Characterization of SiPMs for Use in Cherenkov Telescopes

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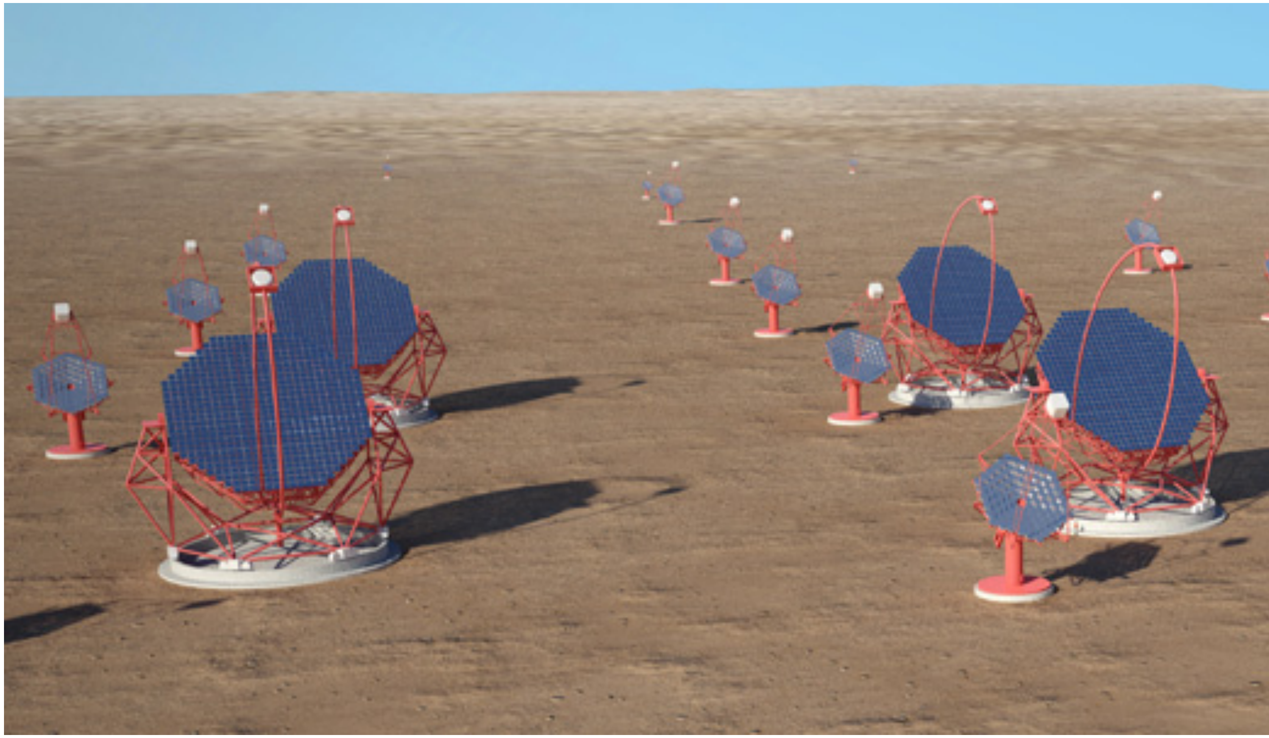


In collaboration with: Aurelien Bouvier, Lloyd Gebremedhin, Naoya Hidaka, Jim Hinton, Caitlin Johnson, Andrey Kuznetsov, Akira Okumura, Nepomuk Otte, Hiro Tajima, Richard White

Camera for Schwarzschild-Couder Telescope

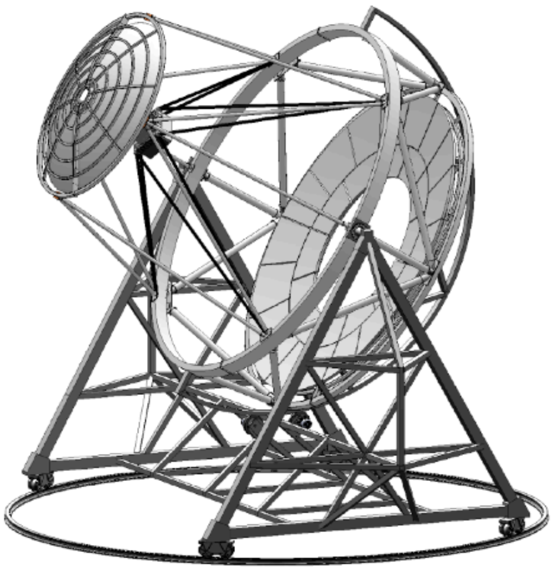
Telescope design aimed at wide FoV, high angular resolution with good off-axis response.

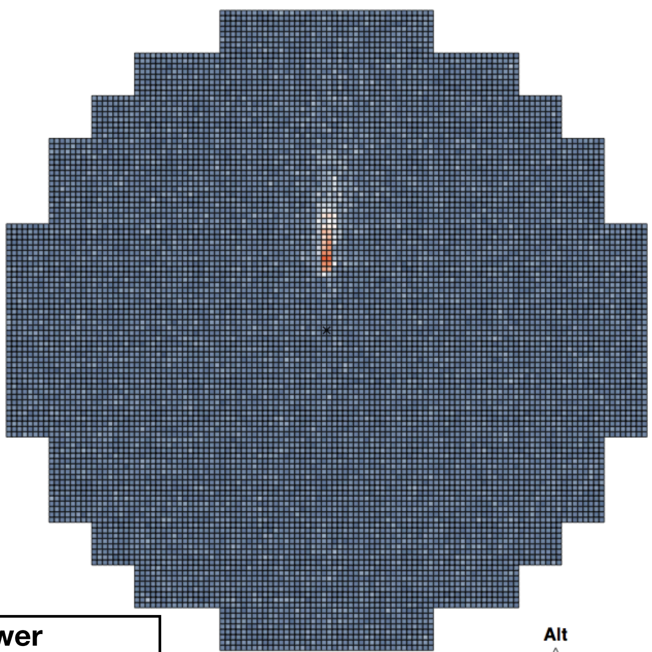
Demagnifying 2-mirror design reduces plate scale allowing MAPMTs/SiPMs and reducing costs below $70 per pixel allowing much higher resolution camera at same cost.

ASIC electronics with a high level of integration (TARGET) for cost and power reduction.

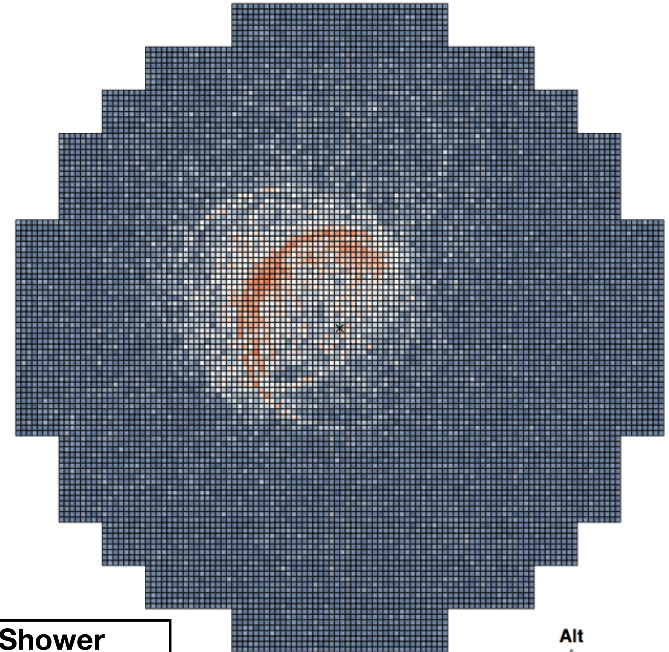
Deep memory for trigger flexibility – e.g., higher multiplicity triggers for close spacing, dynamically reprogrammable data window after trigger, improved hadronic rejection by including non-triggering telescopes.

Modular design aimed at low cost, high reliability, and ease of serviceability.

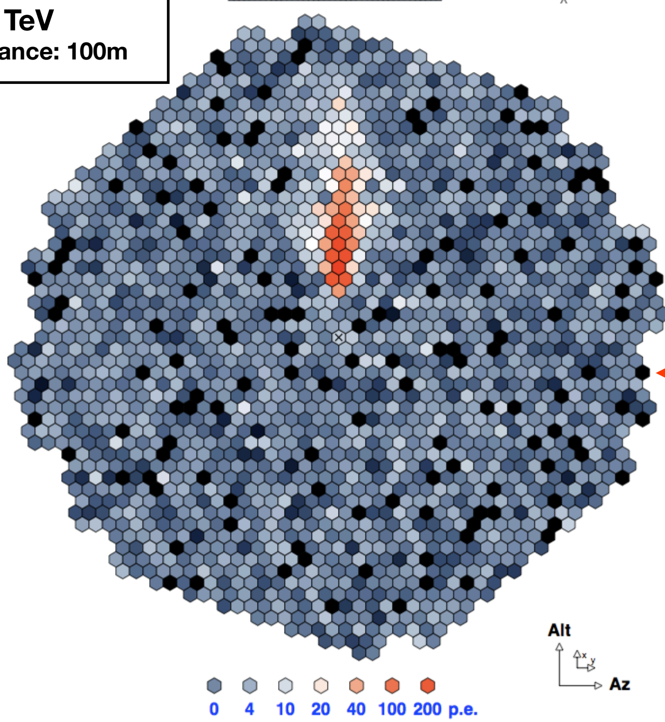




SC

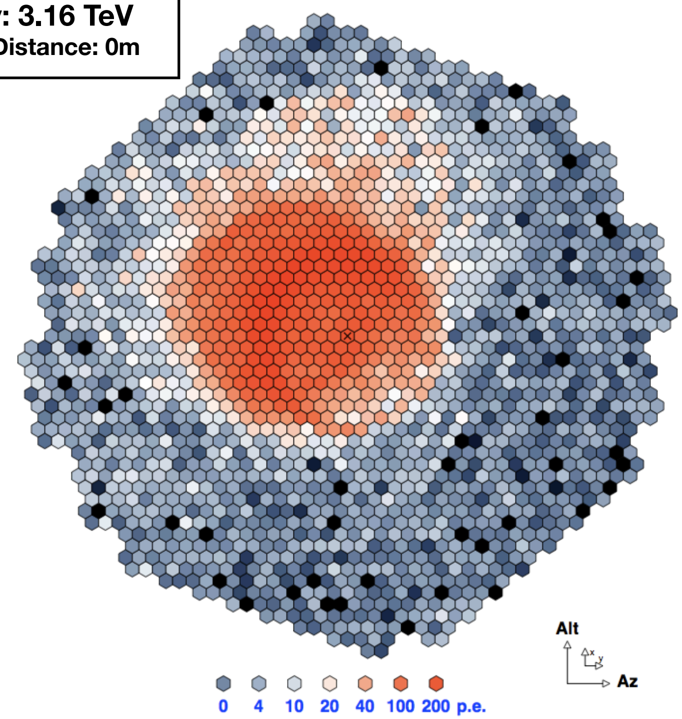


γ-ray Shower
Energy: 1 TeV
Impact Distance: 100m

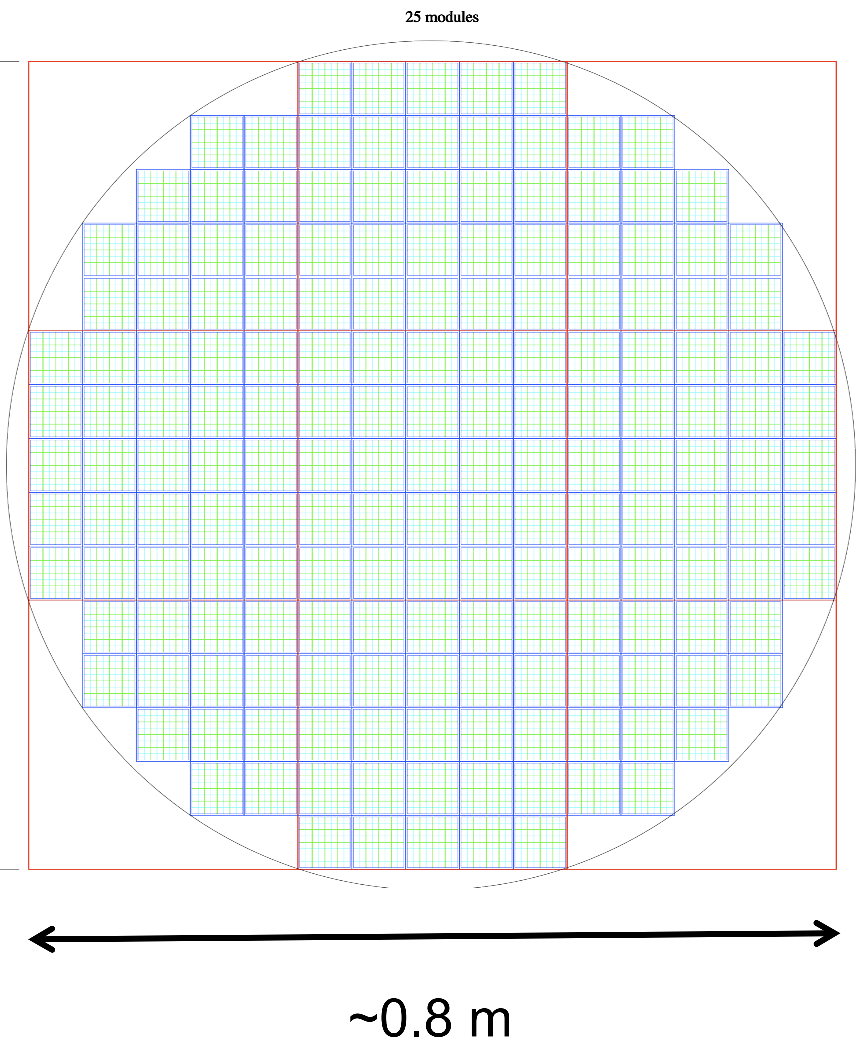


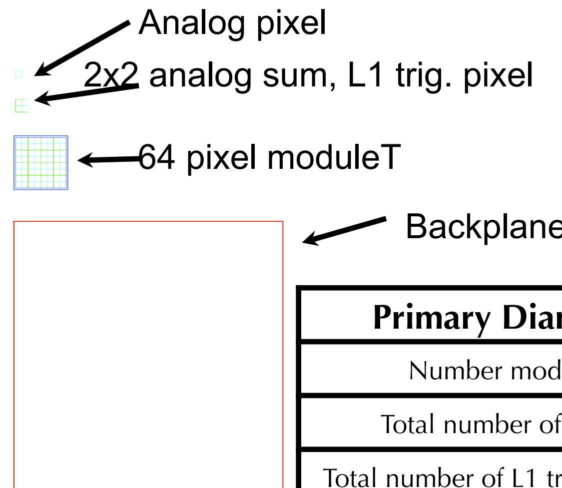
DC

Proton Shower
Energy: 3.16 TeV
Impact Distance: 0m



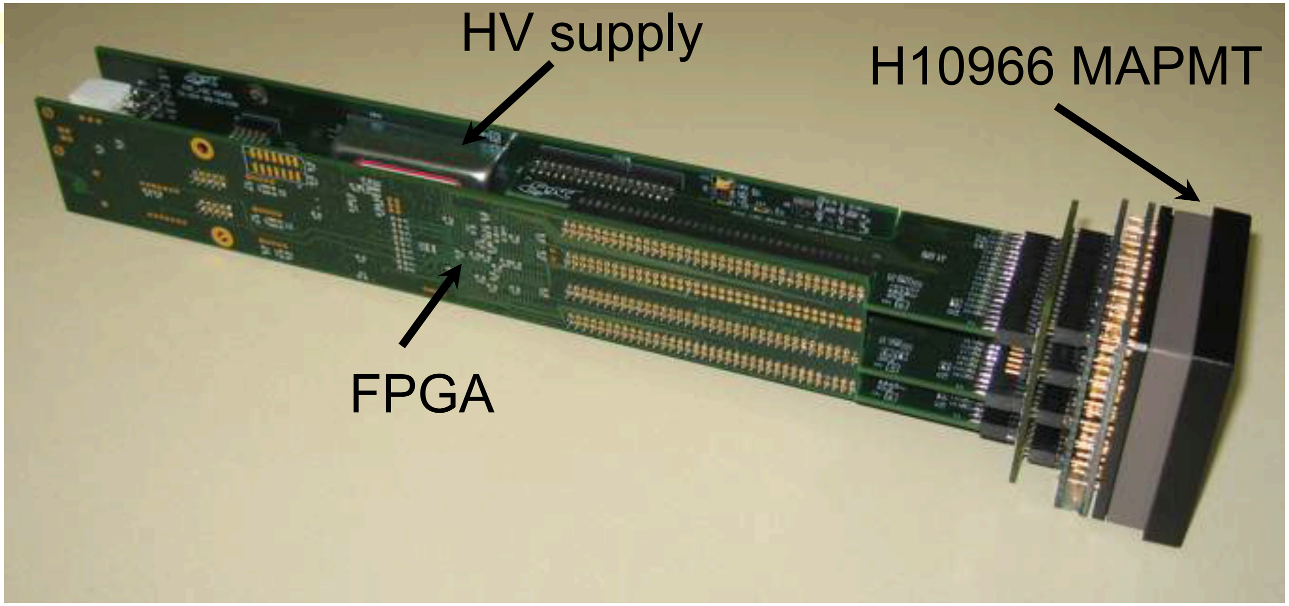
Camera Hierarchy

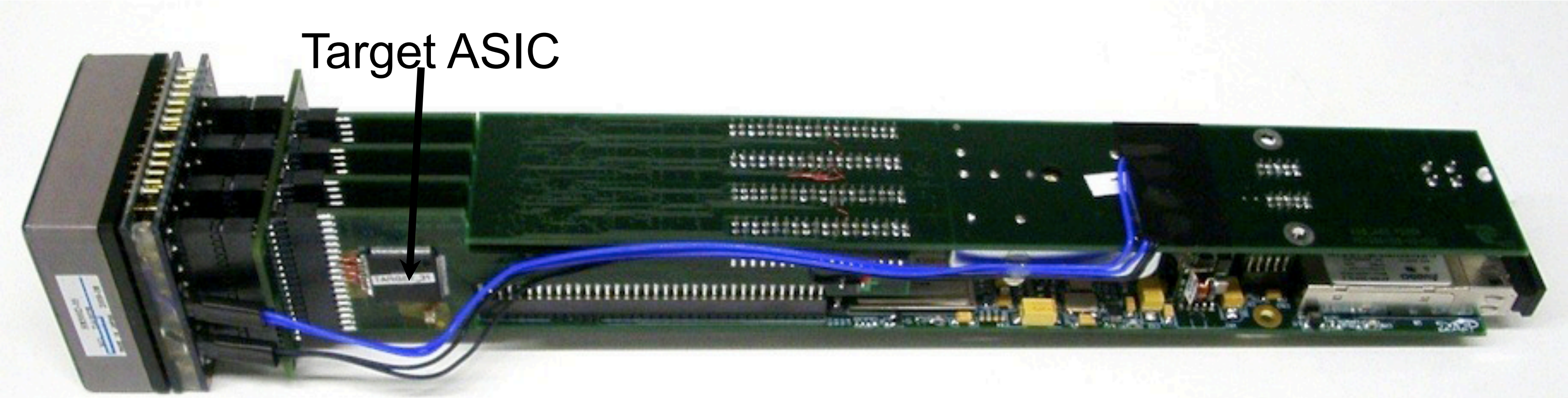




Primary Diameter	**9.5 m**
Number modules	177
Total number of pixels	11328
Total number of L1 trigger pixels	2832
Number of modules per subfield	25
FoV diameter	8.0°
Module size	52–54 mm
Pixel angular size	0.067°
Pixel angular size	4.0’
Camera diameter	0.78 m
Focal plane sag at FoV edge	-2.2 cm
PSF at FoV edge	3.81’

Front-End Electronics

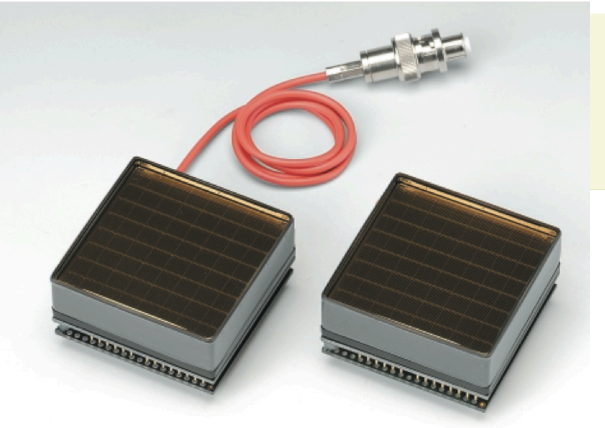




(see J. Vandenbroucke's talk)

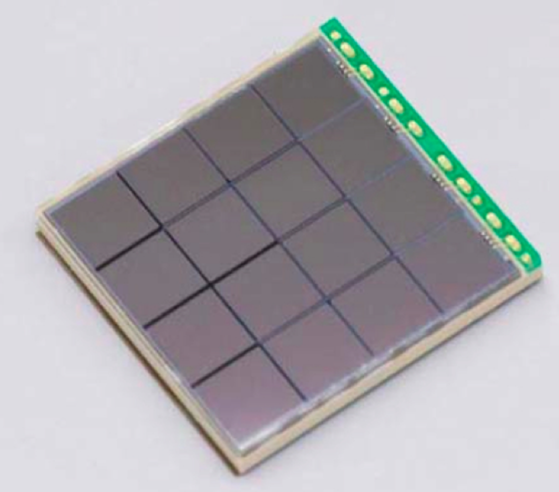
Multianode PMT

Hamamatsu
H8500-10x MOD8 = H10966B-10x



- Familiarity of a PMT
- Adequate performance in most respects
- Disappointing PDE, but perhaps not as bad as we first thought
- Straightforward operation — except for channel suppression for stars
- 2” segment less than ideal for camera optics
- A safe fallback option

SiPM



Much less experience with SiPM

Fussier to operate stably

Star suppression not necessary*

Easily adaptable to camera optics

Several potential vendors

Three main concerns:

1) ~~Long pulse shape~~
2) Optical crosstalk – equivalent to PMT afterpulsing
3) Photon detection efficiency – too poor in blue; too good in red
4) Suitable packing to minimize dead area

SiPM devices tested & expected

Hamamatsu

- S11882-3344M (50 μm), S10943-1071 (100 μm), S12545-3344 (100 μm)
- We heard yesterday about coming developments

Excelitas

- C30742CERH-100-5-1, s/n D4941, D4985 (100 μm)
- Lower crosstalk and higher UV sensitivity devices received recently

SensL

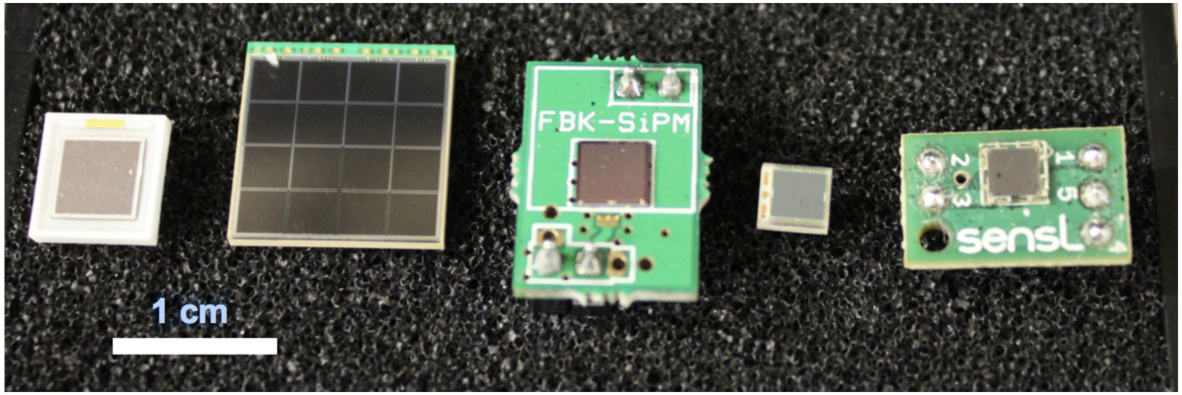
- P2MicroSB-30035-X13 (35 μm)
- Higher UV sensitivity devices expected soon

KETEK

- PM3350 (50 μm)

FBK

- 3x3 mm2 (50 μm)
- 4x4 mm2 (50 μm)

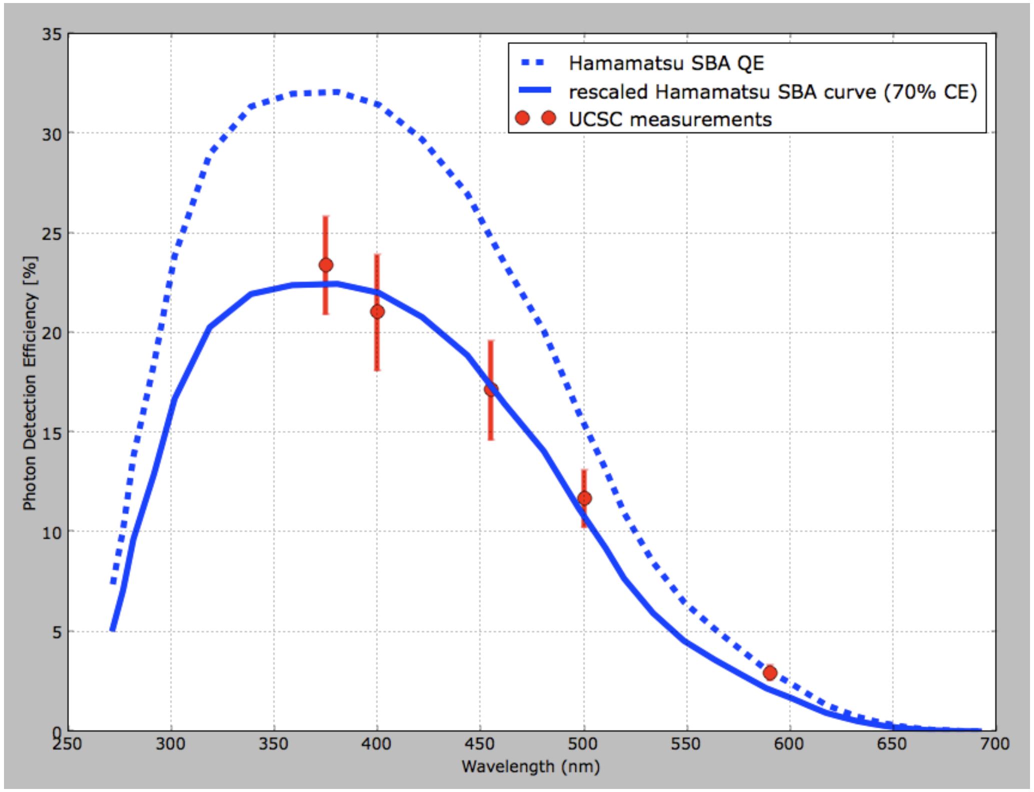


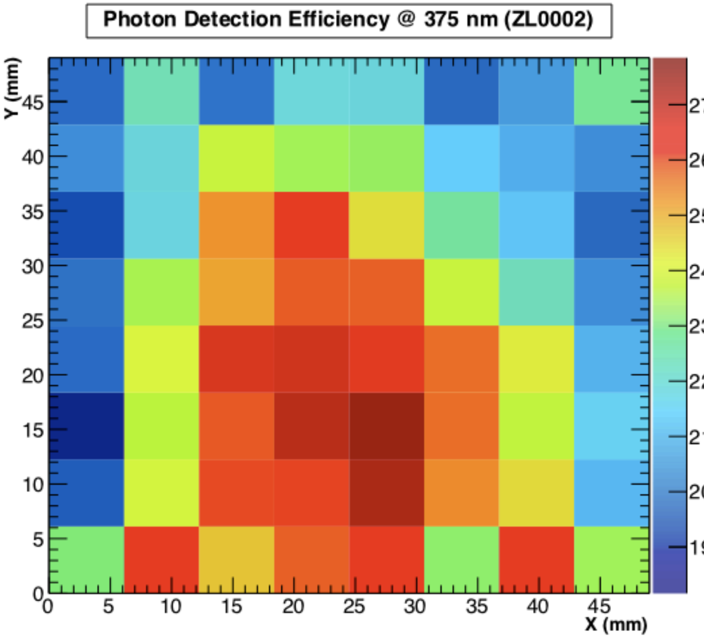
MAPMT PDE

Specs for SBA QE is 32% min at peak (~35% average advertised by Hamamatsu). UCSC PDE measurements at 375 nm is ~23.5% on average => ~70% collection efficiency

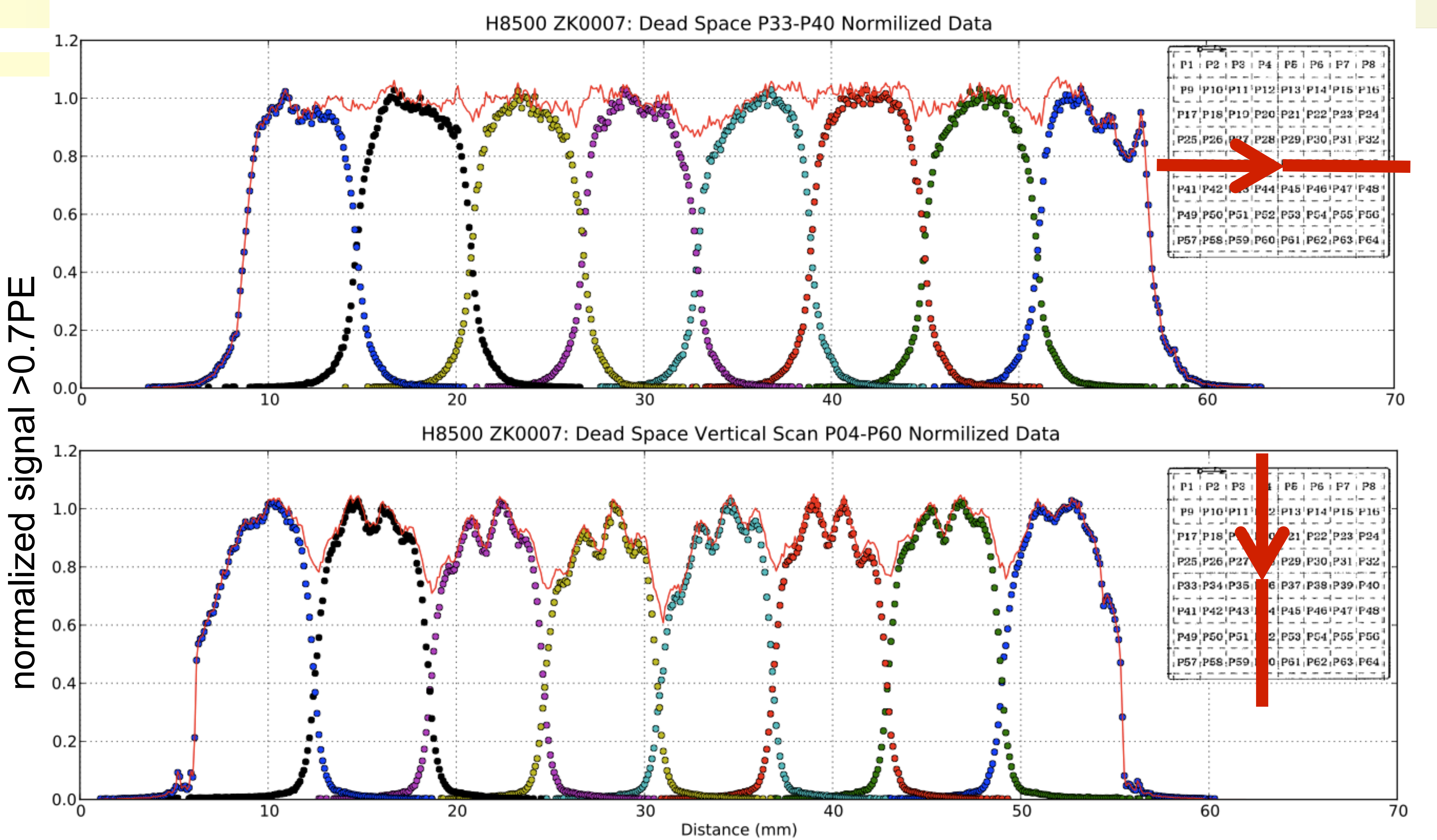
Hamamatsu 1" SBA PMTs purchased for the VERITAS upgrade achieve the advertised QE

Highest PDE values in central pixels of the tube





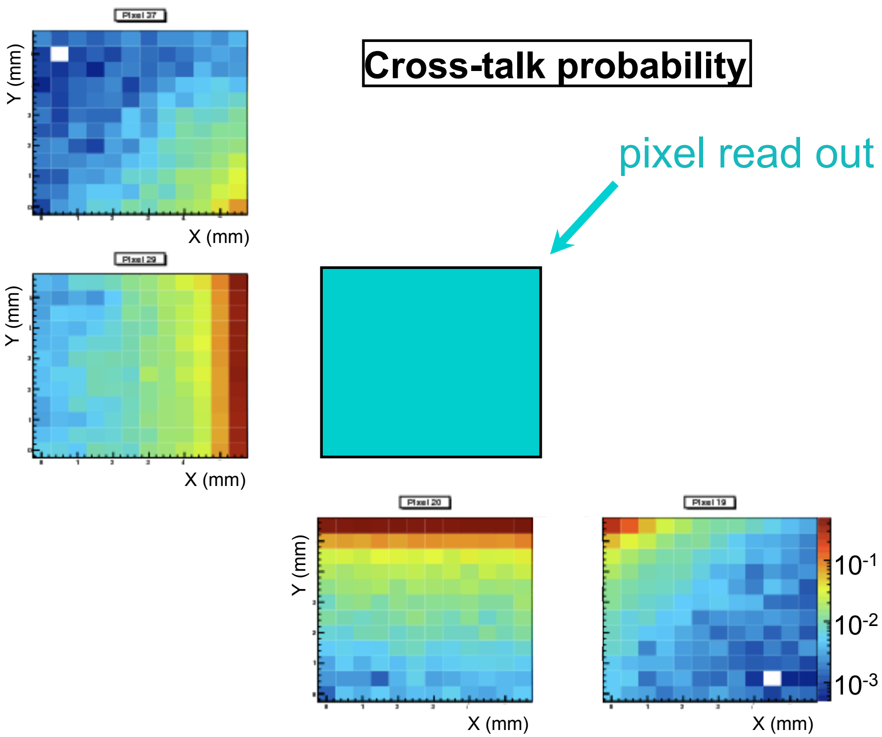
MAPMT Dead Space



Tube edges: ~11% dead area; Inner pixel boundaries ~4% loss

MAPMT Crosstalk I

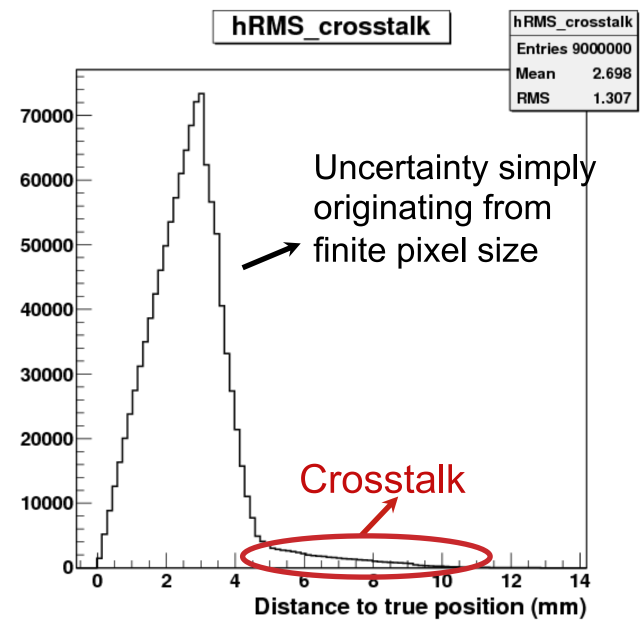
❖ Crosstalk in center of the pixel ~ 1% (less than optical cross-talk) but strongly non-uniform



Optical crosstalk measurement in the center pixel when fiber is positioned where crosstalk values are plotted

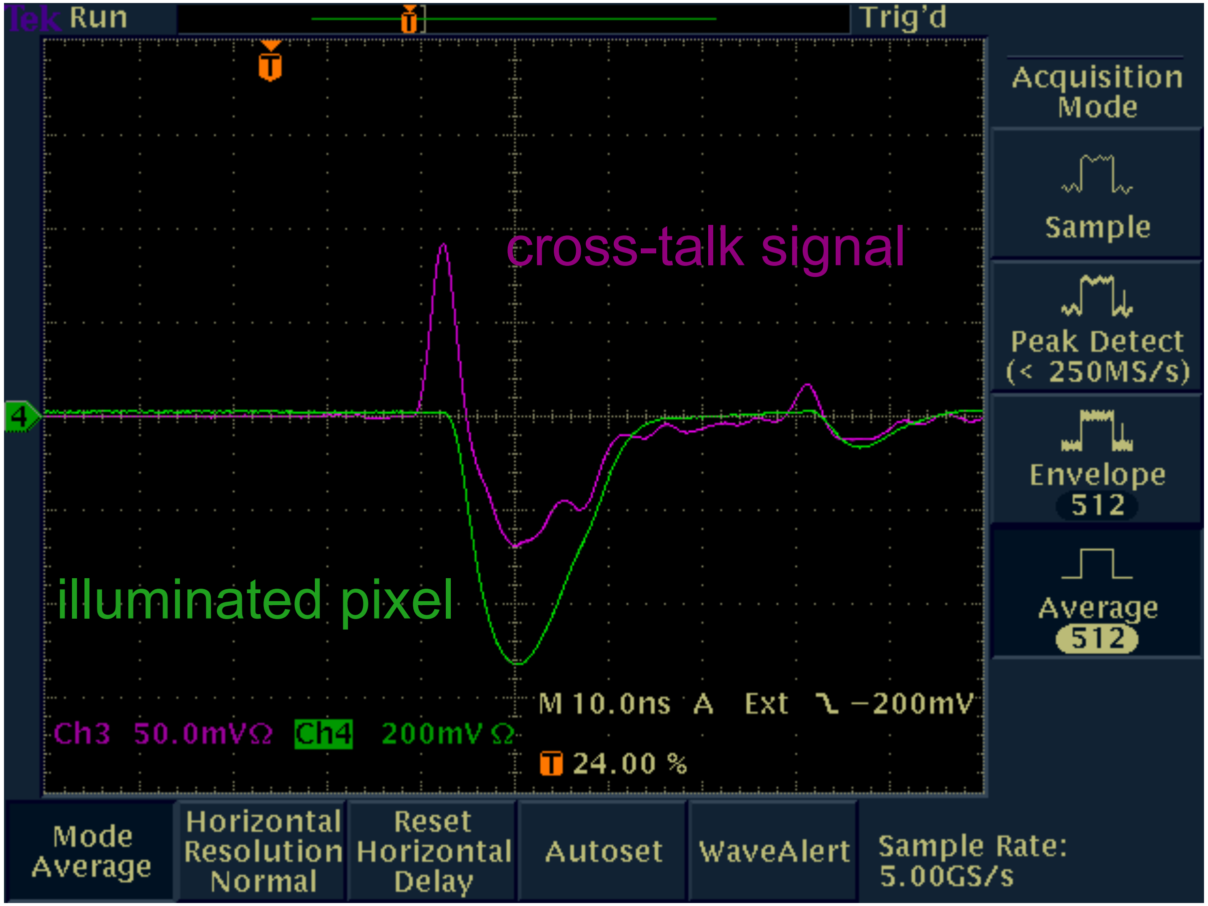
❖ Crosstalk introduces higher uncertainty in photon impact point in the focal plane.

❖ ~15% increase in the mean uncertainty (2.3mm => 2.7mm; 1.5’ => 1.8’)



MAPMT Crosstalk II

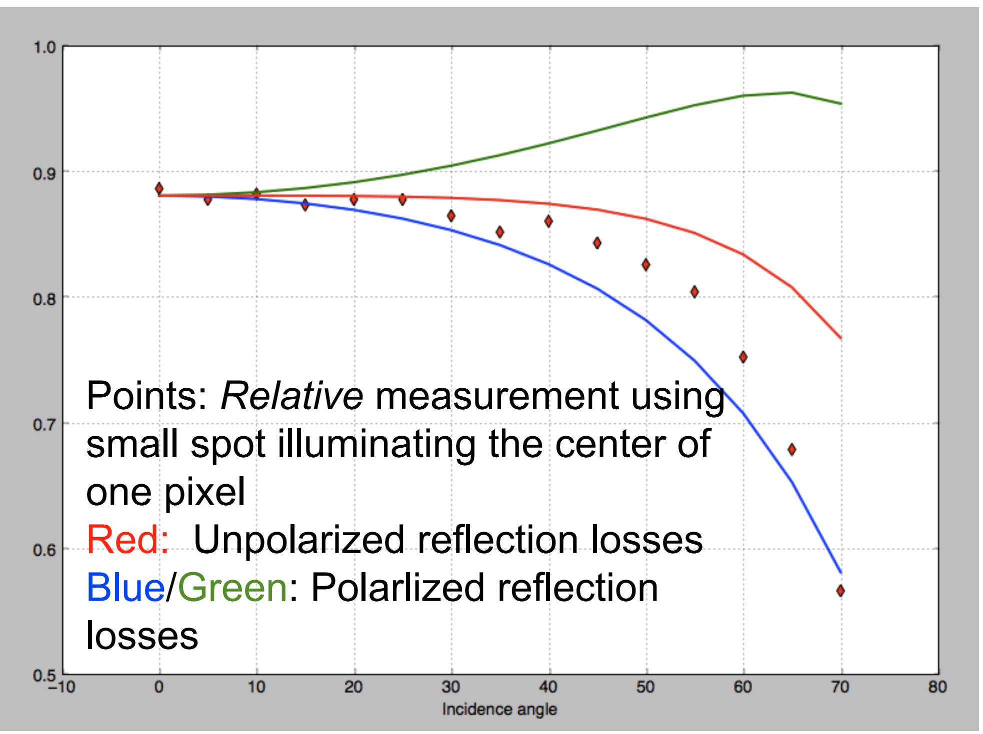
"sympathetic" signal observed in all pixels with amplitude ~0.5% of the large signal



Response vs Incidence Angle

Critical in SCT Design:

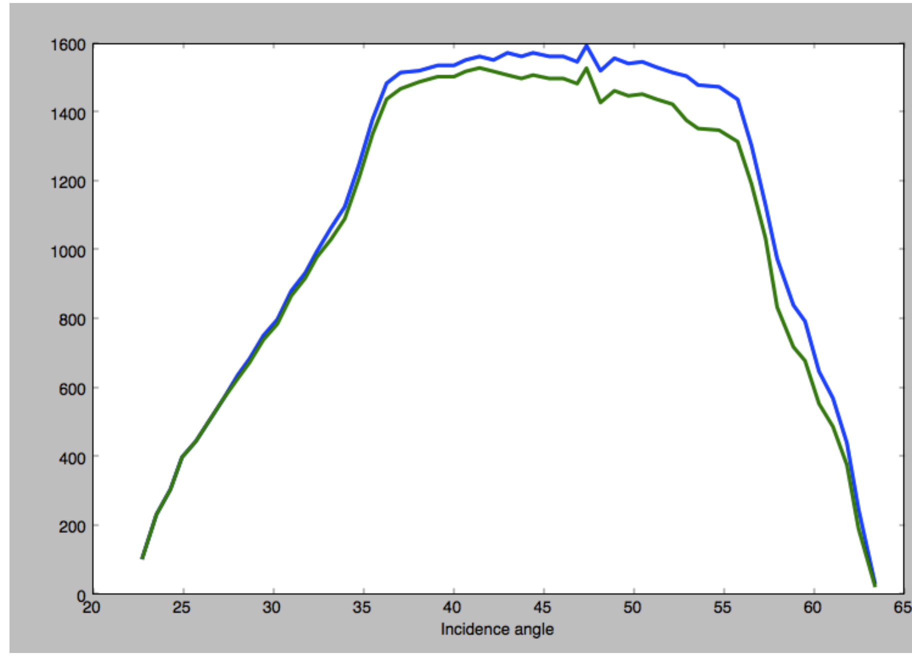
- All light enters camera off axis
- ~20% fall off near limit
- Net loss of ~5% w.r.t. normal incidence



Points: *Relative* measurement using small spot illuminating the center of one pixel

Red: Unpolarized reflection losses

Blue/Green: Polarlized reflection losses



Blue: Incidence angle distribution on surface of MAPMT (using A. Okumura's ROBAST ray tracing code)

Green: convoluted with measured response at left

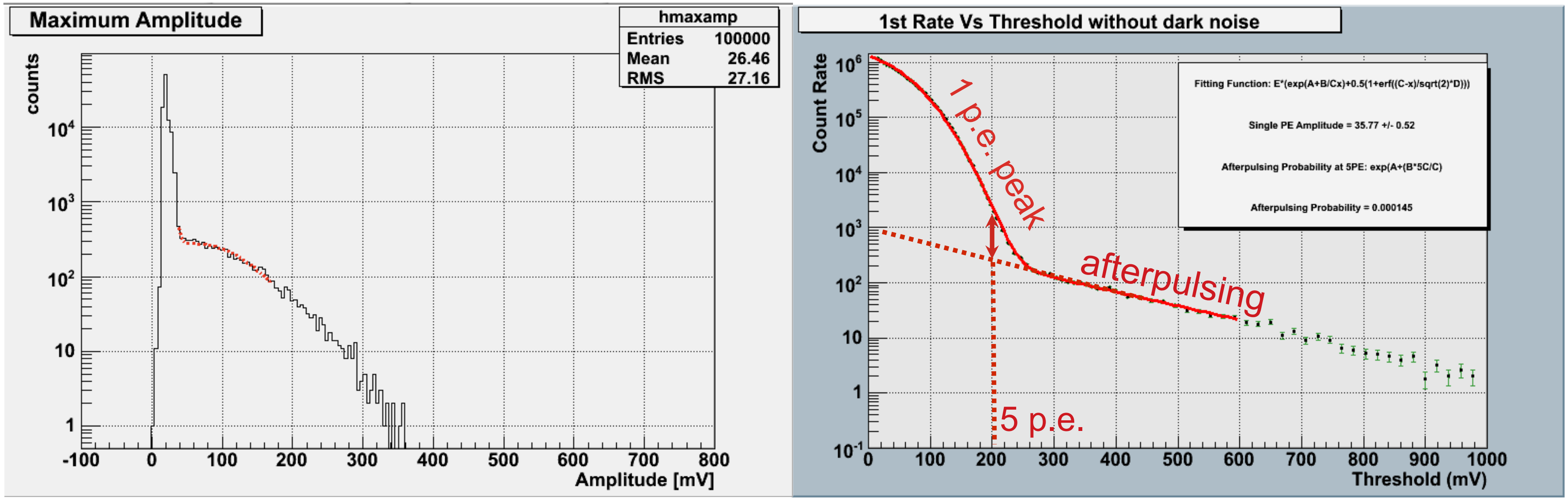
Single pe response & afterpulsing

1 p.e. peak can be difficult to resolve and very broad. Issue for gain calibration?

Low afterpulsing (~0.02%) but >5 p.e. noise will mostly come from tail of 1 p.e. distribution

Single p.e. amplitude distribution tightens with increased HV. Need to compromise with issues occurring at high gain operation (see later slide)

Impact on trigger/analysis?

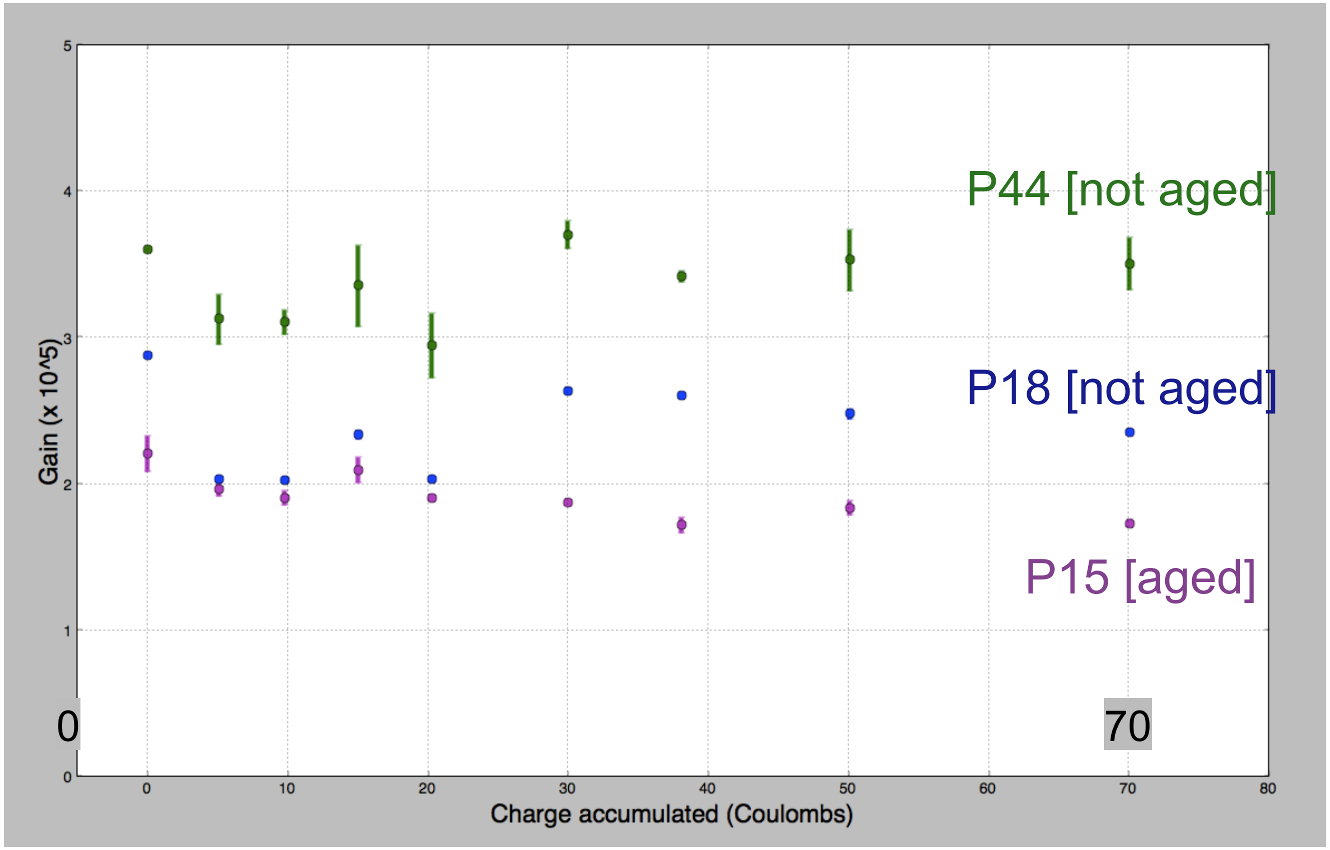


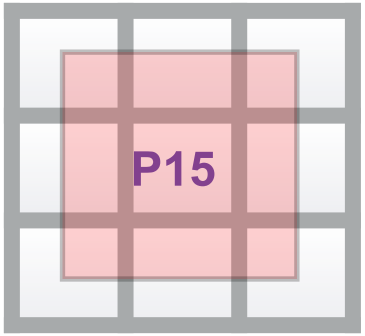
MAPMT (H10966B): Aging

no clear sign of aging up to 70 Coulombs

NSB ok since expected charge from NSB: ~2 Coulombs/season

Stars an issue at which brightness?





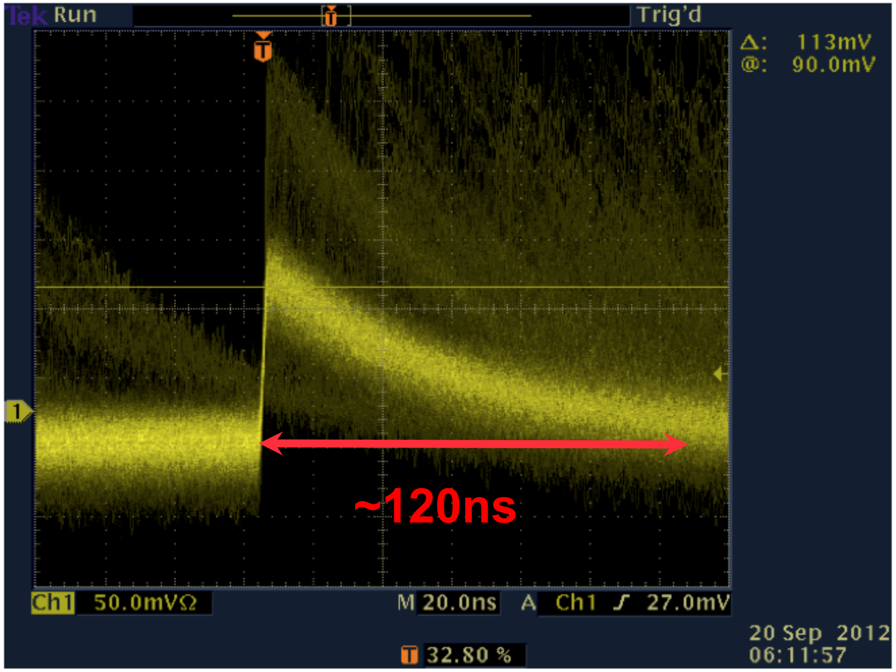
SiPM Pulse Shaping

NSB rates 20–40 MHz; ~25–50 ns separation between pulses

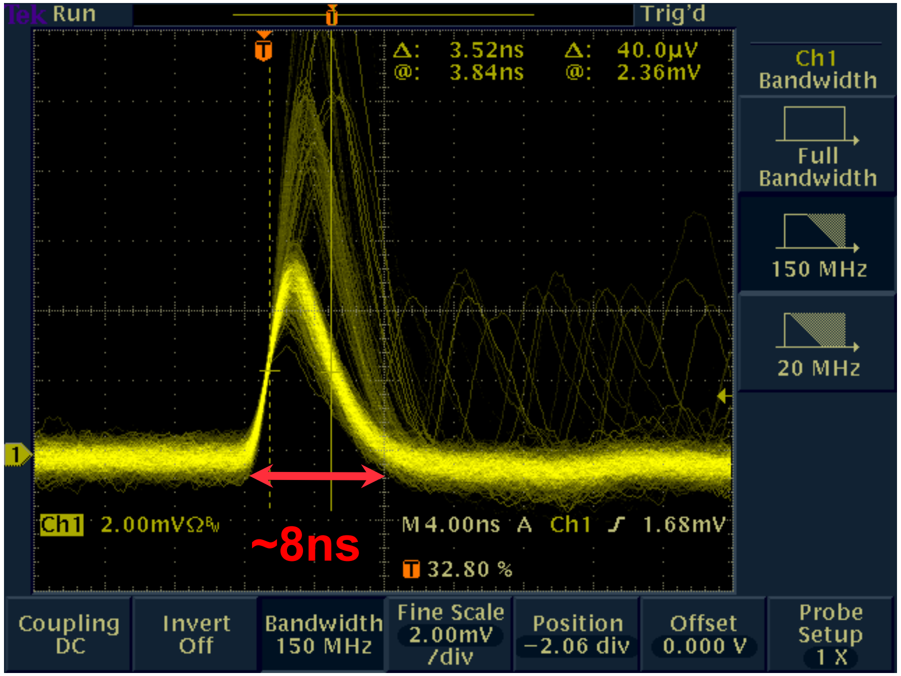
Excelitas: ~10 ns

Hamamatsu (and most others): ~100-150 ns but fast rise allows differentiation to get a fast output pulse: ~8 ns (at cost in gain)

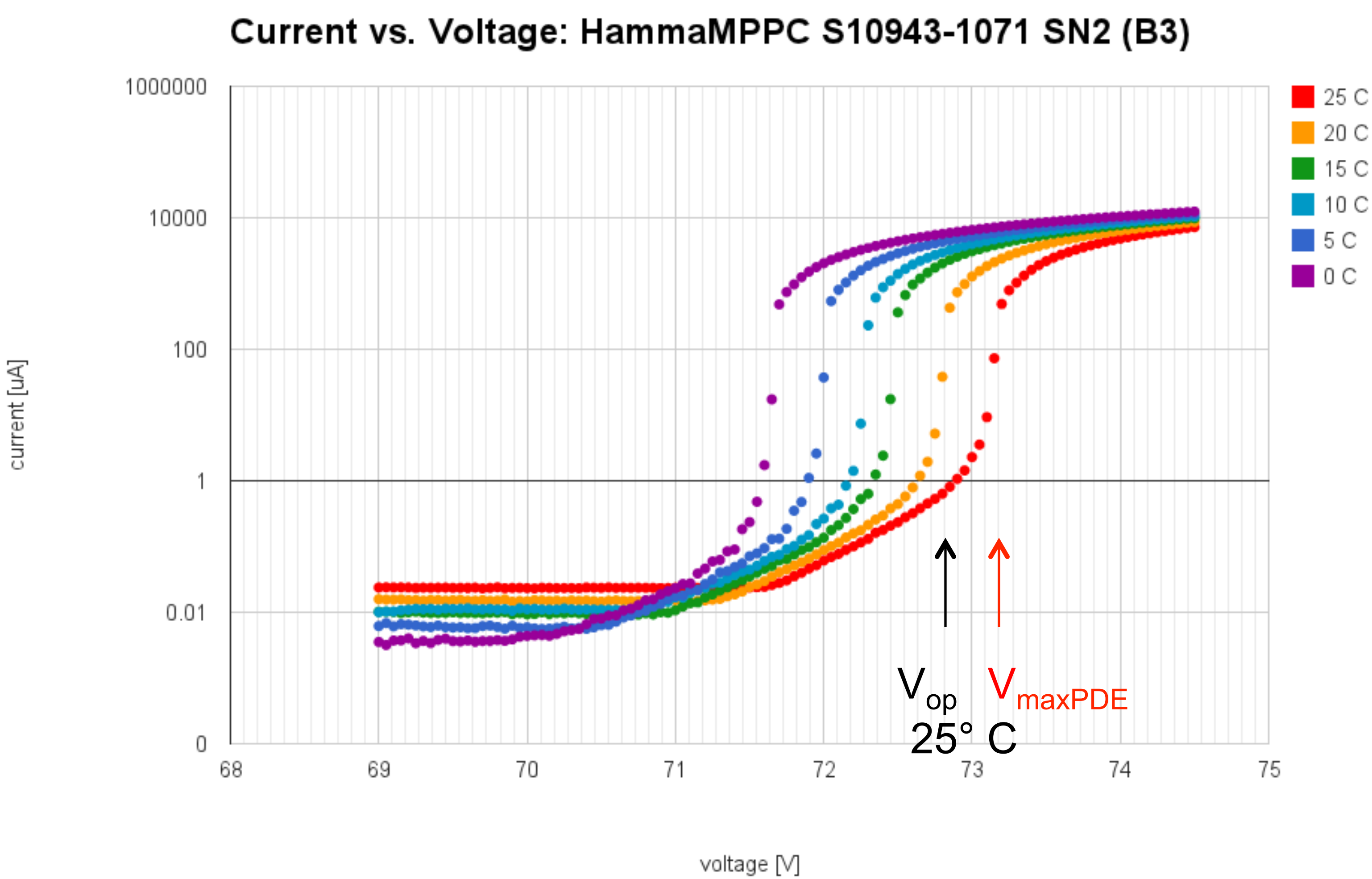
'raw' MPPC pulse



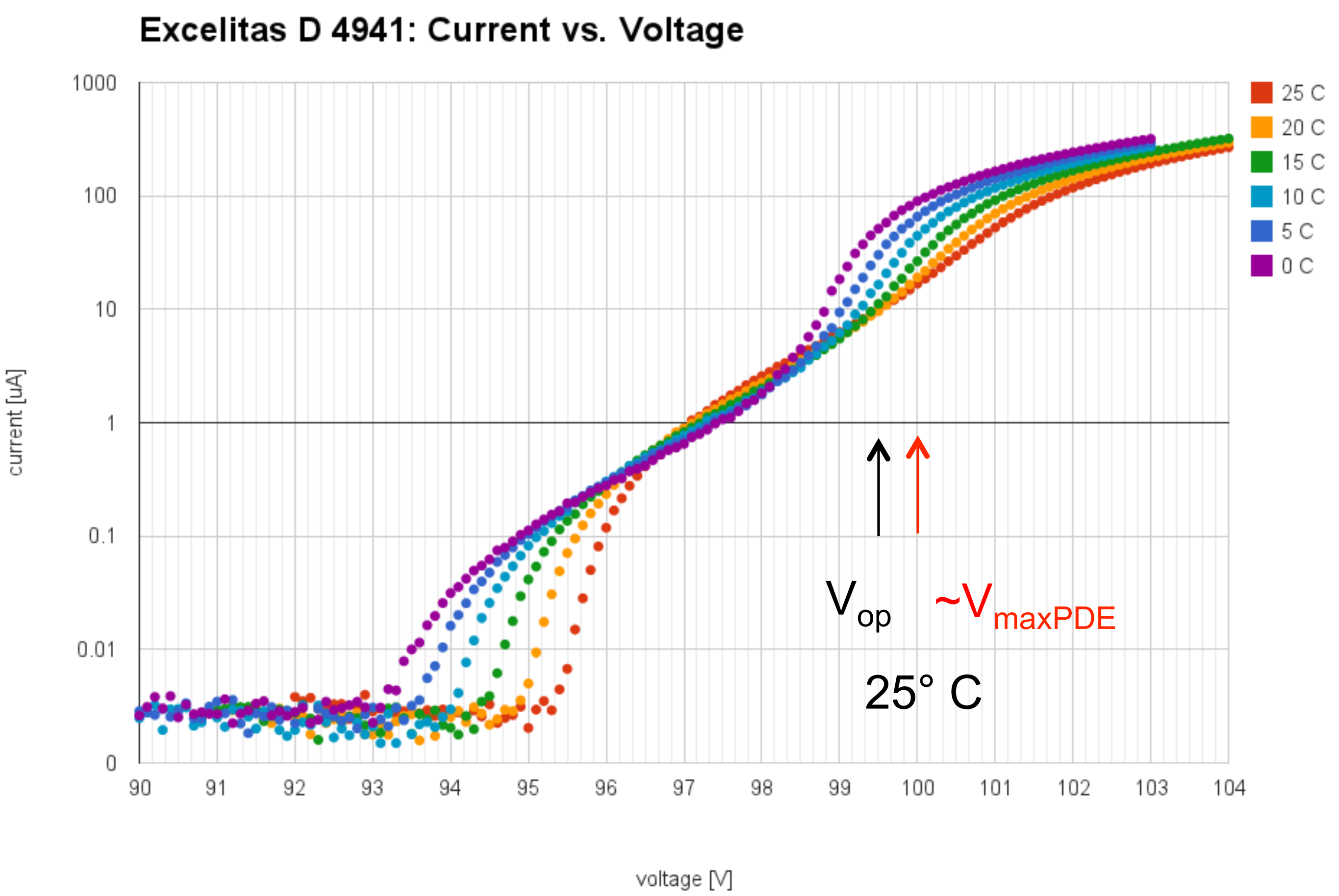
MPPC + differentiator
(note: using 150MHz scope bandwidth)



IV behavior – Hamamatsu

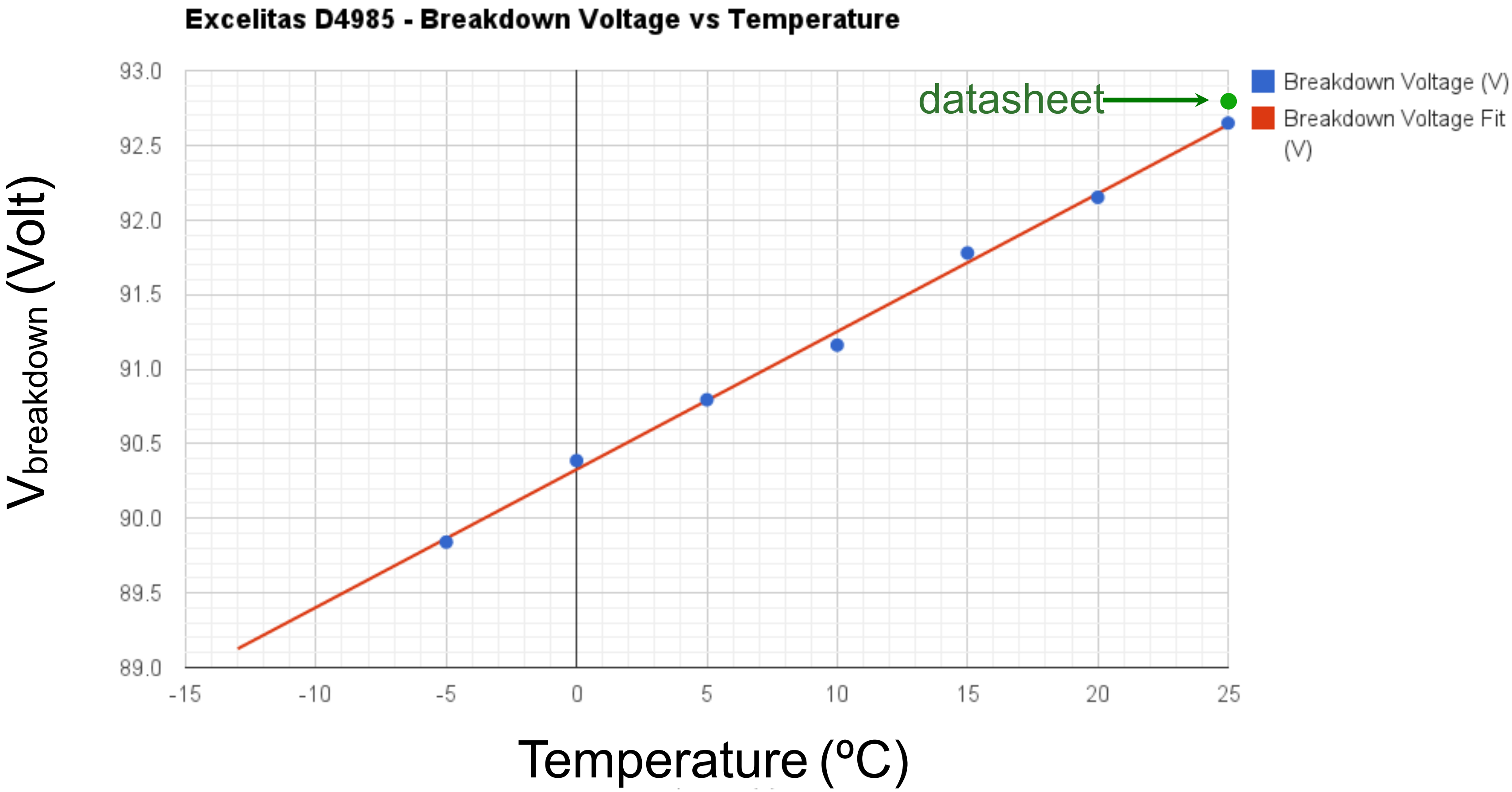


IV behavior – Excelitas



Temp Dependence of V_{br}

Gain = C/e x (V_{bias} - $V_{breakdown}$) => Gain=0 @$V_{breakdown}$



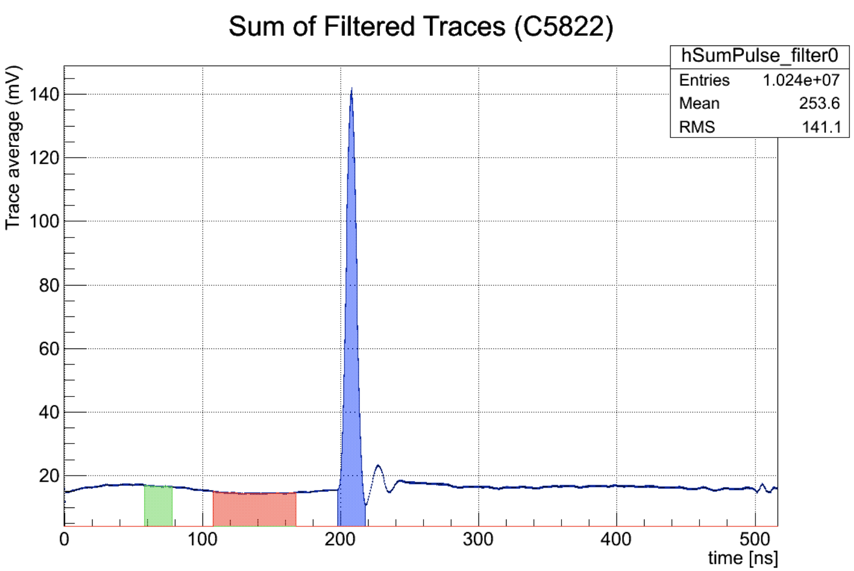
Gain & Xtalk Measurements

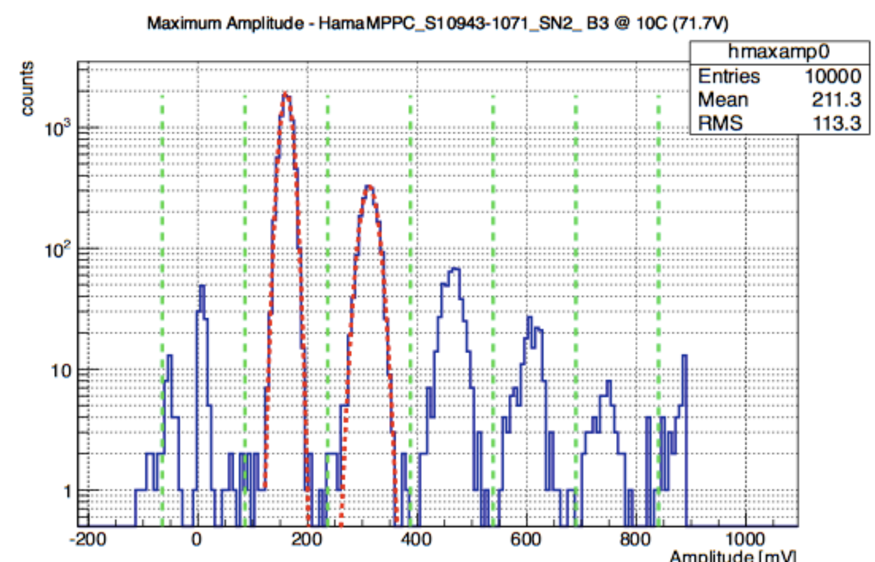
Gain: ΔPE

Cross-Talk: N[>1.5pe]/N[0.5pe]

} derived from pulse height distribution of dark pulses

readout with DRS4

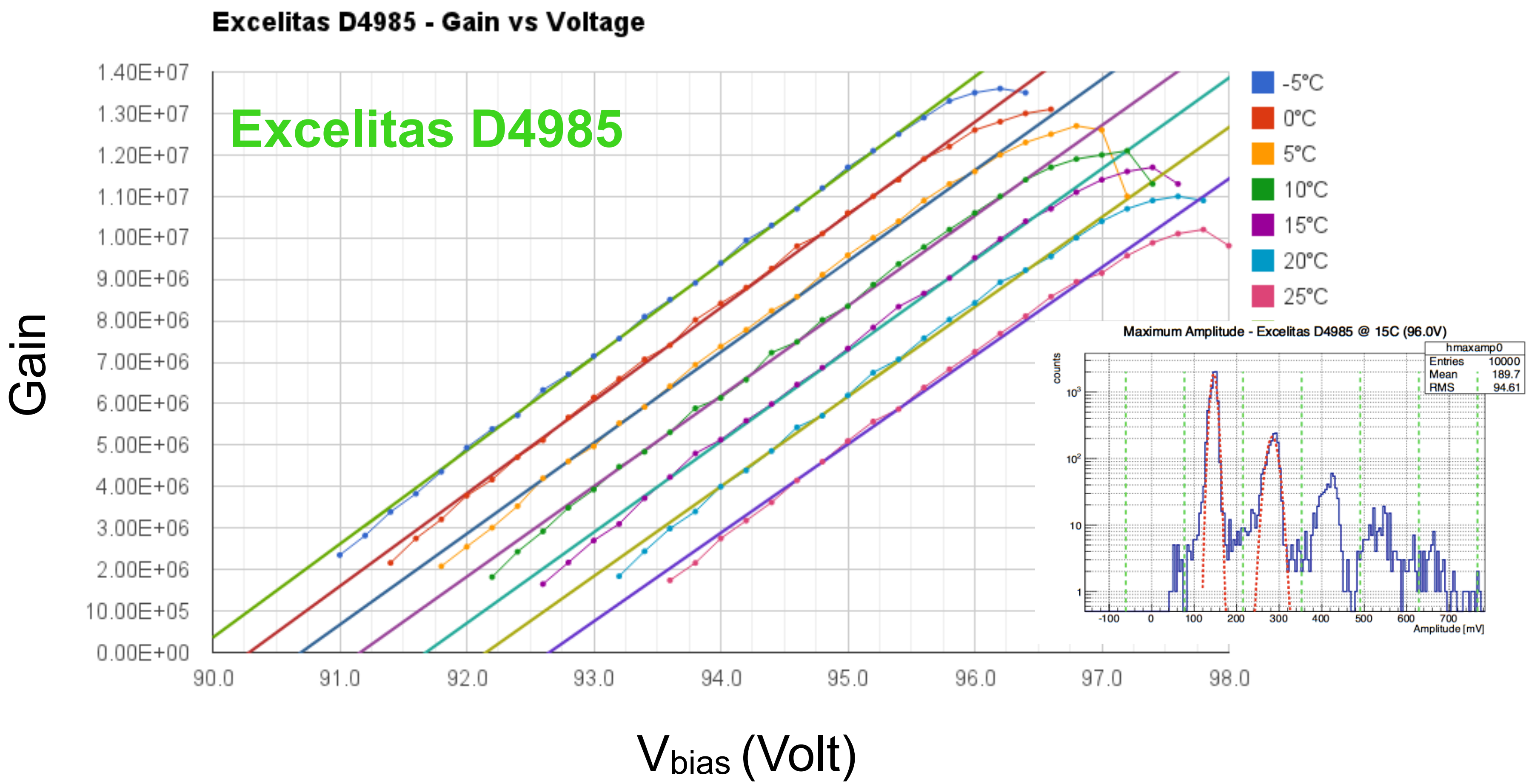




1pe 2pe 3pe 4pe 5pe

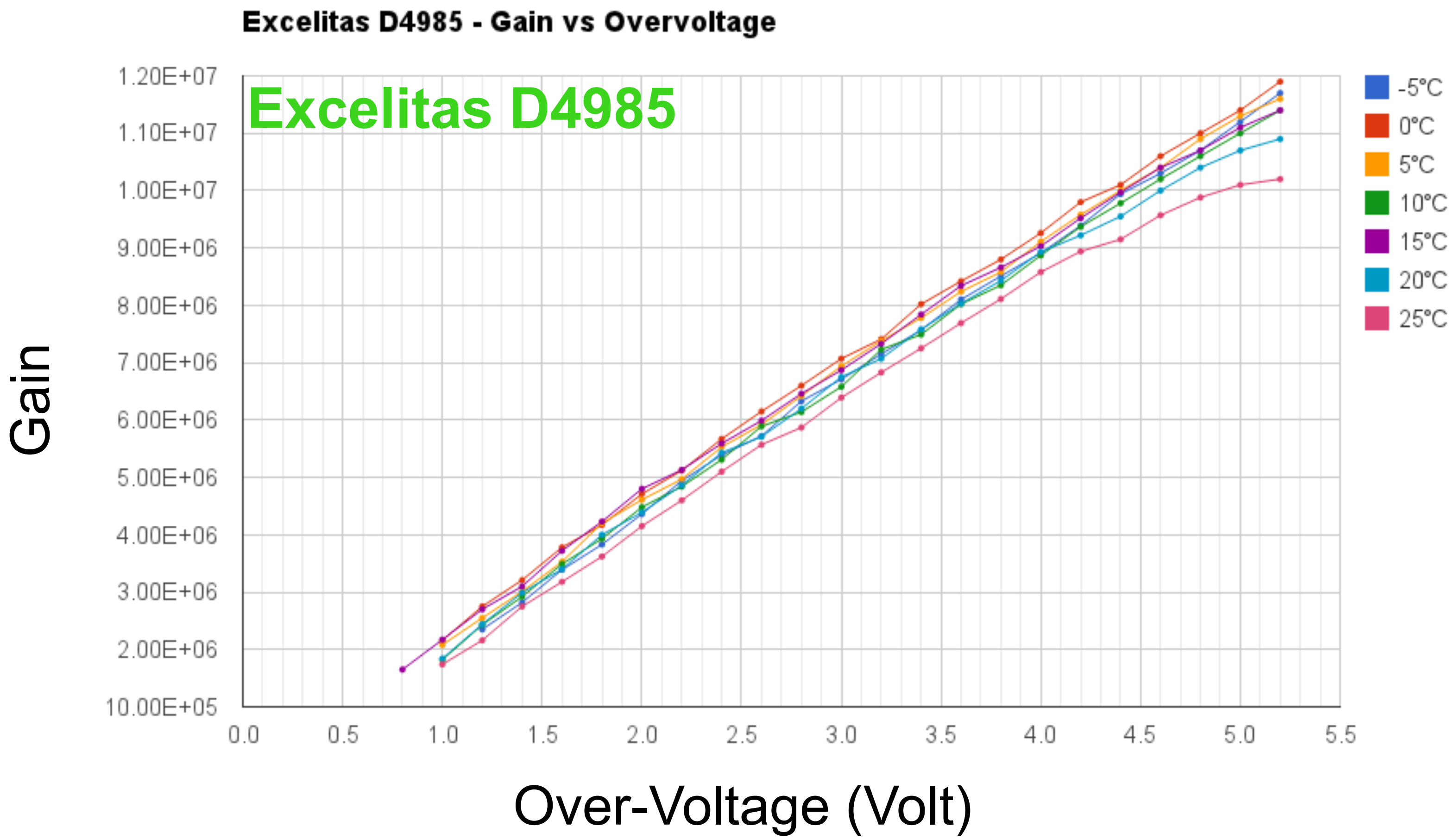
Gain vs V_{bias} (Type I)

Hamamatsu similar



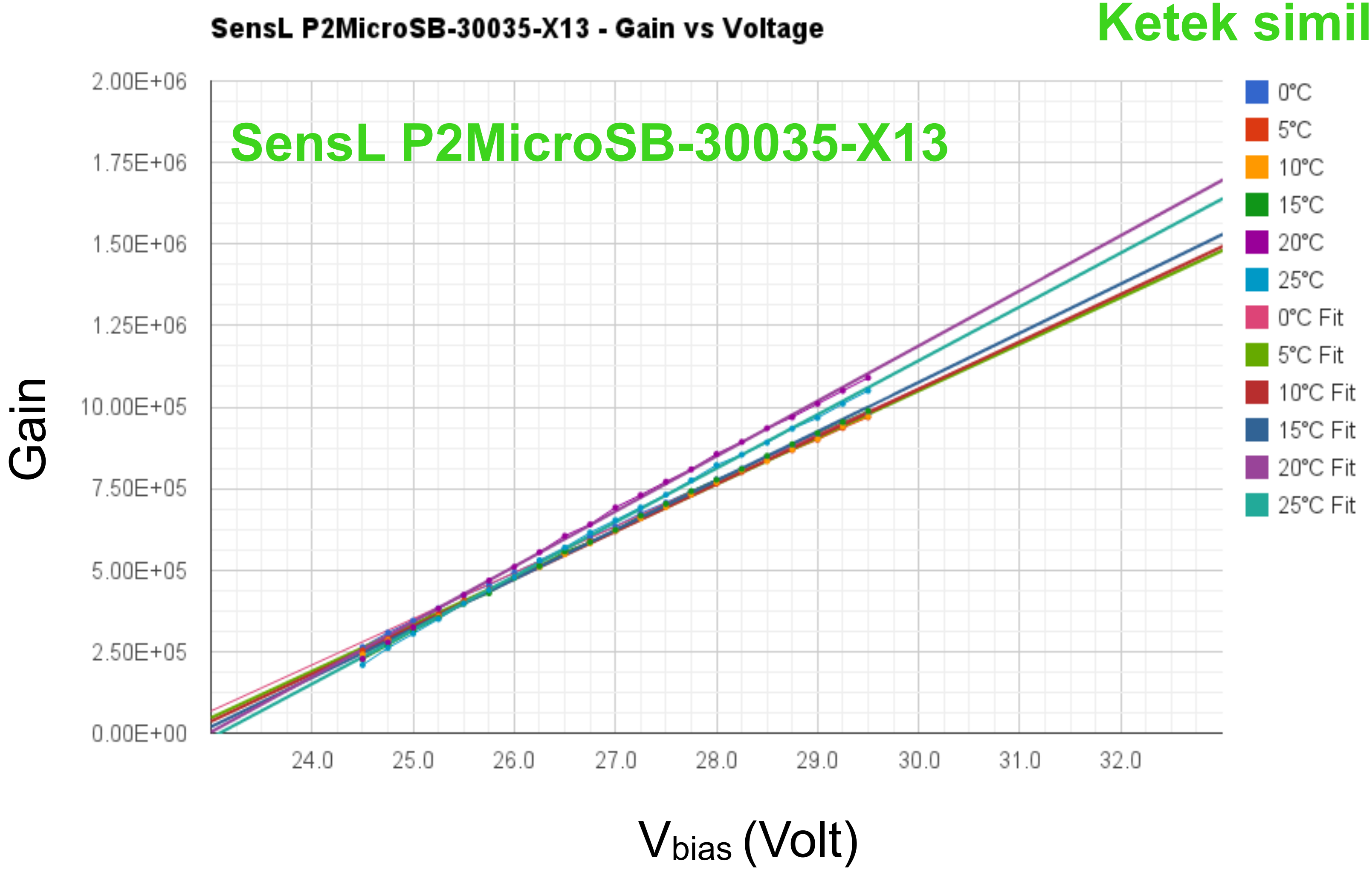
Gain vs Over-Voltage

Over-Voltage (OV) = V_{bias} - $V_{breakdown}$



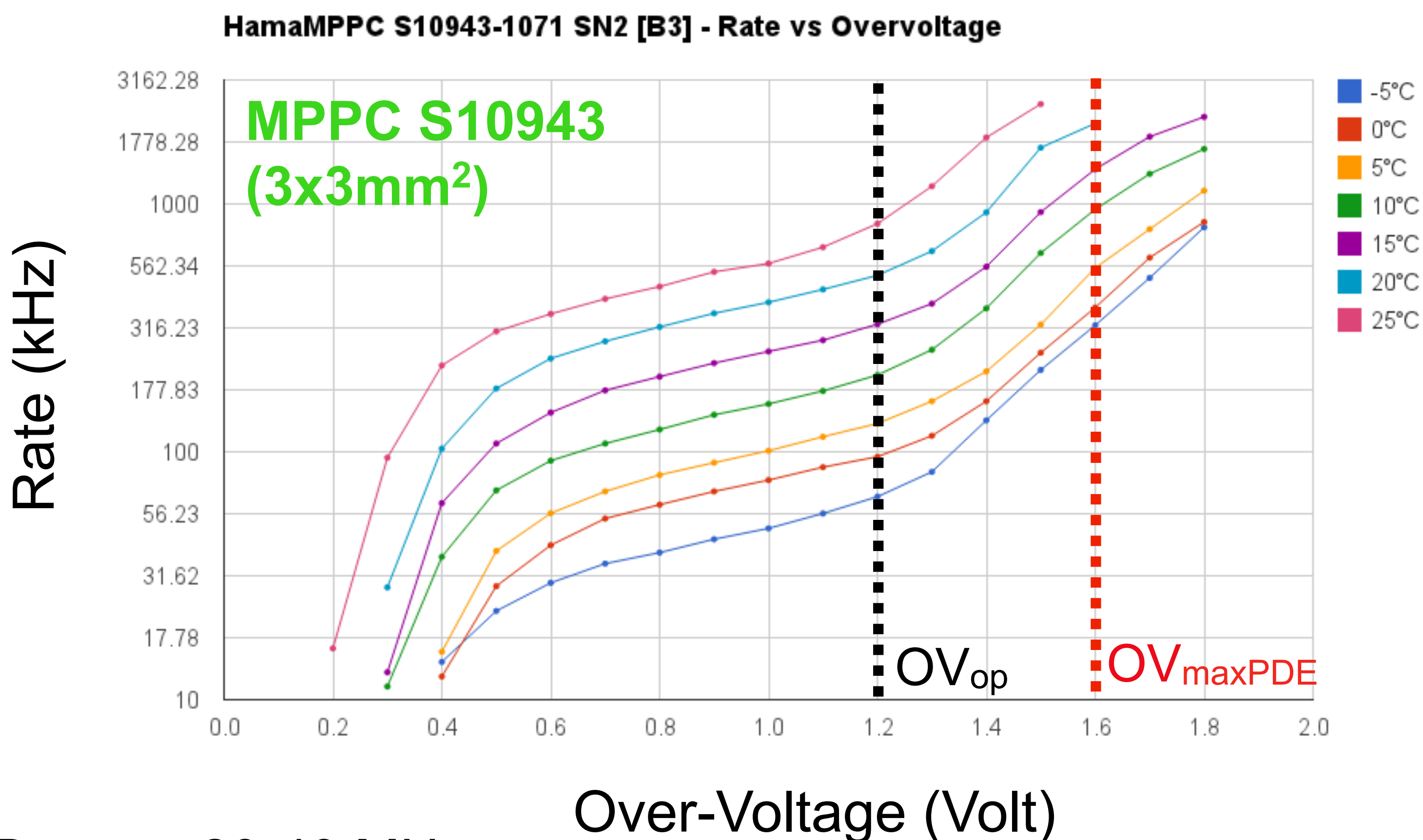
Gain vs V_{bias} (Type II)

Ketek similar



Dark Rate

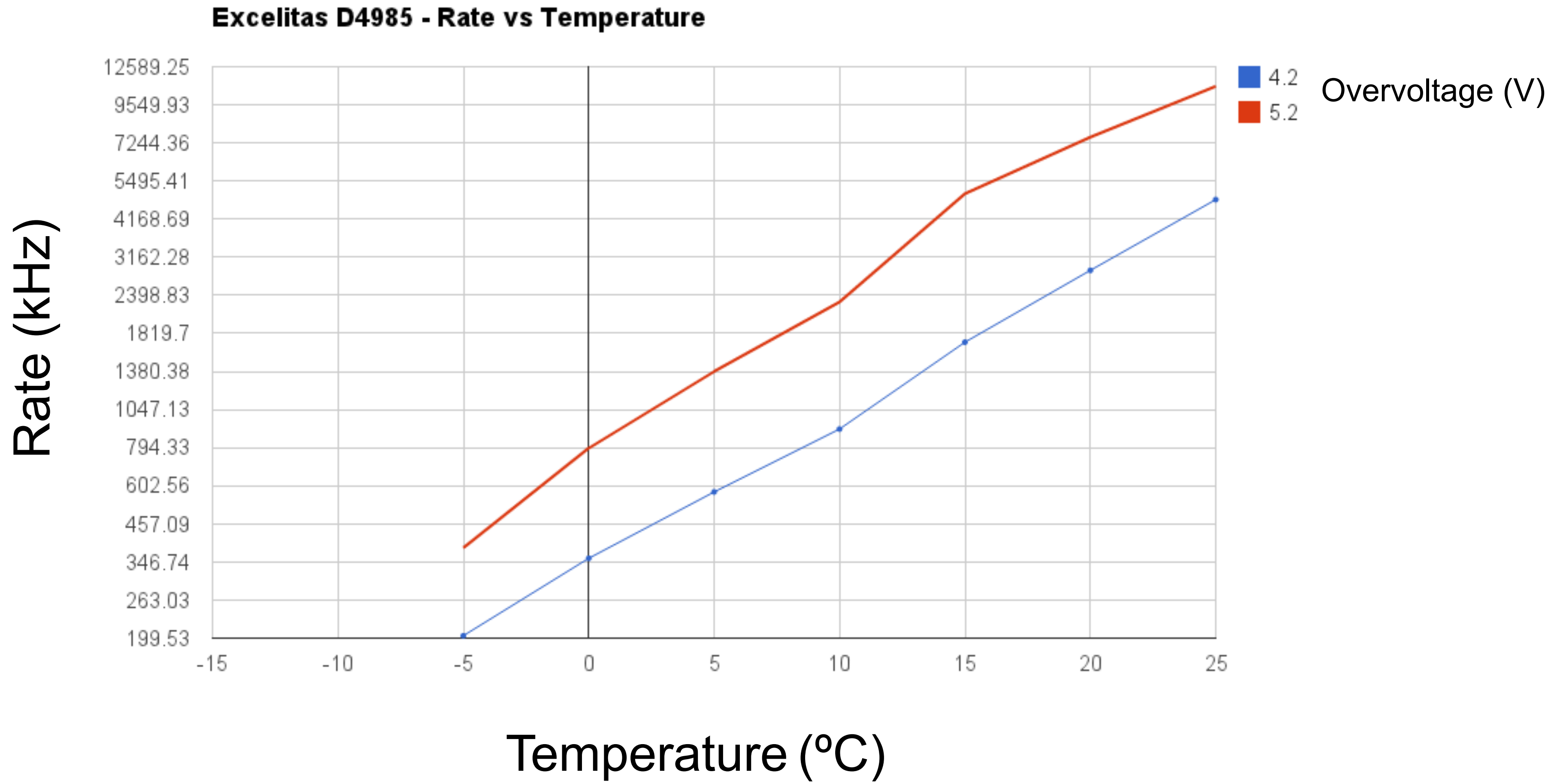
Pixel dark rate @25ºC [V_{op}] ~ 3 MHz



NSB rate ~ 20-40 MHz

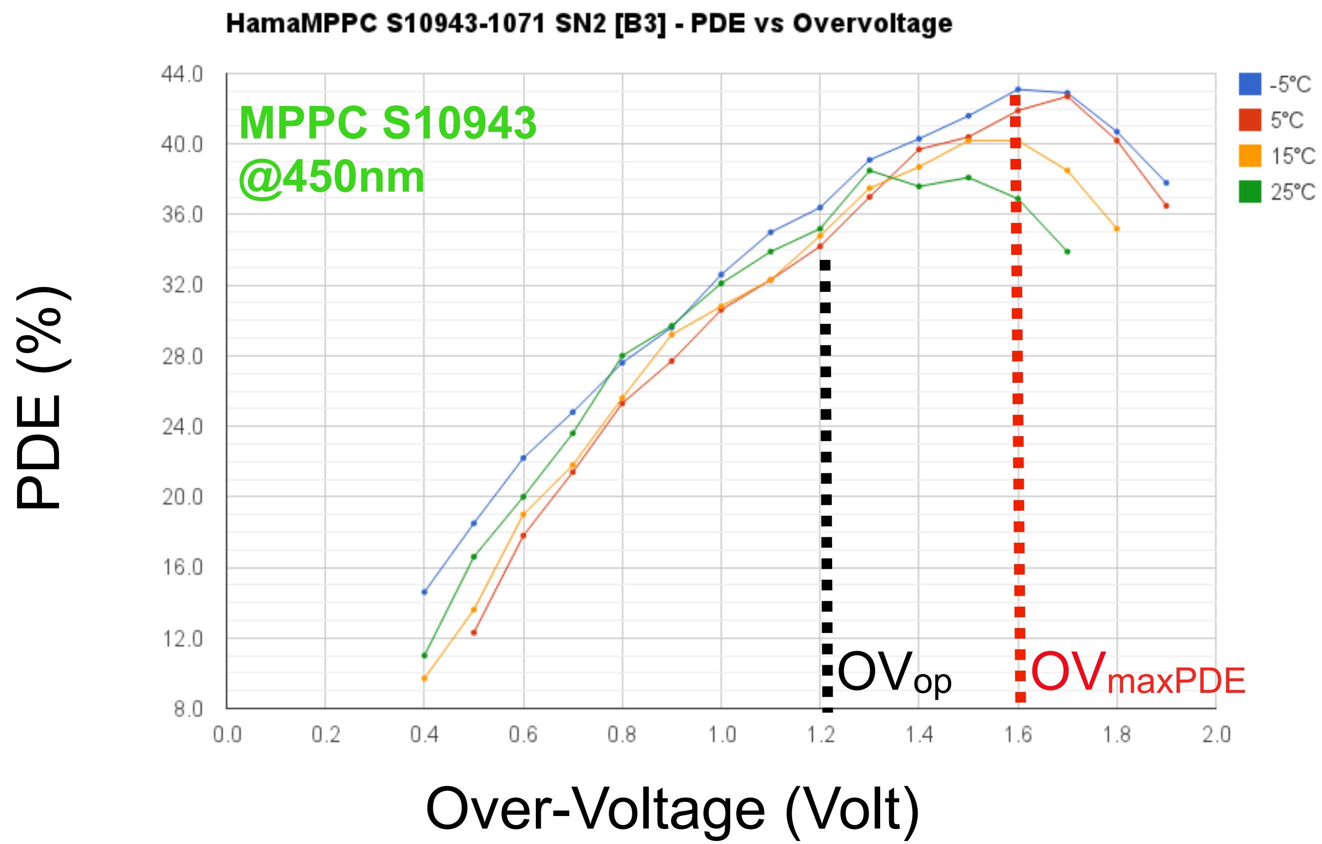
Dark Rate vs Temperature

Dark rate increase by factor ~2.9 every 10ºC (for fixed over-voltage)

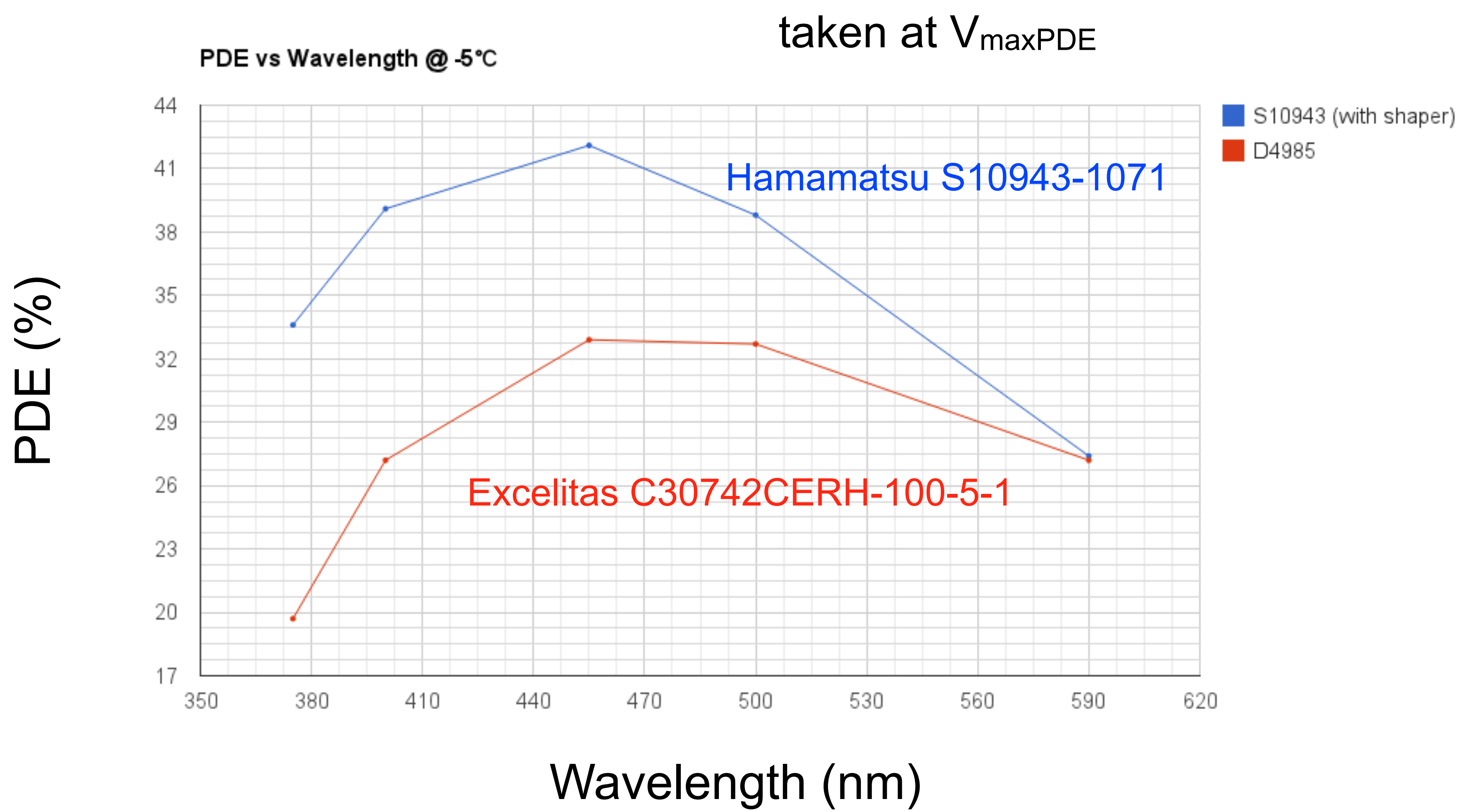


PDE Overvoltage Dependence

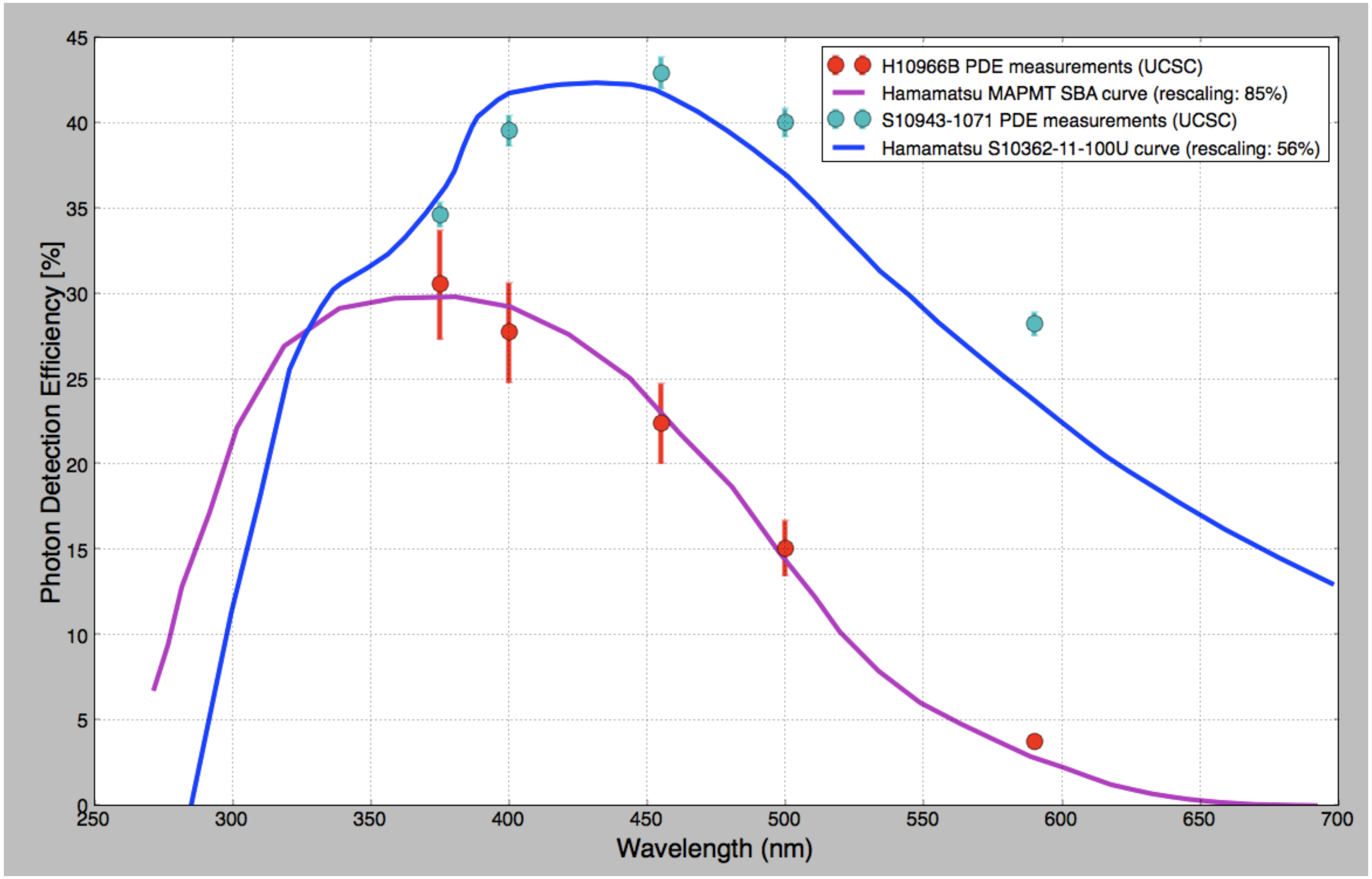
❖ PDE measurement method fails at high voltage due to high dark rate => roll-off at high OV is a result of this experimental limitation



PDE Wavelength Dependence



PDE: MAPMT vs SiPM

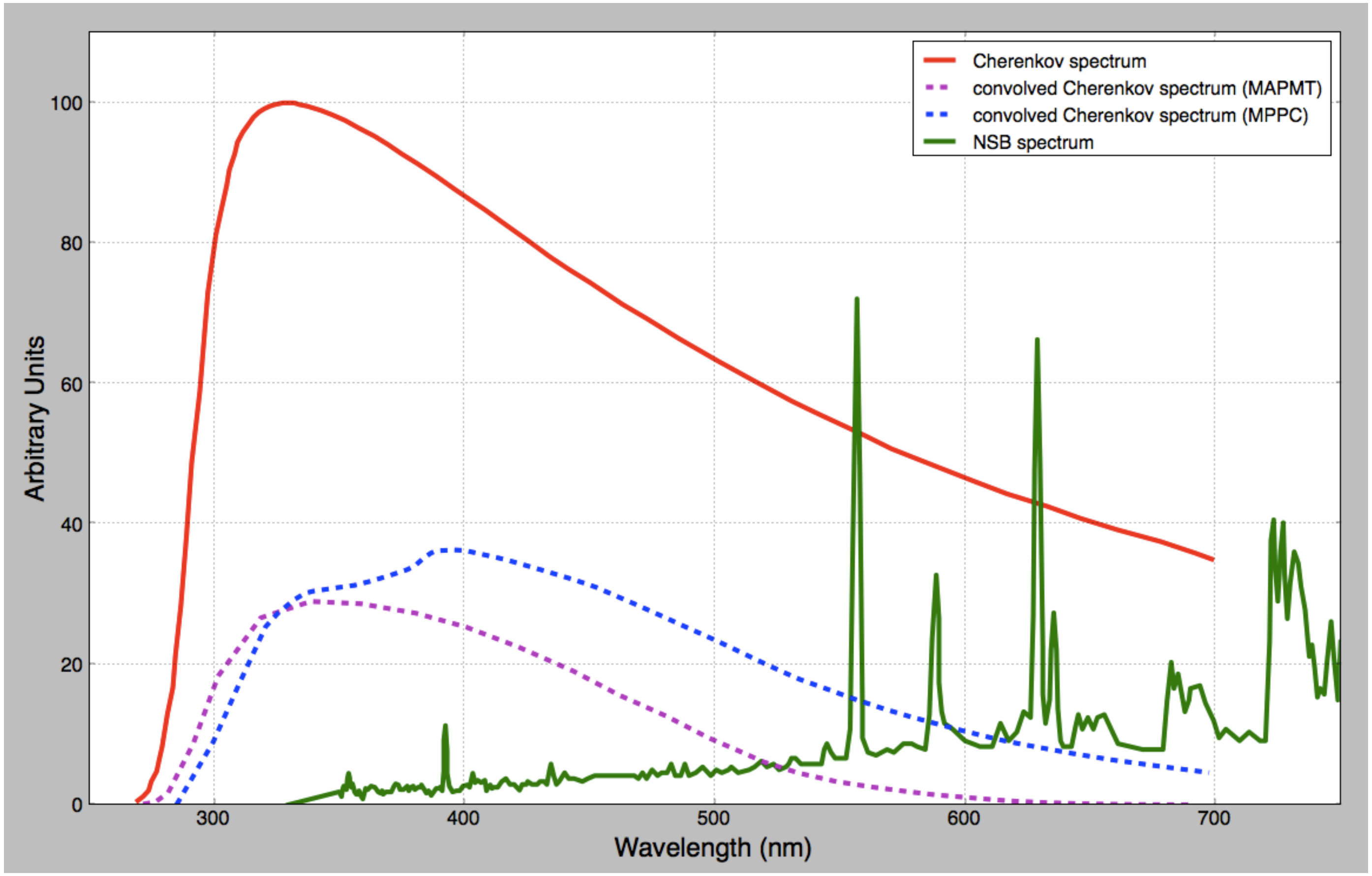


- MPPC ~60% more efficient than MAPMT on the Cherenkov spectrum but yields ~4 times higher NSB rate (~40MHz) without the use of IR filter

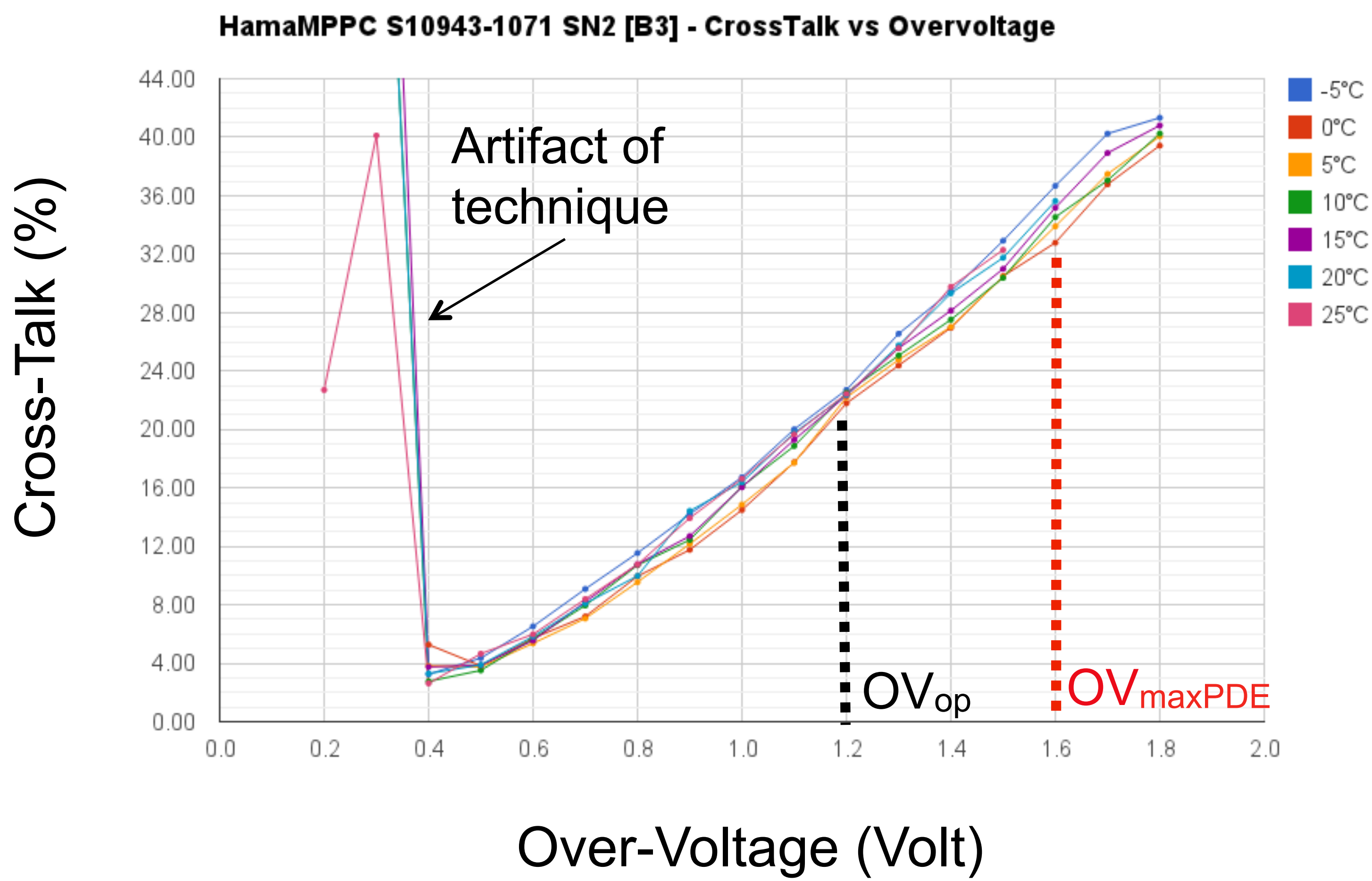
MAPMT vs SiPM

Efficiency on Cherenkov/NSB spectra below 700nm (550nm):

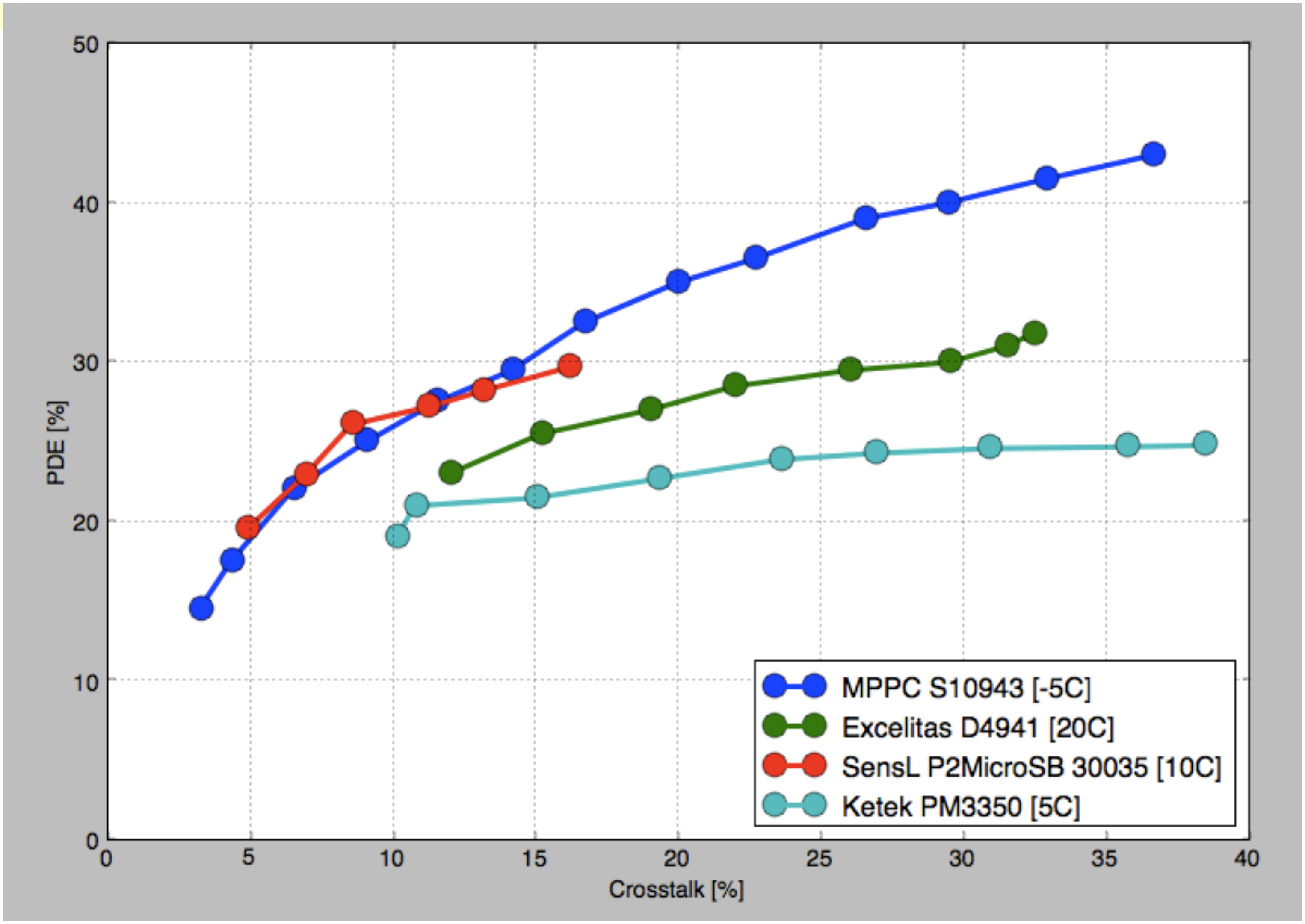
- MAPMT: ~18.5% (18%)
- MPPC S10943: ~30.5% (25.5%)
- NSB_{SiPM} / NSB_{MAPMT} ~ 3.5 (3.5)



OC Rates High in Most Devices



OC Rates High in Most Devices



PDE (%)

Crosstalk (%)

Impact of Crosstalk I

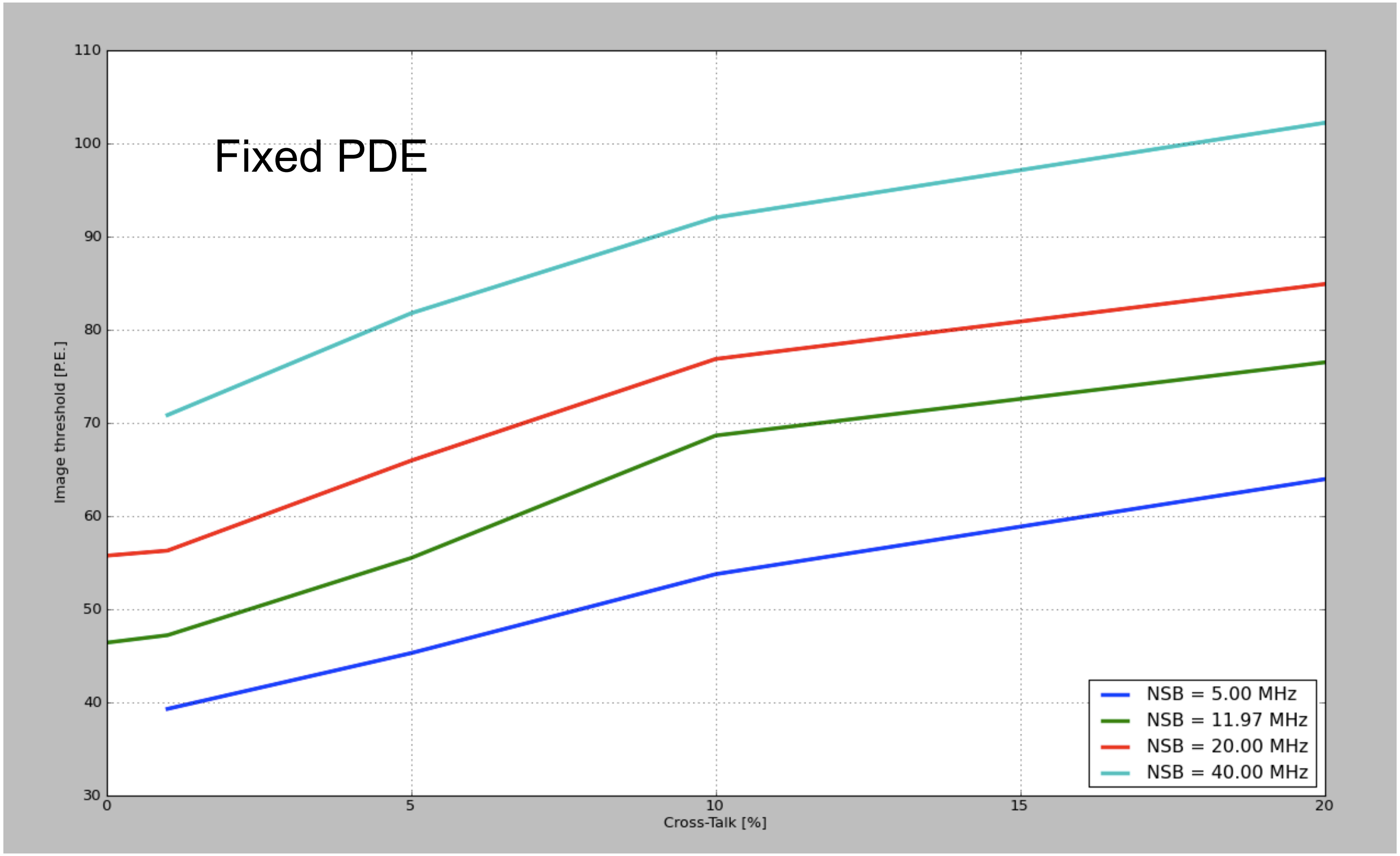
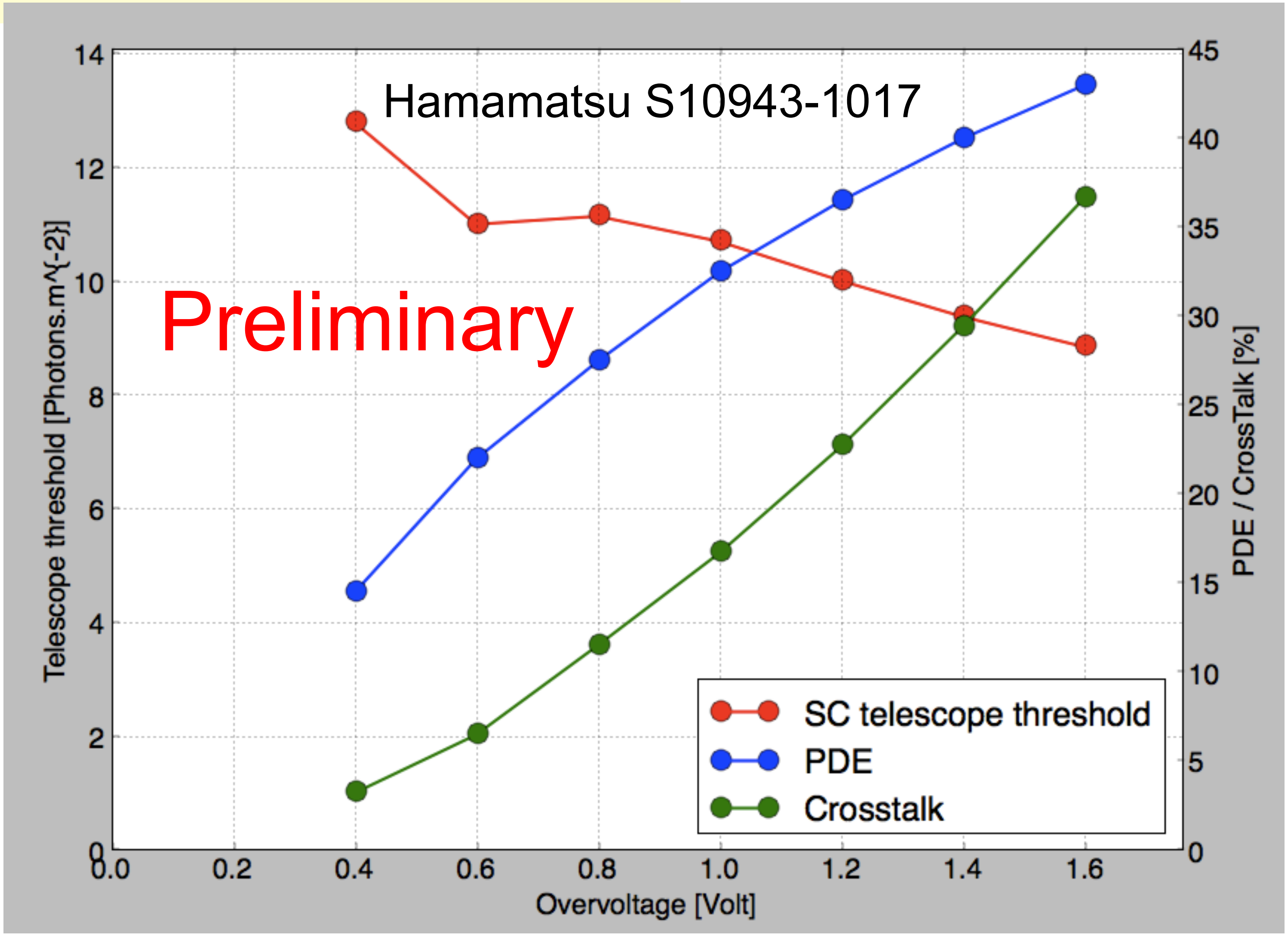


Image Threshold (PE)

Crosstalk (%)

Impact of Crosstalk II



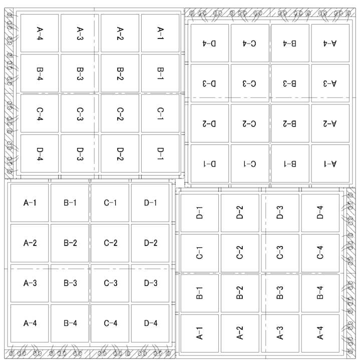
Telescope Threshold (photons m^{-2})

PDE / Crosstalk (%)

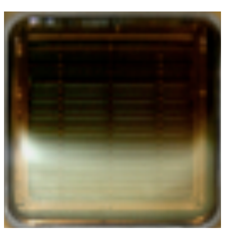
Overvoltage (V)

Modules from H10966B, R11265, S12545

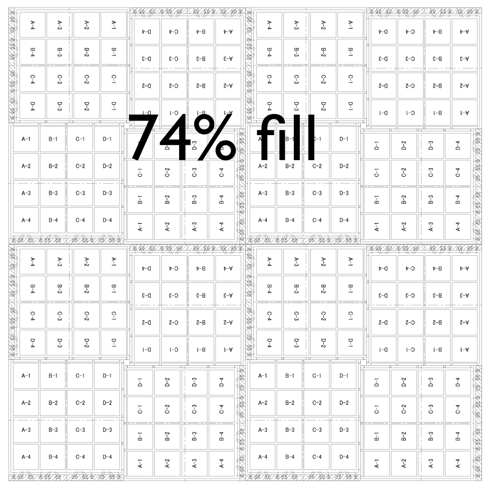
None of these scenarios have the pixel centers on a uniform square grid (Simulators and data reconstructors take note!)



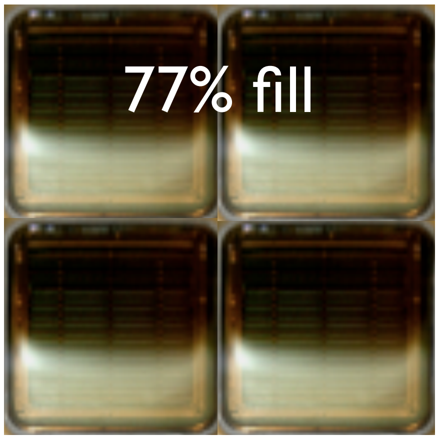
27.9 mm



26.2 mm

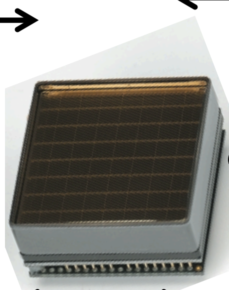


55.8 mm



52.4 mm

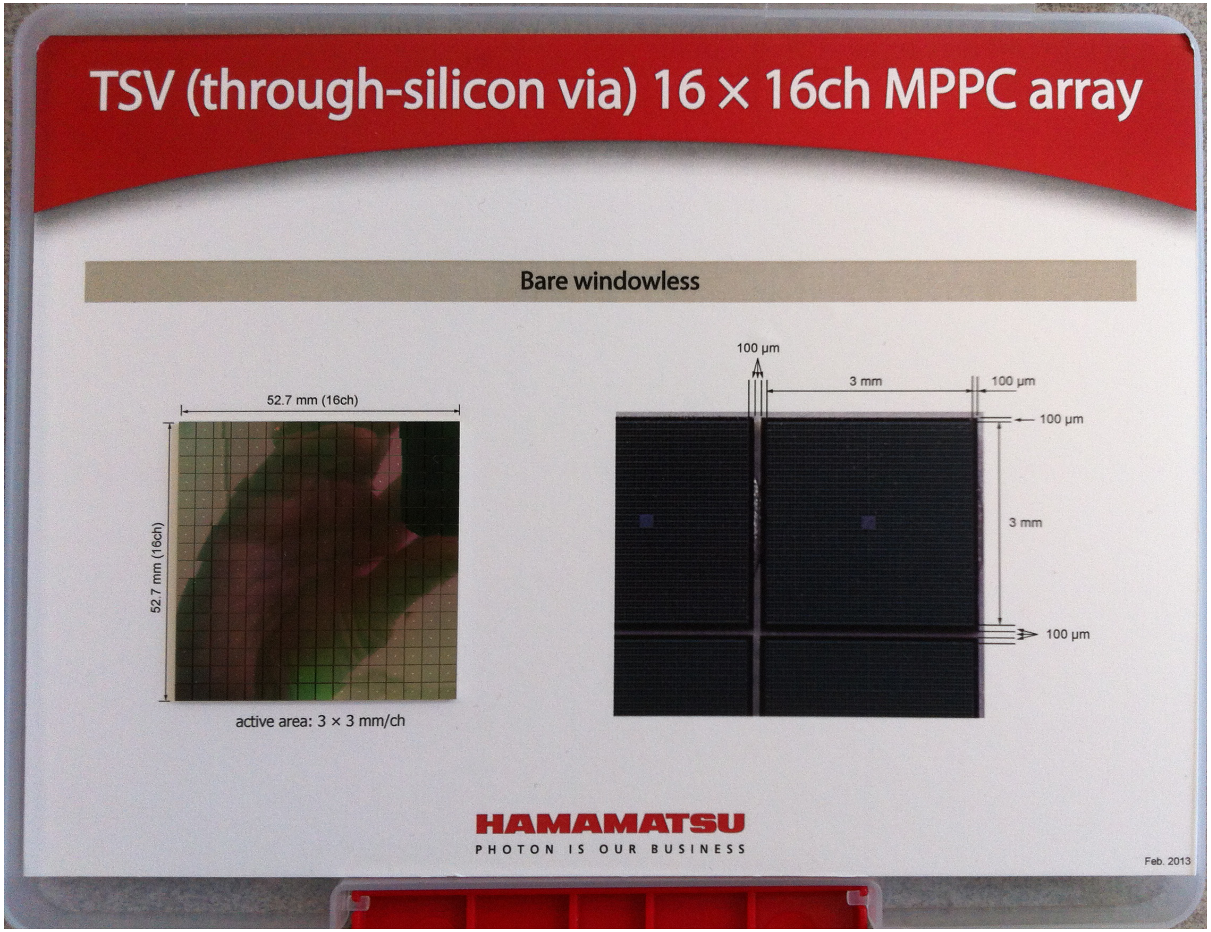
Close packing without any extra space for mechanical tolerances



52.0 mm

89% fill (77% at 55.8 mm pitch)

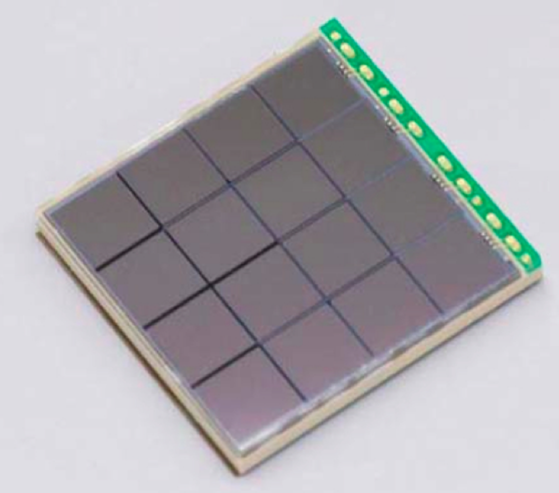
Hamamatsu Modules with TSV



Packing fraction of 81% on 53.2 mm pitch with 3x3 mm devices

Packing fraction of 89% on 50.8 mm pitch with 6x6 mm devices

Where are we?



Some devices straightforward

- Gain depends primarily on overvoltage
- Implicit gain dependence on temp through breakdown voltage

Can deal with pulse shape

Crosstalk improvements still to be seen

- But may be less of a problem than imagined

PDE pretty good in V, not so good yet in U, B

Need progress packing devices into large arrays

Price trends very favorable

Our experience is still limited