CTA小型望遠鏡用カメラの開発

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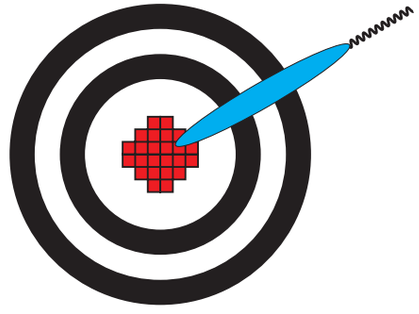

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宇宙線研究所

Small-sized Telescopes (SSTs)

- CTA consist of LST, MST and SST
- SST observes gamma rays above a few TeV
  - Flux is much lower than ~TeV gamma rays
  - Large collection area is required

⬇

  - Large number of inexpensive telescopes
    - Smaller mirrors < 6 mΦ
    - Camera cost becomes dominant

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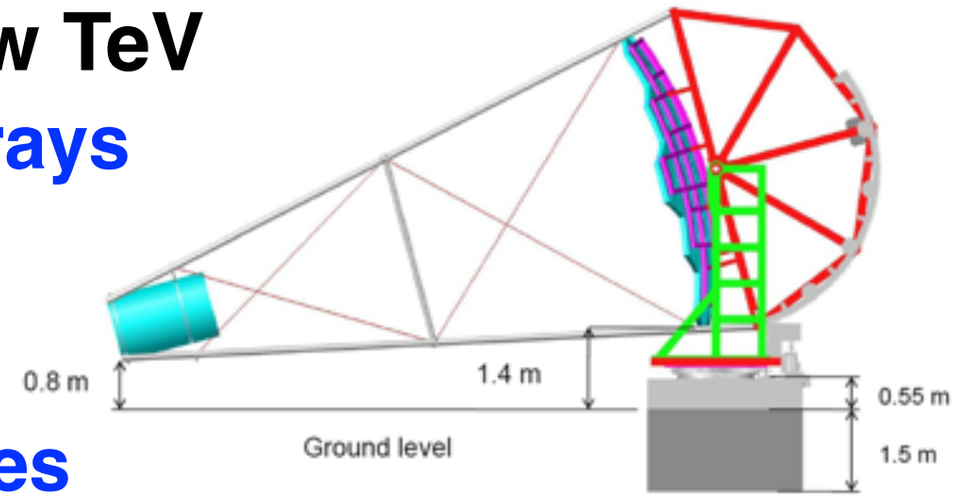
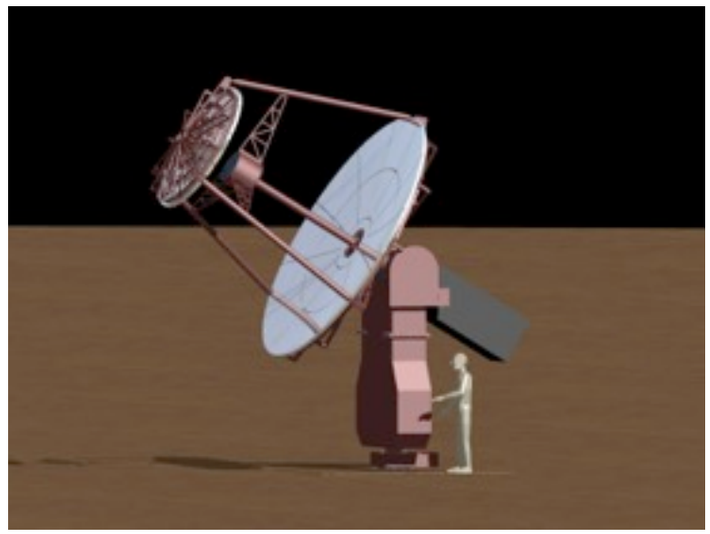
  - Development of inexpensive camera
    - Multi-channel photon sensors
      - SiPMs and MAPMTs
    - Multi-channel waveform recording ICs
      - Reduction of electric parts by integration of functionalities
    - Small pixel size requires short focal length by dual-mirror tel.

single mirror



dual mirror

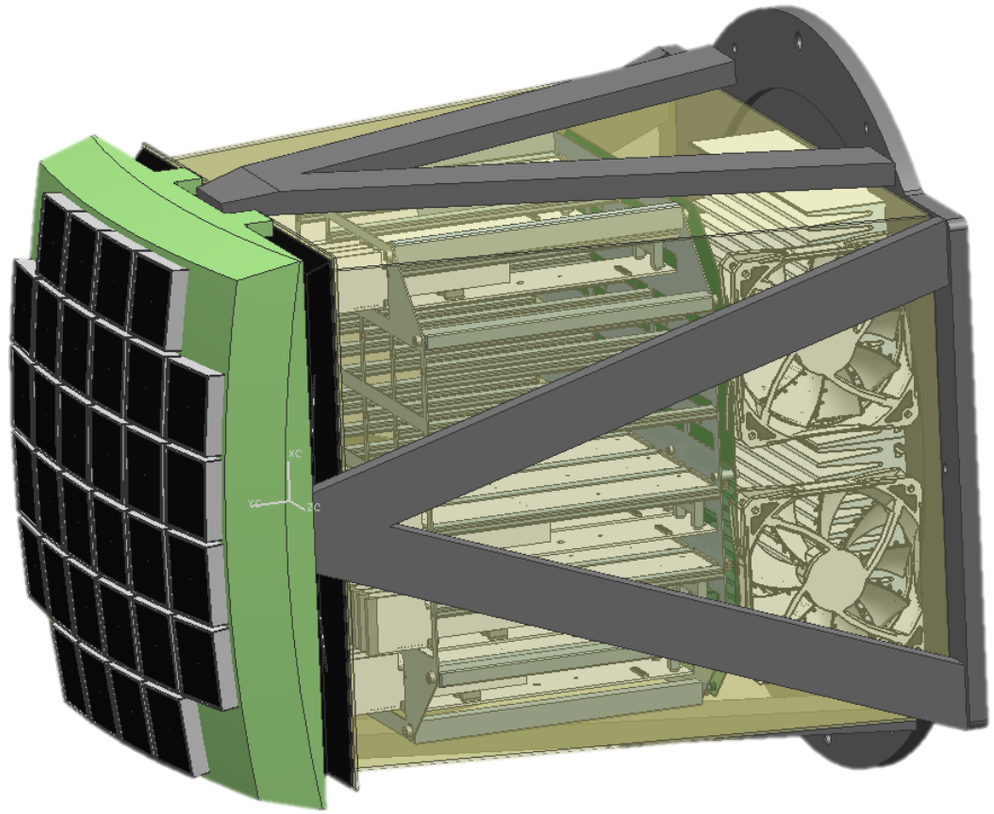


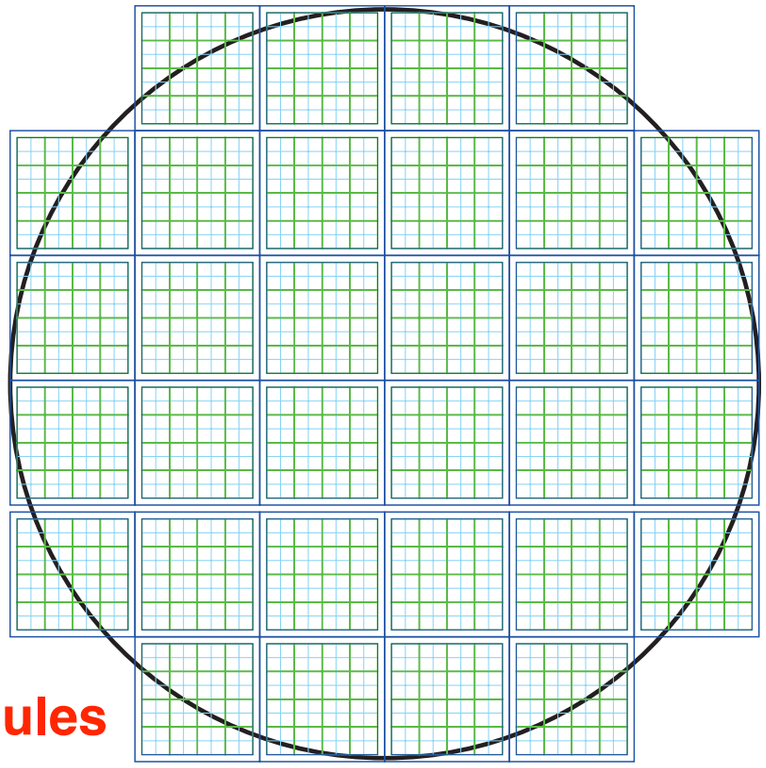
SC-SST Camera Design

❖ SC-SST camera parameters

	32 mod
FOV for 0.18°/pixel (36 mm/°)	8.6°
FOV for 0.28°/pixel (23 mm/°)	13.4°
Angular pixel size for FOV=10°	0.21°
# of pixels per camera	2,048
Power consumption per camera (FE)	145 W
Weight per camera (FE+MAPMT)	11 kg
Total cost (FE+BE) for 50 CAMs*	$2.0M

*Assuming $20/ch, which does not explicitly include labor for mechanical module assembly and calibrations

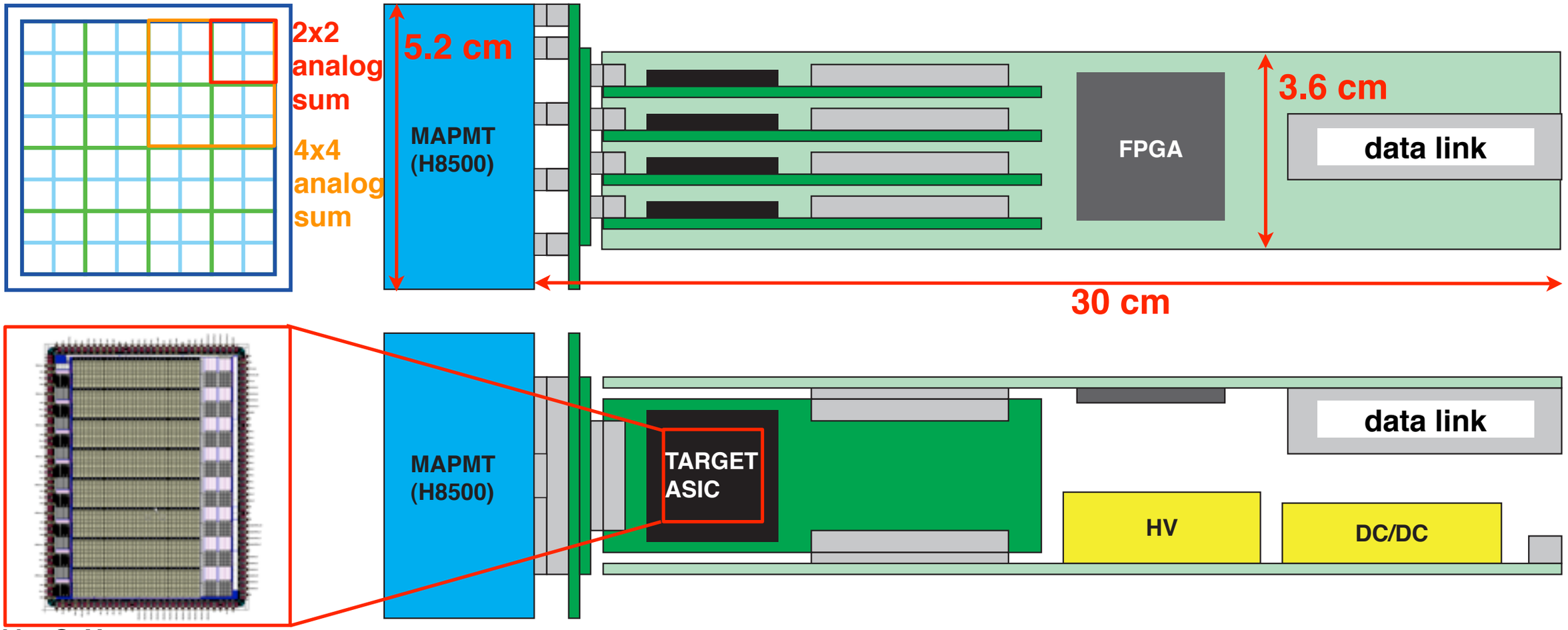




32 modules

SC-SST Camera FE Electronics

- **FE (front-end) board configuration**
  - Sensor board (MAPMT or SiPM array, routing for 4x4 analog sum trigger)
  - ASIC board (16 channels per board)
  - FPGA board: FPGA, data link connector
  - Power supply board: DC/DC converter, HV supply
- **Minimize # of components for cost reduction and reliability**
  - Integration of necessary functionalities into an ASIC



designed by G. Varner (Hawaii)

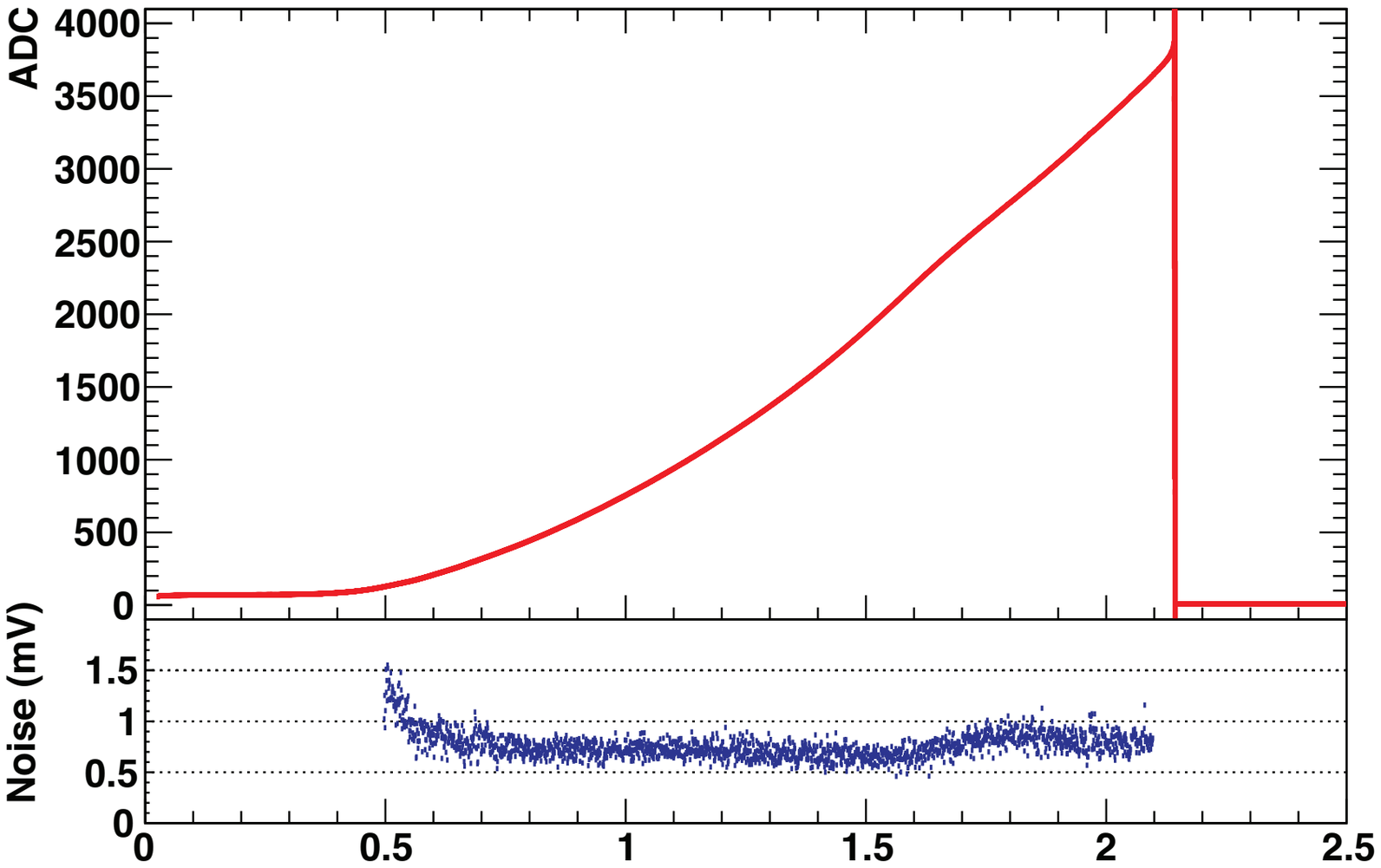
TARGET Specifications

- **Waveform sampling ASIC specifically designed for CTA**
  - **Switched capacitor array + Wilkinson-type ADC**
  - **Integrated trigger circuits**

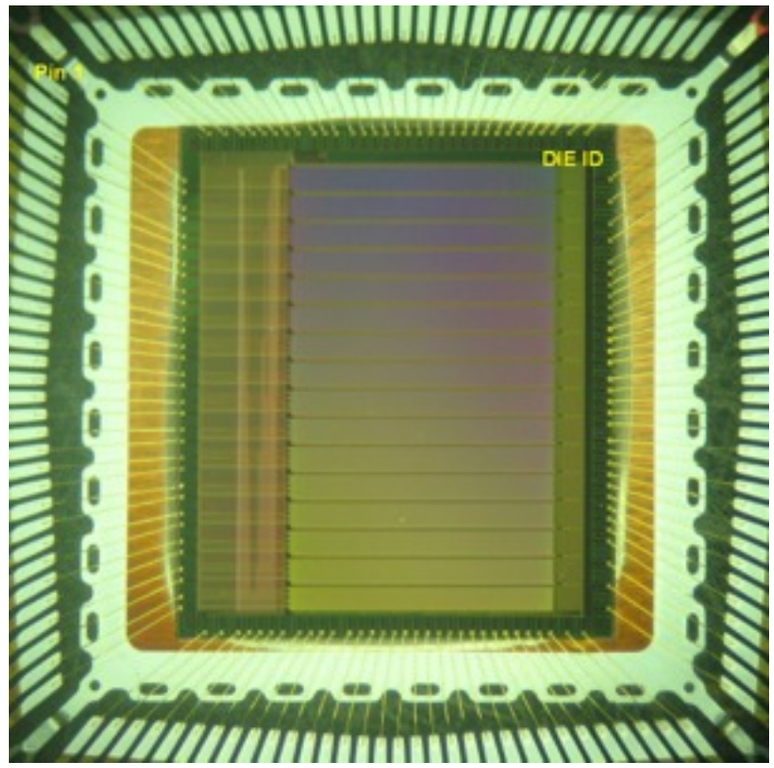
		TARGET-1 (measured)	TARGET-5 (expected/measured/new)
# of channels		16	16
# of cells/channel		4,096	16,384
Sampling frequency		0.5 – 2.5 GHz	0.4 – 1.2 GHz
Bandwidth		150 MHz	> 380 MHz
Crosstalk (@ -3dB)		4%	< 1%
Dynamic range		~10 bits (~1 mV/1 V)	10.5–11.2 bits (0.6–1.0 mV/1.5 V)
Digitization time		1 μs (9 bit), 2 μs (10bit)	1.1 μs (10 bit), 4.6 μs (12 bit)
# of cells/digitization		16 cells x 2 ch	32 cells x 16 ch
Data transfer speed		—	100 Mbps x 16 ch
Dead time (48 cells/ch)	10 bit	49 μs	2.3 + 7.2 μs
	12 bit	197 μs	9.1 + 7.2 μs
# of trigger output		1 (OR of 16 triggers)	4 (analog sum of 4 ch) + 1 (16 ch)

TARGET ASIC Development Status

- Development of TARGET-5 to address issues found in TARGET-2
- TARGET-5 (qty. 240) was delivered to Nagoya/STEL on Aug/24
- Initial measurements indicate TARGET-5 satisfy requirements
  - Dynamic range, crosstalk, bandwidth are most critical
  - Evaluation of trigger performance in progress



TARGET5
designed by Gary Varner

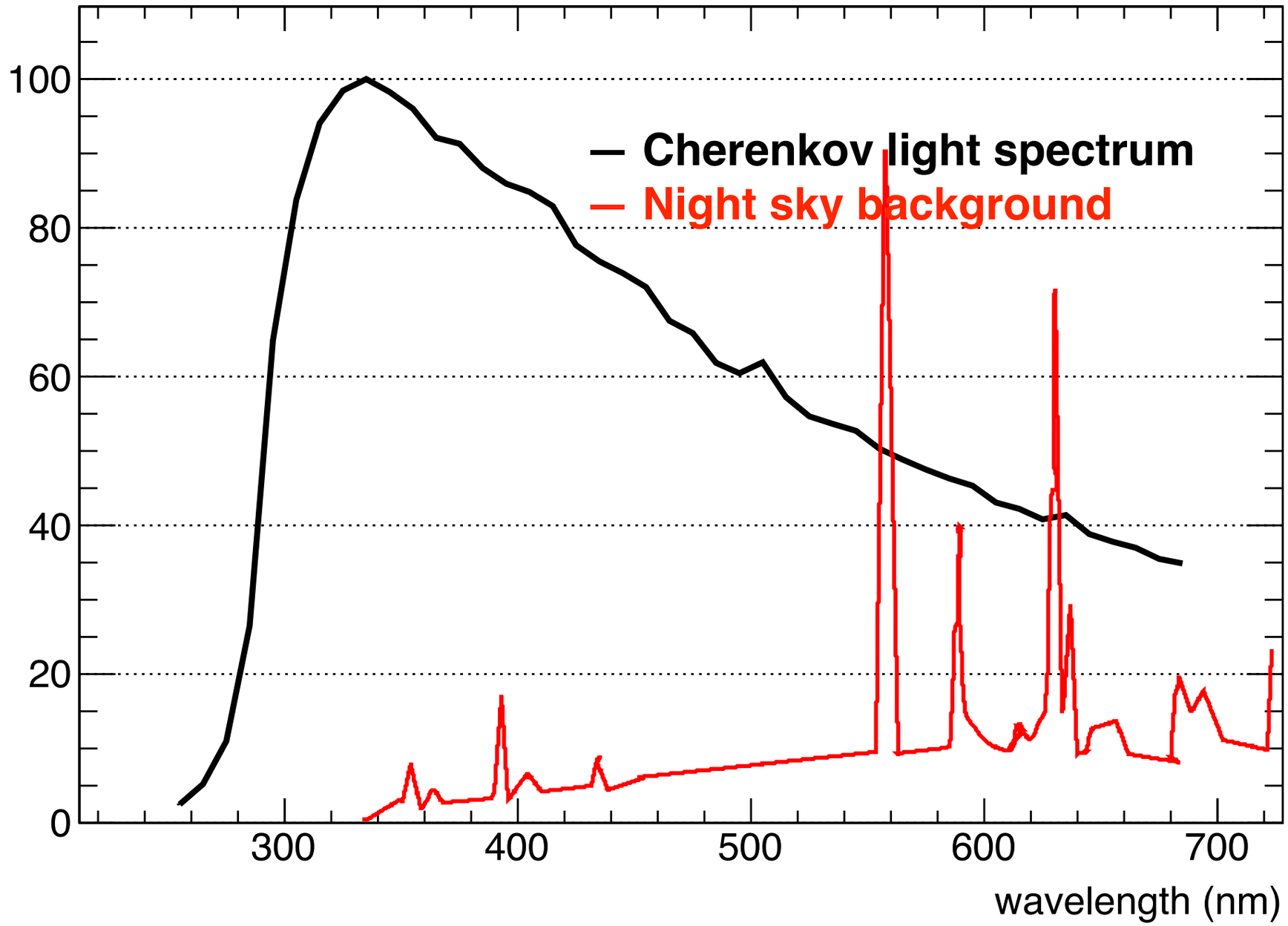


Comparison of Photon Detectors

	MPPC(SiPM)	MAPMT	HPD	APD
Size	55 mm	52 mm	73 mm	—
Pixel size	6.0 mm	6.1 mm	4.9 mm	—
# of pixels	8x8	8x8	12x12	—
aperture ratio	69–76%	89%	64%	—
Q.E. (peak)	65%	27–35%	32%	85%
peak wavelength	450 nm	340–380 nm	360 nm	~800 nm
Gain	~10^6	10^4–10^6	10^4–10^5	10–100
HV	30–70 V	1–2 kV	8 kV	100–500 V
Timing	30 ps	~100 ps	~100 ps	~ 1 ns
Cost (kJPY)	125	138		—
Dynamic range	~10^3	~10^6	>10^5	—
Dark noise rate	10^3-10^6 Hz			—

Calculation of Cherenkov Light Yield

- **Integrate Cherenkov light spectrum weighted by photon detection efficiency up to 550 nm**
  - **Avoid Oxygen fluorescent line**
  - **MPPC PDE from catalog**
  - **MAPMT PDE from MPPC PDE and PDE ratio**



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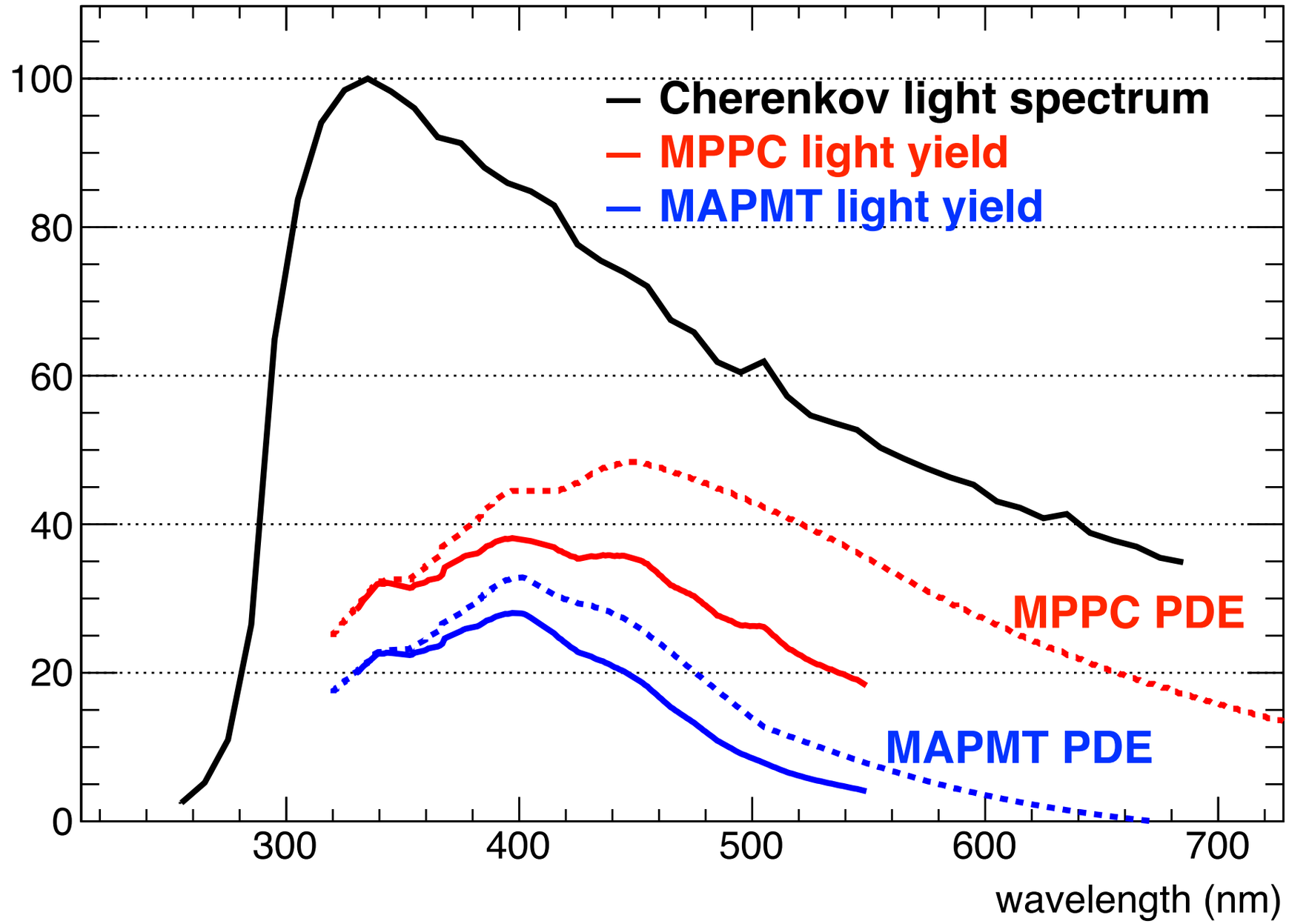

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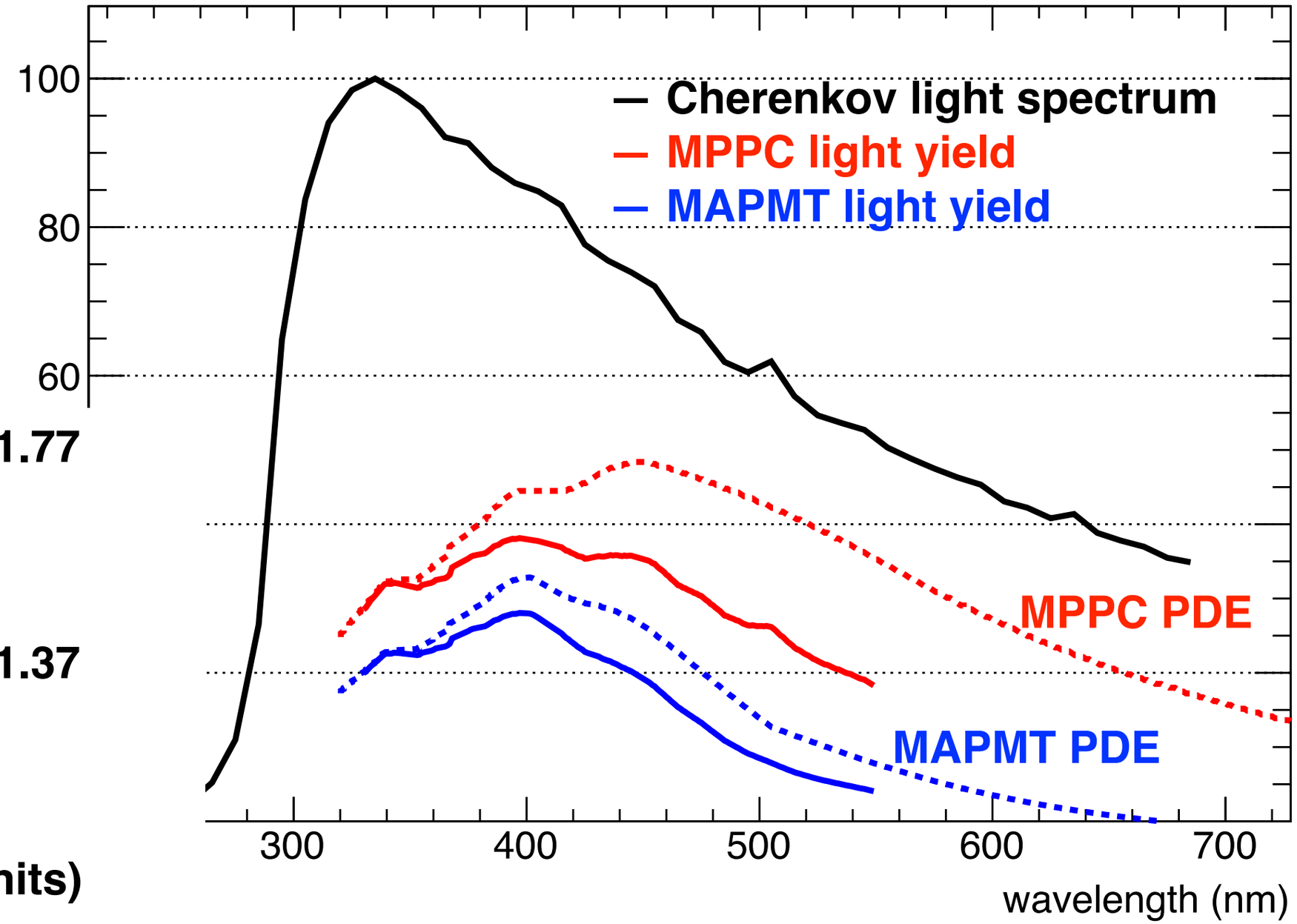


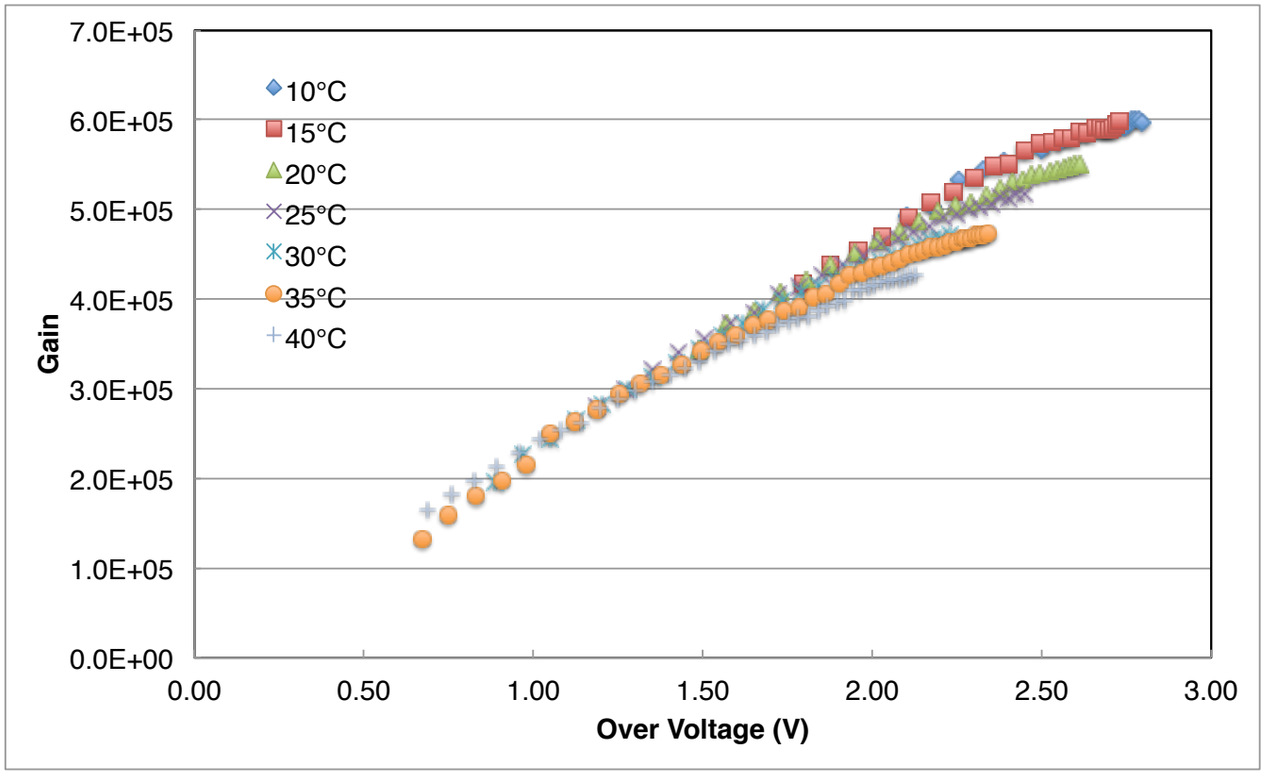
LY(MPPC)/LY(MAPMT)=1.77

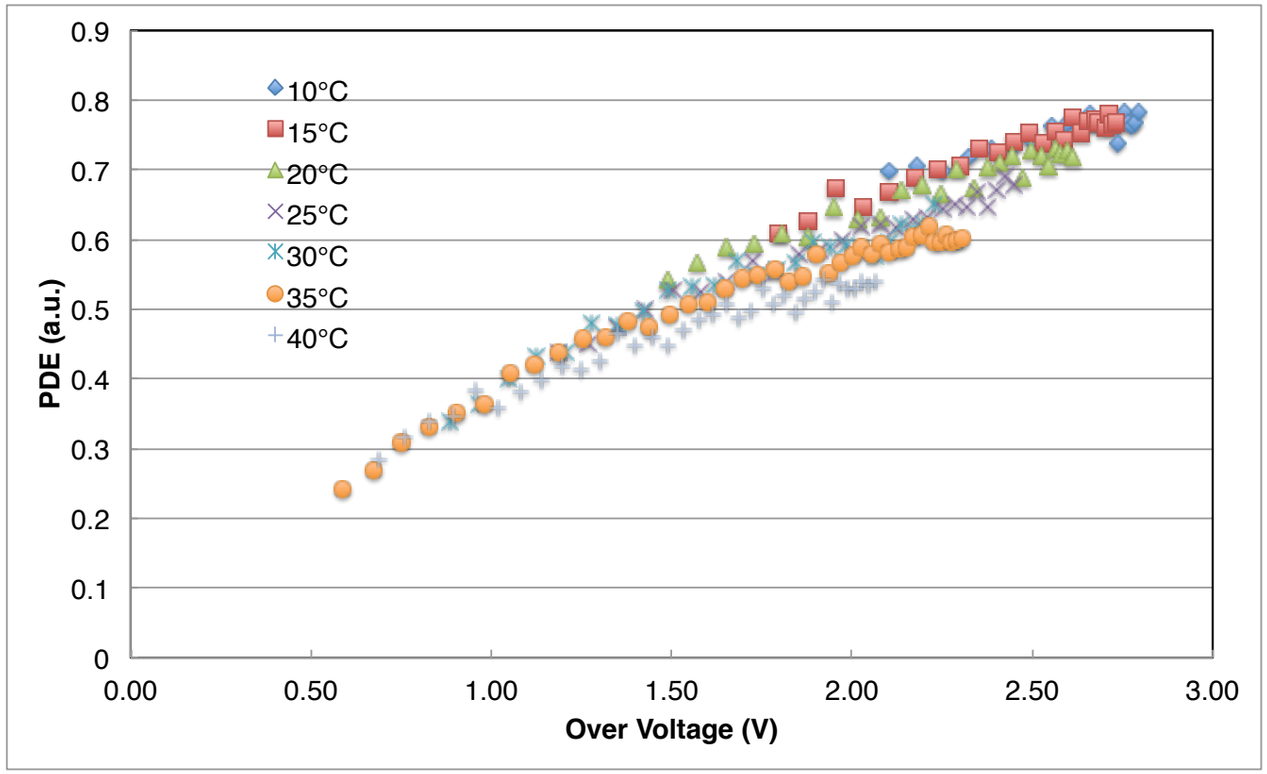
Correcting light loss at boundary of each unit
LY(MPPC)/LY(MAPMT)=1.37

ε(MAPMT)=89%
ε(MPPC)=69%
(0.5 mm gap between units)

SiPM Characterization

- **MPPC (Multi-Pixel Photon Counter) by HPK**
  - **Characterize performance under possible conditions**
  - **Study requirements on camera temperature control**





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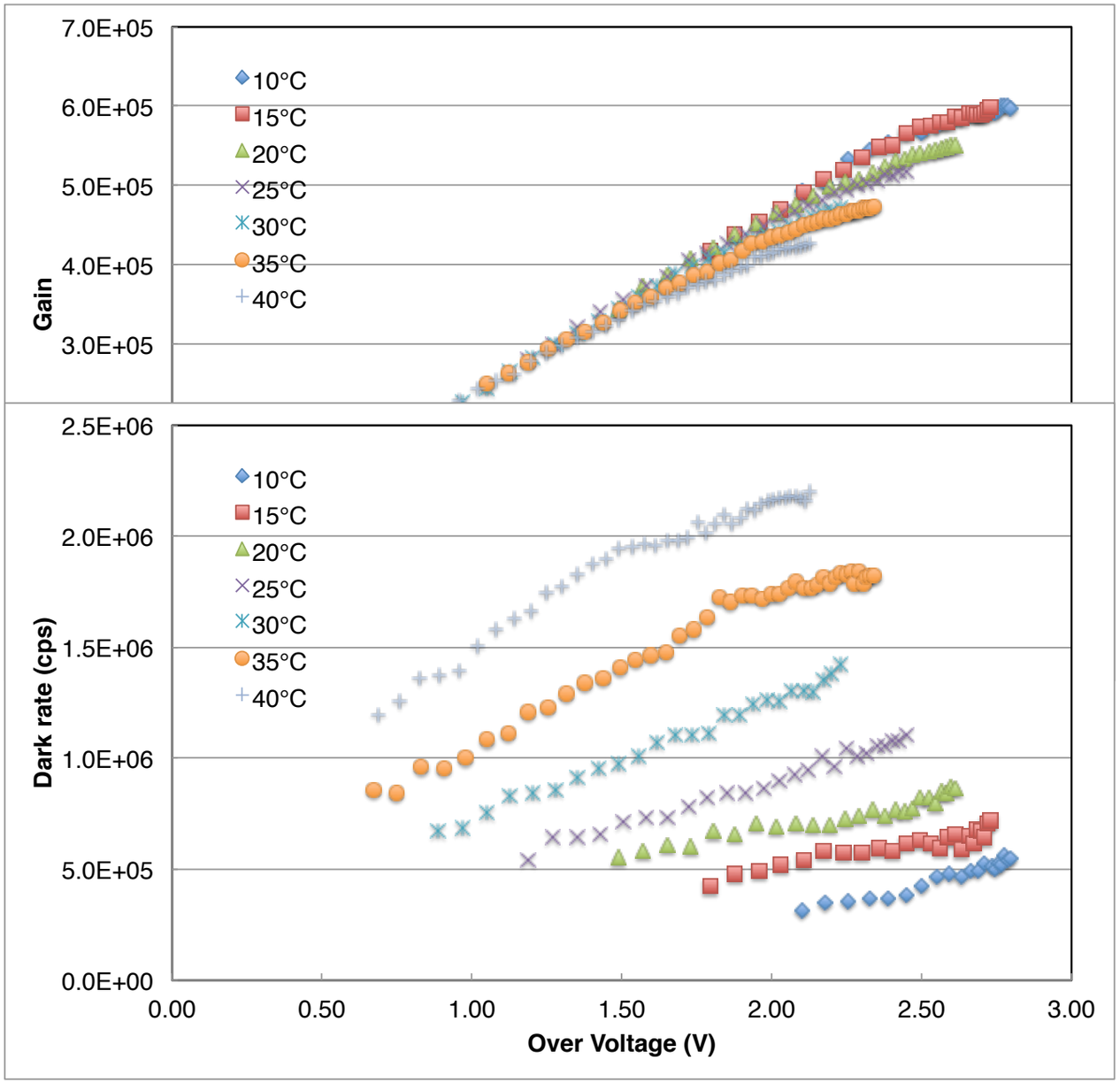

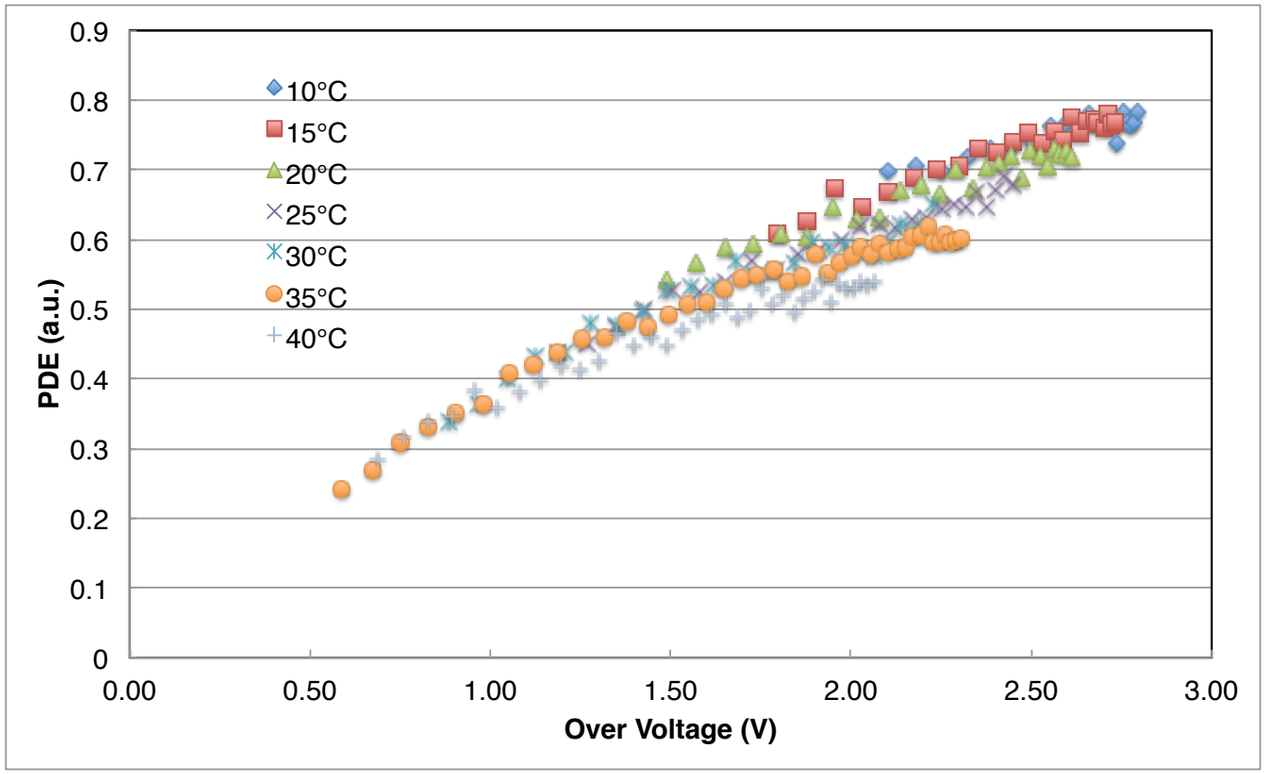

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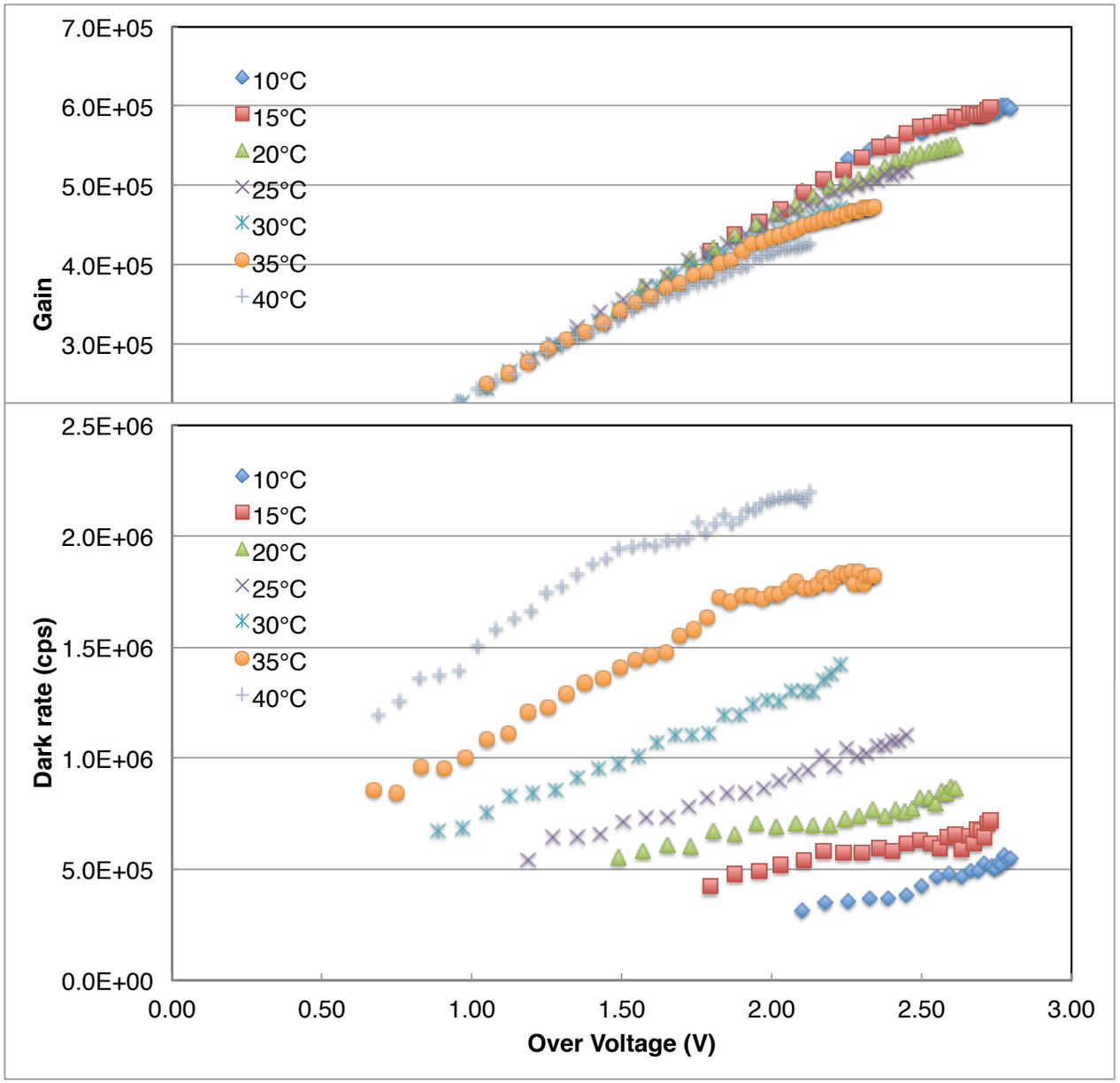
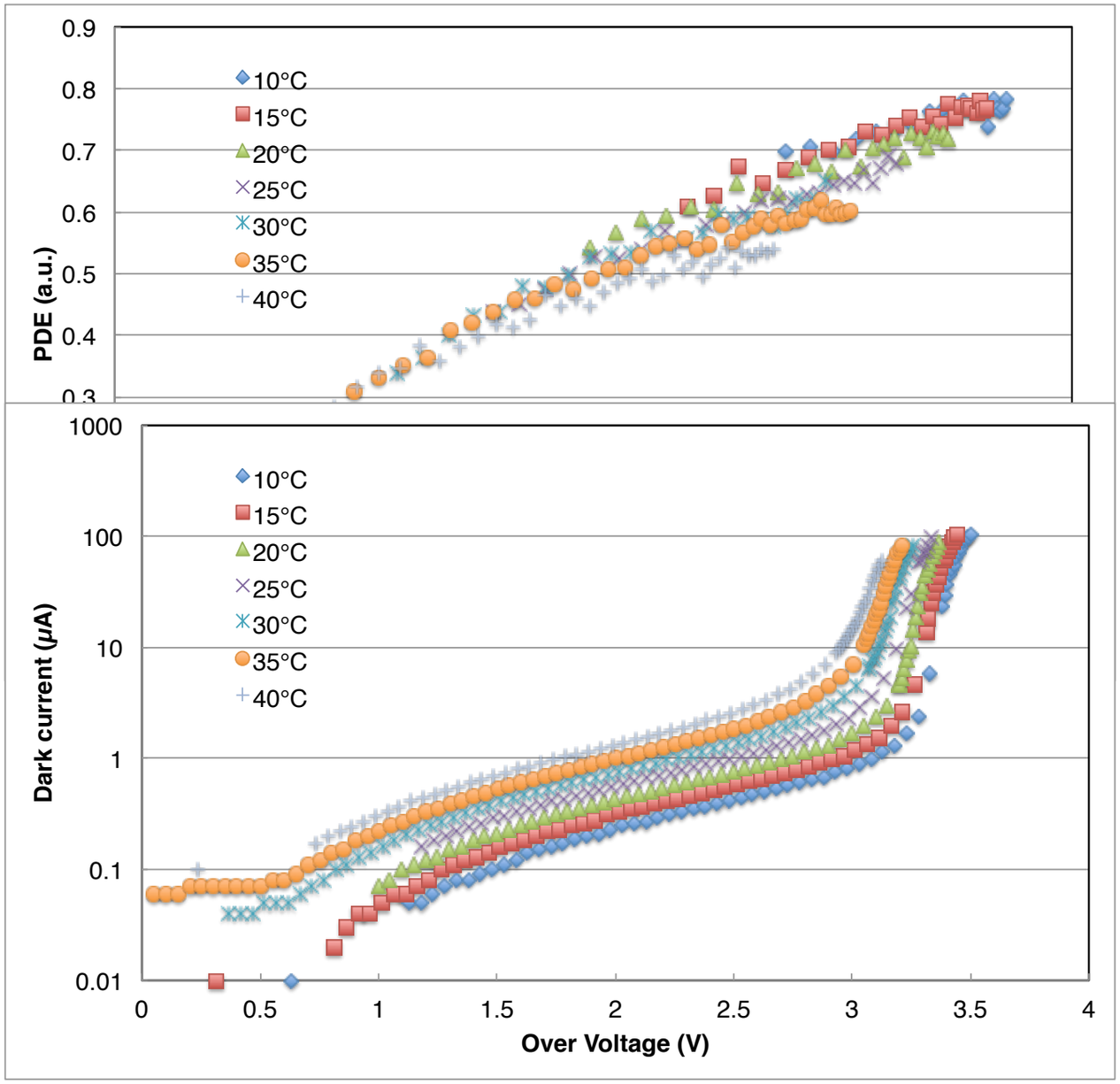
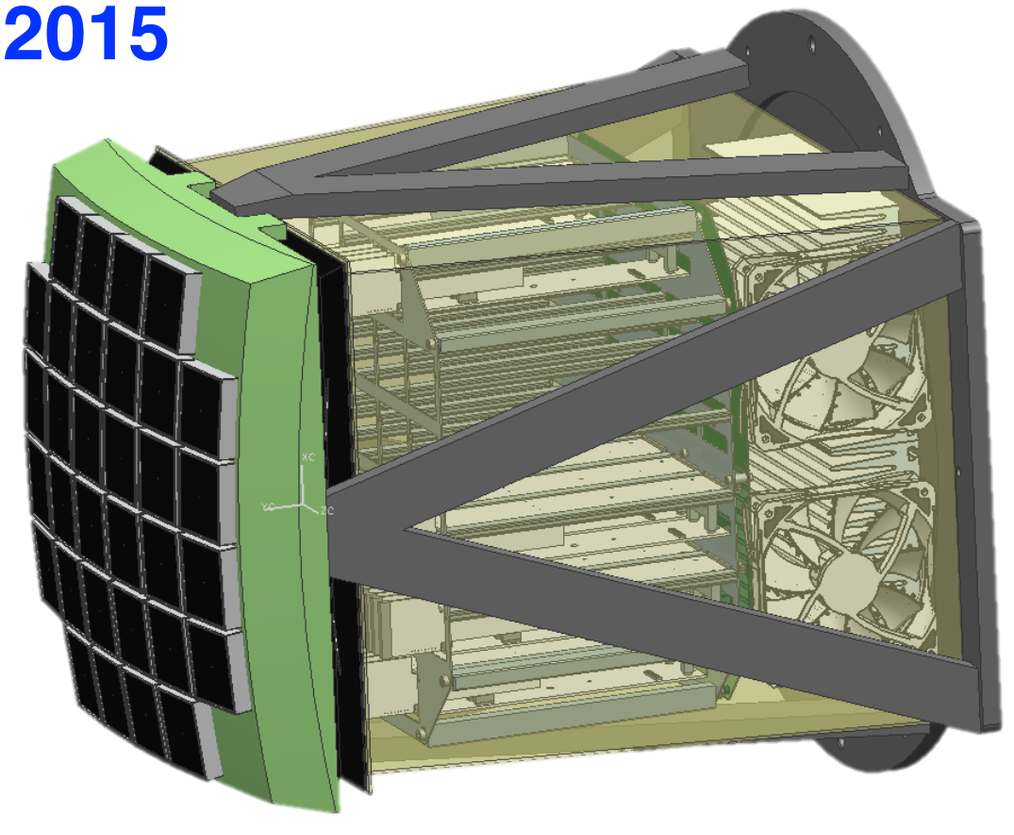




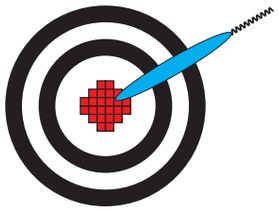
Summary

- Making good progress in TARGET ASIC development
  - Trigger performance needs adjustments
- MPPC performance being characterized
  - Cooling may be required to maximize photon detection eff.

- Fabrication of a complete prototype of MPPC SST camera by late 2014
  - to be mounted on prototype SSTs in 2015

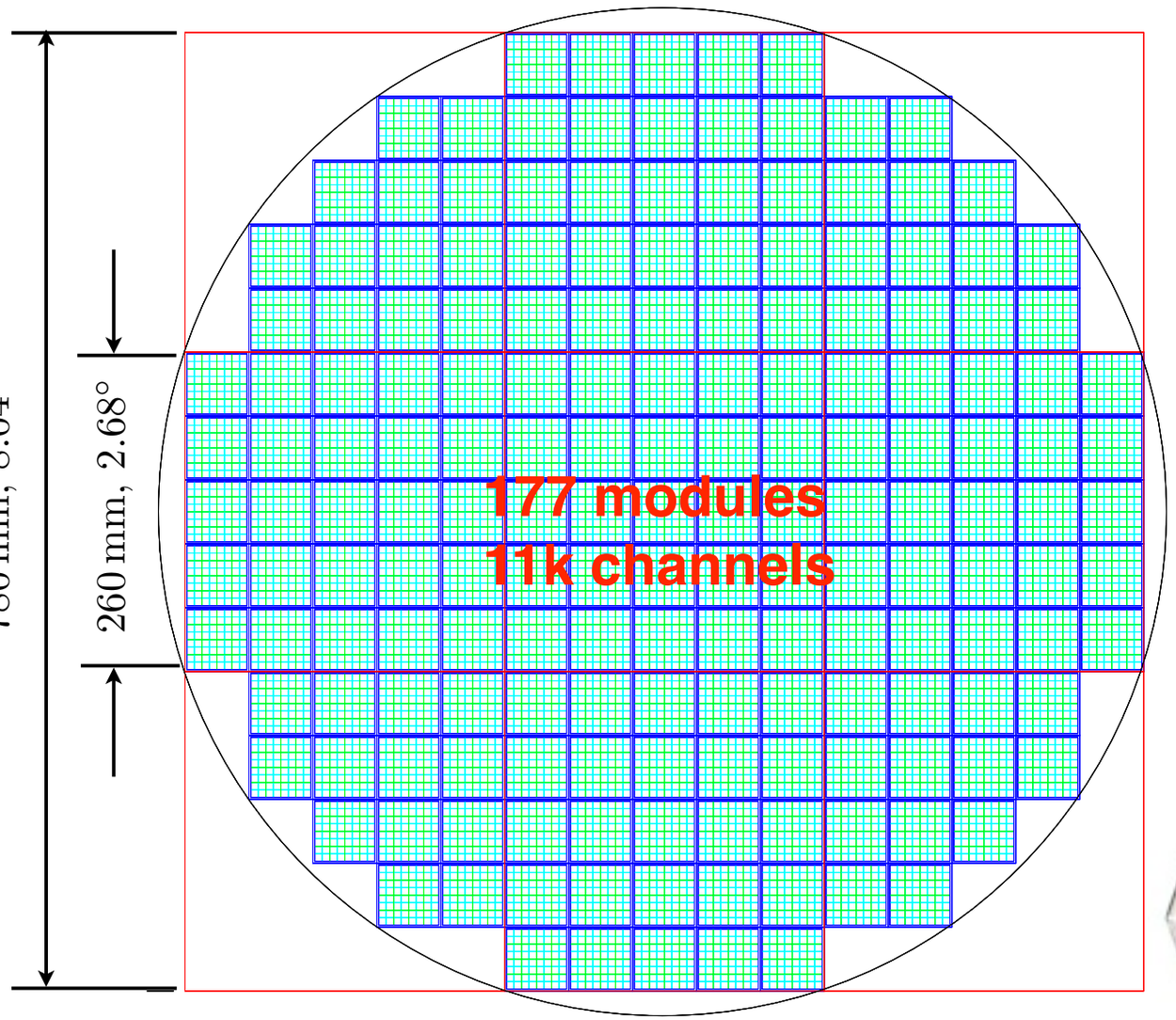


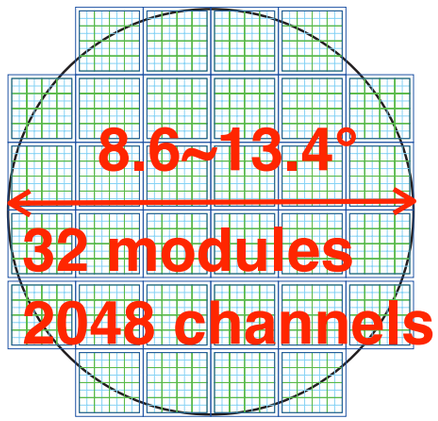
Supplemental slides

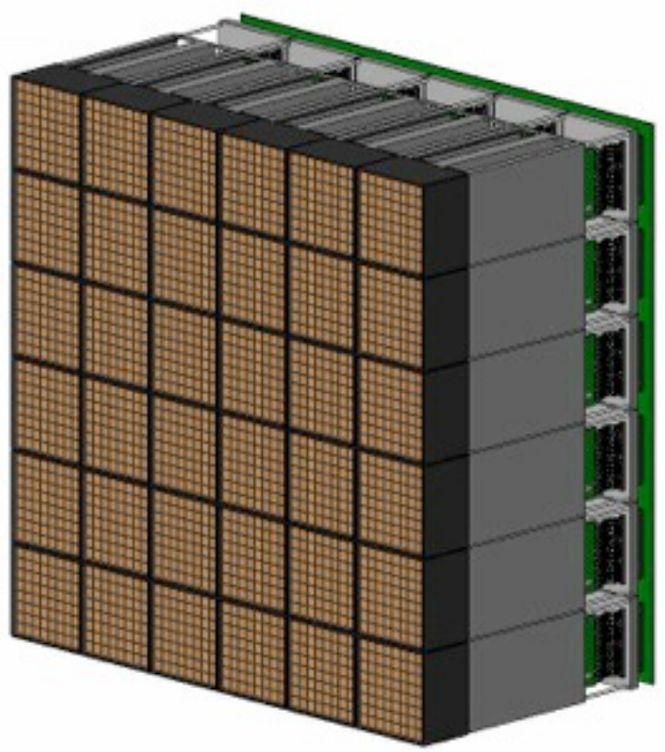


SC-MST/SST Camera Design Concept

- **Modular camera design**
  - **Divided into subfields**
    - **Logical unit for trigger generation, easy maintenance**

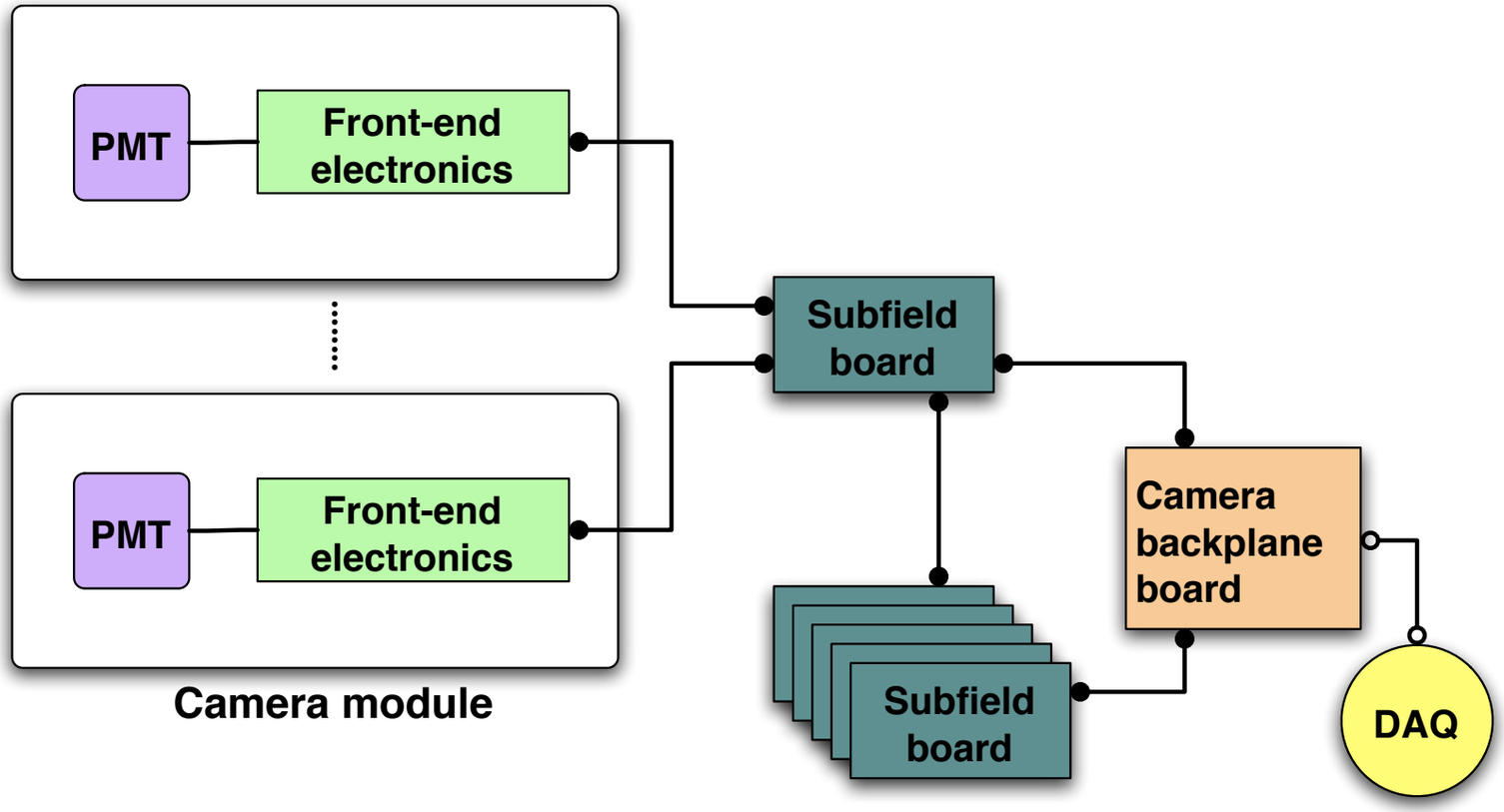






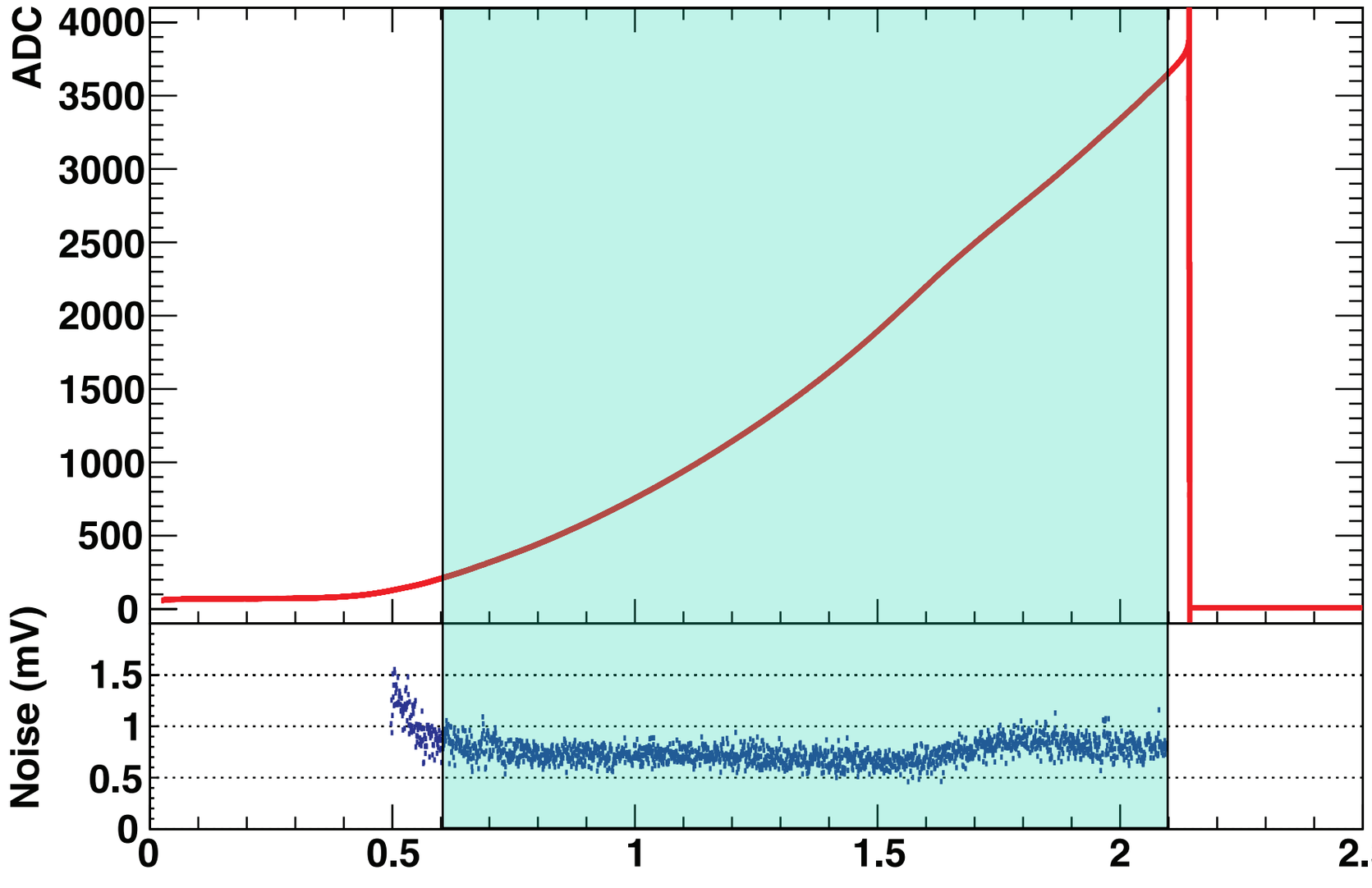
SC-MST Camera Electronics Overview

- **SC-MST Camera electronics consists of**
  - **Camera modules: ~180/camera (~11k pixels)**
    - **64-channel PMT/GAPD + front-end electronics**
    - **Waveform sampling and digitization, 16 triggers**
  - **Subfield boards: 9/camera (25 modules/board)**
    - **Cross-link trigger information**
    - **Subfield trigger**
  - **Camera backplane**
    - **Camera trigger**
    - **Gb ethernet link to DAQ (or any other commercial solution)**



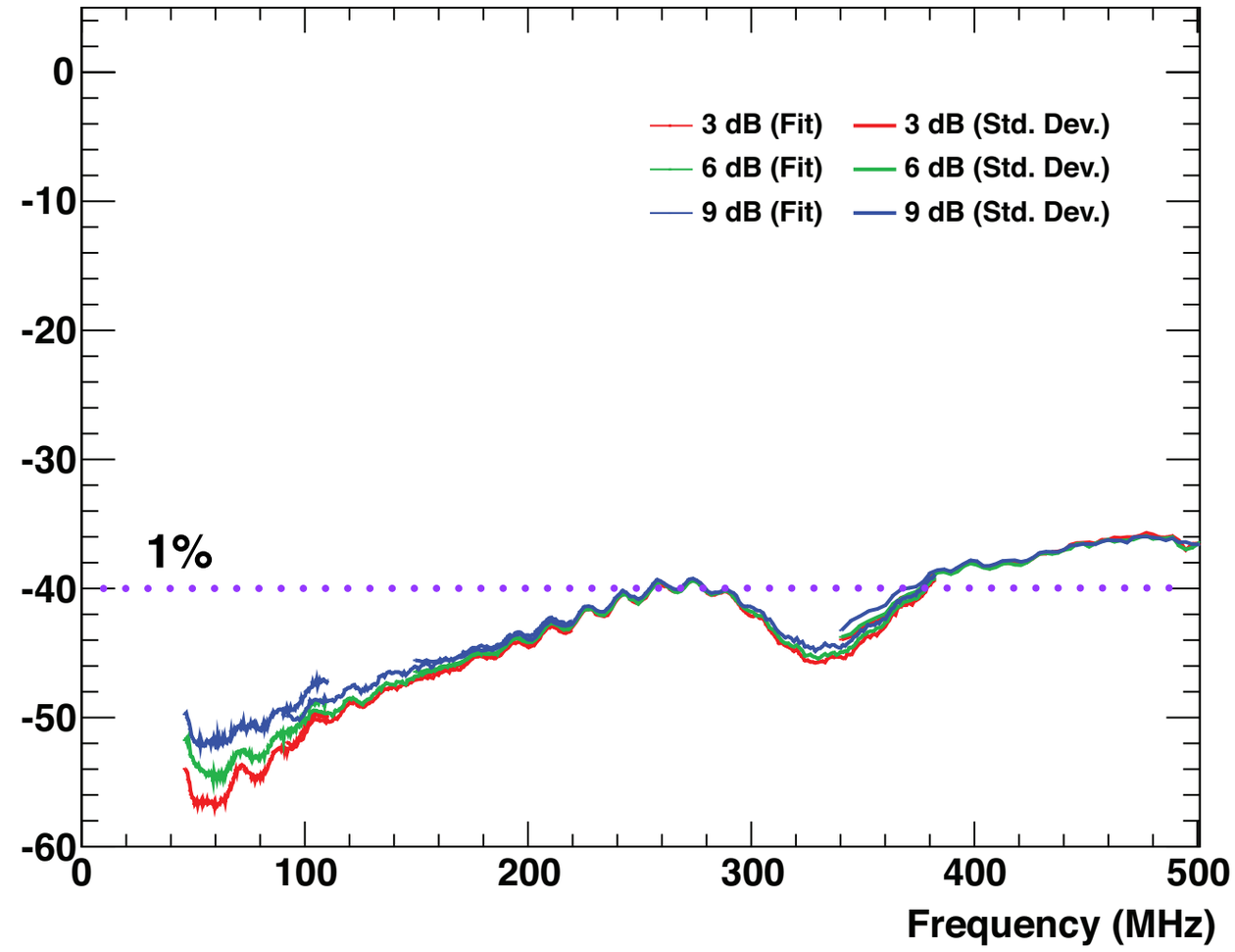
Dynamic Range

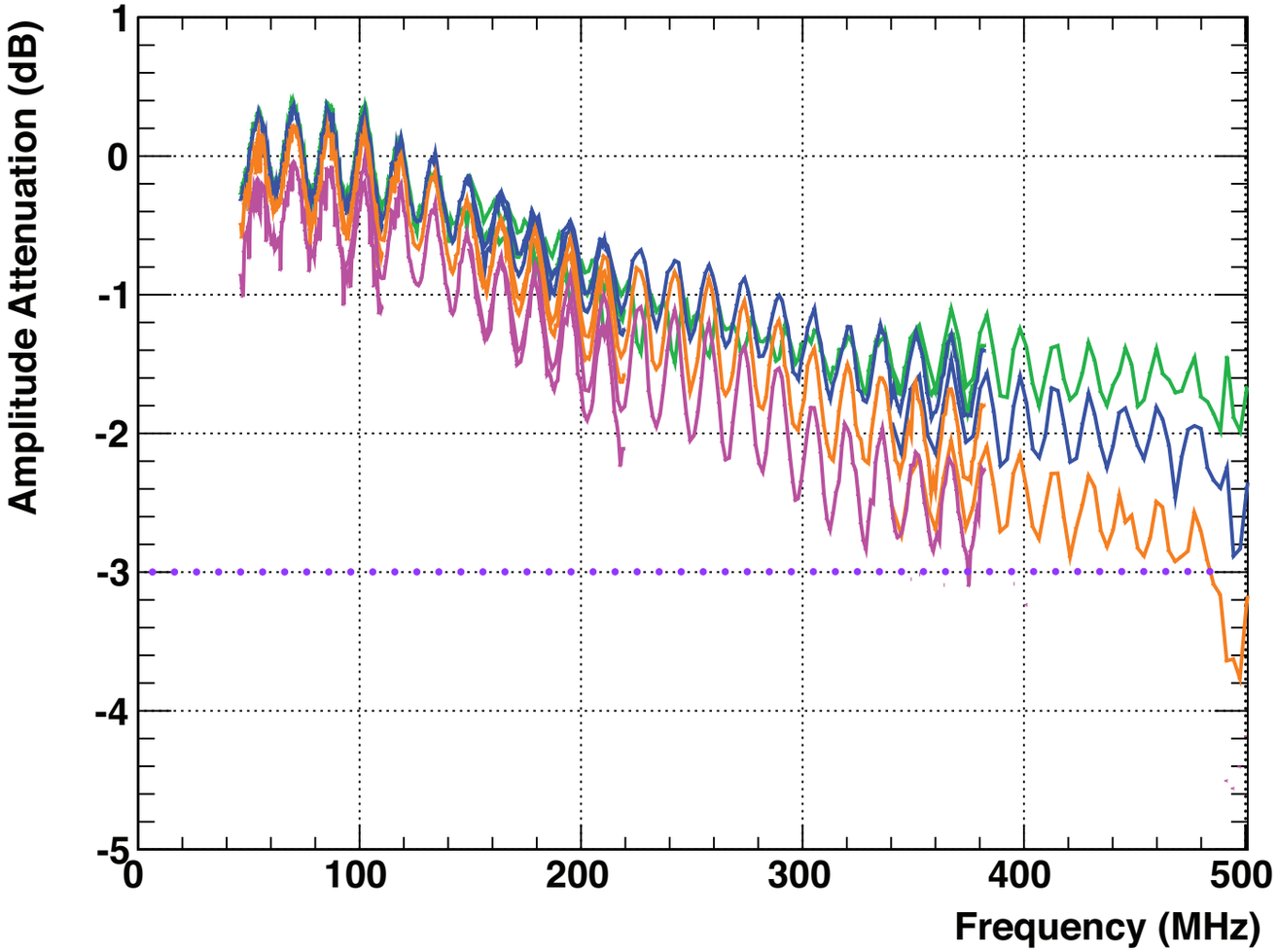
- Input voltage range: 0.6 – 2.1 V
- Noise: 0.6 – 1.0 mV
- Dynamic range: 1.5 V/(0.6 – 1.0 mV) = 10.5 – 11.2 bits
  - Better noise at lower voltage prefers positive pulse



Cross Talk and Band Width

- Cross talk is less than 1% up to ~380 MHz
- Band width up to 480 MHz
  - Root cause of oscillating behavior under investigation



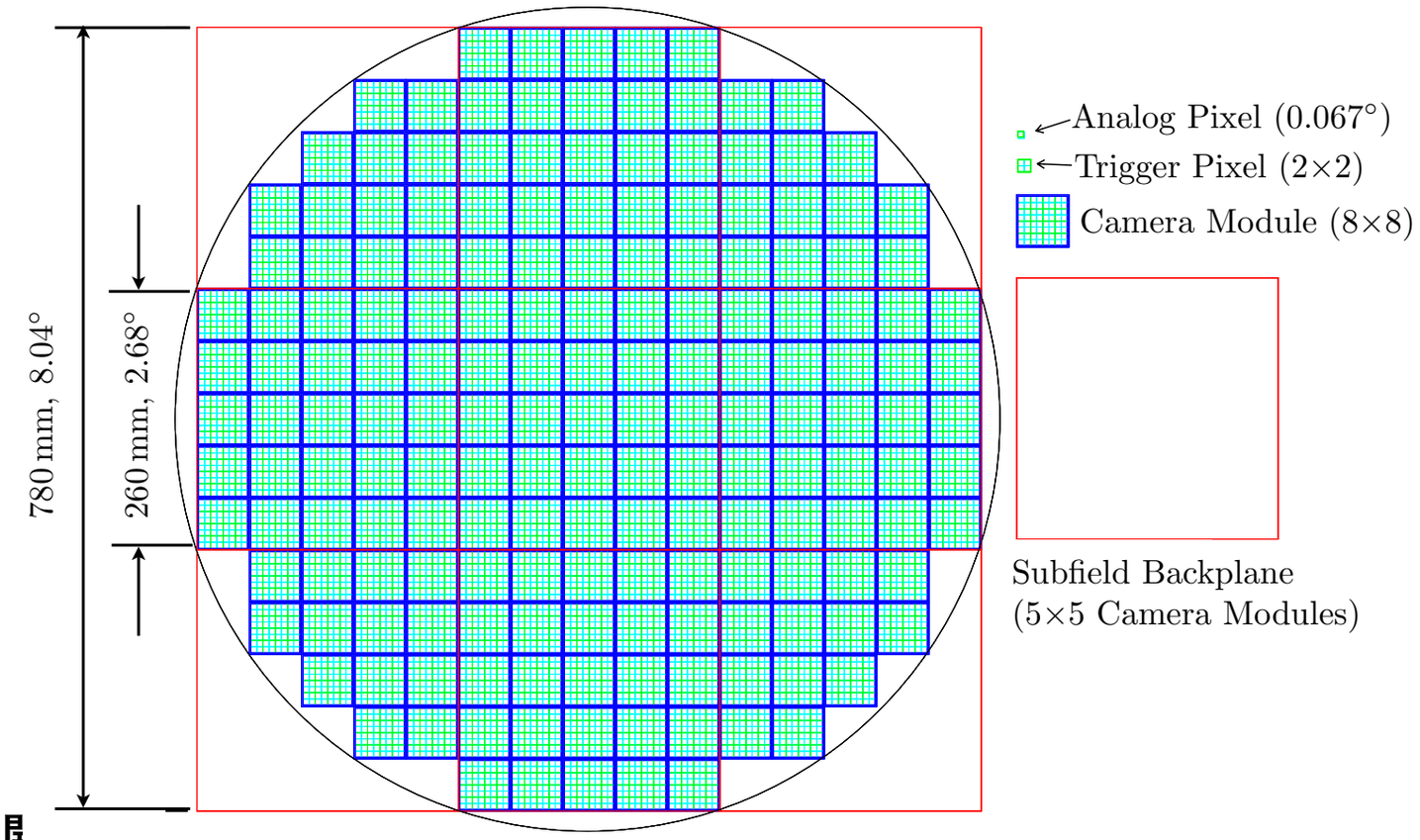


SC-MST Camera Design

❖ SC-MST camera parameters

FOV	8.0°
Angular pixel size	0.067°
# of pixels per camera	11,328
Power consumption per camera (FE)	800 W
Weight per camera (FE+MAPMT)	61 kg
Total cost (FE+BE) for 50 CAMs*	$11M

***Assuming $20/ch, which does not explicitly include labor for mechanical module assembly and calibrations**



Front-End Electronics Requirements

- **SC-MST General requirements**
  - **Target cost: $15 per channel**
    - **Large # of pixels ~ 500k**
      - **More telescope, wider FOV, smaller pixels**
    - **Current cost estimates (conservative estimate)**
      - **Camera FE module: $19/ch (11k channels), $12/ch (500k ch)**
      - **Back-end electronics: $6/ch (11k channels), $4/ch (500k ch)**
      - **PMT, mechanical structure and calibrations not included**
  - **Reliability: low failure rate to minimize maintenance efforts**
    - **Integration of "necessary" functionalities (small # of components)**
- **SC-MST requirements for camera front-end electronics**
  - **Waveform sampling at ~ 1 GSa/s**
  - **Signal bandwidth > 380 MHz**
  - **Cross-talk < 1%**
  - **Look-back time: > 12 μs**
  - **Dynamic range: > 9 bits**
  - **Readout (dead) time: < 30 μs**
  - **Trigger timing: < 4 ns**
  - **Trigger segment: 0.1° x 0.1° ~ 0.2° x 0.2°**

TARGET2 Architecture

❖ TARGET ASIC designed for CTA by G. Varner (Univ. of Hawaii)