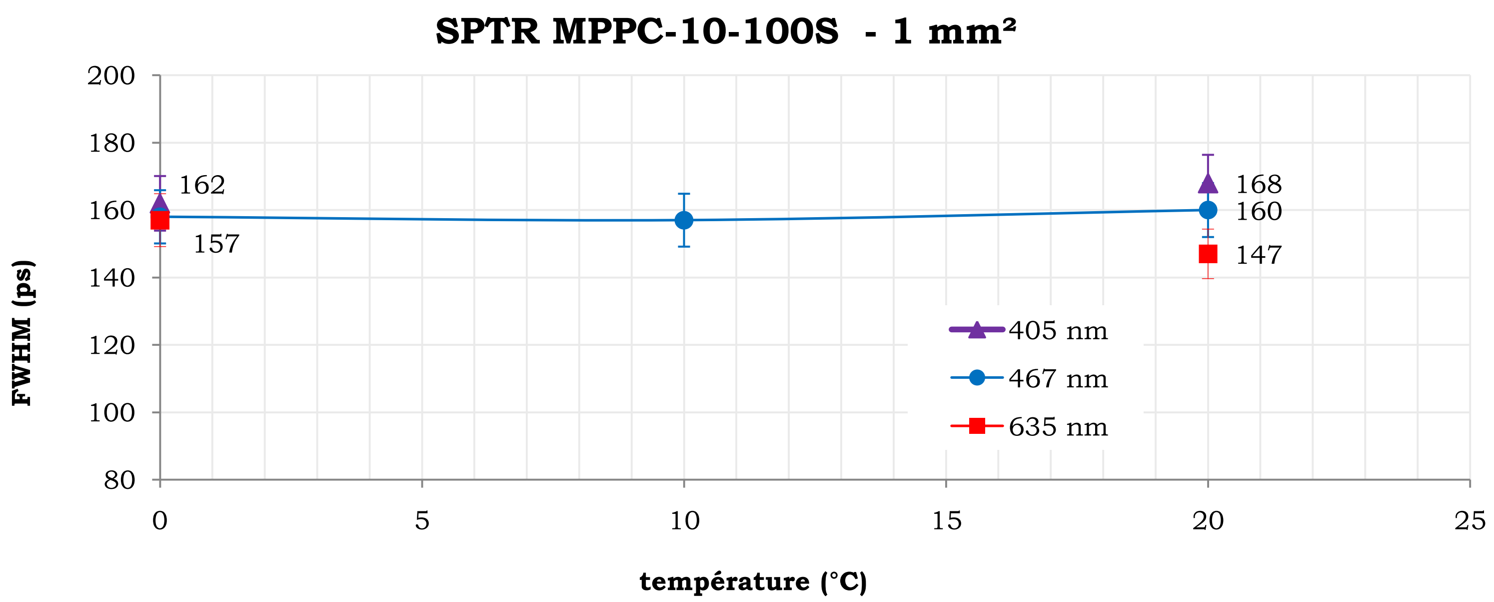




SPTR ASD SiPM1S-M-50
170
150
130
110
90
70
50
FWHM (ps)
400
450
500
550
600
650
lamnda (nm)
105
139
+ 32 %
ASD 1M-50 @ 1 V


SPTR MPPC 25 & 100 µm 9 mm²
280
260
240
220
200
180
160
140
120
100
FWHM (ps)
400
450
500
550
600
650
lamnda (nm)
242
242
225
231
216
196
- 20 %
MPPC 10362-33-25 @ 4 V
MPPC 10362-33-100 @ 1 V

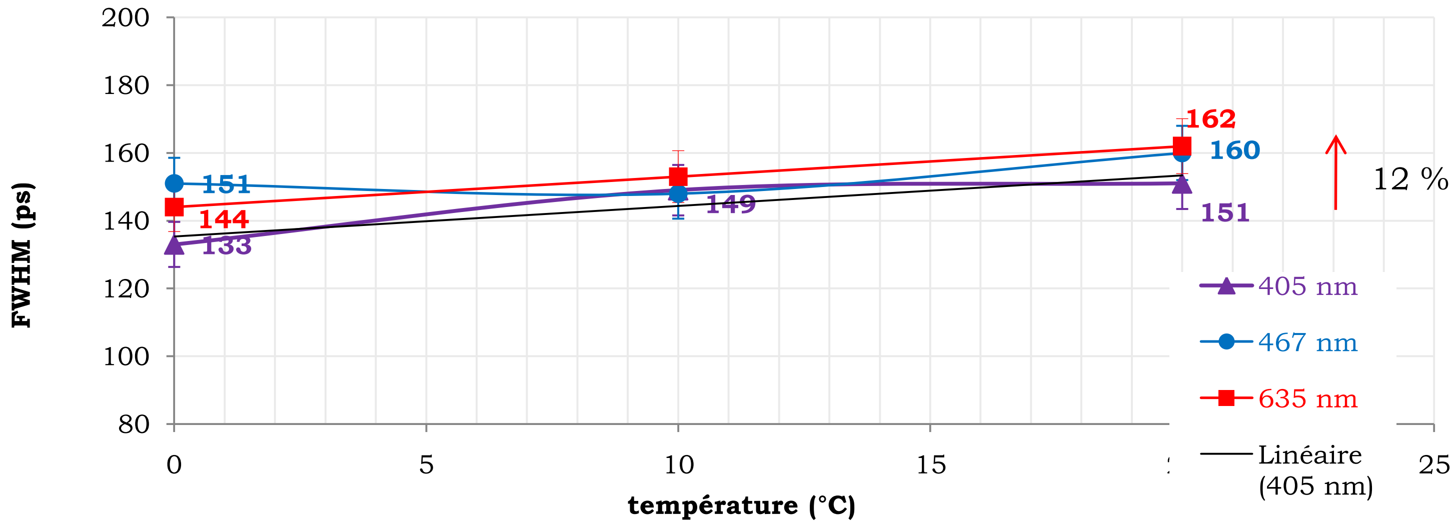
# 1 mm² SiPM SPTR = f(temperature) @ Vbias max



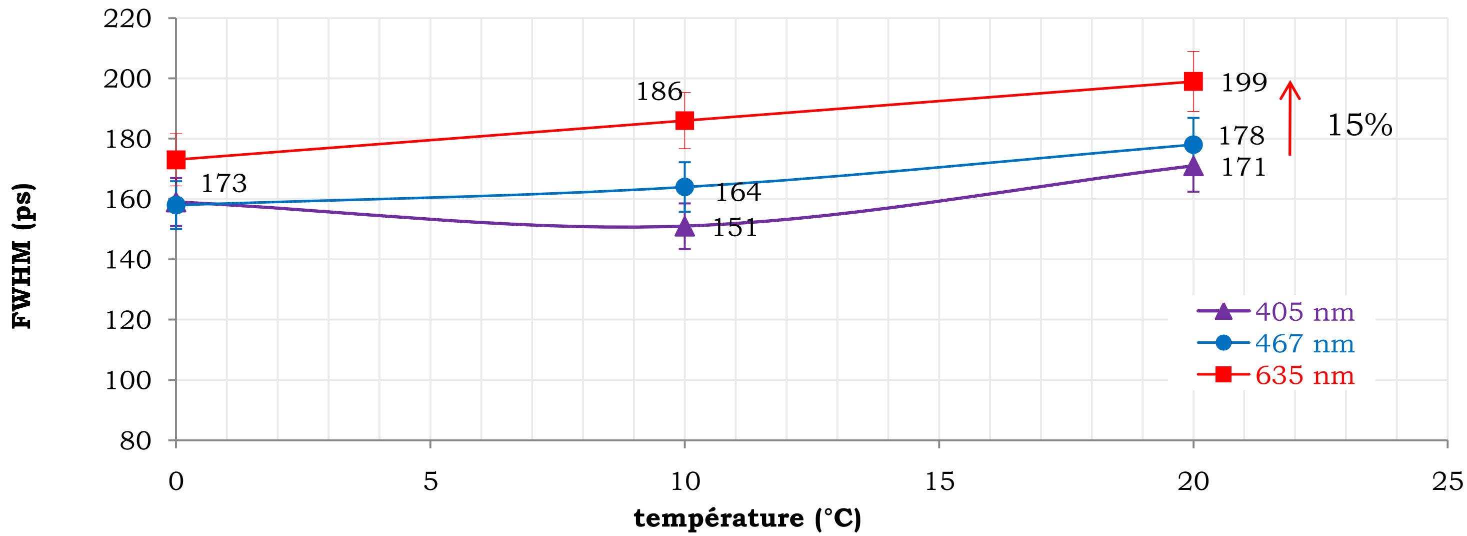



# 1 mm² SiPM SPTR = f(temperature) @ Vbias max

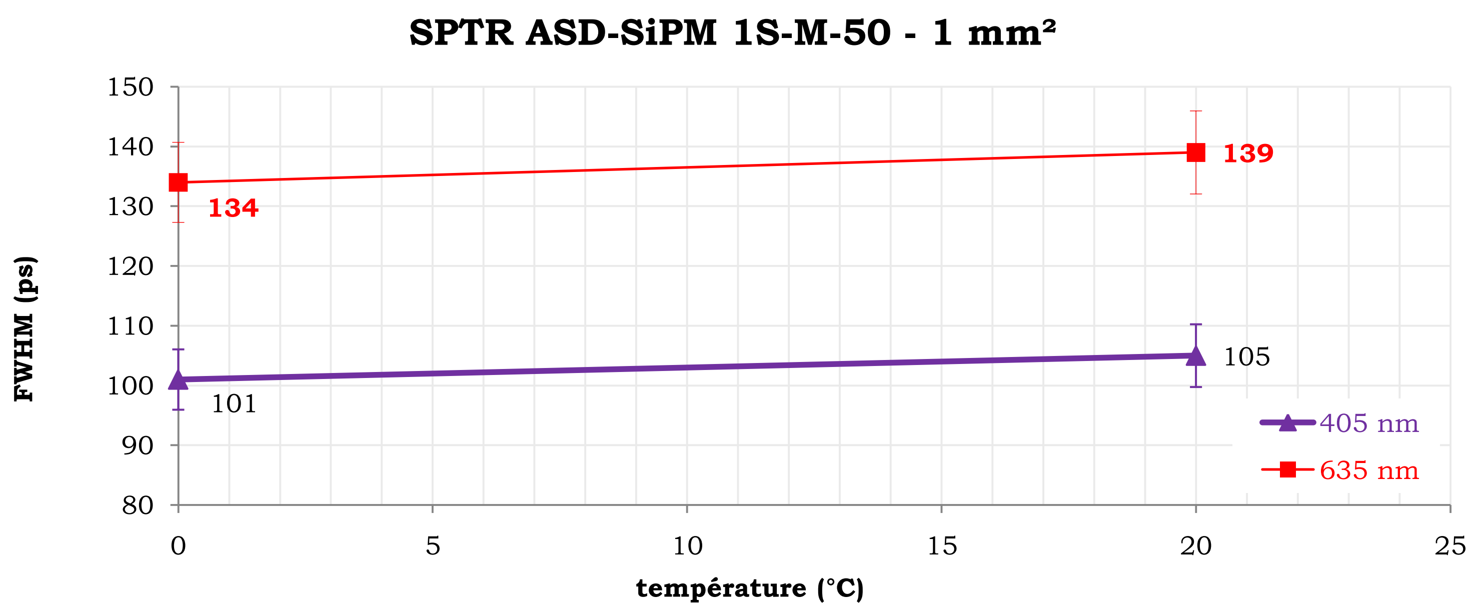
SPTR SPM1020x13 -1 mm²




SPTR SPM1035x13 - 1 mm²



# 1 mm² SiPM SPTR = f(temperature) @ Vbias max



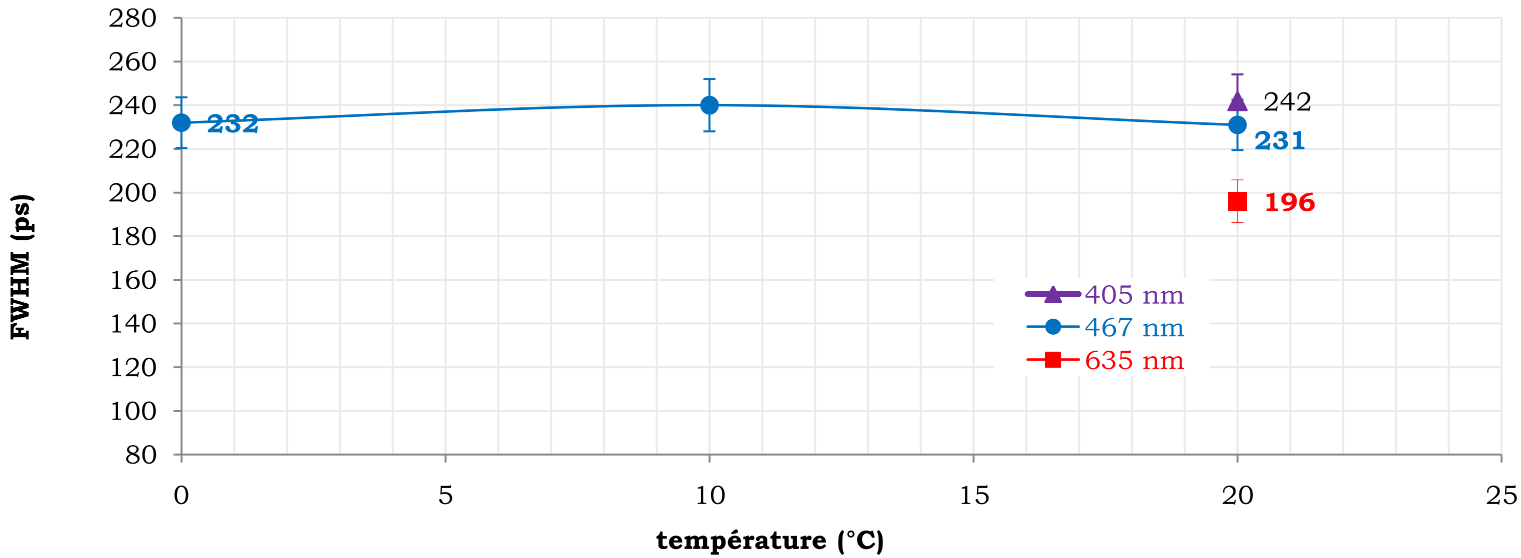

# 9 mm² SiPM SPTR = f(temperature) @ Vbias max

**ASD 9S-M-50**
and
**SPM-3035X13** (Sensl)

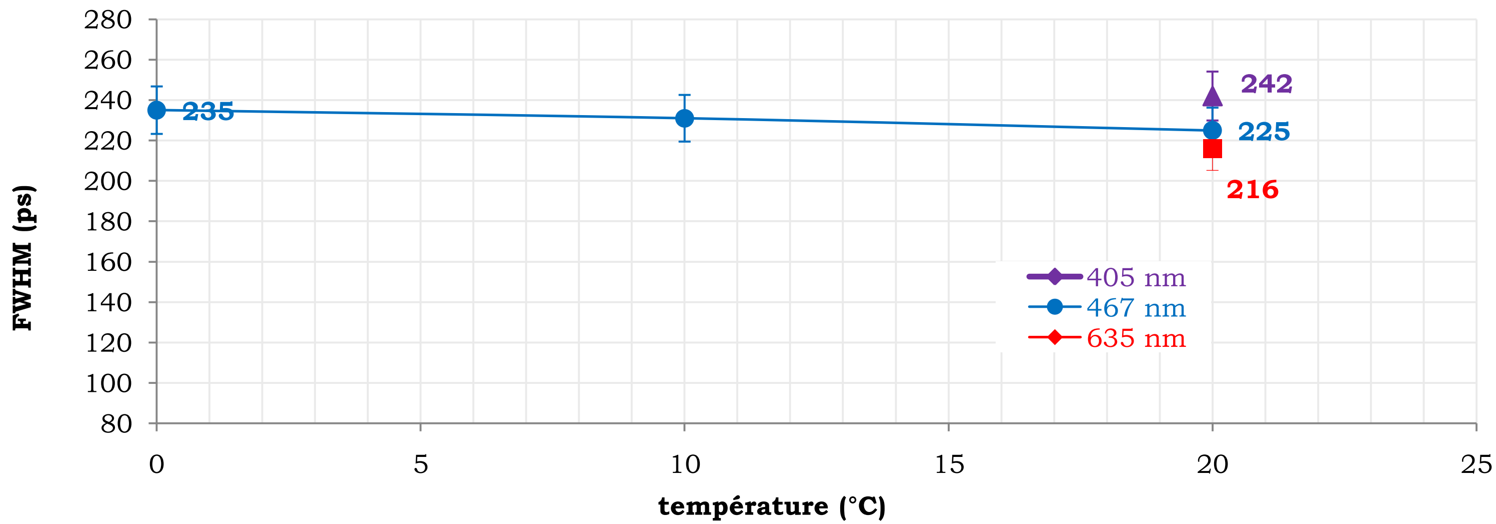
too difficult to measure at 1 p.e

# 9 mm² SiPM SPTR = f(temperature) @ Vbias max

SPTR MPPC S10362-33-100 - 9 mm²




SPTR MPPC S10362-33-25 - 9 mm²



| Area ($mm^2$) | Producer | Pixel size (µm) | Best SPTR (FWHM -± 5 %) @ 467 nm & Vbias max | SPTR Variation 405 nm → 635 nm | SPTR variation 0 °C → 20 °C |
|---|---|---|---|---|---|
| 1 | HAMAMATSU | 50 | 150 ps | ≈ 0 % | ≤ 5 % |
| 1 | HAMAMATSU | 100 | 160 ps | ≈ 10 % | ≤ 5 % |
| 1 | Sensl | 20 | 160 ps | ≈ 0 % | ≤ 10 % |
| 1 | Sensl | 35 | 200 ps | ≈ 15 % | ≤ 15 % |
| 1 | ASD (FBK) | 50 | 140 ps | ≈ 30 % | ≈ 0 % |
| 9 | HAMAMATSU | 25 | 250 ps | ≈ 10 % | ≈ 0 % |
| 9 | HAMAMATSU | 100 | 170 ps | ≈ 20 % | ≈ 0 % |
| 9 | Sensl | 35 | measurement impossible at single p.e level | | |
| 9 | ASD (FBK) | 50 | 300 ps ± 10 % | measurement impossible | |

# Additional slides

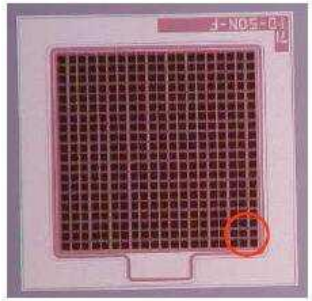
# References of the plots

***Characterization of a prototype matrix of Silicon Photomultipliers***, N. Dinu, P. Barrillon, C. Bazin, N. Belcari, M.G. Bisogni, S. Bondil-Blin, M. Boscardin, V. Chaumat, G. Collazuol, C. de La Taille, A. del Guerra, G. Llosá, S. Marcatili, M. Melchiorri, A. Tarolli, C. Piemonte, V. Puill, J.F.Vagnucci, N. Zorzi J.F.Vagnucci, , **Nuclear Inst. and Methods in Physics Research A 610 (2009), pp. 101-104**

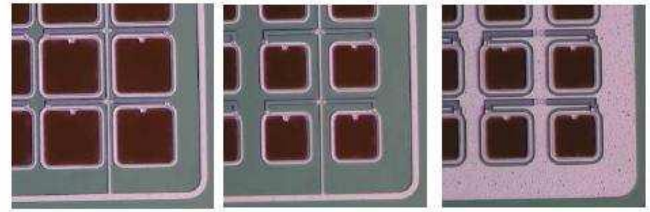
***Electro-optical characterization of SiPM: a comparative study***, N. Dinu, Z. Amara, C. Bazin, V. Chaumat, C. Cheikali, G. Guilhem, V. Puill, C. Sylvia, **Nuclear Inst. and Methods in Physics Research A 610 (2009), pp. 423-426**

***Temperature and Bias Voltage Dependence of the MPPC Detectors***, NSS IEEE Knoxwille Proceedings, N. Dinu, C. Bazin. V. Chaumat, C. Cheikali, A. Para*, V. Puill, C. Sylvia, J.F. Vagnucci*

MPPC 50 µm « wide trace »



Quenching resistance = 130KΩ by forward IV curve



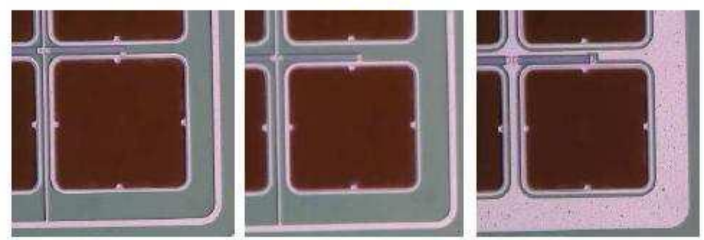
| Sample name | STD | Small pixel | Wide trace |
|---|---|---|---|
| Fill factor | 62 % | 38 % | 38 % |
| ΔV(Vop−Vbr) #1 | 1.31 V | 2.02 V | 2.01 V |
| Dark count at Vop | 535 Kcps | 484 Kcps | 502 Kcps |
| Pixel capacitance (Cd) #2 | 90 fF | 59 fF | 60 fF |
| Stray capacitance / pixel #3 | 2.5 fF | 11 fF | 23 fF |
| PDE at Vop , 440nm | Not measure | Not measure | Not measure |

#1 : Vop is at 7.5E05 #2 : by GAIN vs VR curve #3 : Ctotal / 400 – Cd at 25℃

**NEW HAMAMATSU PROTO**

MPPC 100 µm « wide trace »

Quenching resistance = 115KΩ by forward IV curve



| Sample name | STD | Small pixel | 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℃

*Temperature and Bias Voltage Dependence of the MPPC Detectors,* NSS IEEE Knoxwille Proceedings, N. Dinu, C. Bazin. V. Chaumat, C. Cheikali, A. Para, *V. Puill, C. Sylvia, J.F. Vagnucci*