# SensL B-Series Silicon Photomultipliers for TOF-PET

NDIP2014

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# Outline

- Performance-limiting physics of SiPM sensors
  - Photon Detection Efficiency
  - Dark count rate
  - Crosstalk
  - Afterpulsing
  - Microcell dimension
  - Effect of load resistances on output pulse shape
    - Rise-time
    - Recovery time
- Coincidence Resolving Time of B-Series SiPM sensors
  - LYSO
  - Crystal effects

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# Large Diversified Markets and Applications


## Medical Imaging

PET/CT, PET/MR, SPECT


## Hazard and Threat Detection

Radiation Detection, Cargo Scanning


## Automotive and Industrial

Advanced Driver Assistance, Laser Range Finding, Robotic Automation


## Biophotonics

Hematology, Flow Cytometry, DNA Analysis

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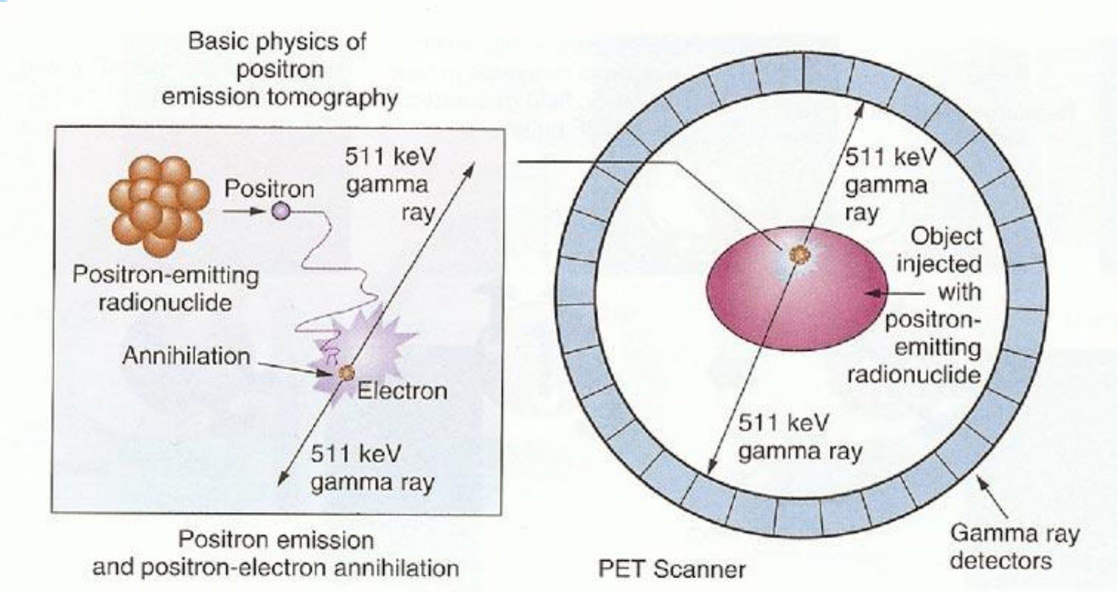
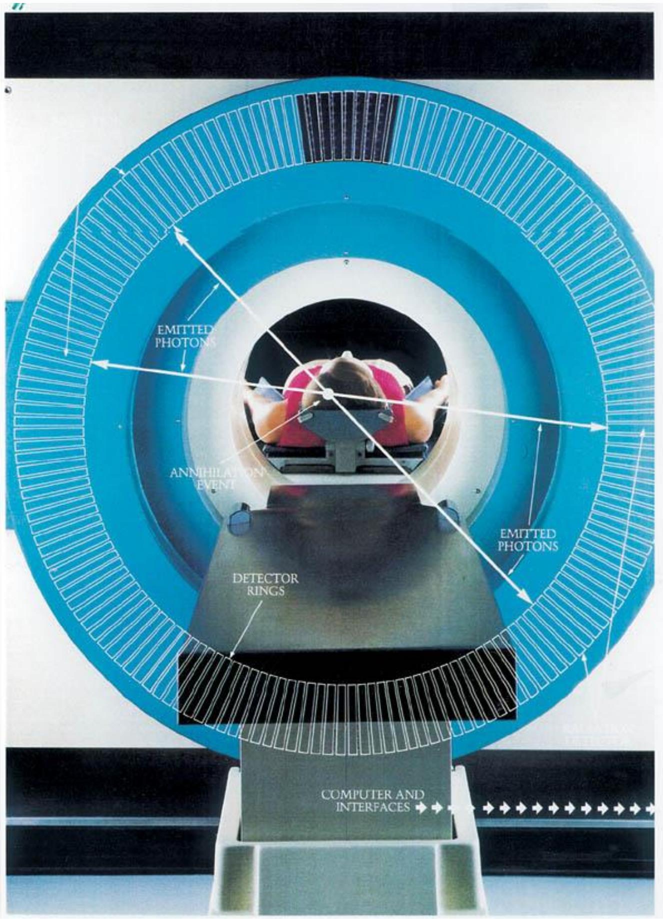
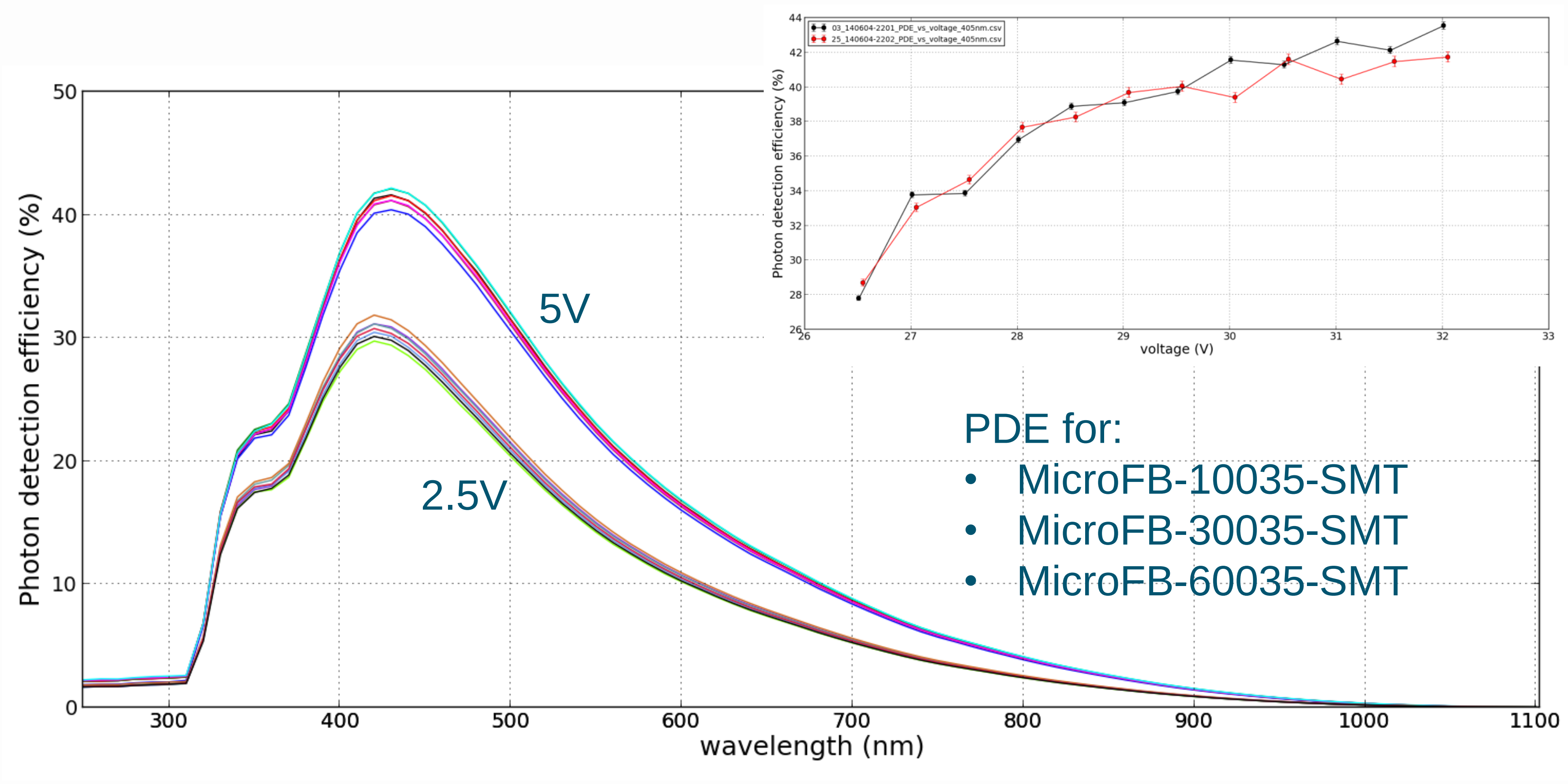
# Positron Emission Tomography (PET)



# Photon Detection Efficiency (PDE)




PDE for:

- MicroFB-10035-SMT
- MicroFB-30035-SMT
- MicroFB-60035-SMT

PDE optimized at 420nm for LYSO

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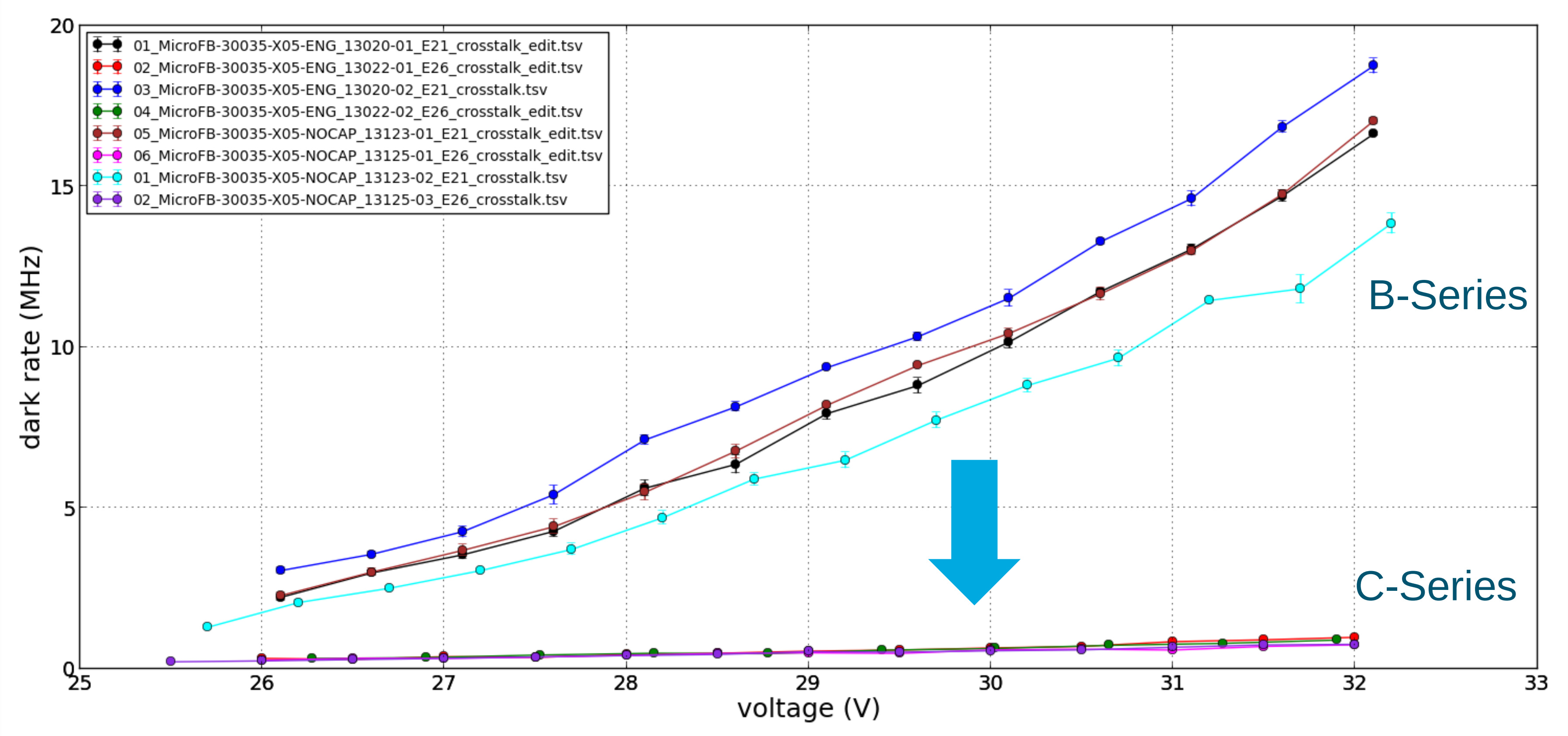
# Dark Count Rate (DCR)




Significant reduction of DCR in C-Series

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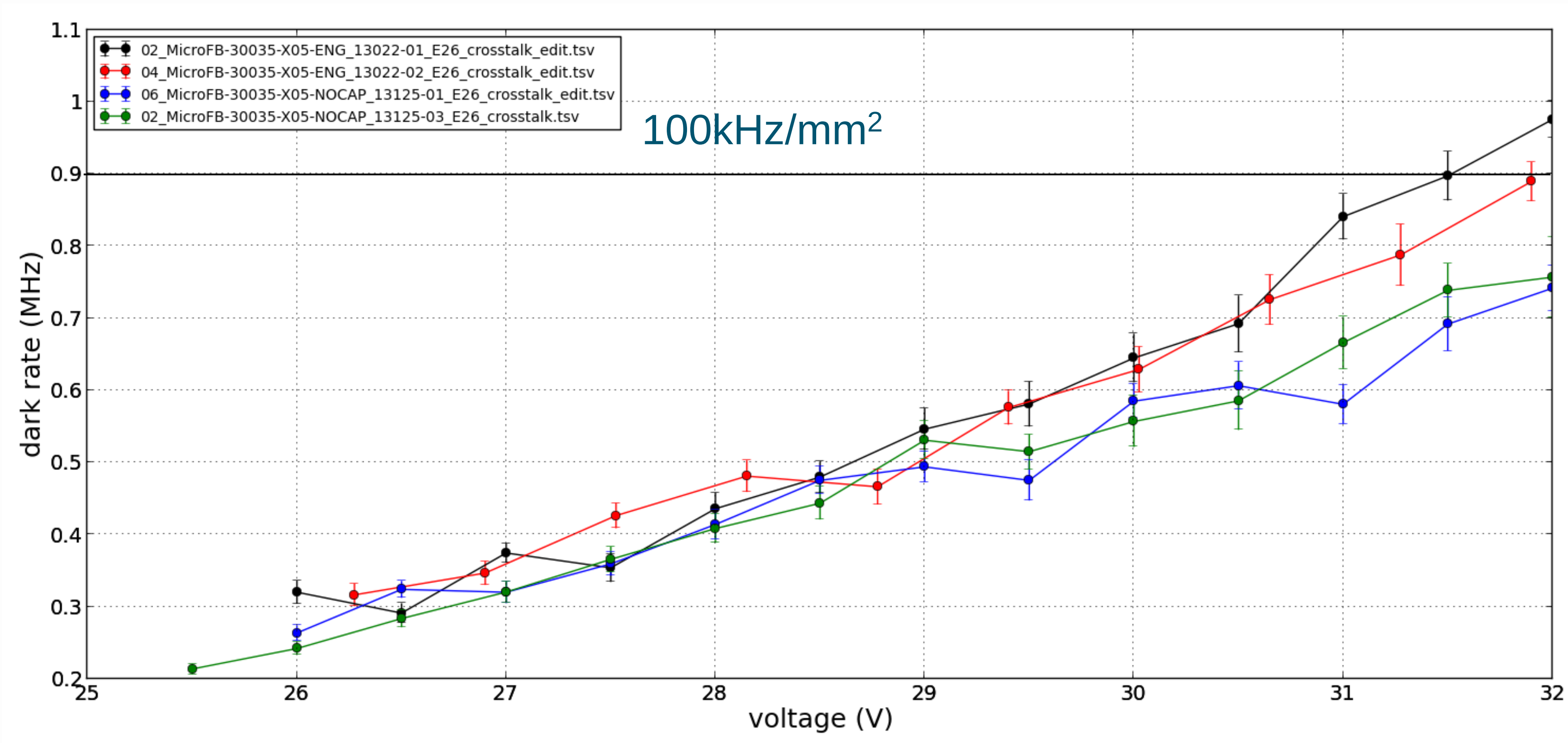
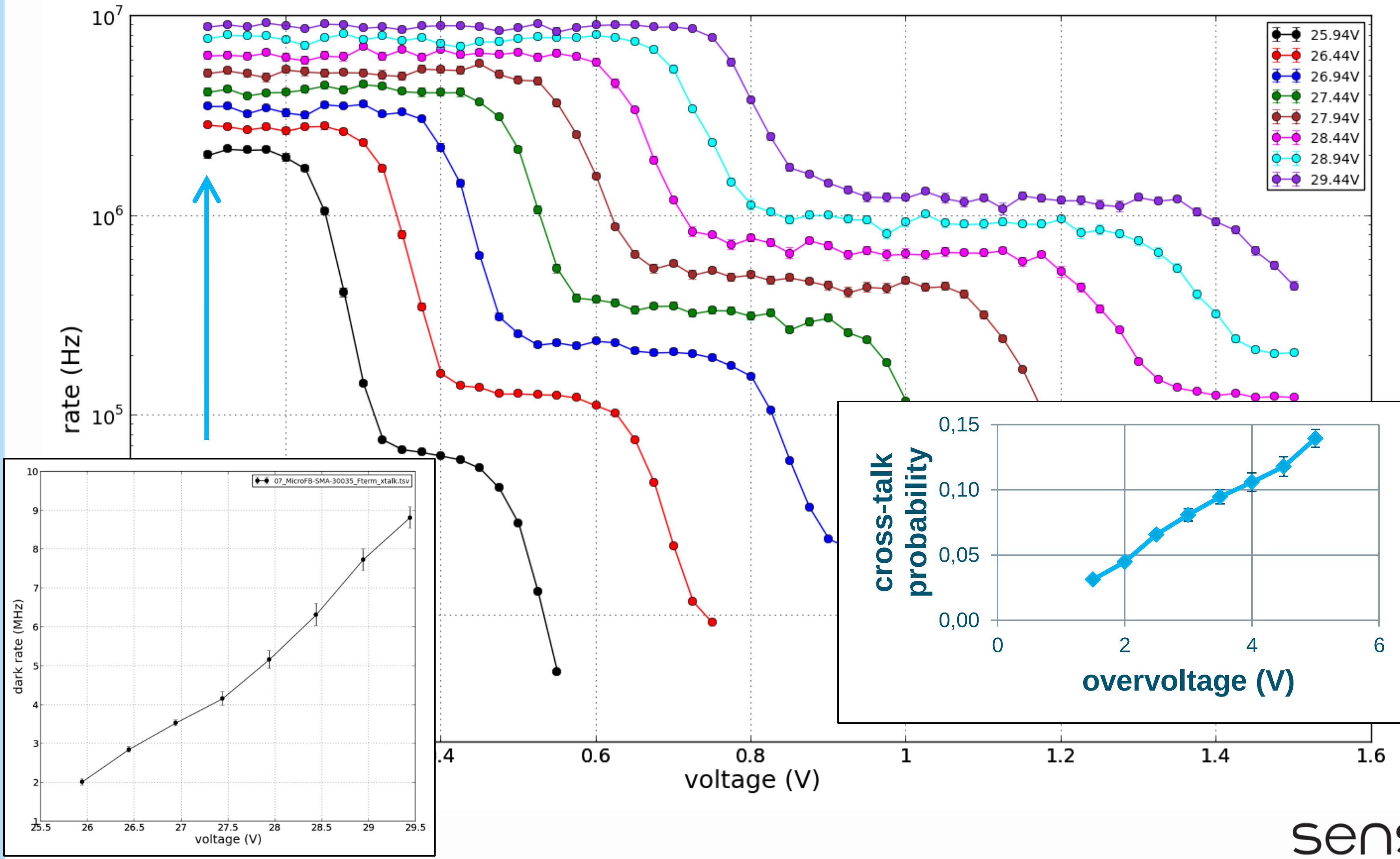
# Dark Count Rate – C-Series




OVB up to ~7.5V

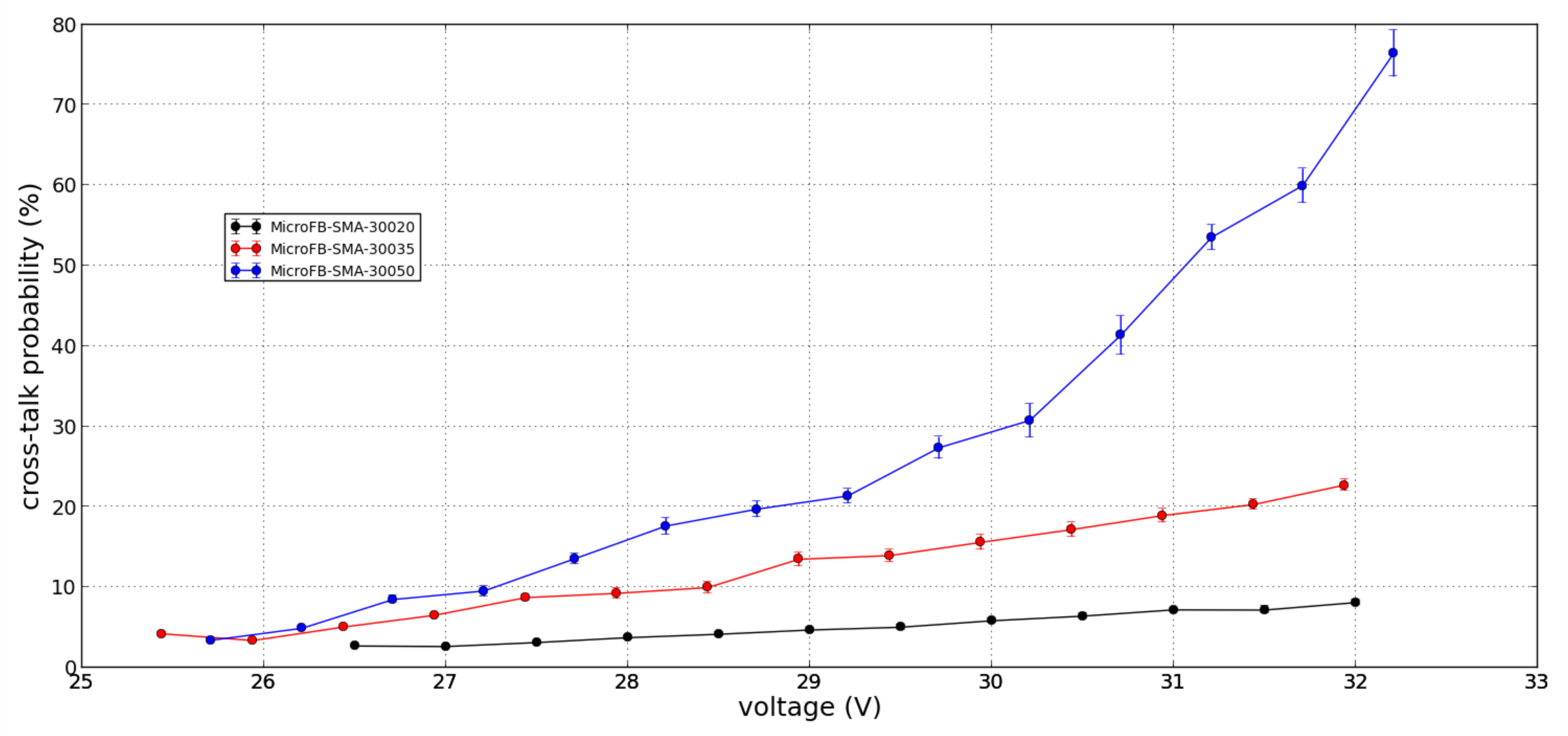
VBR2=~24.5V

# Crosstalk



rate (Hz)
$10^7$
$10^6$
$10^5$
voltage (V)
.4
0.6
0.8
1
1.2
1.4
1.6
25.94V
26.44V
26.94V
27.44V
27.94V
28.44V
28.94V
29.44V
07_MicroFB-SMA-30035_Fterm_xtalk.tsv
dark rate (MHz)
voltage (V)
25.5
26
26.5
27
27.5
28
28.5
29
29.5
1
2
3
4
5
6
7
8
9
10
cross-talk probability
0,15
0,10
0,05
0,00
0
2
4
6
overvoltage (V)

# MicroFB-30020/30035/30050-SMT Crosstalk Comparison




Larger microcell dimension→higher crosstalk probability

*Eckert, P.; Schultz-Coulon, H.-C.; Shen, W.; Stamen, R. & Tadday, A.
Characterisation studies of silicon photomultipliers
*Nuclear Instruments and Methods in Physics Research A*, **2010**, *620*, 217-22

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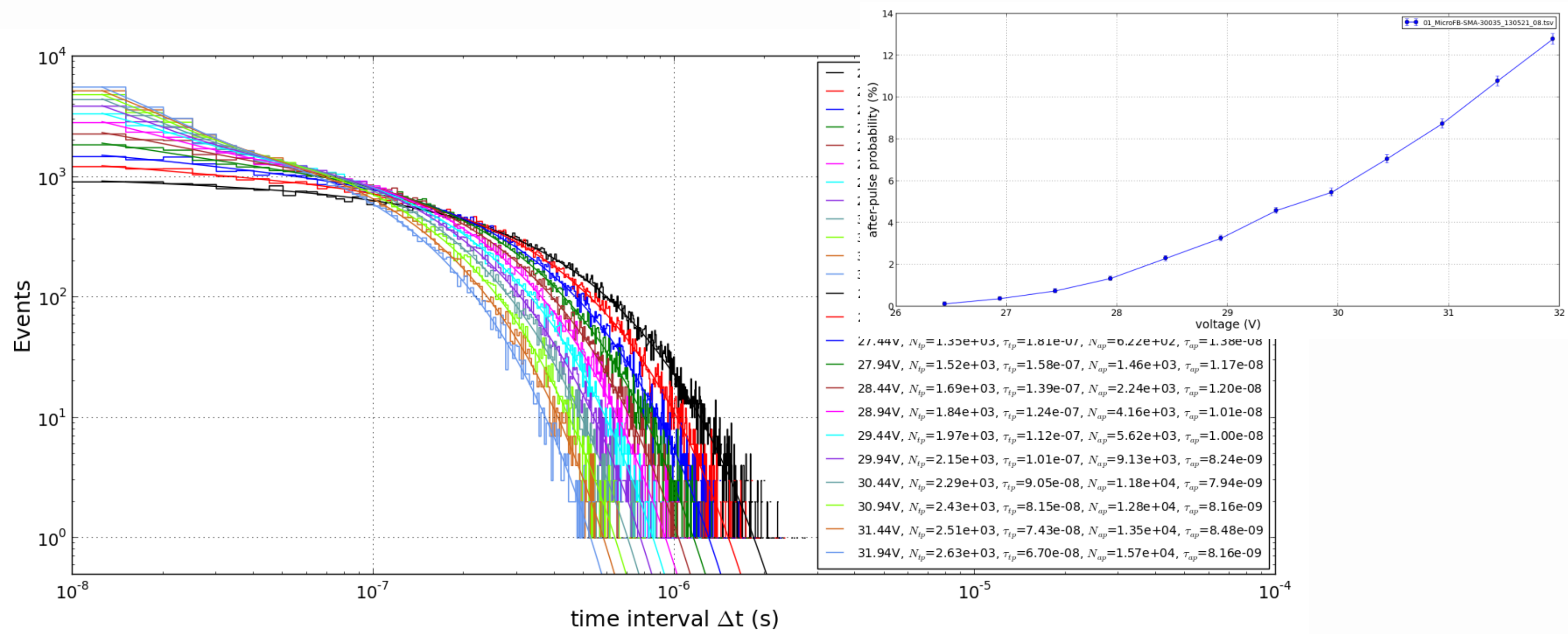
# Afterpulsing Probability

Lifetime style experiment – look at distribution of consecutive dark pulses




$$n_{\mathrm{tp}}(\Delta t) = N_{\mathrm{tp}}/\tau_{\mathrm{tp}} \cdot \mathrm{e}^{-\Delta t/\tau_{\mathrm{tp}}}$$

$$n_{\mathrm{ap}}(\Delta t) = N_{\mathrm{apf}}/\tau_{\mathrm{apf}} \cdot \mathrm{e}^{-\Delta t/\tau_{\mathrm{apf}}} + N_{\mathrm{aps}}/\tau_{\mathrm{aps}} \cdot \mathrm{e}^{-\Delta t/\tau_{\mathrm{aps}}}$$

$$P_{\mathrm{ap}} = \frac{\int_0^\infty \xi \cdot n_{\mathrm{ap}} \, \mathrm{d}\Delta t}{\int_0^\infty \xi \cdot (n_{\mathrm{ap}} + n_{\mathrm{tp}}) \, \mathrm{d}\Delta t}$$


*Eckert, P.; Schultz-Coulon, H.-C.; Shen, W.; Stamen, R. & Tadday, A.
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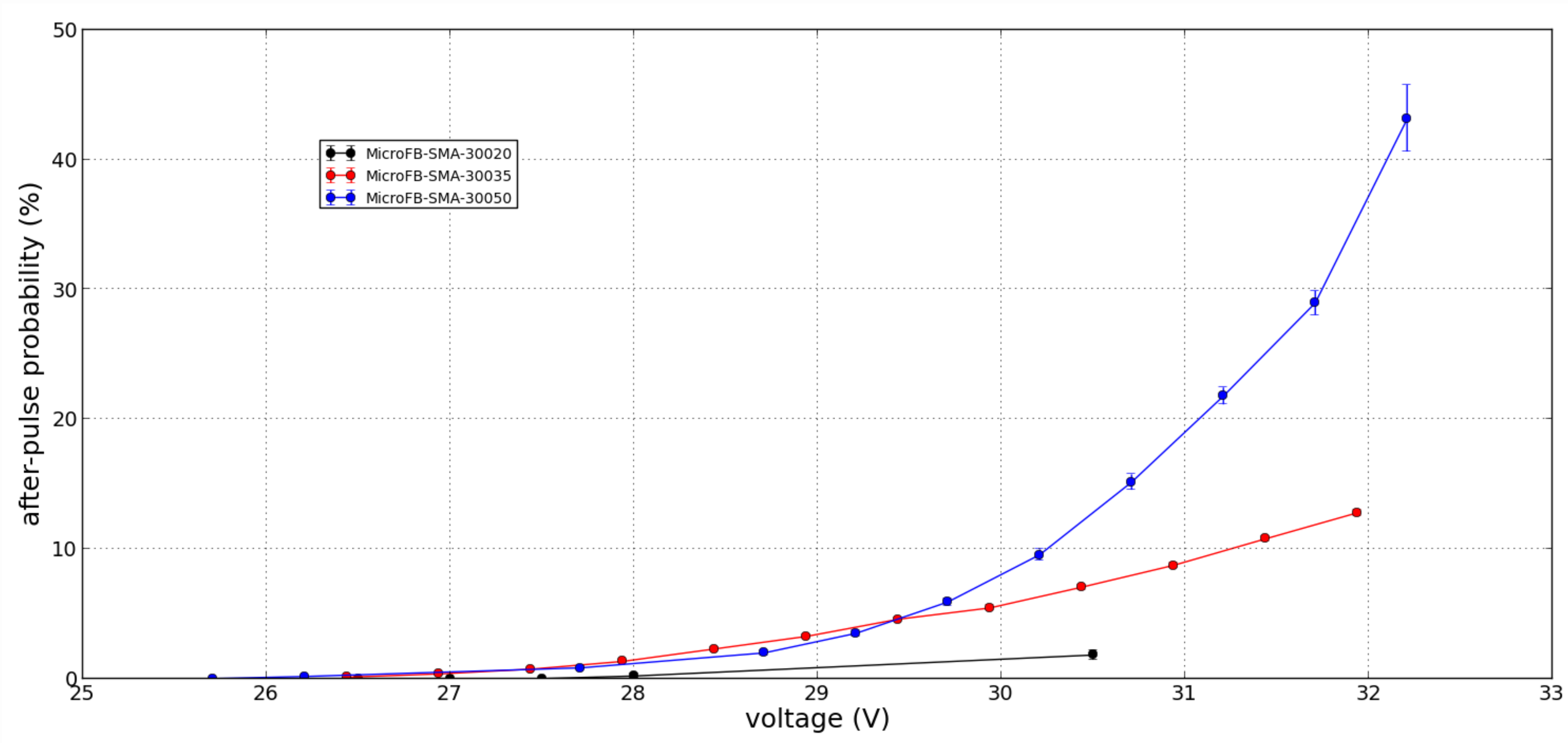
# MicroFB-30020/30035/30050-SMT Afterpulsing Comparison




Larger microcell dimension→higher afterpulsing probability

- More pronounced at higher over-biases

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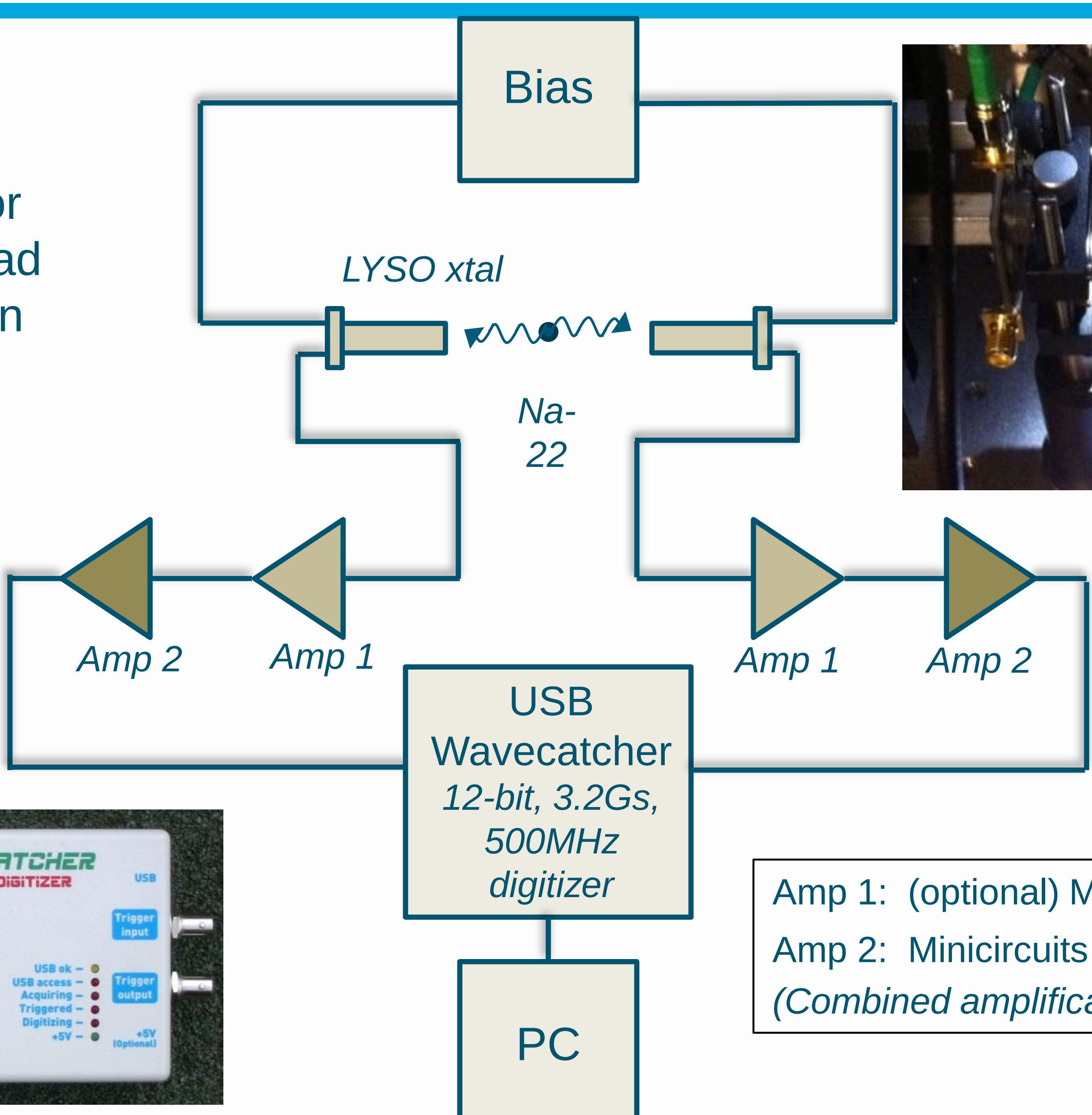
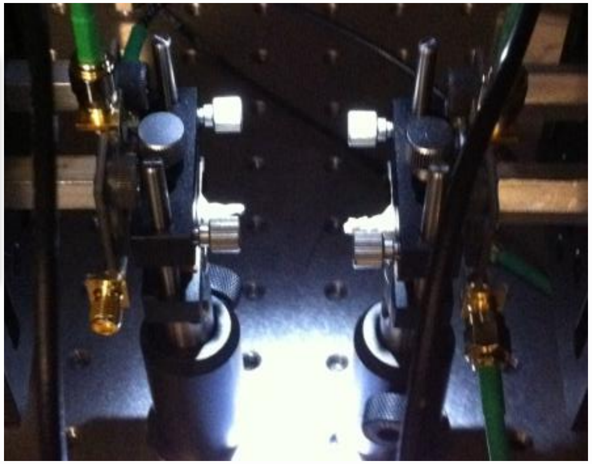
# Coincidence Resolving Time (CRT) for TOF-PET

- SiPM sensor
- Head-to-head configuration




Amp 1: (optional) Minicircuits ZFL-1000
Amp 2: Minicircuits ZX60-43-S+
*(Combined amplification of ~200x)*

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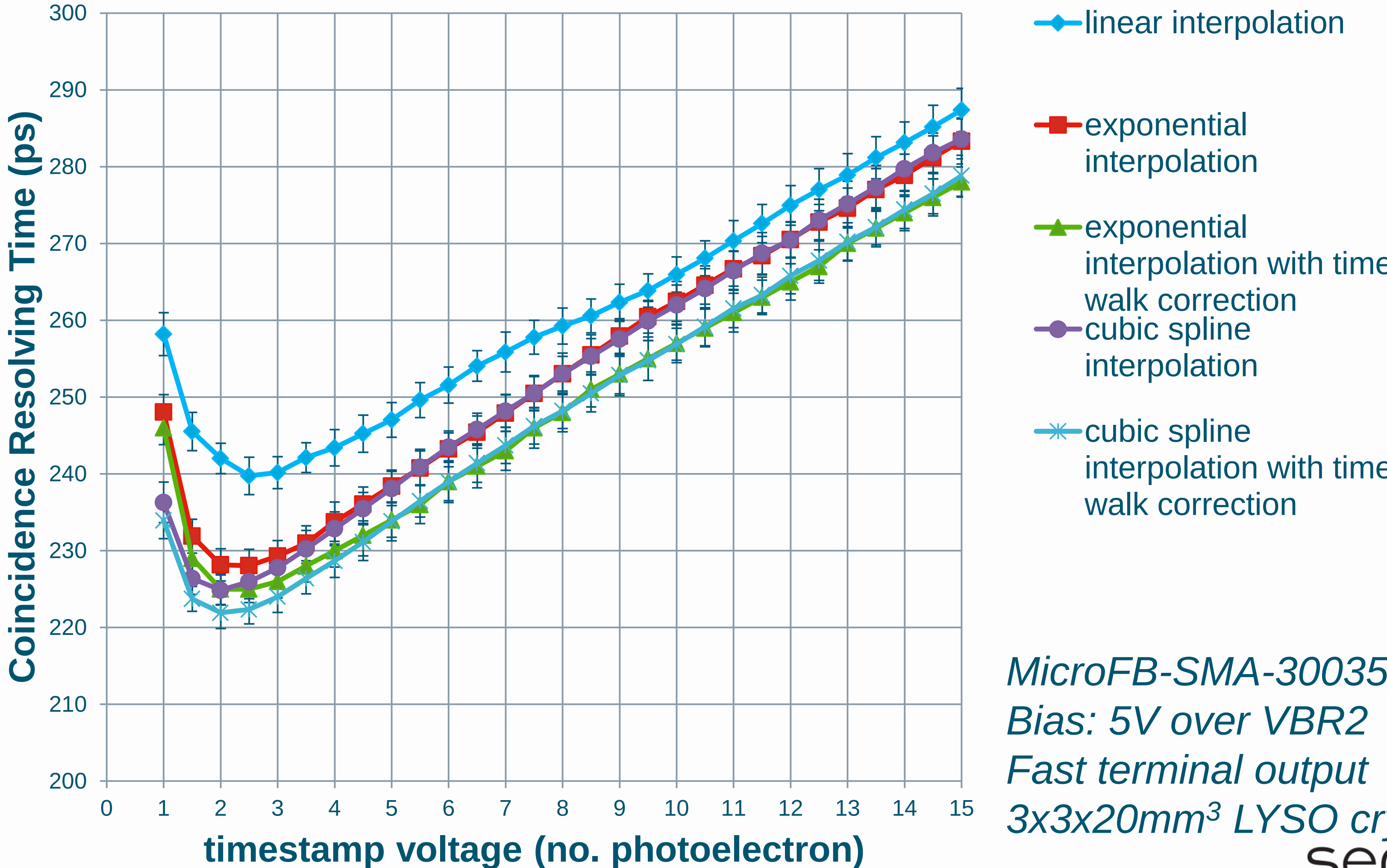
# CRT Analysis Methods




*MicroFB-SMA-30035*
*Bias: 5V over VBR2*
*Fast terminal output*
*3x3x20mm$^3$ LYSO crystals*

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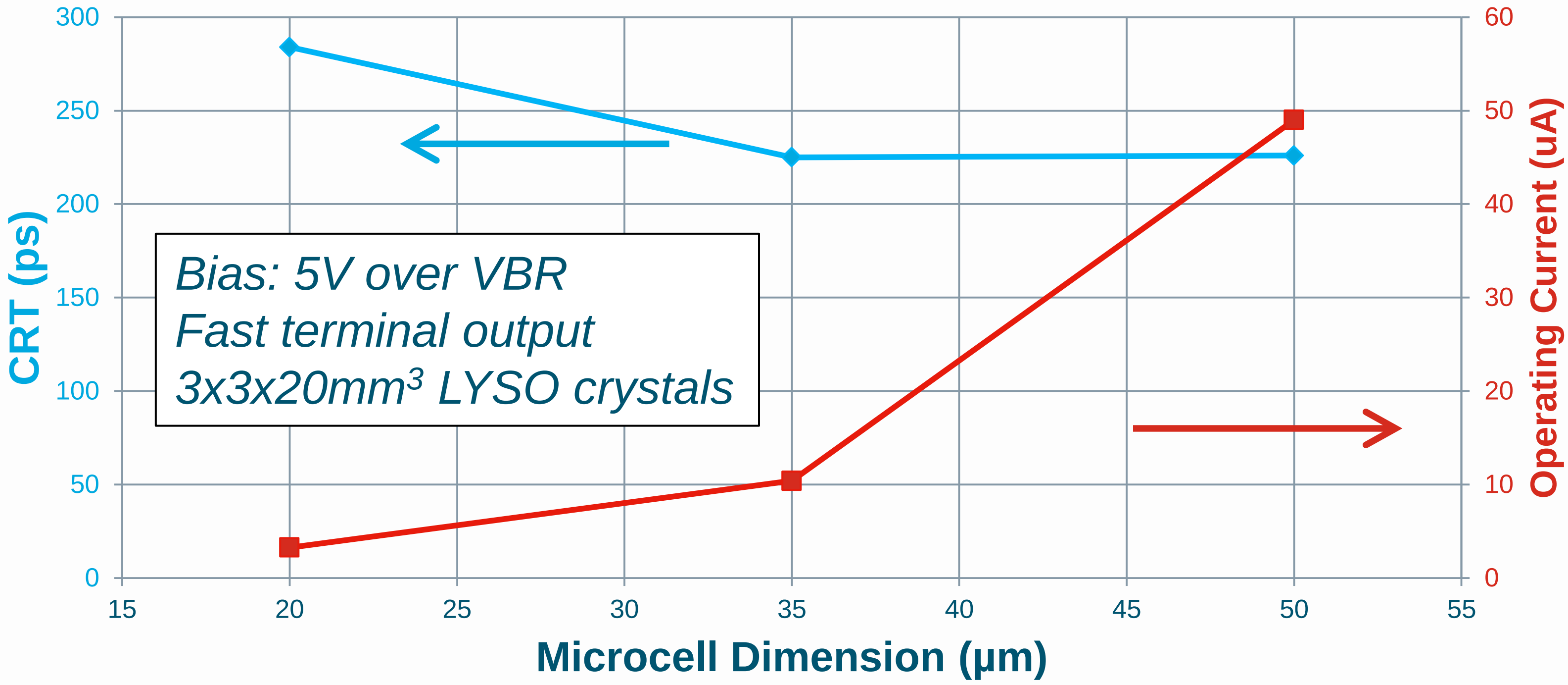
# Overvoltage Impact on Coincidence Resolving Time (CRT)




Trade-off between CRT performance and SiPM operating current
MicroFB-30035-SMT provides best trade-off.

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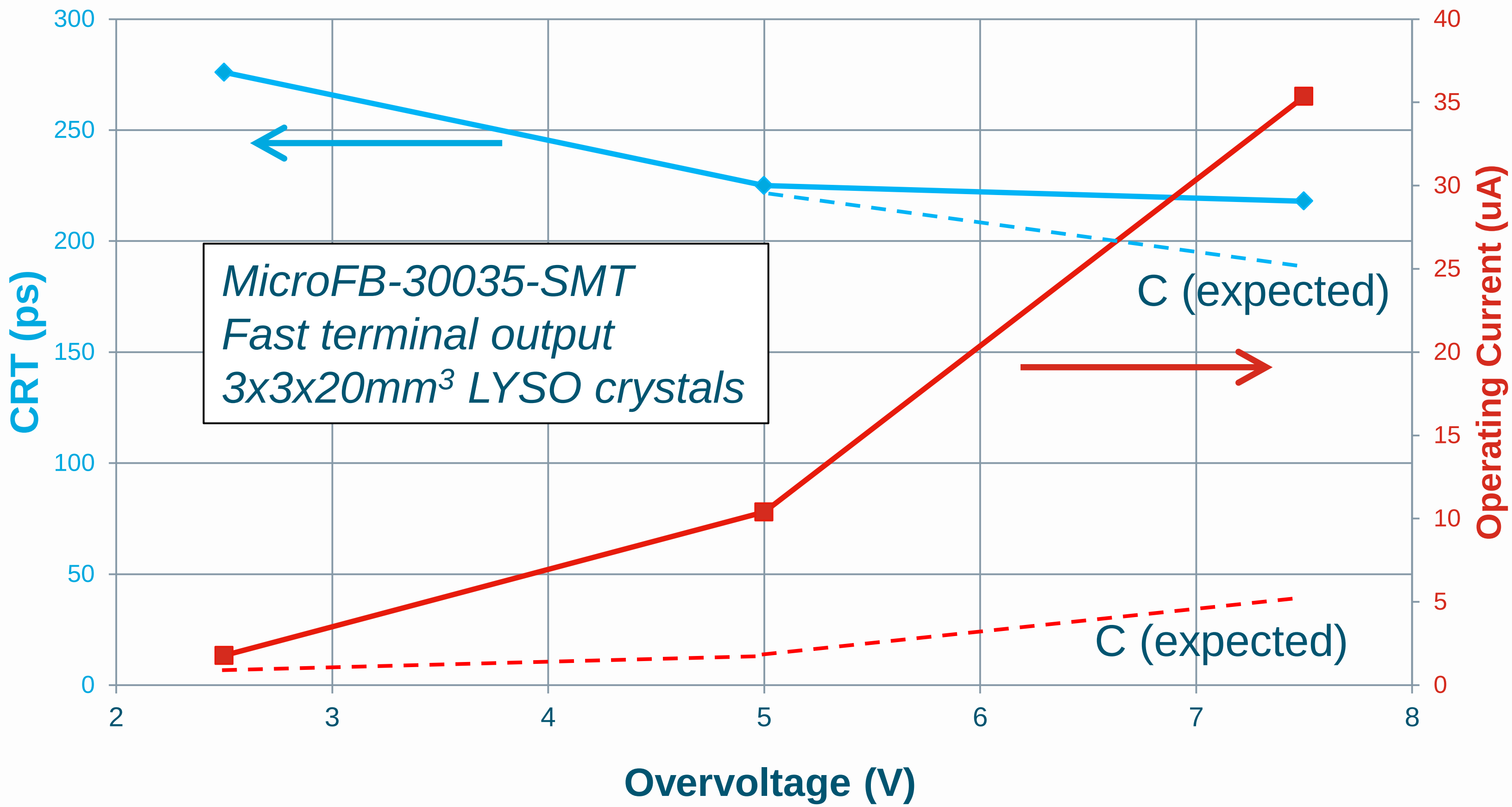
# Microcell Size Impact on Coincidence Resolving Time (CRT)

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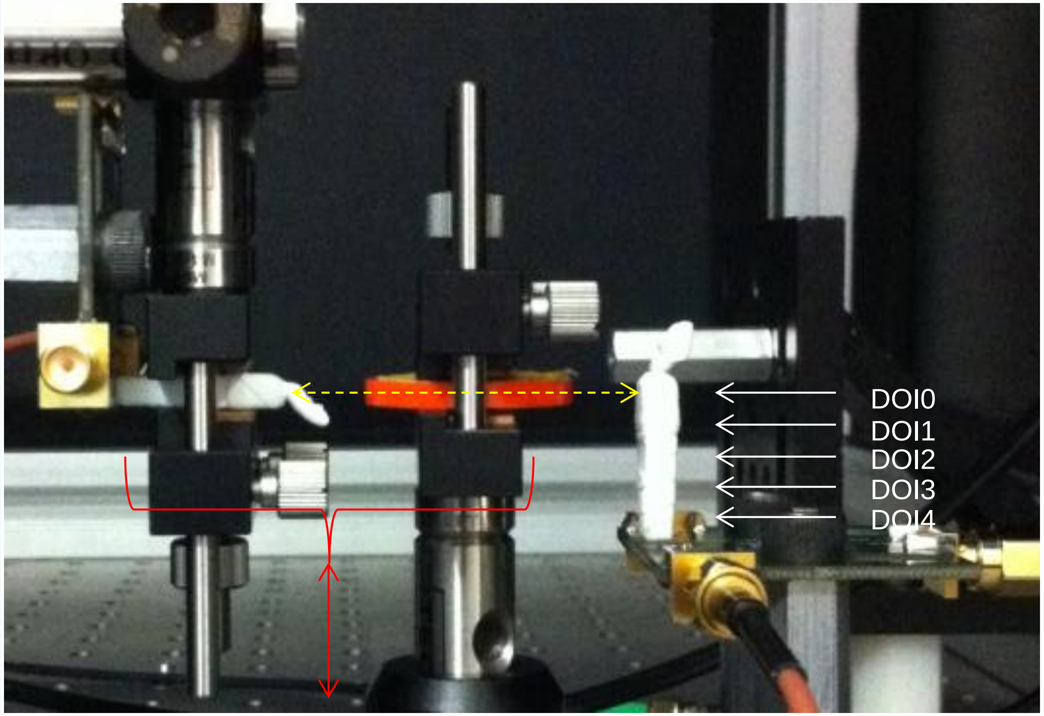
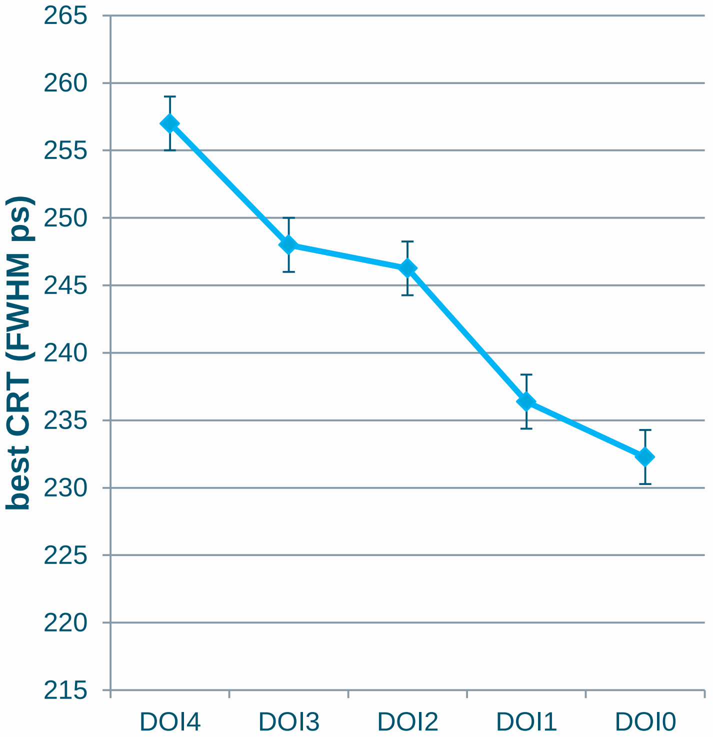
# Depth of Interaction Study (1) – Head-on/Side-on

*Left detector:*
*head on*




511keV light collimated by xtals




*Right detector:*
*Side on*

MicroFB-30035-SMA detectors
3mmx3mmx20mm LYSO (Teflon wrapped)
5V over breakdown (VBR2)

Ref to stanford paper

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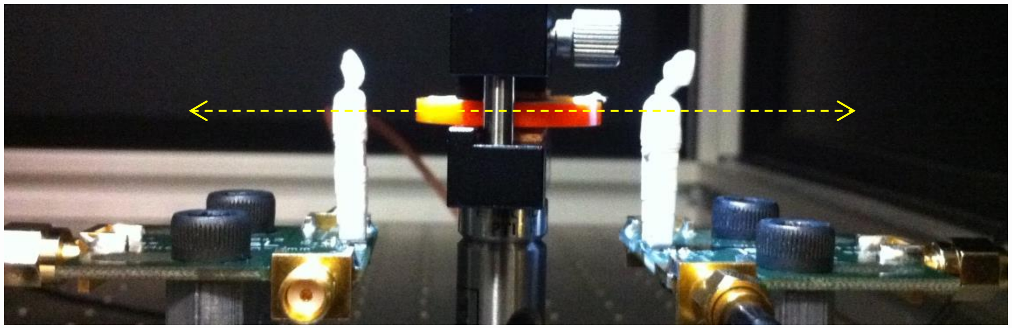
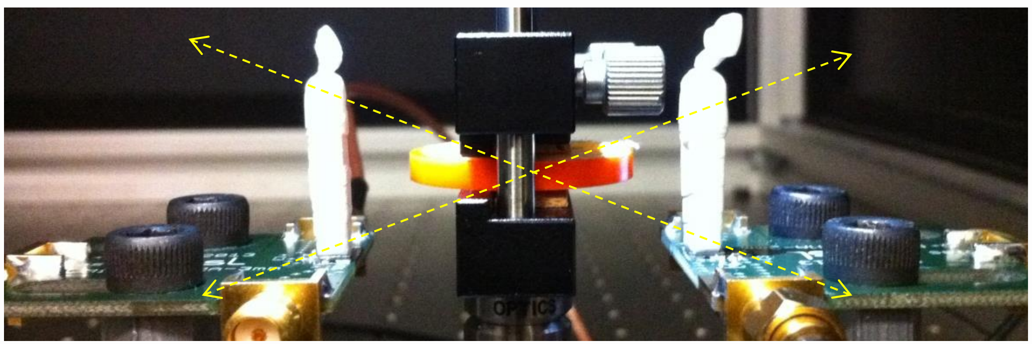
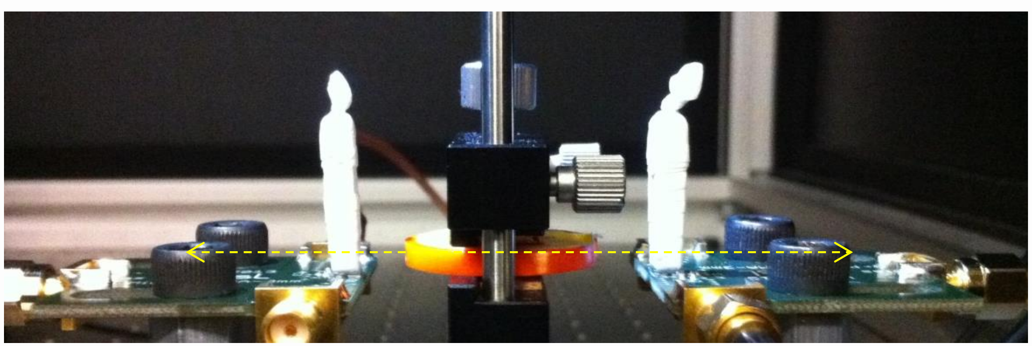
# Depth of Interaction Study (2) – Side-side Illumination, Different Positions



511keV light collimated by xtals
→ CRT=232±2ps



511keV light uncollimated
→ CRT=278±2ps



511keV light collimated by xtals
→ CRT=284±2ps

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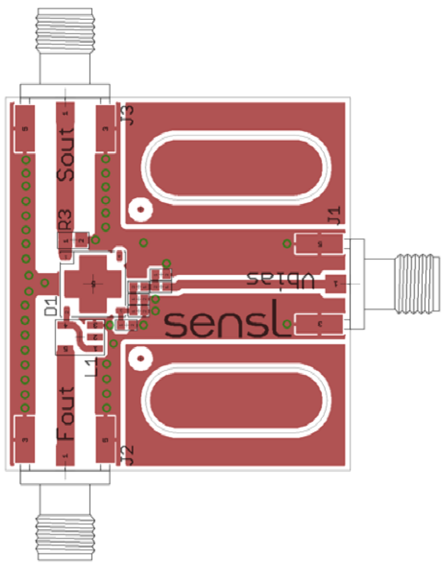
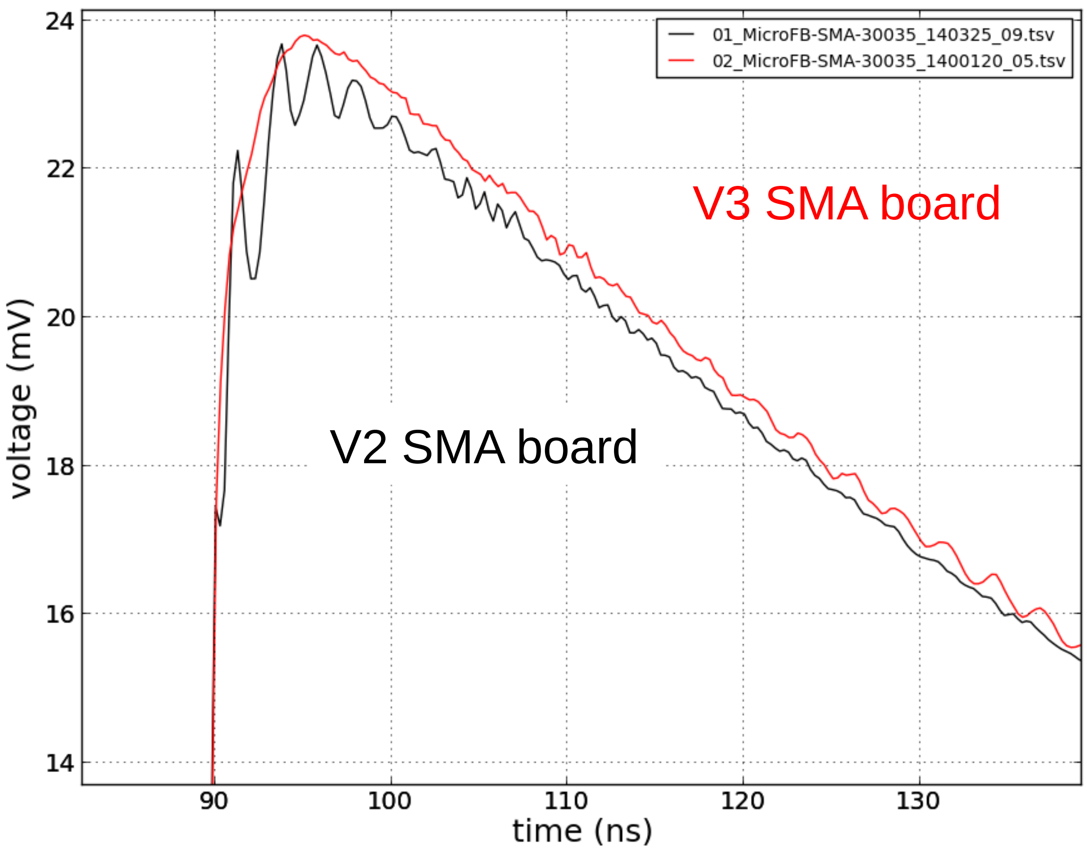
# Importance of High Frequency Board Optimization

V3 PCBs made for engineering trials

- Two layer PCB
- Impedance matches tracks for 50oh
- All components on the same side as the SiPM (no vias)

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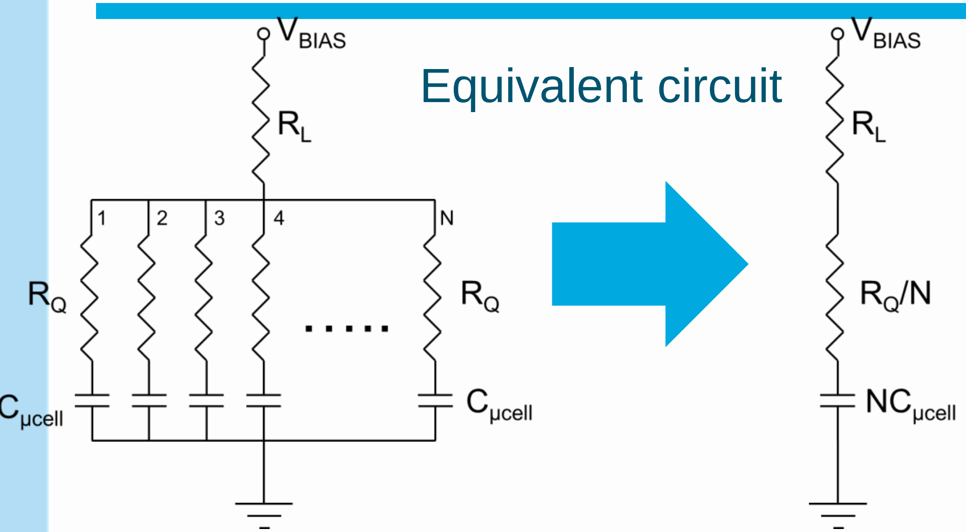
# SiPM Microcell Recovery: Simple RC Model With Load




$$\tau = C_{\mu cell}\left(R_Q + NR_L\right)$$

| Device | Average S terminal recovery time | Simple model recovery time |
|---|---|---|
| MicroFB-30020-SMA | 89.6ns | 100ns |
| MicroFB-30035-SMA | 180ns | 175ns |
| MicroFB-30050-SMA | 345ns | 345ns |
| MicroFB-60035-SMA | 345ns | 341ns |
| MicroFB-60035-SMA (MOD)* | 234ns | 236ns |

$R_L$ consists of combination of 5Ω in series with 5.5Ω in series with 50Ω||50Ω

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END