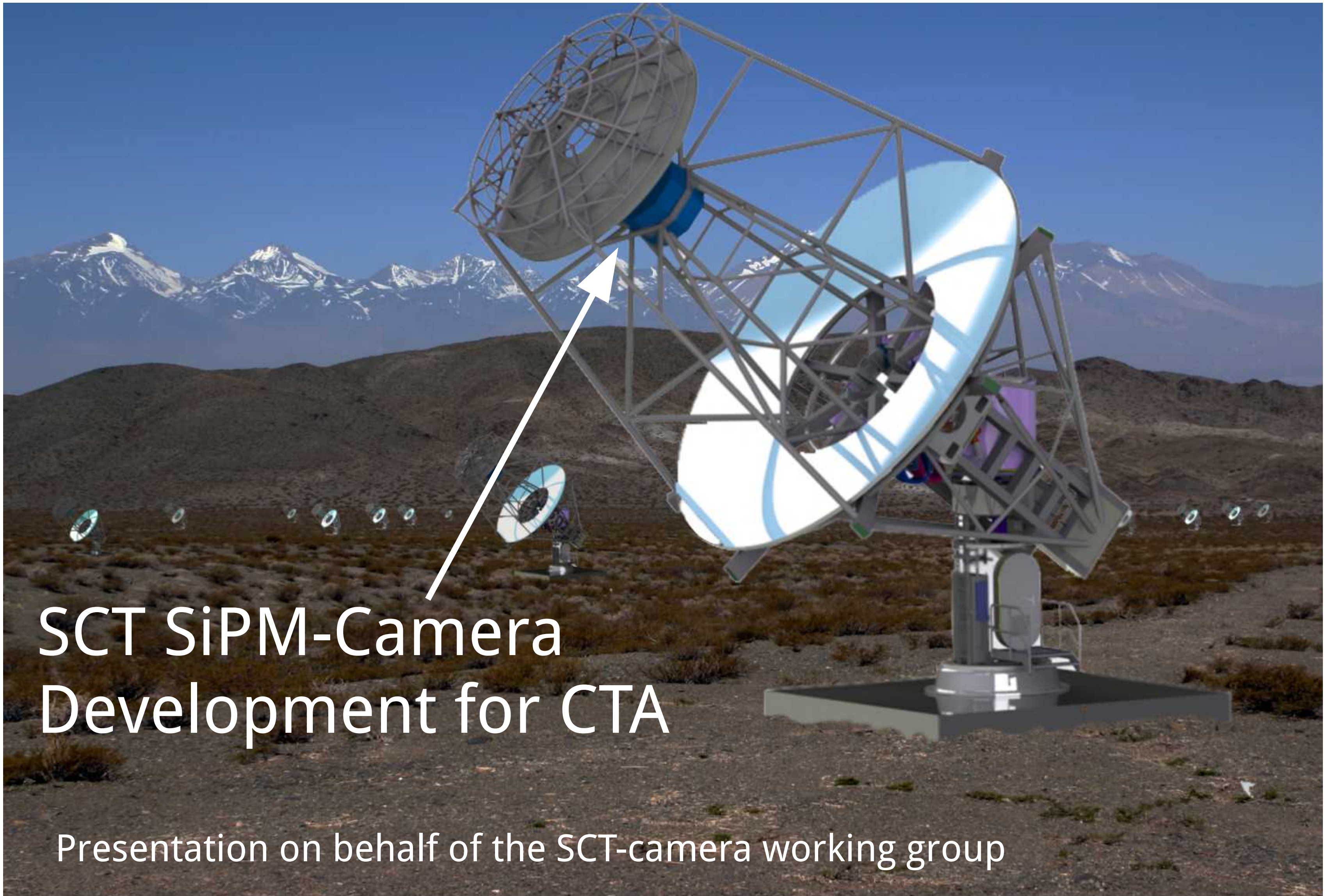
Georgia Tech Physics
College of Sciences

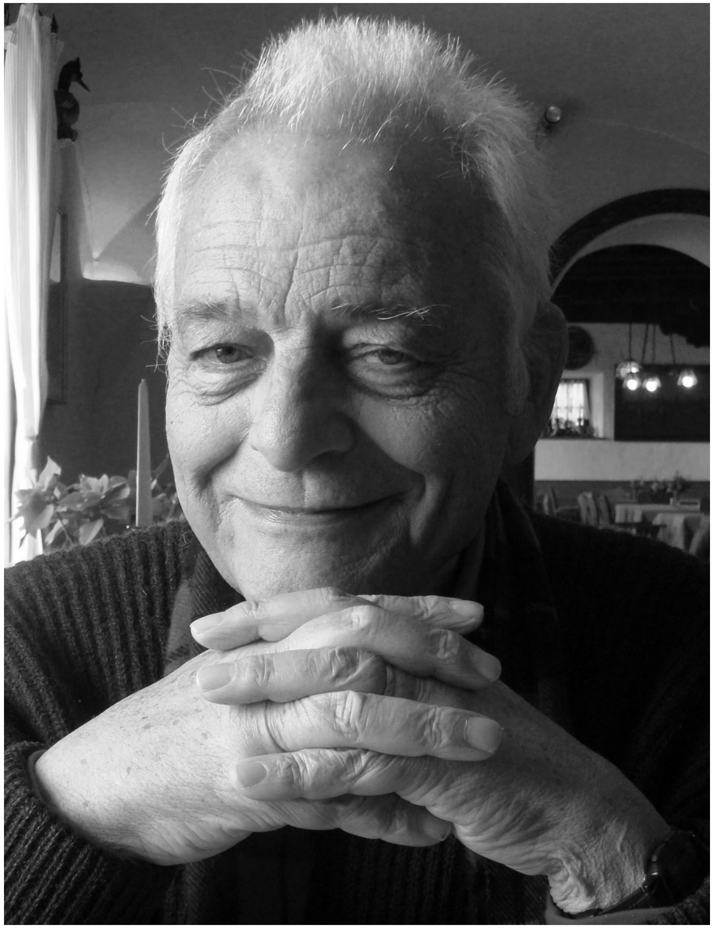


SCT SiPM-Camera Development for CTA

Presentation on behalf of the SCT-camera working group

Nepomuk Otte

School of Physics &
Center for Relativistic Astrophysics
Georgia Institute of Technology

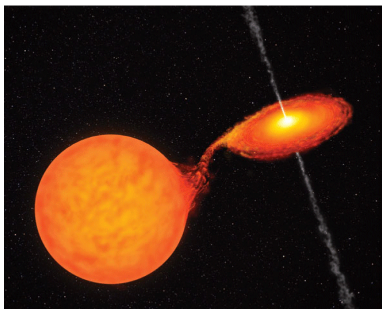


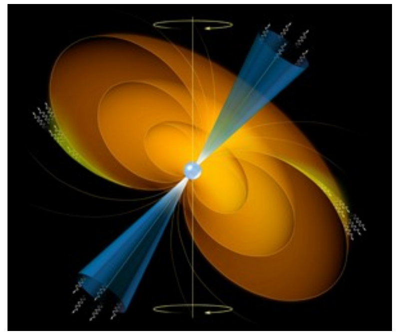
Eckart Lorenz

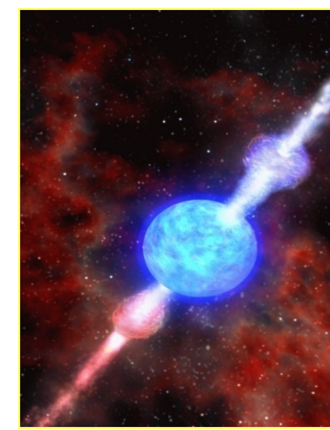
* 7.6.1938

† 21.6.2014

The Very-High Energy Gamma-Ray Universe

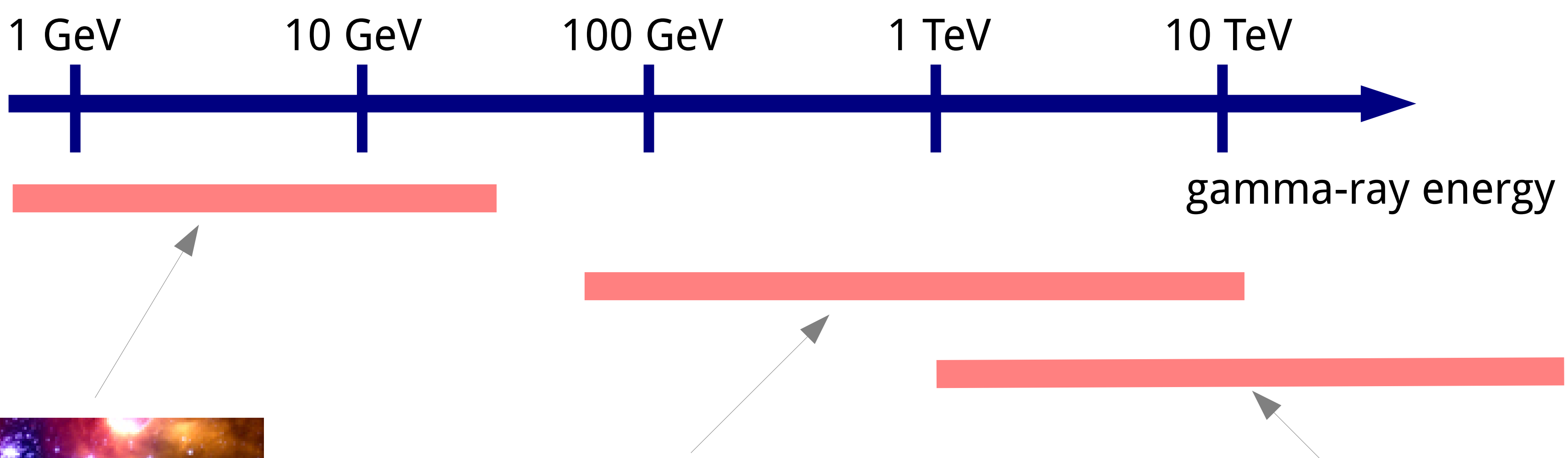






- Understanding the origin of cosmic rays and their role in the Universe.
- Understanding the nature and variety of particle acceleration around black holes.
- Searching for the ultimate nature of matter and physics beyond the Standard Model.

Gamma-Ray Instruments

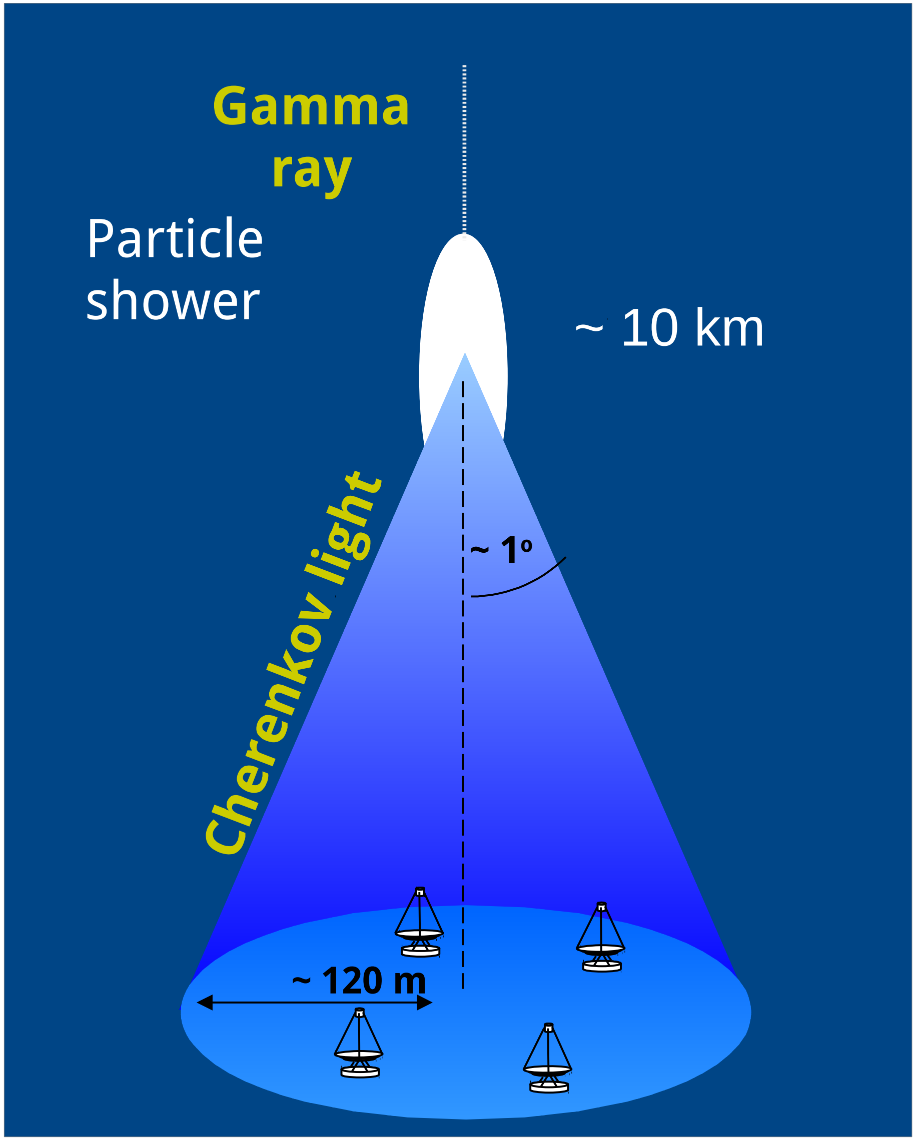


Satellites

Cherenkov telescopes

Water Cherenkov detectors

Imaging Atmospheric Cherenkov Technique

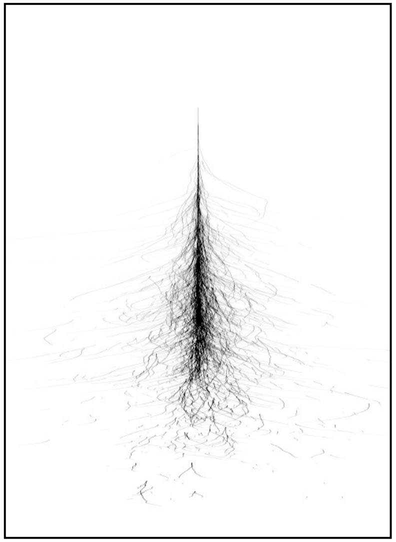


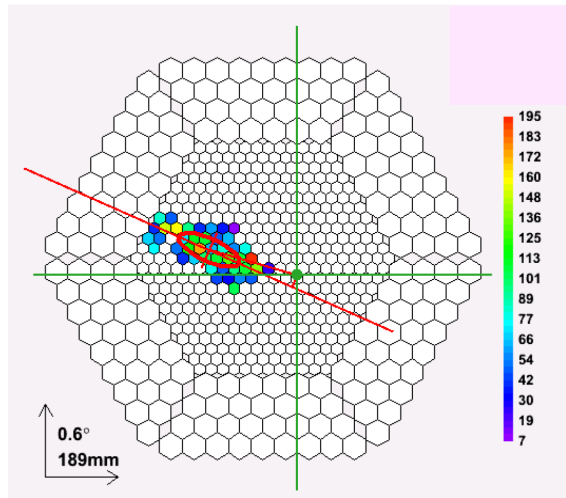
A 1 TeV gamma ray produces 150 Cherenkov photons per m^2 on the ground

Cherenkov signal contaminated by night sky background photons

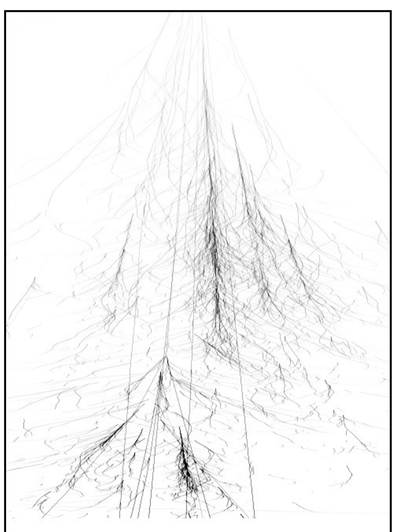
Light pool is 100,000 m^2
= effective detection area for existing Cherenkov telescopes

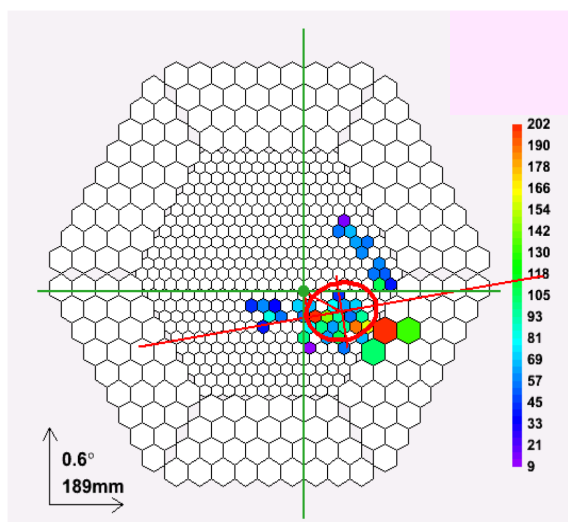
Imaging Technique





Gamma ray





Background:

Charged cosmic rays (hadrons) $10^3 \ldots 10^4$ times more abundant

Photon Detector Requirements for IACTs

Fishing the faint Cherenkov signal (lasting a few ns) out of the sea of night sky background:

- Fast photon detectors
- Sensitive range ~280 nm … ~600 nm
- Count rate capability of 1 phe / µs / mm^2
- Dynamic range < 100 phe / mm^2
- Mechanically robust / insensitive to accidental exposure to sun / insensitive to magnetic fields
- Small variations in performance between devices
- Low cost

Silicon photomultipliers and classical photomultipliers

Observing in bright Moon Light

full moon @ FACT 2012

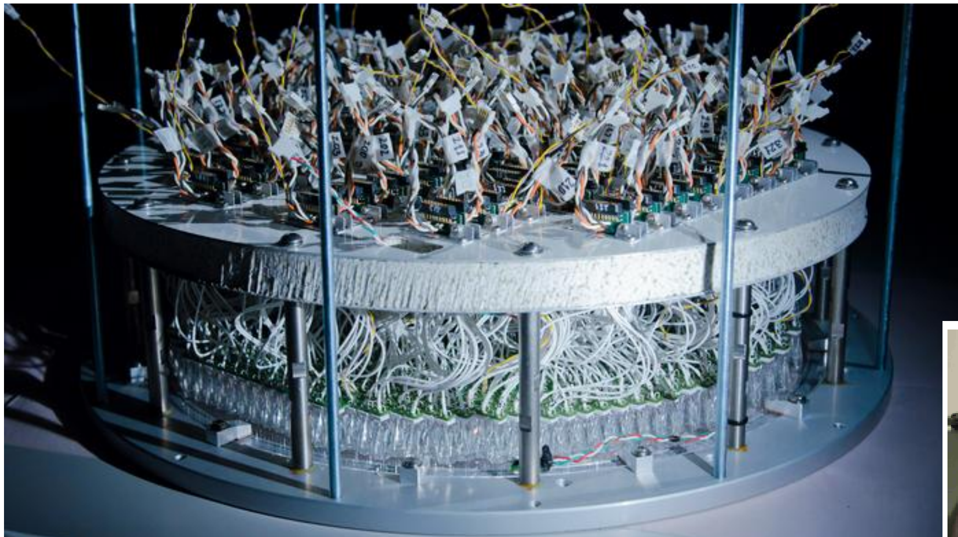
Yes we can

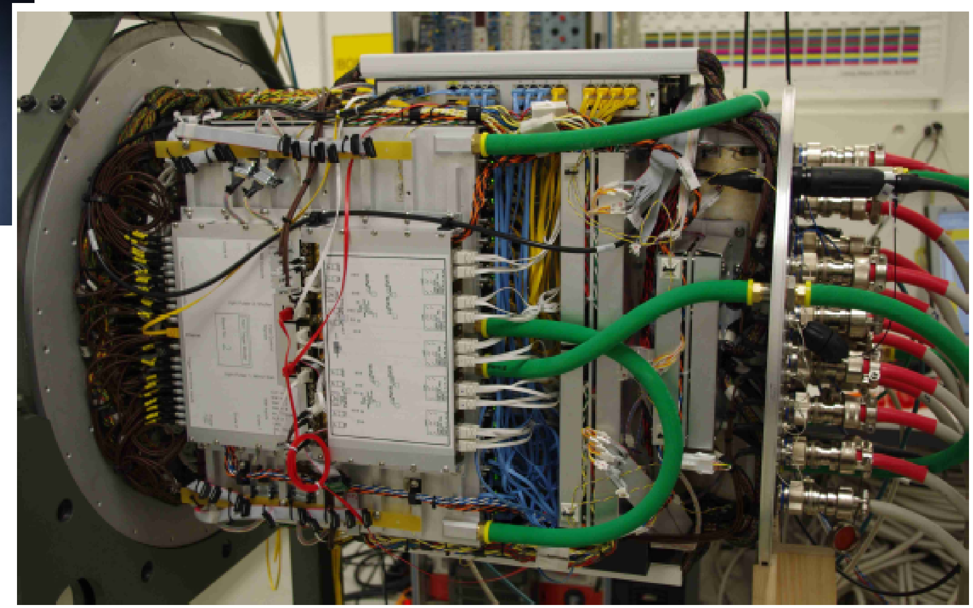
full moon @ VERITAS 2009

40% increase in duty cycle
Increased threshold but no loss in sensitivity at high energies

Standard observing mode for FACT, MAGIC II, and VERITAS

FACT: The First G-APD Cherenkov Telescope

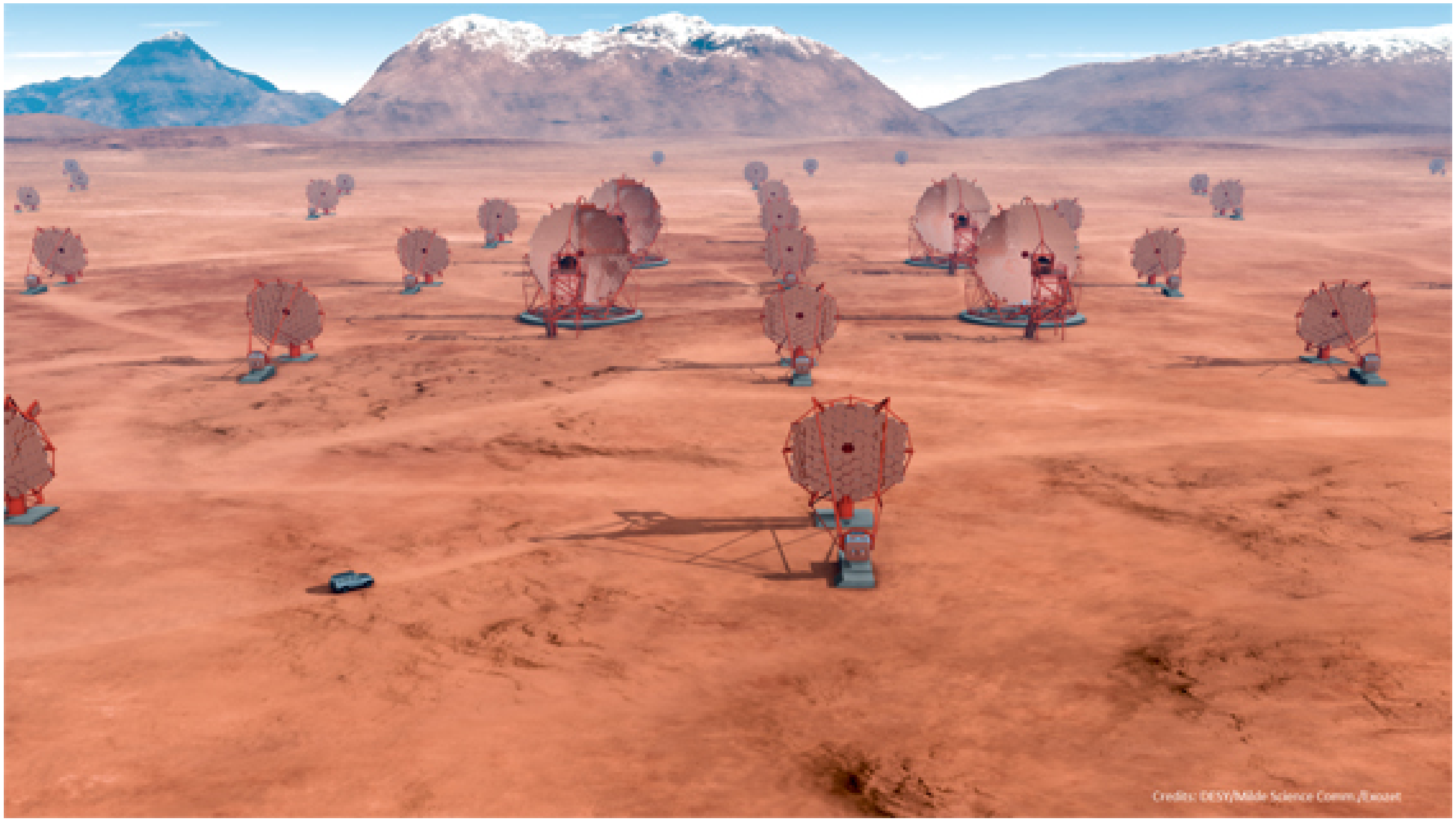




- 1595 SiPMs
- 3x3 mm^2 from Hamamatsu
- Solid PMMA light concentrators
- Readout with DRS4 @ 2GS/s
- 200 MHz bandwidth

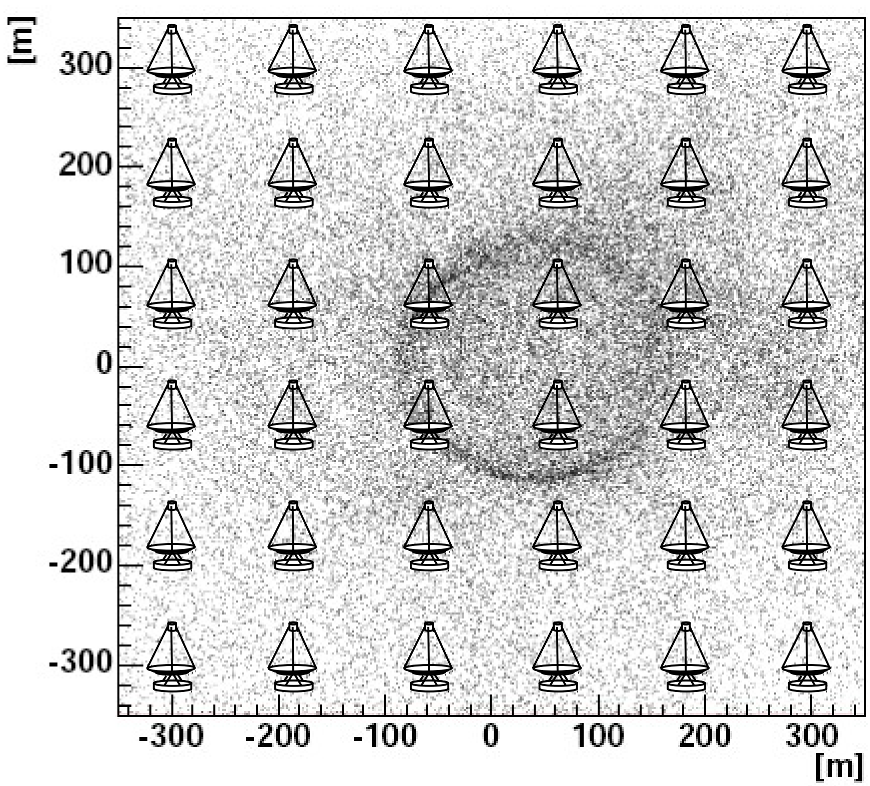
arXiv:1304.1710

Cherenkov Telescope Array



- Tenfold improvement in sensitivity
- Three different telescope sizes
- ~100 telescopes per site

Imaging Atmospheric Cherenkov Technique



Cherenkov photon density on ground for a 50 GeV gamma ray

A 1 TeV gamma ray produces 150 Cherenkov photons per m^2 on the ground

Cherenkov signal contaminated by night sky background photons

Light pool is 100,000 m^2
= effective detection area for existing Cherenkov telescopes

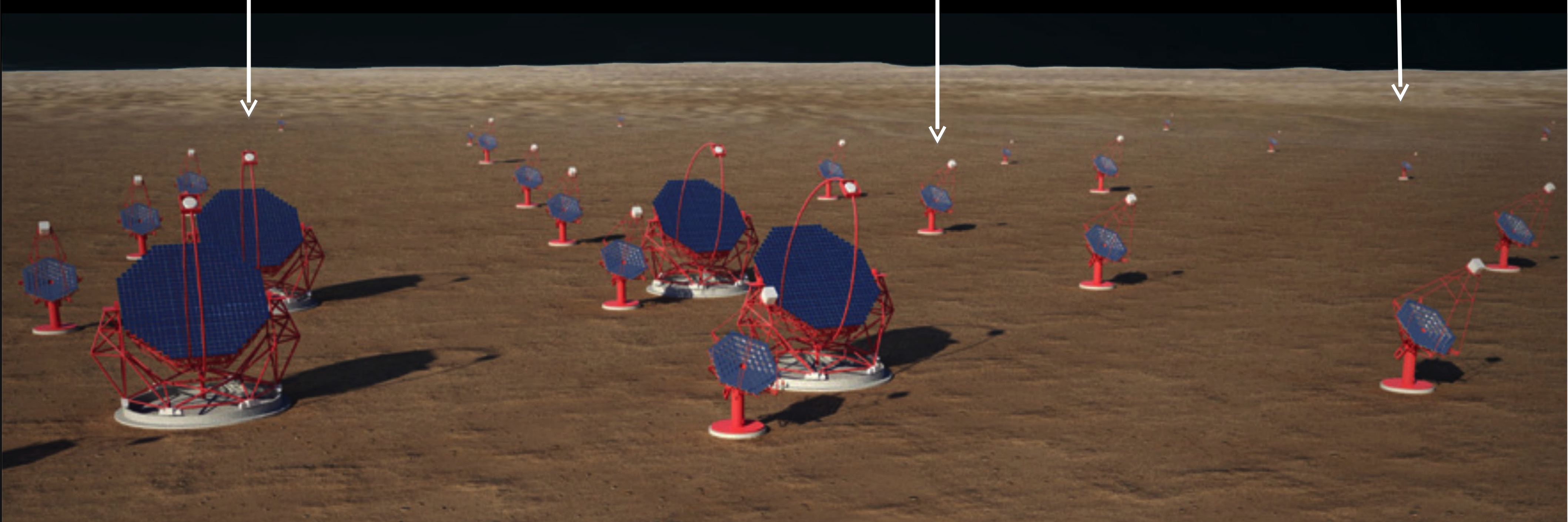
CTA detects gamma-rays that fall within an area that is fifty times larger than the light pool

Cherenkov Telescope Array Design

Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes

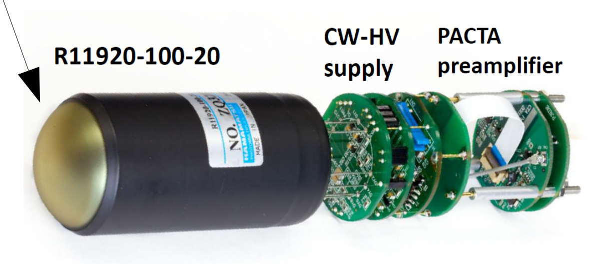
Medium energies
100 GeV – 10 TeV
9.5 to 12 m diameter
25 single-mirror telescopes
24 dual-mirror telescopes

High energies
10 km^2 area at few TeV
4 m diameter
up to 70 telescopes



Camera Concepts for CTA a Selection

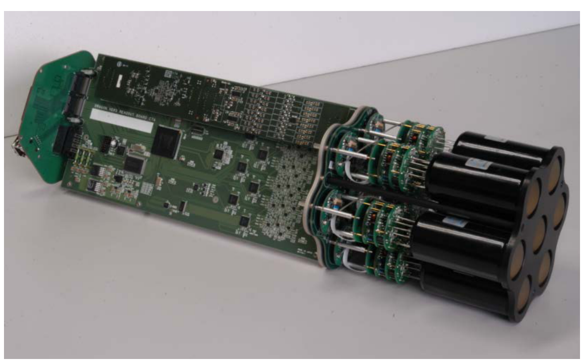
42% efficiency at 400 nm



Same PMT for LST and MST telescopes

Different Readout concepts:

Dragon camera uses DRS4



- SCA with 4096 cells
- 1GS/s sampling
- External ADC (12bit)
- Bandwidth 300MHz

NectarCAM uses NECTAr

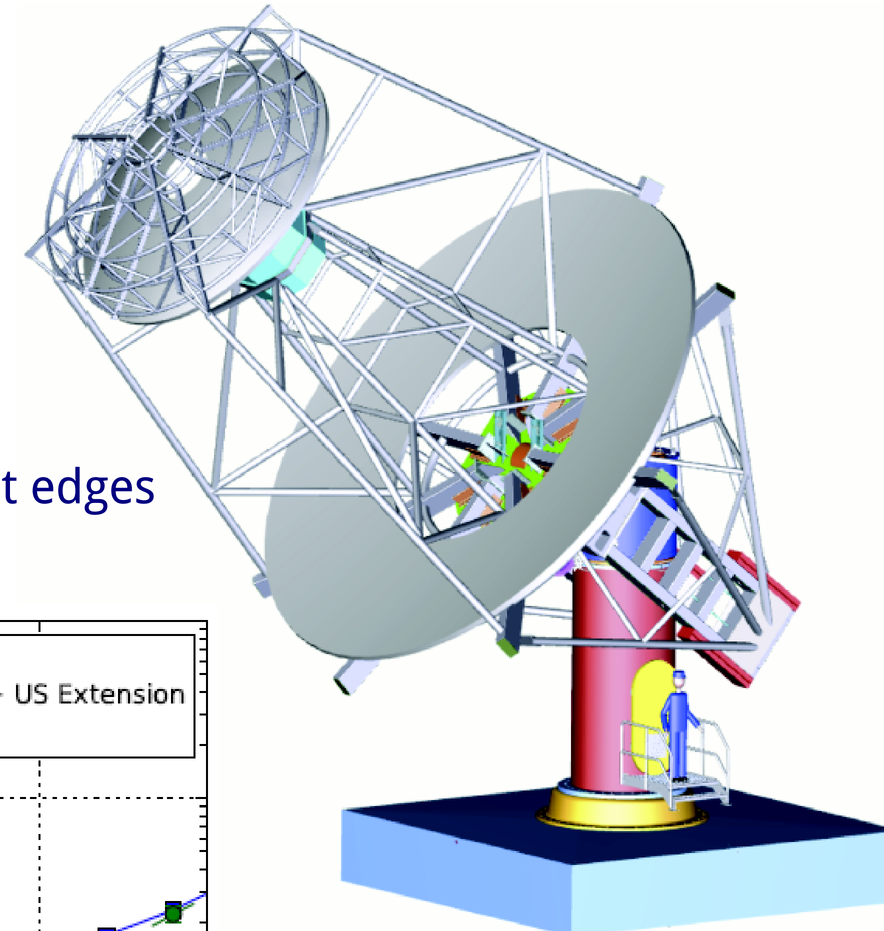
- SCA with 1024 cells
- Integrated digitizer 500MS/s to 3.2GS/s
- 11.3 bit effective resolution
- Bandwidth 400MHz
- 2% deadtime for 9kHz readout rate

See poster on SiPM camera for single mirror SST telescopes by Matthieu Heller

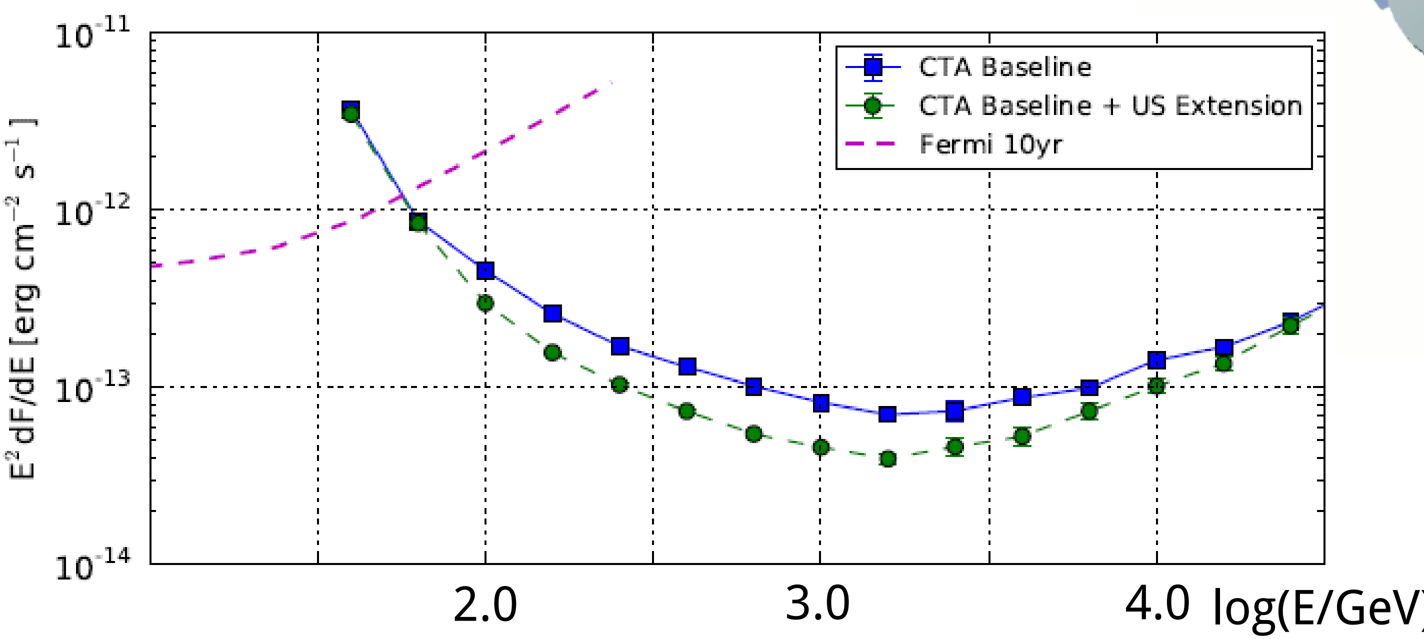
And more developments ongoing: Flashcam, CHEC-S and -M, DigiCam ...

The Midsize Schwarzschild-Couder Telescope

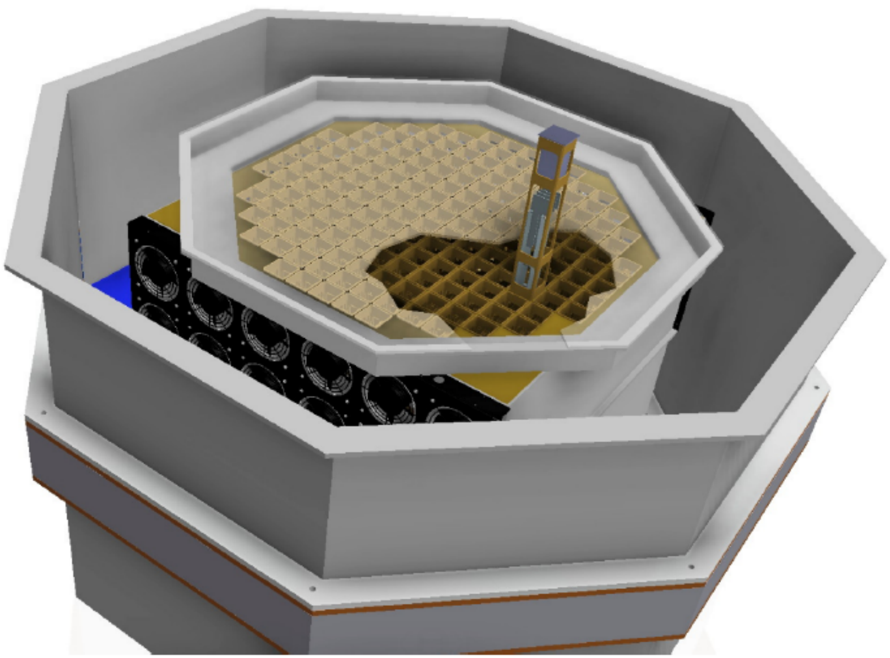
- Extending CTA Baseline array with ~25 telescopes
- Factor two gain in sensitivity

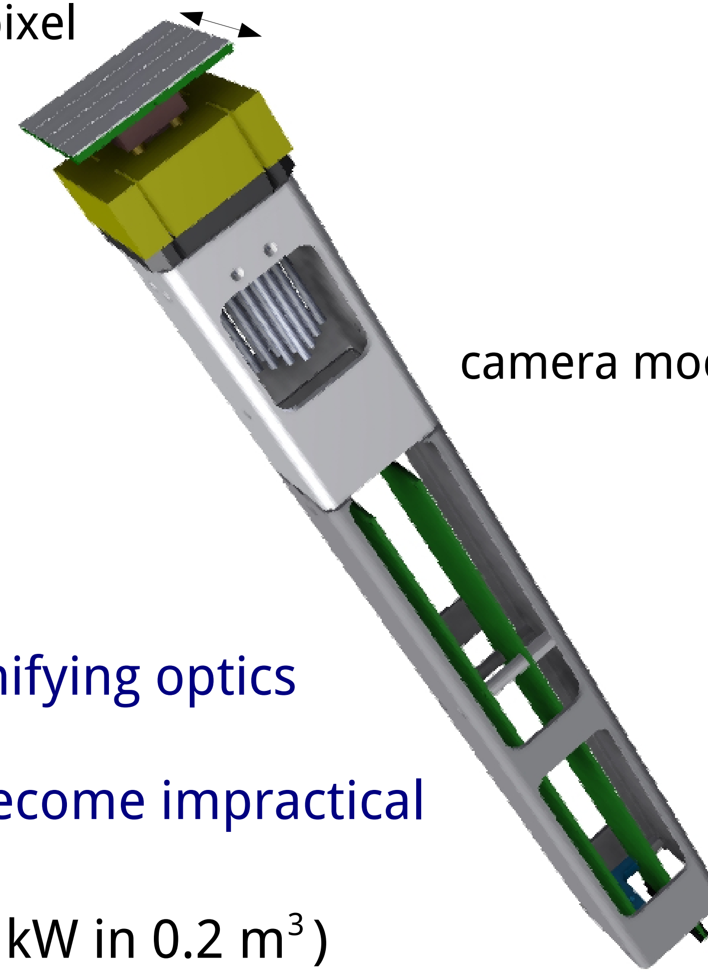


Main reason for SCT development is large field of view with little loss in optical performance at edges



SCT Camera

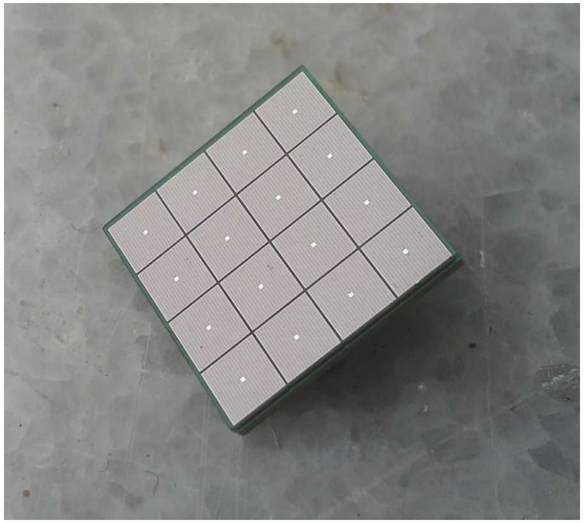


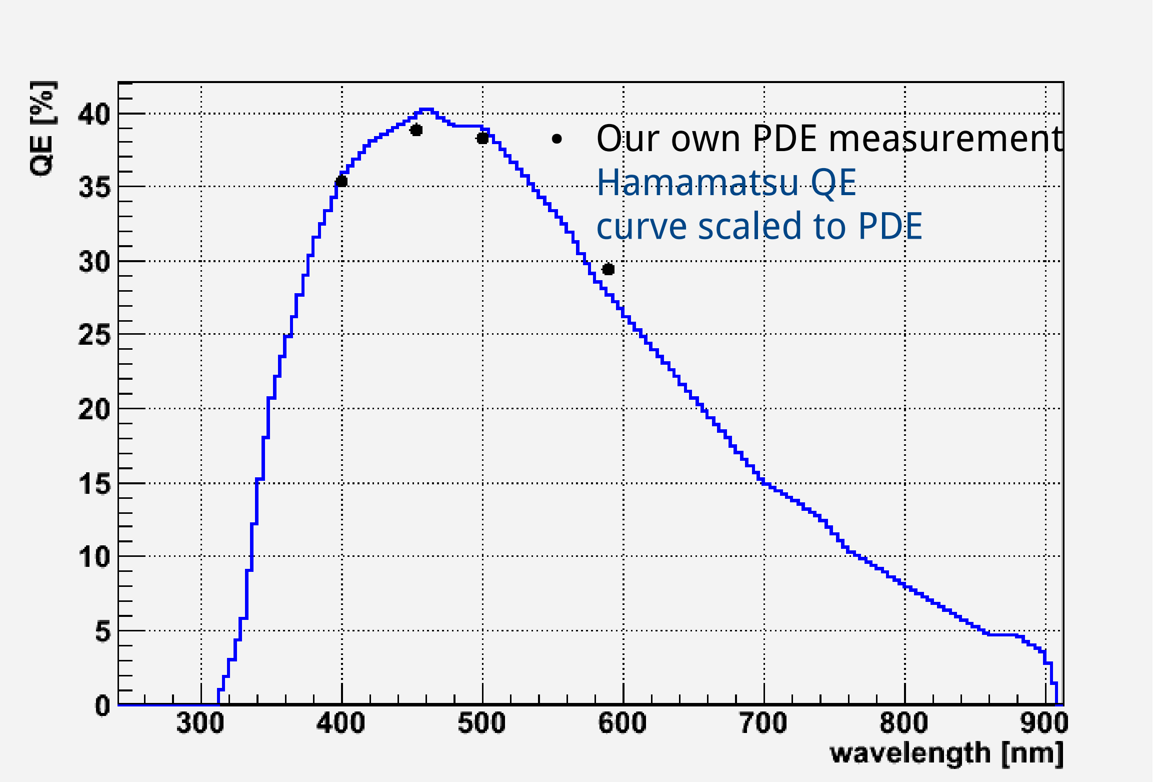


Practical advantage of SC optics is demagnifying optics
--> very compact camera
Disadvantage is that light concentrators become impractical

- 8° FoV
- Camera with ~12 000 pixel (~3 kW in 0.2 m^3)
- Pixel size 0.064°; 6x6 mm^2
- Silicon photomultipliers

Photon Detector for the Prototype





Hamamatsu (S12642-0404PA-50):

- 3x3 mm^2 SiPMs in 4x4 matrix
- TSV technology (reduced dead space)
- 50 µm cells

At 3 V above breakdown

- Peak PDE @ 450 nm is ~38%
- Optical cross talk 48%
- Dark Rate 200 kHz/mm^2 (5 times below NSB)

Choice for prototype but we continue to evaluate devices before we have to make a choice for the final array

Devices are rapidly improving

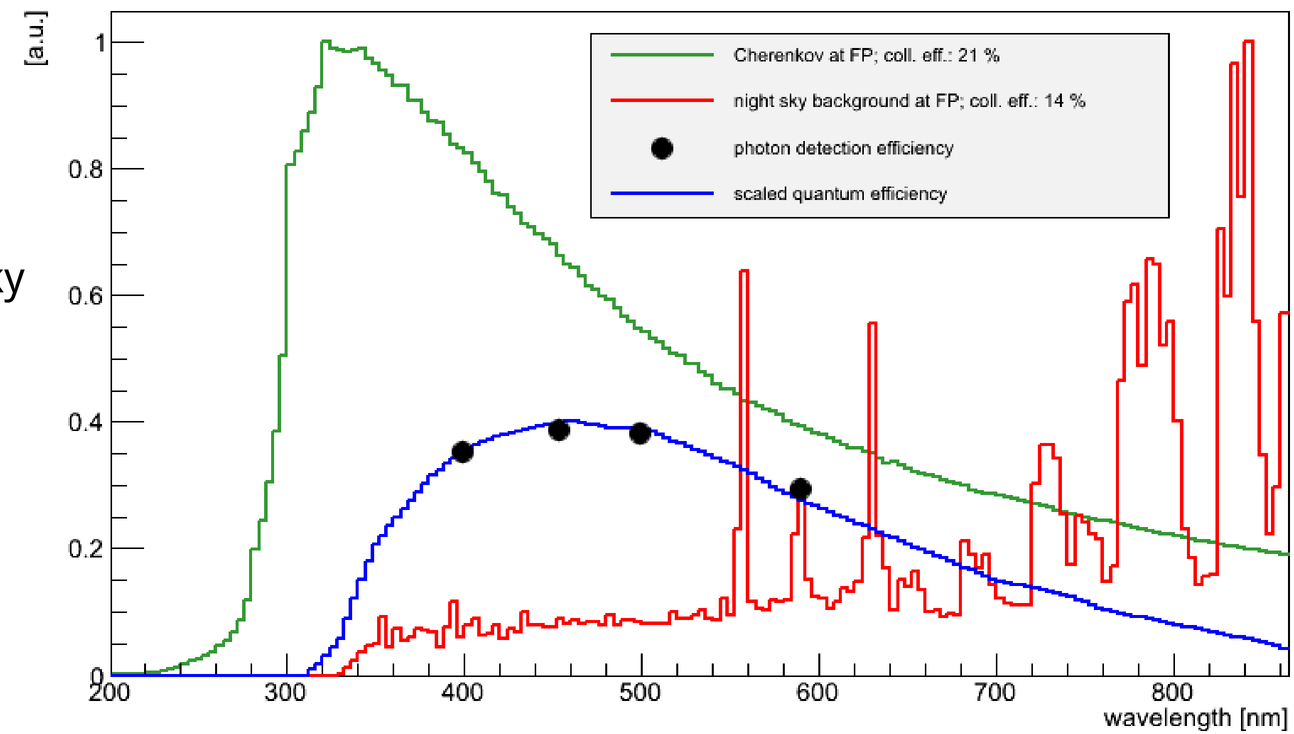
Figure of Merit

Obvious goal: Maximizing collection efficiency of Cherenkov light: 21%

Is a good figure of merit
BUT

it does not take into account:

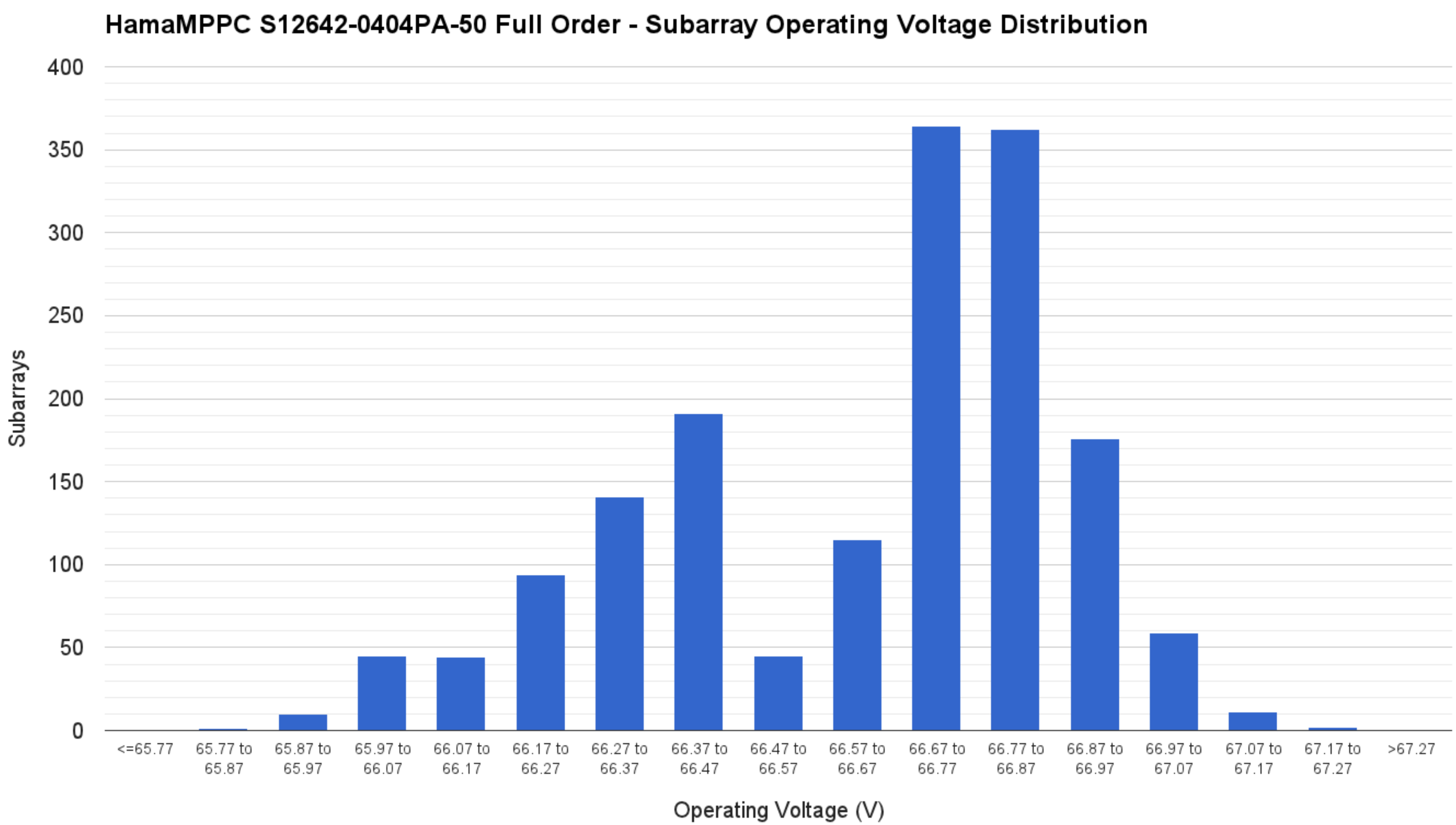
- Detection efficiency of night sky background light
- Optical cross talk
- Afterpulsing (PMT)
- Pulse shapes
- Temperature dependencies
- Intrinsic dark rates
- Fill factors
- …



Evaluating the full impact of a photon detector on performance of an IACT requires end to end simulations

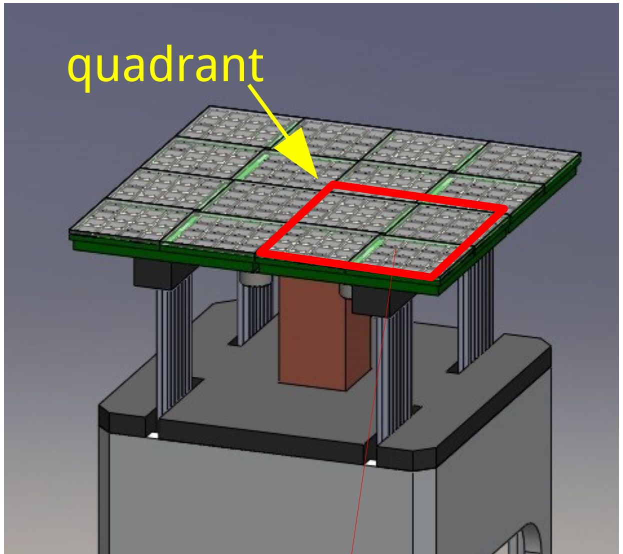
Nepomuk Otte

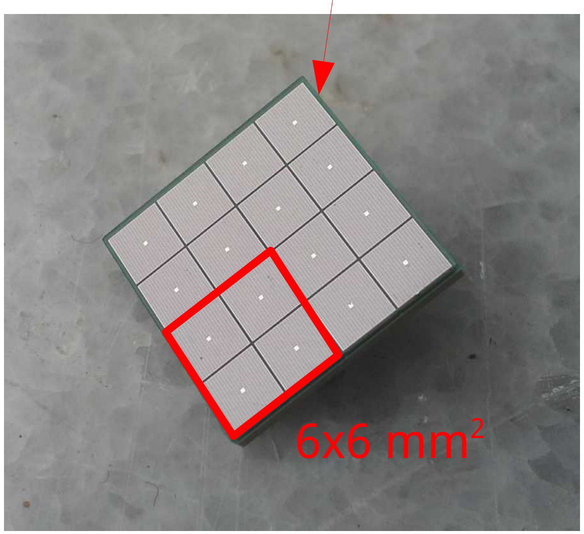
Received and tested full SiPM Order



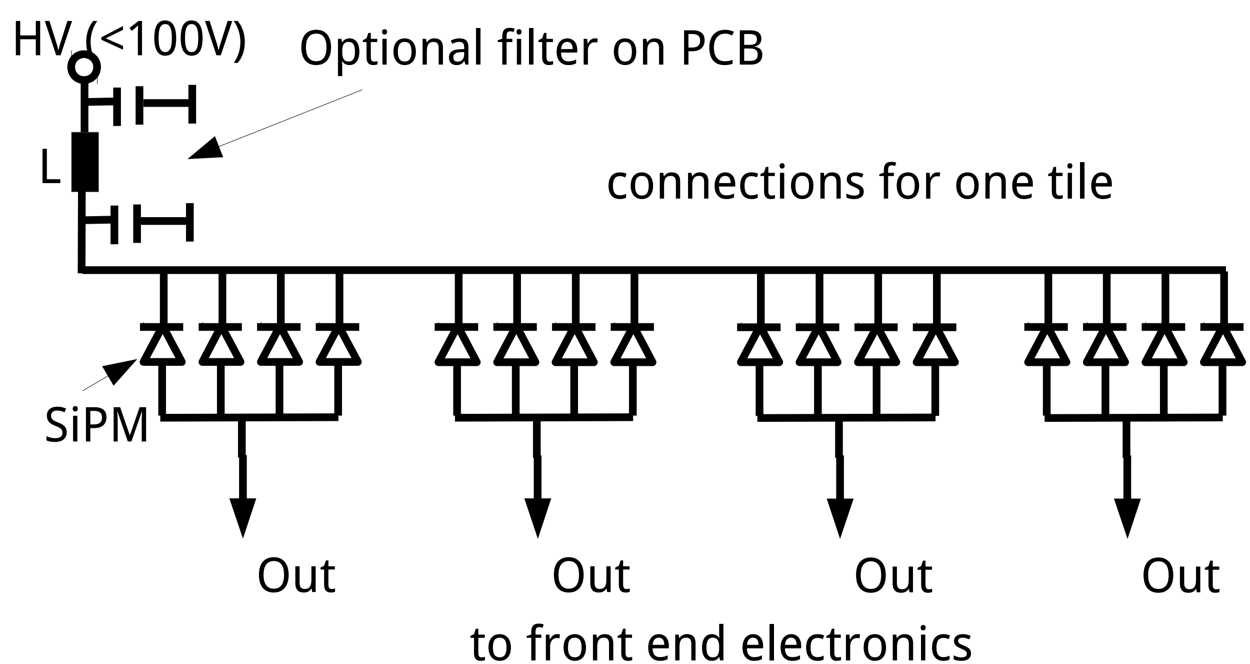
415 TSV tiles, 1.45 \$ / mm^2 sensitive area (<\$1 for larger quantities)

SiPM Carrier Boards



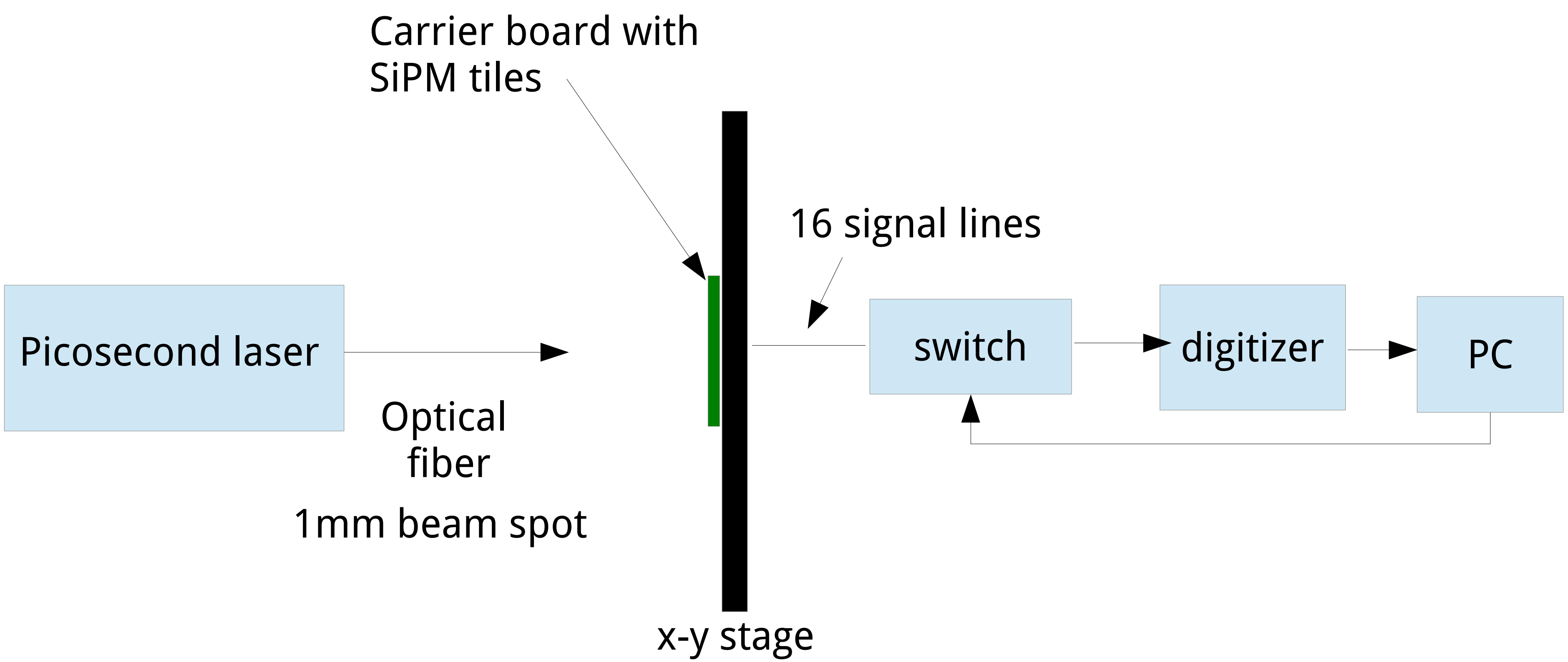


- A camera module is split into quadrants
- Each quadrant hosts four tiles reflow soldered on one PCB
- 4 SiPMs are connected in parallel to form one imaging pixel in readout
- Micro-coax cables connect to the front end electronic
- Each board has a thermistor to monitor the temperature



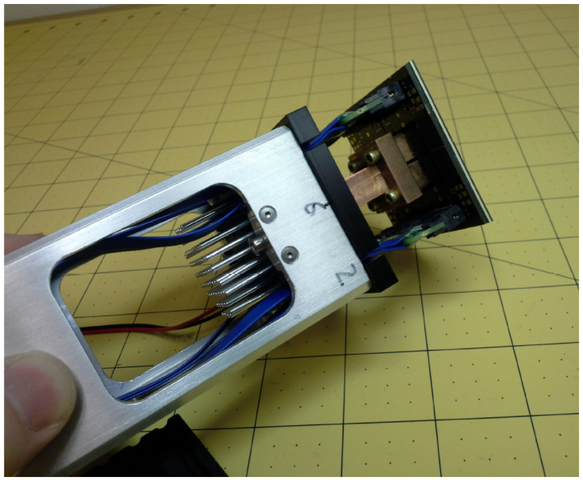
Quadrant Testing

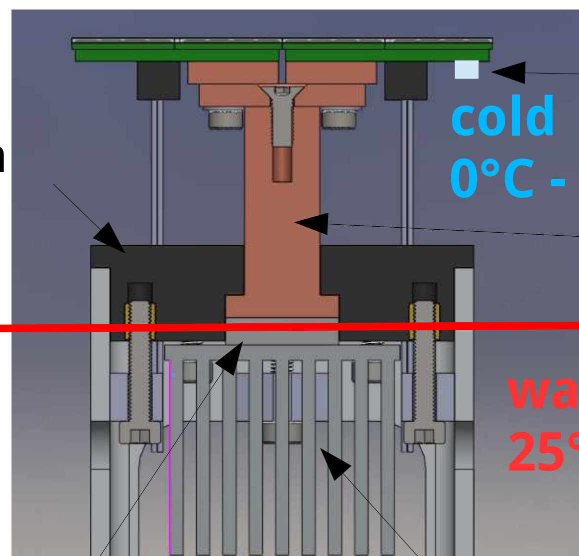
Test connectivity of each 3x3 mm^2 SiPM

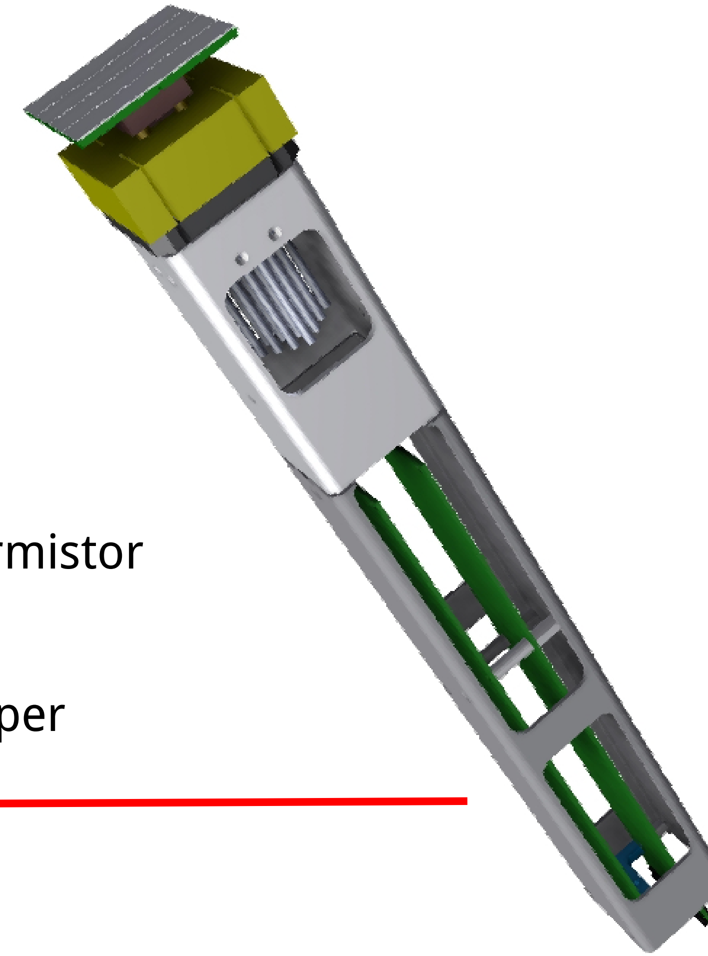


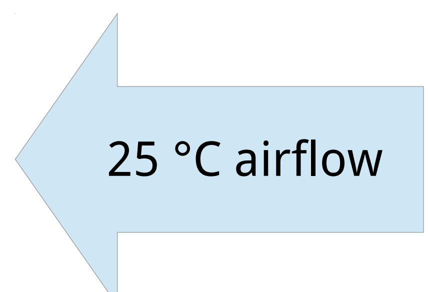
Automatically scans all 64 SiPMs on one board.

Temperature stabilized Sensor Module

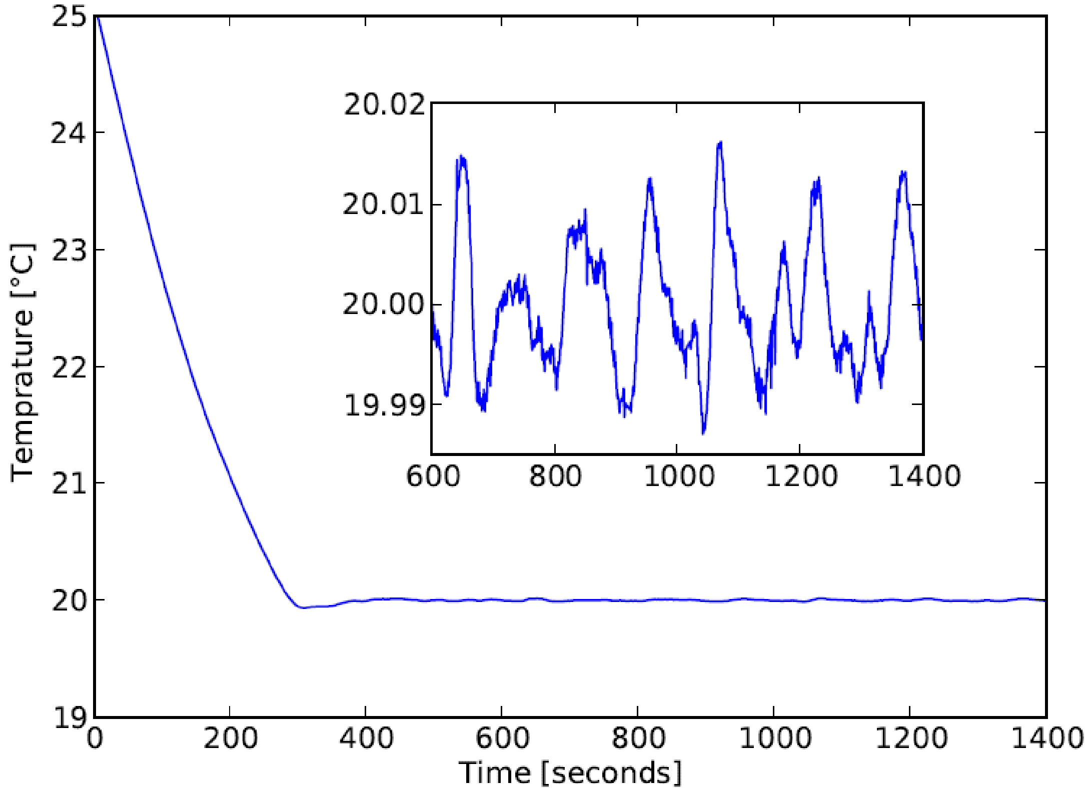




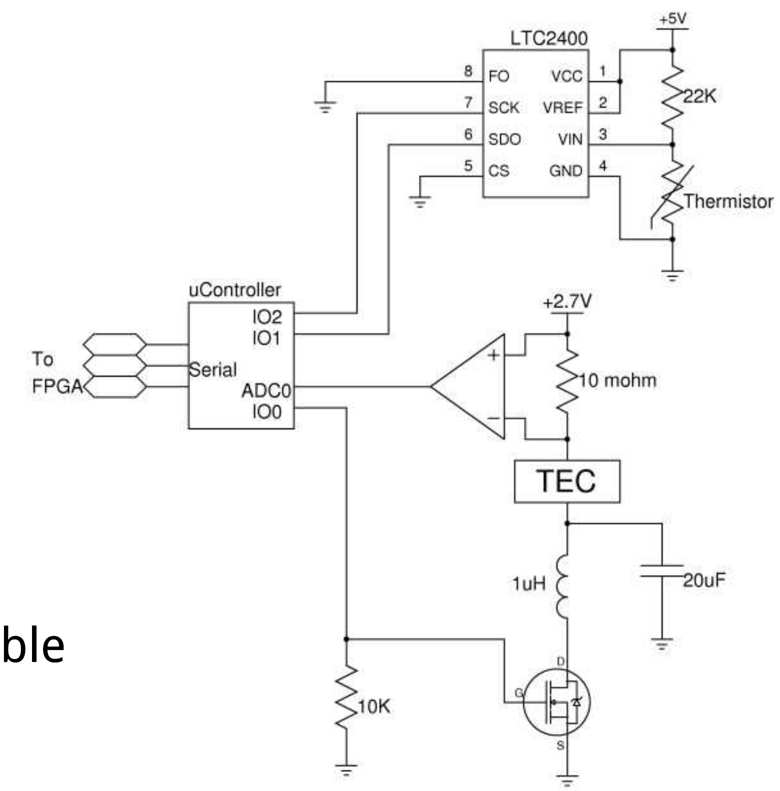




Temperature Stabilization



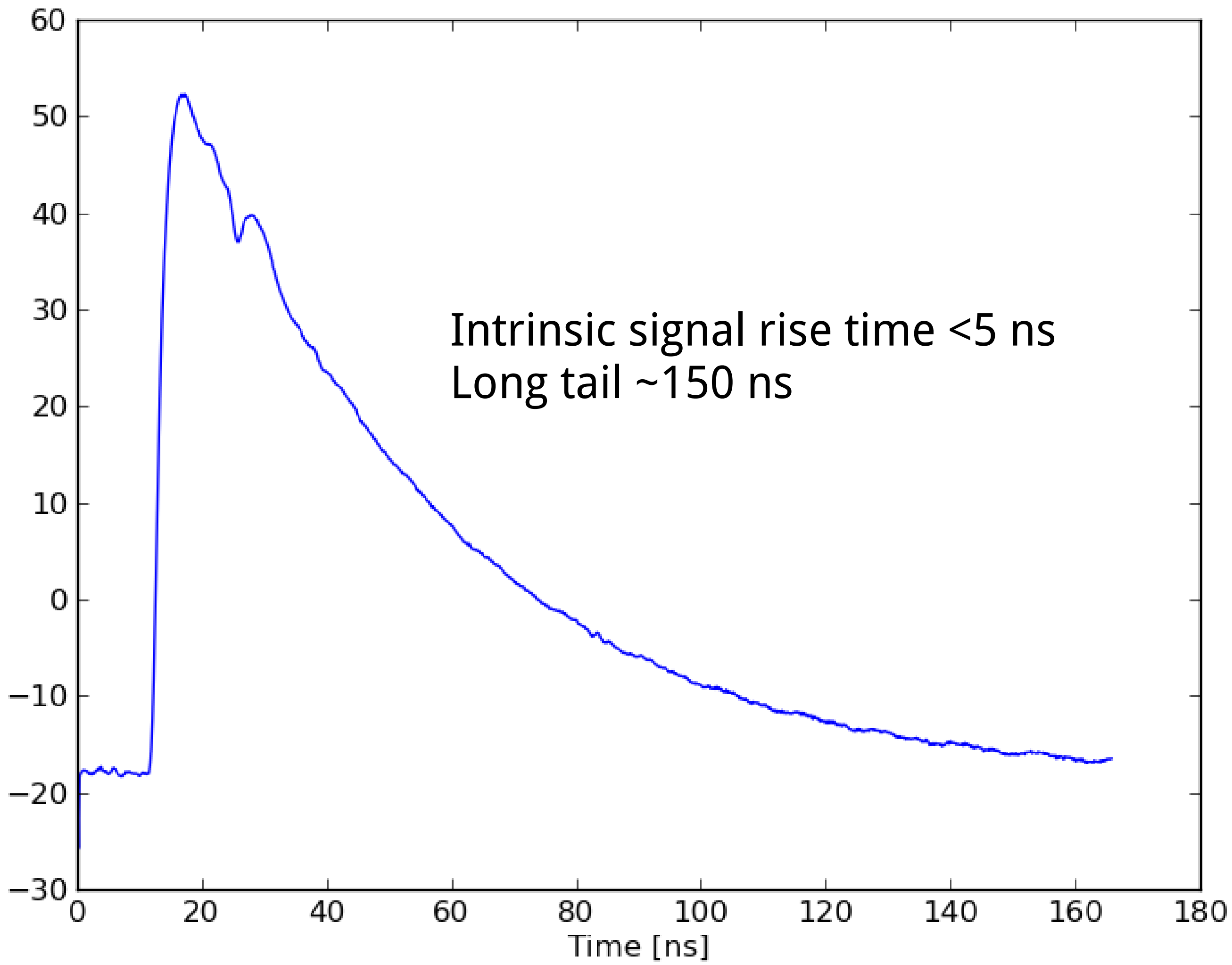
Peltier power 2-3 Watts per module (~10% of total camera power budget)



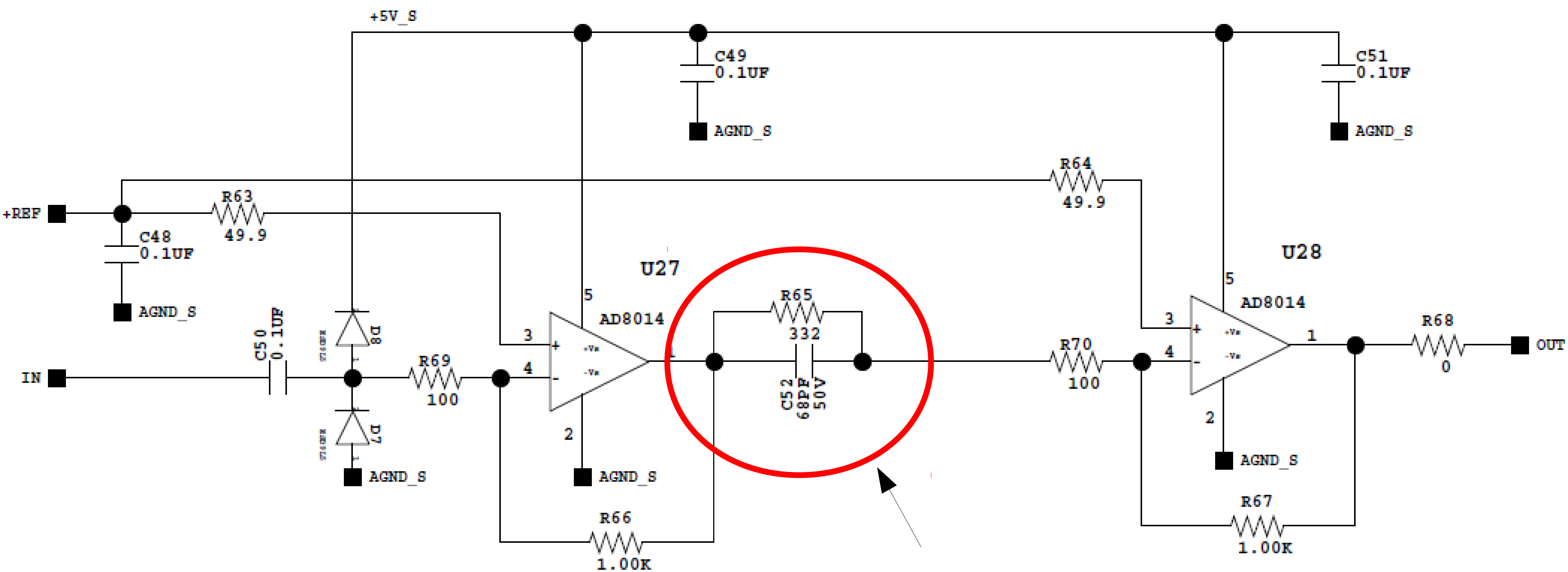
Stabilize as close to ambient temperature as possible
-> minimizes power

SiPM Signal Processing

Want short signals (<10 nsFWHM) to reduce contamination from background photons



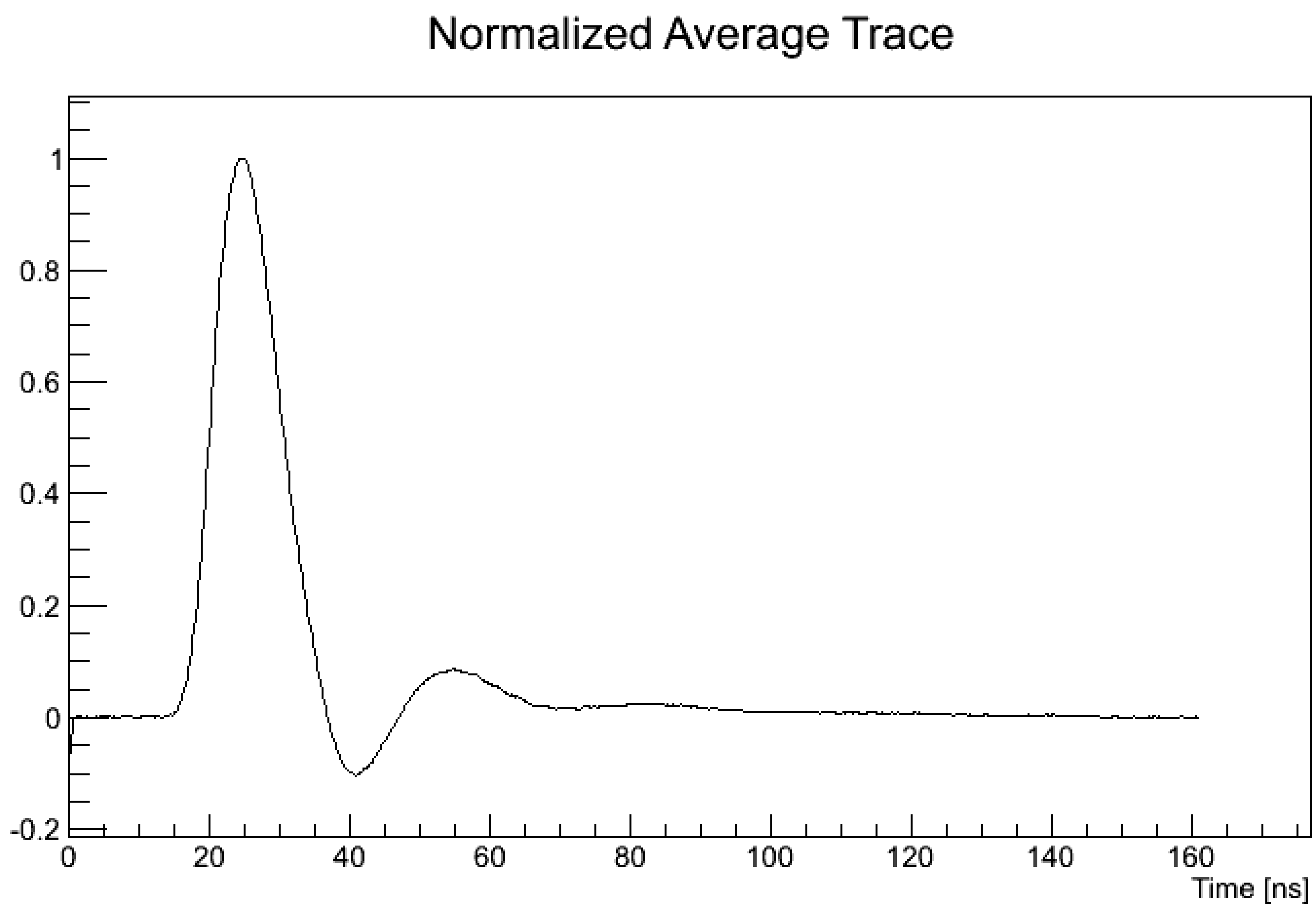
Preamplifier



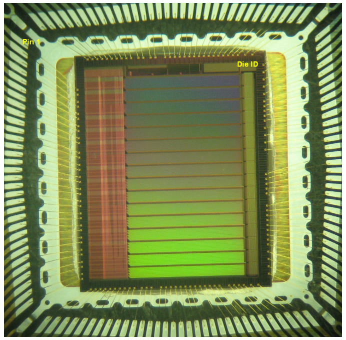
passive shaping
high-pass filter with pole zero cancellation

Low power preamplifier ~10 mW

Signal after Shaping

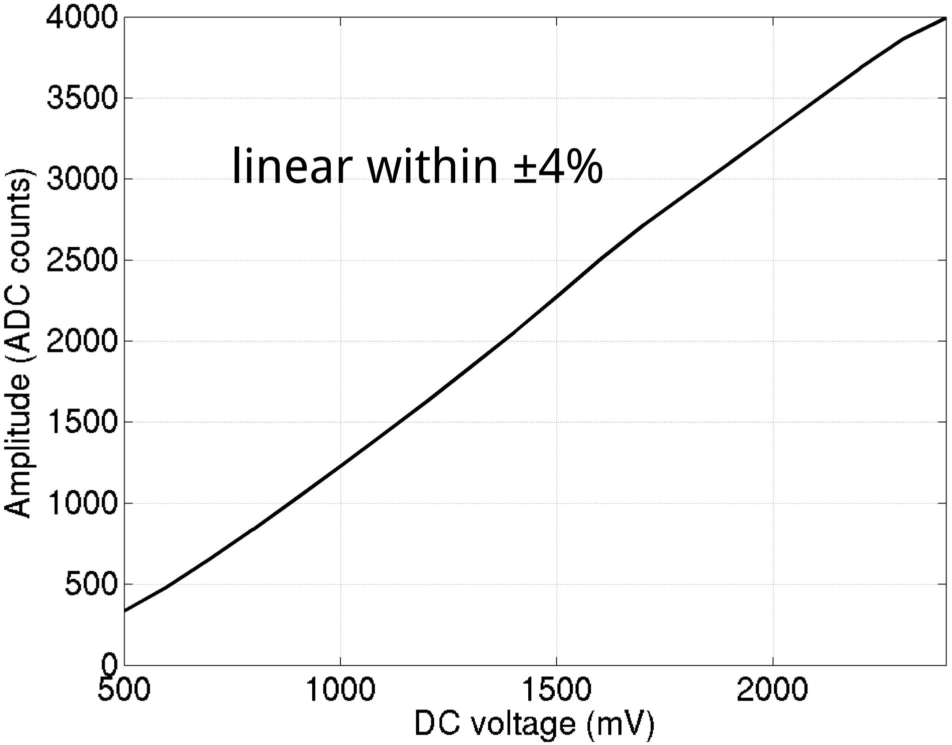


Digitization with TARGET 7



ASIC originally designed for HEP adapted for IACTs

- Application-specific integrated circuit featuring switched capacitor array analog sampling followed by self-triggered digitization
- Designed by Gary Varner (U Hawaii)
- 1.0 or 0.5 GSa/sec analog sampling per channel
- ~380 MHz analog bandwidth
- 16 channels per chip
- 16,384 cells of analog memory per channel
- Self triggering with analog sum trigger (sum of 4 channels)
- LVDS trigger output
- Currently characterizing version 7 (to be used for prototype SCT)
- ~10 bits effective (1.9 V range, 2 mV noise)

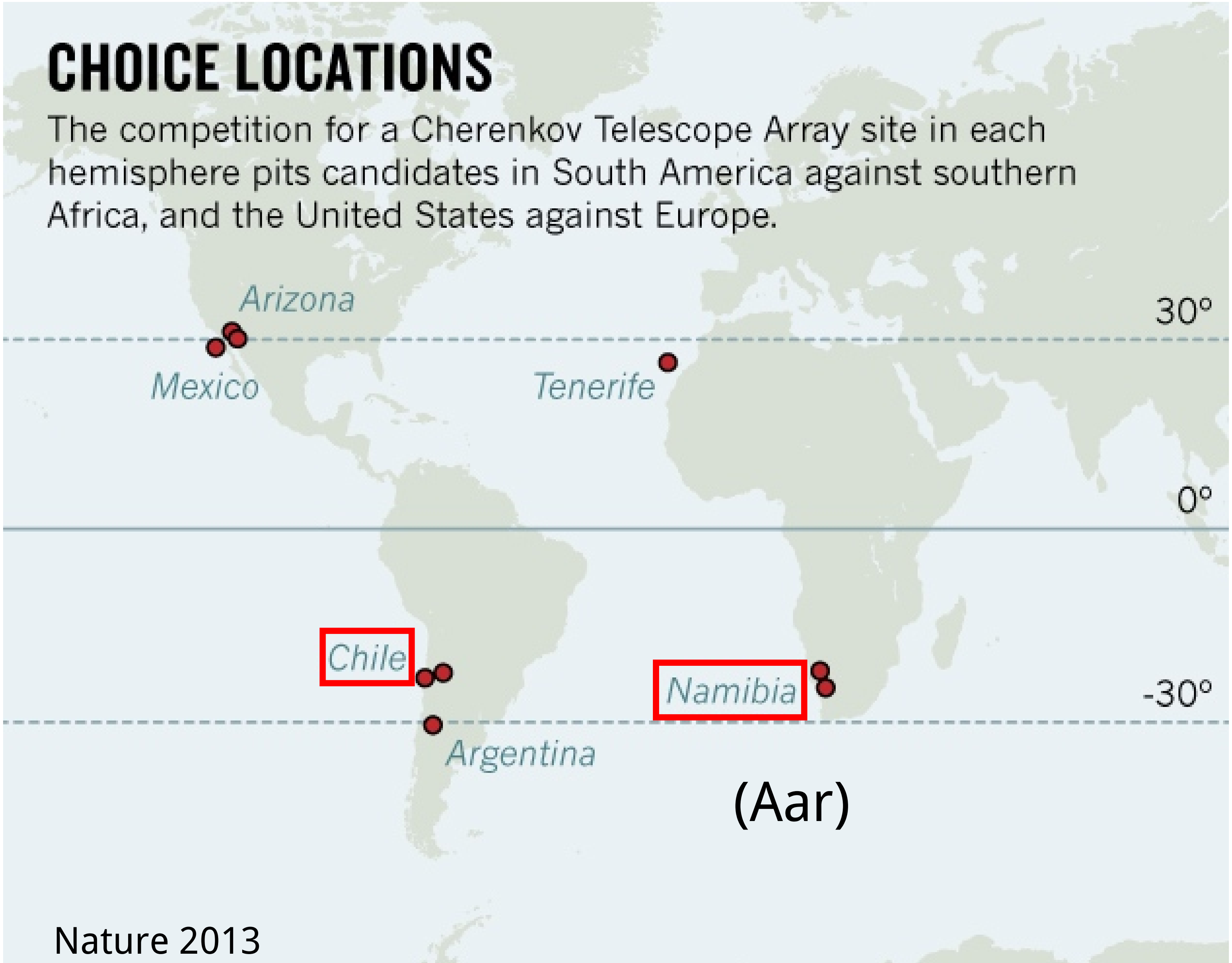


Summary & Conclusions

- The developed SCT camera is very compact, modular and highly integrated
- Cost effective approach ~$60 per channel ($30 for SiPMs) -> photon detectors are still the cost drivers
- Sensors are temperature stabilized to < 1° C
- We use Hamamatsu MPPCs for the prototype ($1.45/mm^2), Cherenkov detection efficiency of 21%
- There is still a lot of room for improvement: higher Cherenkov detection efficiency, reduced sensitivity > 600 nm, lower costs

We gratefully acknowledge support from the agencies and organizations listed under Funding Agencies at this website: http://www.cta-observatory.org/.

Backup


CHOICE LOCATIONS
The competition for a Cherenkov Telescope Array site in each hemisphere pits candidates in South America against southern Africa, and the United States against Europe.
Arizona
Mexico
Tenerife
30°
0°
-30°
Chile
Namibia
Argentina
(Aar)
Nature 2013

9 Candidate Sites

- South:
  - **Cerro Armazones, Atacama, Chile (ESO)**
  - **Aar, Namibia: private farmland 1600 masl, 120 km west of Luderitz**
  - Khomas Highland, Namibia
  - El Leoncito, Argentina
  - San Antonio de los Cobres, Argentina (now ruled out)
- North:
  - Metero Crater, Arizona, United States
  - Yavapai Ranch, Arizona, United State
  - San Pedro Martir, Mexico
  - Teide, Tenerife, Canary Islands