Argonne NATIONAL LABORATORY

... for a brighter future

Technology Overview of the Advanced Gamma-ray Imaging System (AGIS)

presented by Robert (Bob) G. Wagner

Argonne National Laboratory

for the AGIS Collaboration

Technology and Instrumentation in Particle Physics (TIPP09)

Friday 13 March 2009

U.S. Department of Energy

UChicago Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

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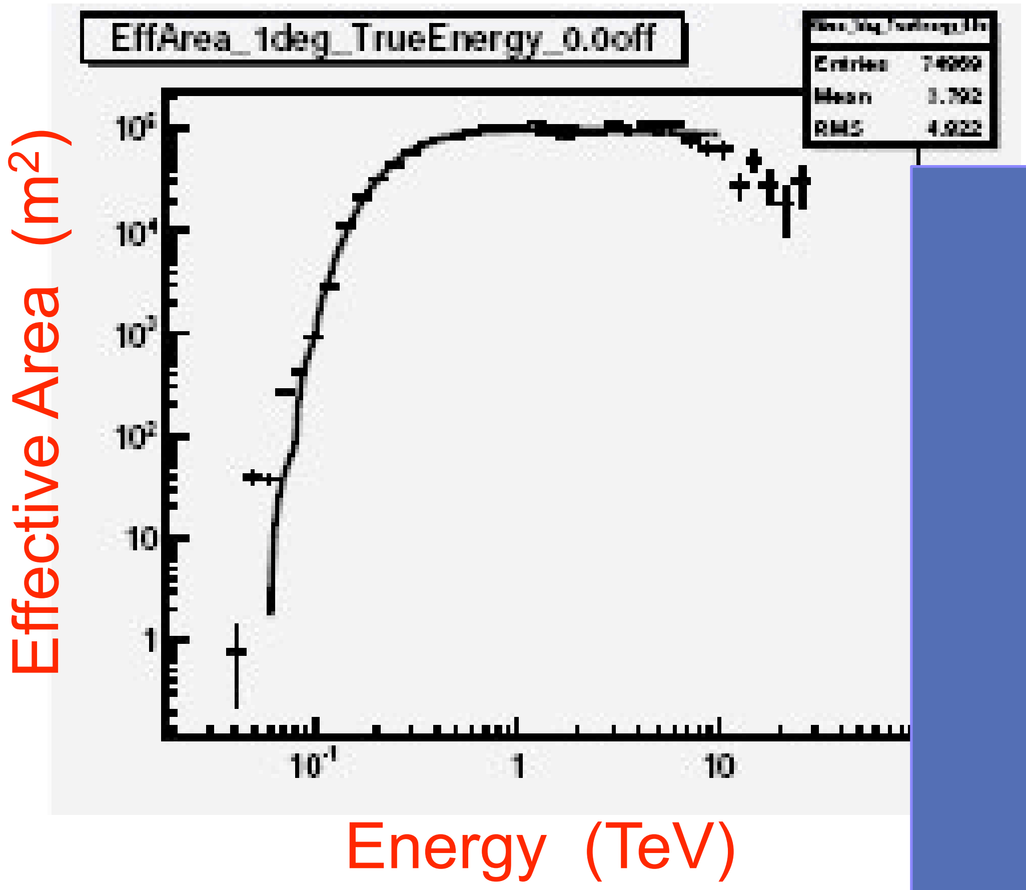
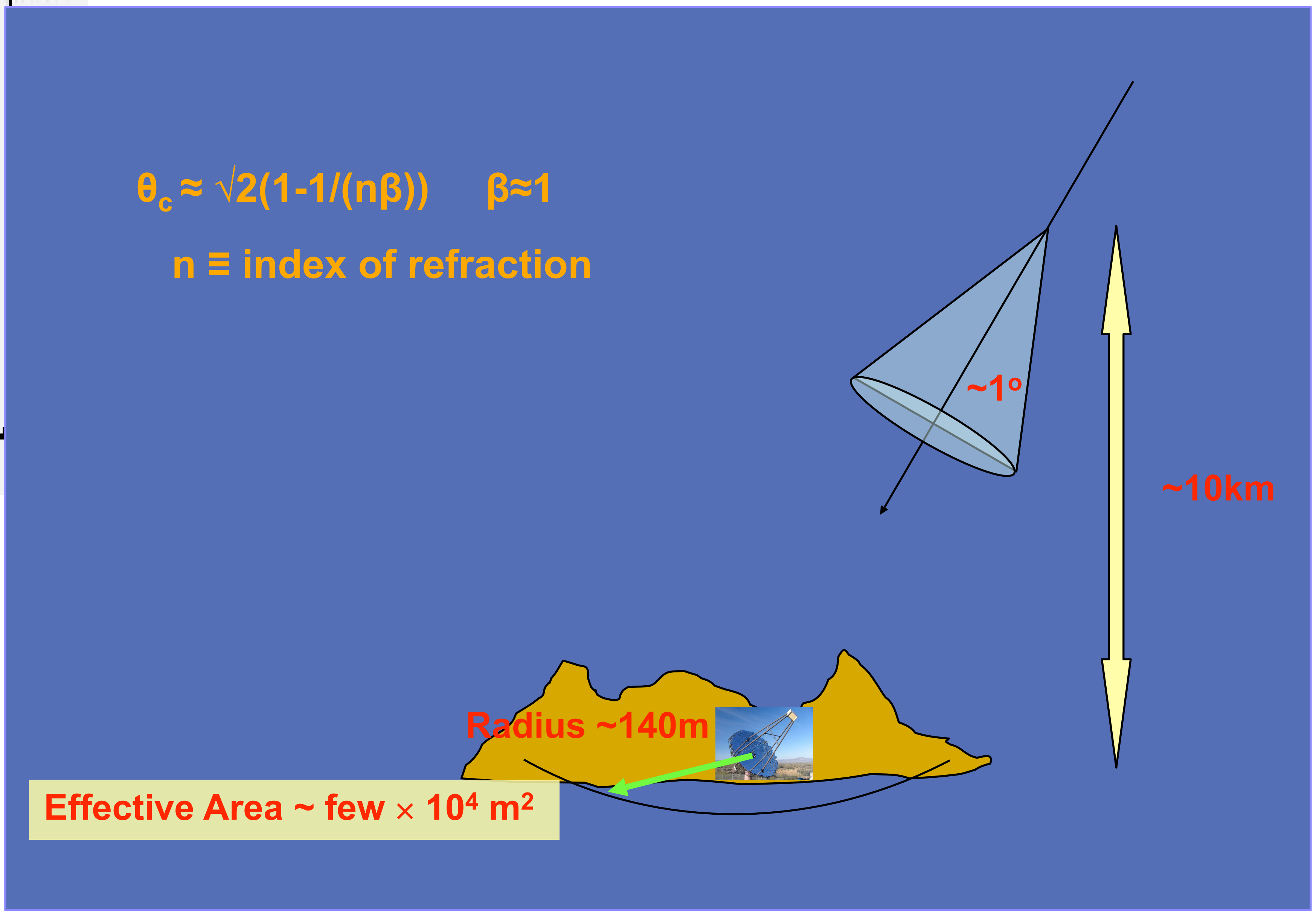
Technique and Effective Observing Area





Scientific Motivation I: History and Scope

- First Very High Energy (VHE) Gamma-ray Source detected: 1989
  - Crab Nebula; now the VHE “standard candle”
  - Whipple 10m, Mt. Hopkins, Arizona (SAO/FLWO), first generation IACT
- Several sources (~10) discovered in 1990s
  - Whipple, CANGAROO, Telescope Array, Durham, Crimea
  - HBL Blazars, Supernova Remnants, Pulsar Wind Nebulae
- VHE source list grows to ~100 in 2000-2009
  - Galactic Center, PWN, Pulsars, SNR, Compact Binaries, HBL/LBL Blazars, FRI
  - Unidentified and Dark Accelerators
  - HEGRA initiates stereo observations
  - Milagro Water Cherenkov
  - Current generations IACTs: VERITAS, MAGIC, HESS, CANGAROO
  - Space: Fermi Gamma-ray Space Telescope
- **Areas of Study**
  - Dark Matter Search: Neutralino Annihilation → γ-rays (main interest for particle physics)
  - Particle acceleration mechanisms
  - Origin of cosmic rays: SNR? (<10^{14-15}eV), AGN? (10^{15-20}eV)
  - Extragalactic Infrared Background Light
  - Dark TeV Sources
  - New Phenomena Discovery Potential

History I: First VHE Gamma-ray Source Detections

Whipple 10m IACT
1st VHE source 1989: Crab Nebula
Crab is now VHE “Standard Candle”
Still in operation! Mainly blazar monitoring

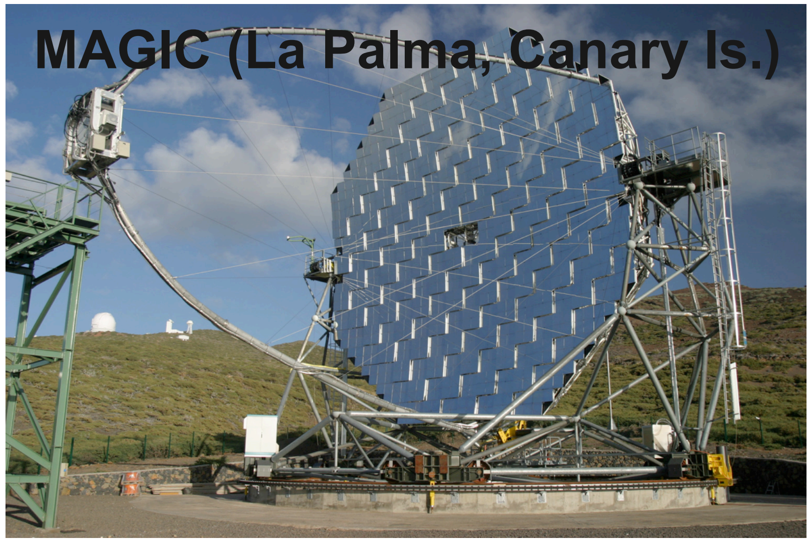
1990-2000: CANGAROO, Durham, Crimea, TA, HEGRA
VHE → ~10 (blazars, SNR, PWN)

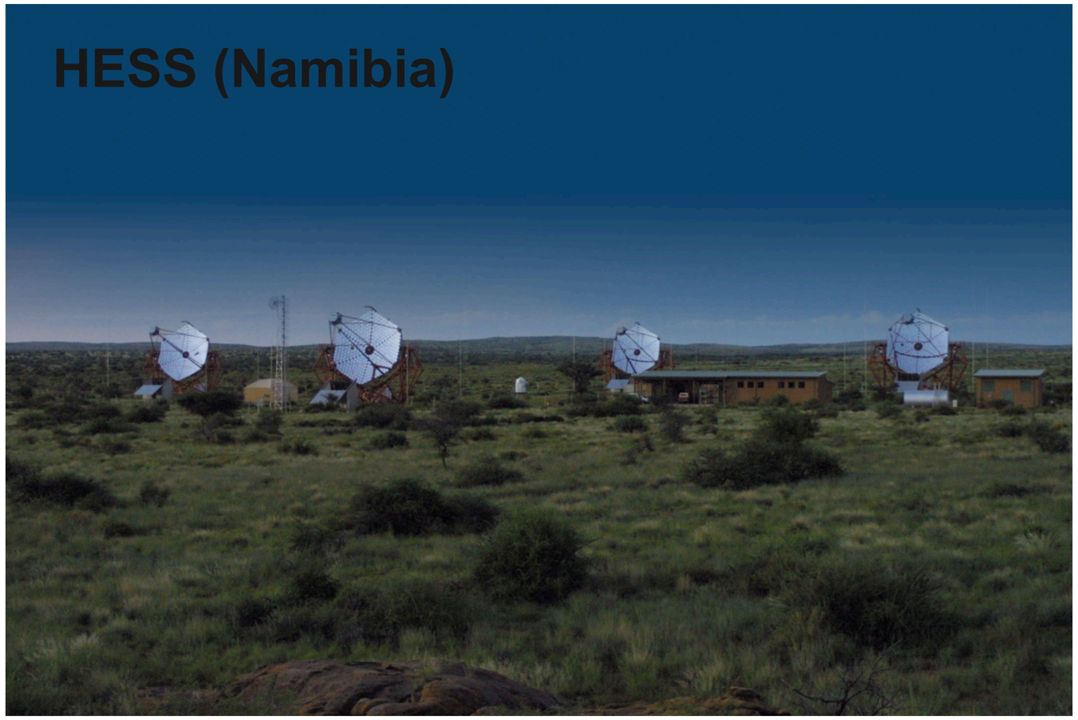
Development of stereo imaging technique
Discovery of TeV2032: 1st unidentified TeV source (2002)

Milagro:
Wide Field
Water Cherenkov Gamma-ray Telescope
First data Feb. 1999

History II: Current Generation IACTs

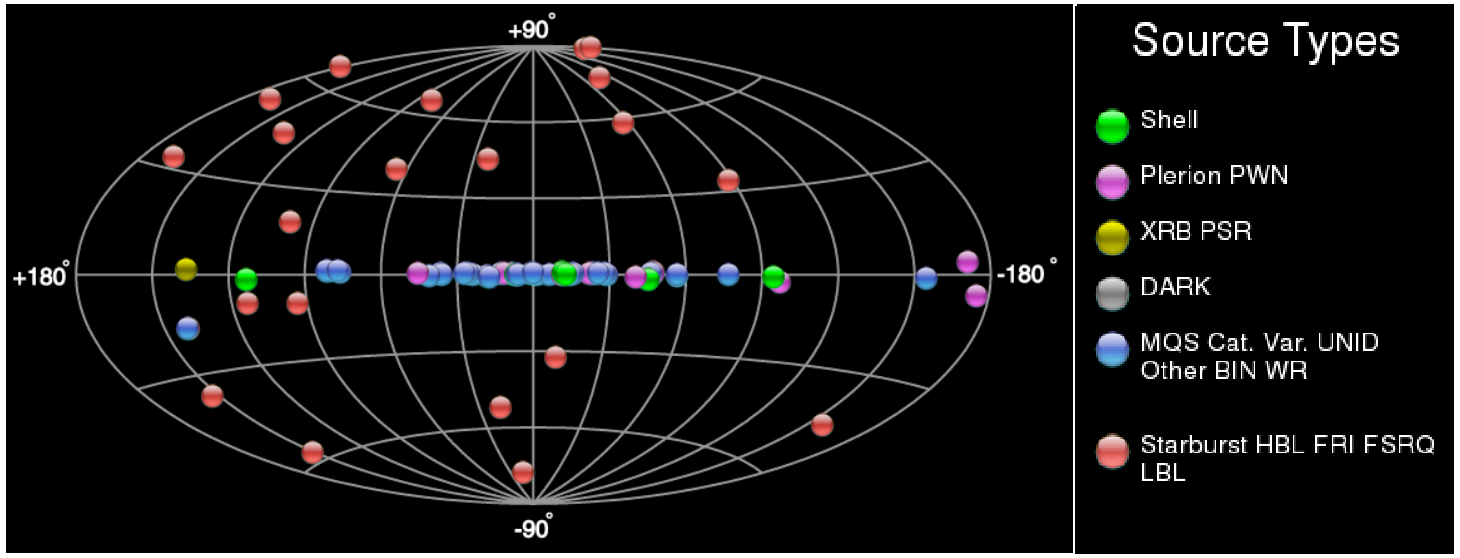
Four telescope operation: September, 2007





Four telescope operation: December, 2003

Number VHE Sources ~100 as of 2009
Typical angular resolution ~0.1°
Threshold 50-200 GeV



display courtesy of TeVCat (Horan & Wakely): http://tevcat.uchicago.edu

History and Composition of AGIS Collaboration

- Concept for AGIS Observatory and Collaboration emerged from a series of "Toward the Future..." workshops:
  - "1st" meeting: Towards the Future of Ground-based Gamma-ray Astronomy,
    Malibu, California, Oct 21-22, 2005 (host: UCLA)
  - "2nd" meeting: Towards the Future of Ground-based Gamma-ray Astronomy,
    Santa Fe, New Mexico, May 11-12, 2006 (host: LANL)
  - **AGIS R&D Group formed**: Future of VHE Gamma-ray Astronomy,
    Chicago, Illinois, May 13-14, 2007 (host: U. Chicago/ Argonne)
  - "3rd" meeting: Towards the Future...,
    Palo Alto, California, Nov 8-9, 2007 (host: Stanford Univ/ SLAC)
  - **AGIS Collaboration Formed**,
    1st AGIS Collaboration Meeting,
    Los Angeles, California, June 27-28, 2008 (host: UCLA)
  - **AGIS Cost & Scope Workshop**
    Ames, IA, Mar 6-7, 2009 (host: Iowa State Univ)
  - **AGIS 2nd Collaboration Meeting**, Argonne, Illinois, April 18, 2009 (host: Argonne Natl. Lab.)

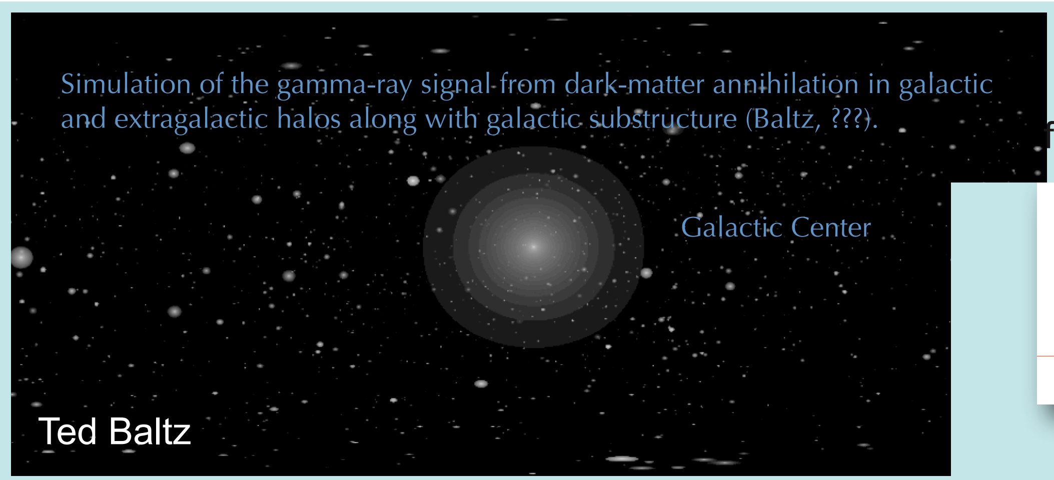
Institutions:

Adler Planetarium	SAO
Argonne Natl Lab	Stanford/SLAC
Barnard College	UNAM (Mexico)
Univ. Delaware	UCLA
IAFE (Argentina)	UC-Santa Cruz
Iowa State	Univ. Chicago
Los Alamos Natl Lab	Univ. Iowa
McGill Univ (Montreal, CA)	Univ. Utah
Penn State Univ.	Yale Univ.
Purdue Univ.	Washington U.

Executive Board:

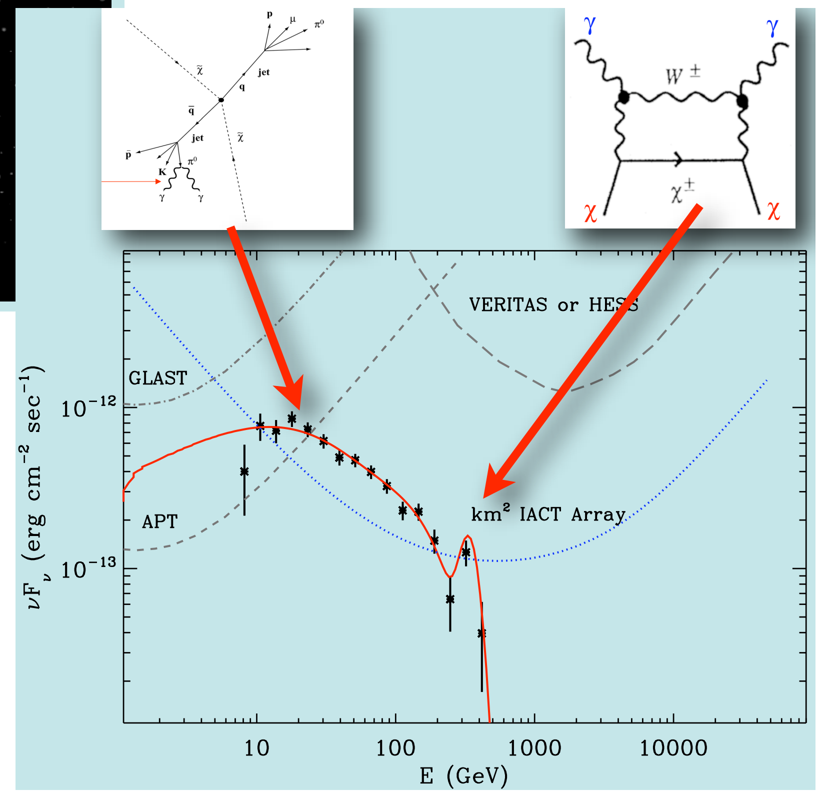
Frank Krennrich (Iowa State), Spokesperson
Jim Buckley (Washington Univ.)
Stefan Funk (SLAC)
Henrik Krawczynski (Washington Univ.)
Vladimir Vassiliev (UCLA)

AGIS Science Focus

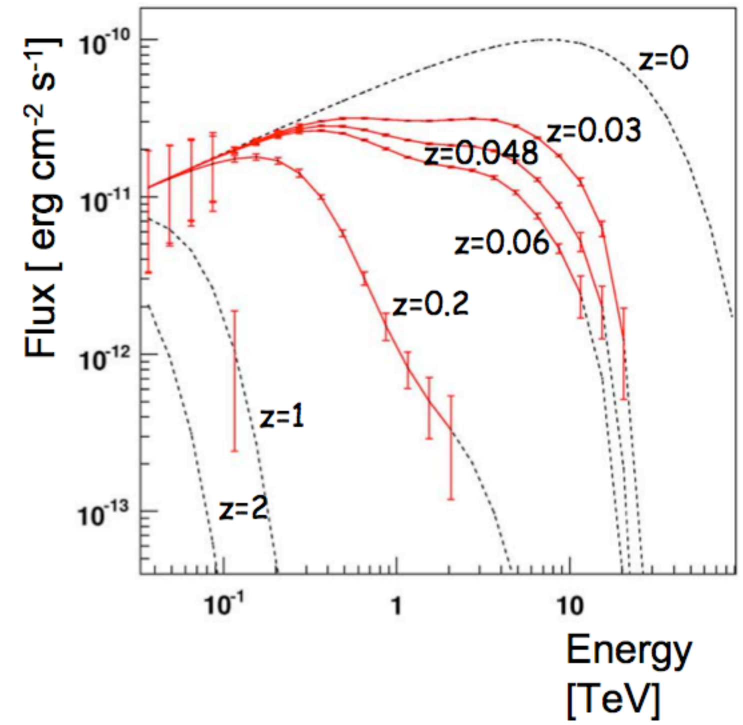


Dark Matter

from poster,J. Buckley, Gamma2008, Heidelberg

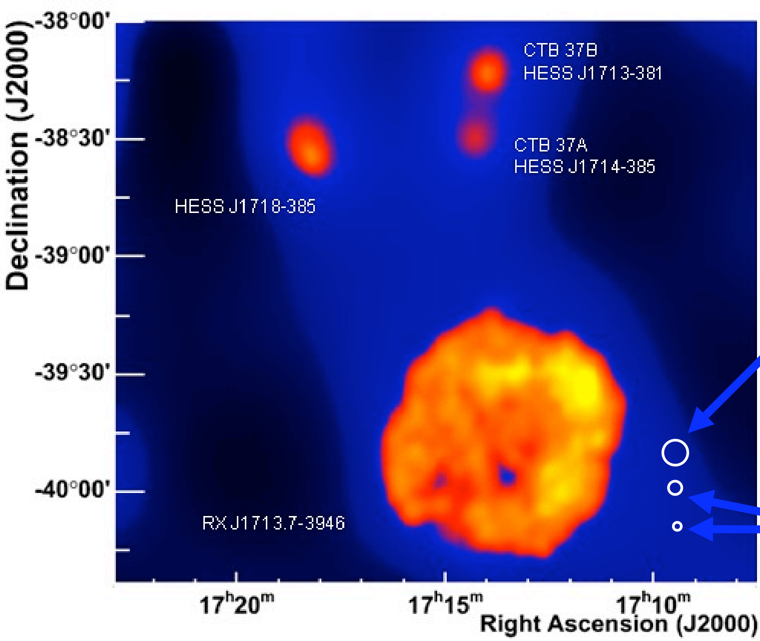


See Further



Extragalactic Bkgd Light Study
Lorentz Invariance Violation:
energy dependent light speed
Gamma-ray Bursts

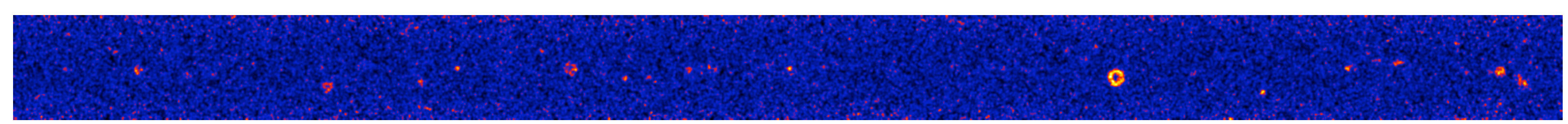
Angular Resolution, e.g. source substructure



HESS PSF

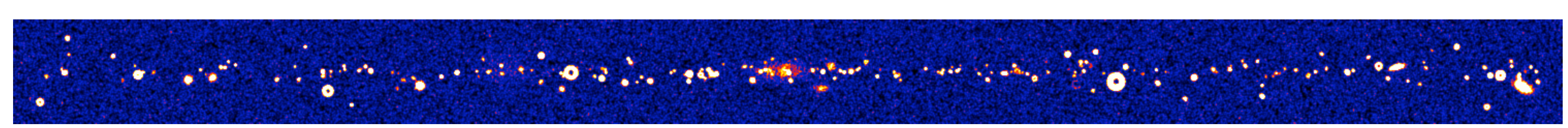
AGIS PSF

HESS Simulation (real exposure)



TeV Source Discovery, e.g. MW Galactic Plane

AGIS/CTA Simulation (flat exposure)



Digel & Funk 2008; Funk, Hinton, Hermann, & Digel, 2009

The AGIS Array

Overview of the AGIS Array Concept

- **Based on conclusions from AGIS Cost & Scope Workshop, Mar 6-7,2009 @ Iowa State**
  - Outcome of workshop was more concrete concept for AGIS array

- **Array will be composed of 36 Schwarzschild-Couder wide FOV telescopes**
  - Somewhat less than original idea of 50-100; based on per telescope cost and ~$100M cost for total complement of instruments
  - Parameters:
    - *Primary Mirror -- 11.5m; Secondary -- 6.6m*
    - *Field of View -- 8°*
    - *Point Spread Function within FOV -- 3 arcmin*
    - *Angular Resolution -- ~0.03°*
    - *Pixel size -- 0.0545° square (camera tiled with square multi-anode PMTs)*
    - *3 Level Trigger*
      - Discriminated Threshold Level 1
      - Moment (Hillas Parameters) Trigger Level 2
      - Parallactic Displacement Level 3 Array Trigger
    - *ASIC waveform sampling digitization on camera*

Technology R&D

AGIS Technology R&D

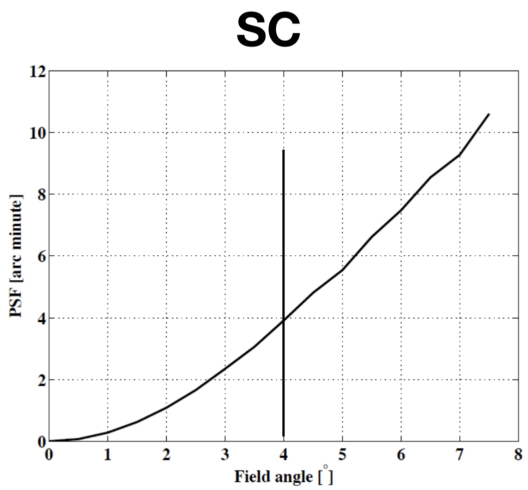
- **Goals for Next Generation Cherenkov Gamma-ray Telescope Array**
  - VERITAS/HESS Sensitivity ×10
  - VERITAS/HESS Angular Resolution / (2-3)
  - Energy Threshold < 100 GeV
  - VERITAS/HESS Field of View ×(~1.5-2)

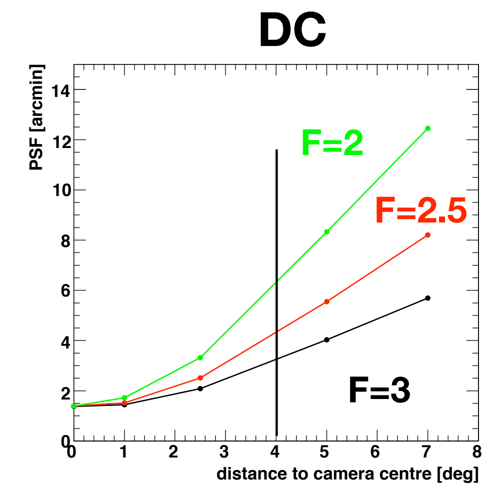
- **Key Technologies and Detector R&D**
  - Telescope Design: Traditional Davies-Cotton vs. Two mirror (Schwarzschild-Couder)
  - Photodetectors: Multi-Anode PMT vs. Silicon Photomultiplier vs. ???
  - Trigger & Readout: Fast Topological Trigger, ASIC waveform sampling readout
  - Overall robust design to minimize operation & maintenance demands
  - Cost effective design

- **Simulation of Instrument Performance**

Simulation of AGIS Performance

- **Studied with 6×6 (36) telescope array using modified VERITAS simulation package**
  - 12m Schwarzschild-Couder (Davies-Cotton with f=3)
  - 2500m a.s.l. with magnetic field effects
  - Standard VERITAS PMT response and trigger
  - Free parameters: array spacing and pixel size



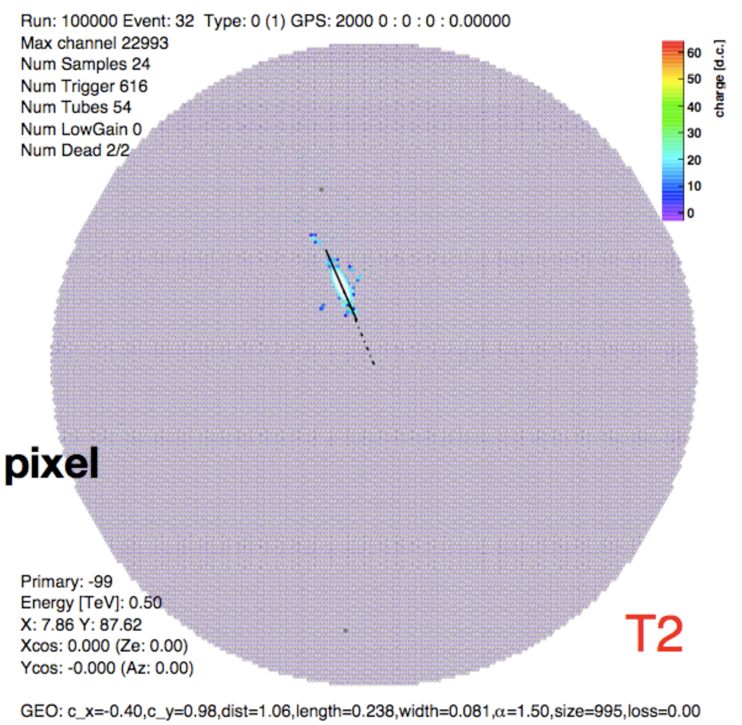


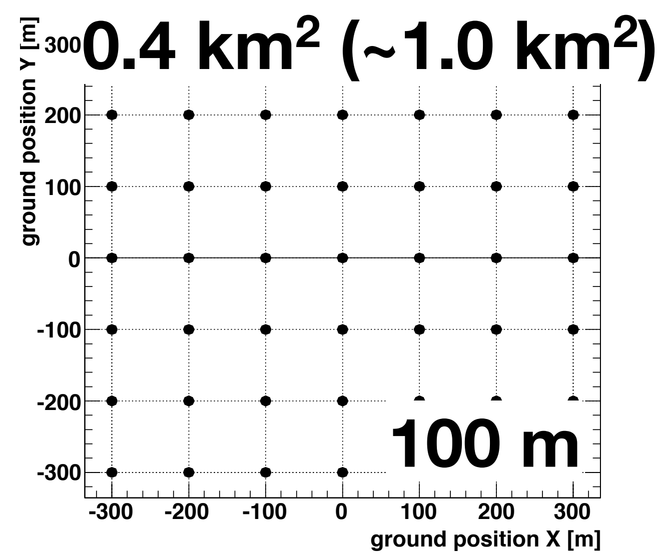
Vassiliev & Fegan
(astro-ph/0708.2741)

F=3

Pixel size 0.05°

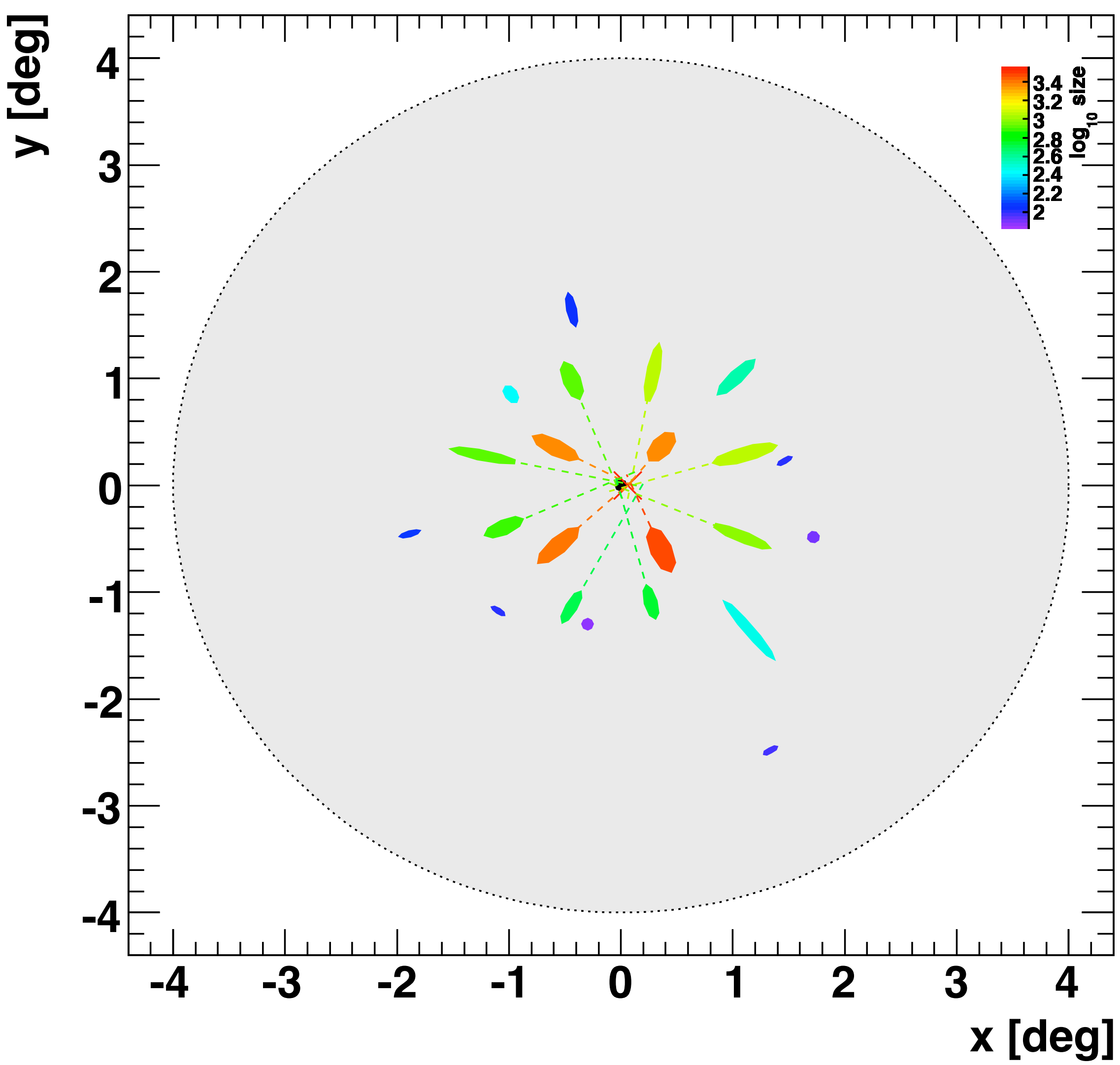
22993 pixel



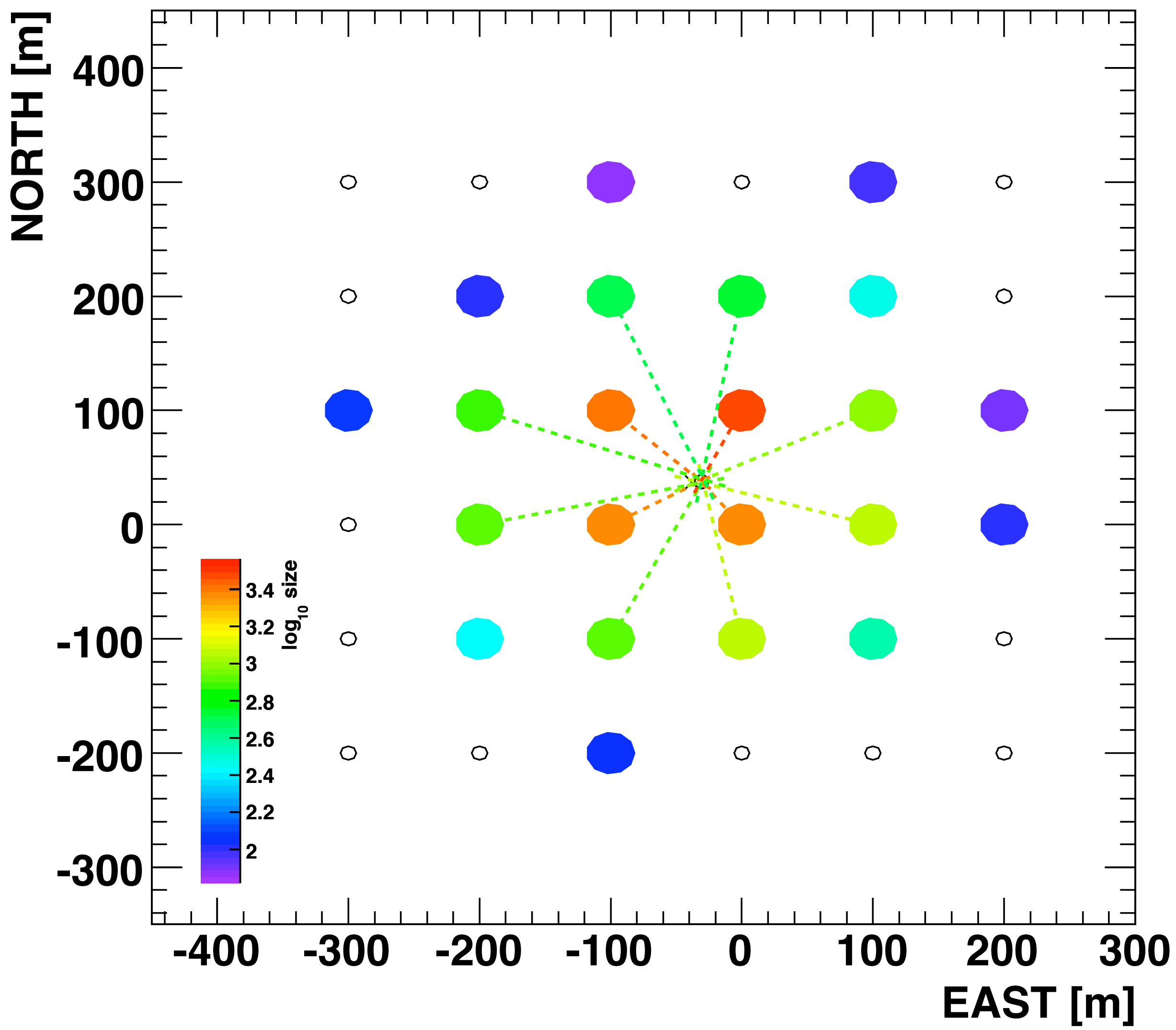


Simulation analysis and figures courtesy Gernot Maier, McGill Univ.

AGIS Simulation - II



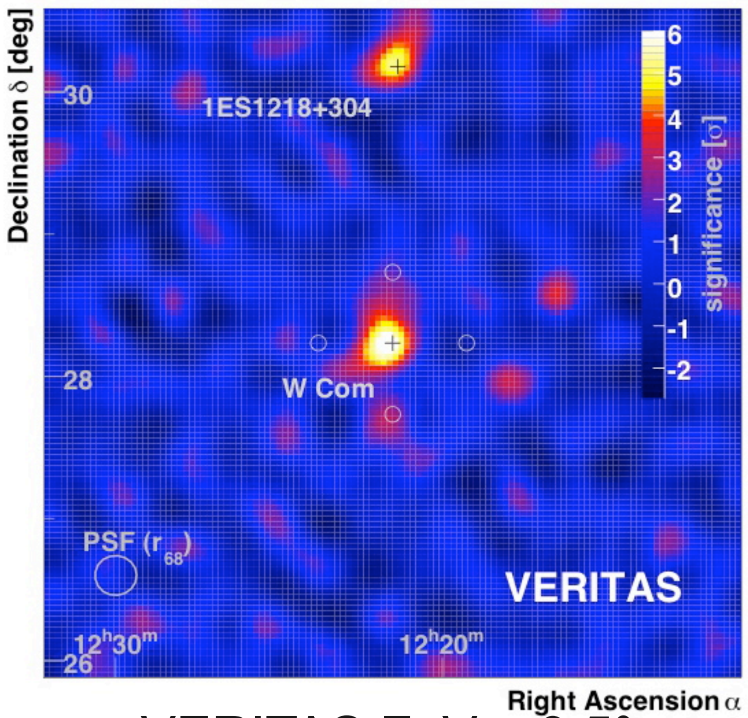
100m telescope distance



500 GeV γ-ray

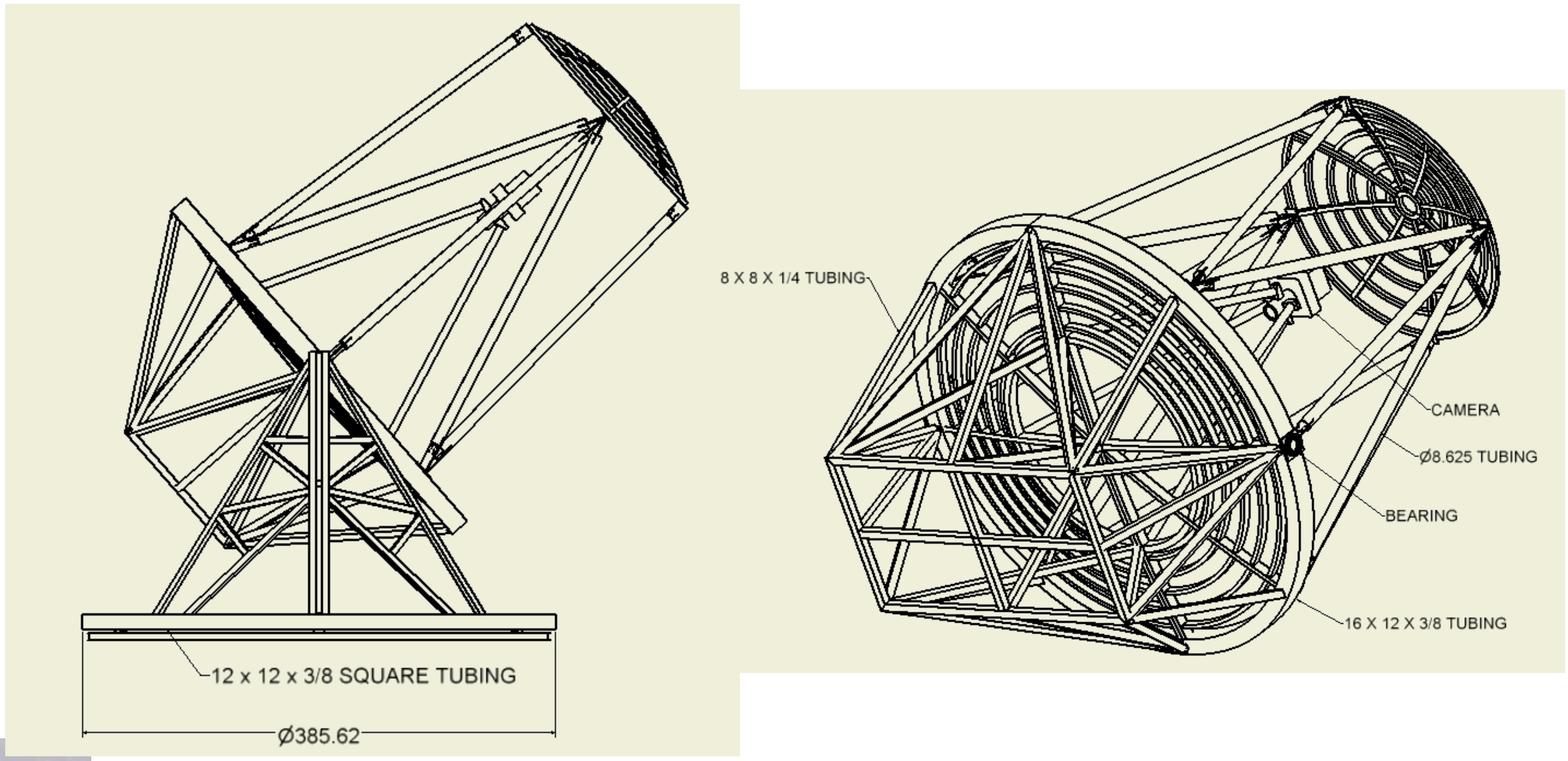
Figures courtesy Gernot Maier, McGill Univ.

Telescope Design - Field of View



VERITAS FoV = 3.5°

Initial 9m Schwarzschild-Couder Telescope

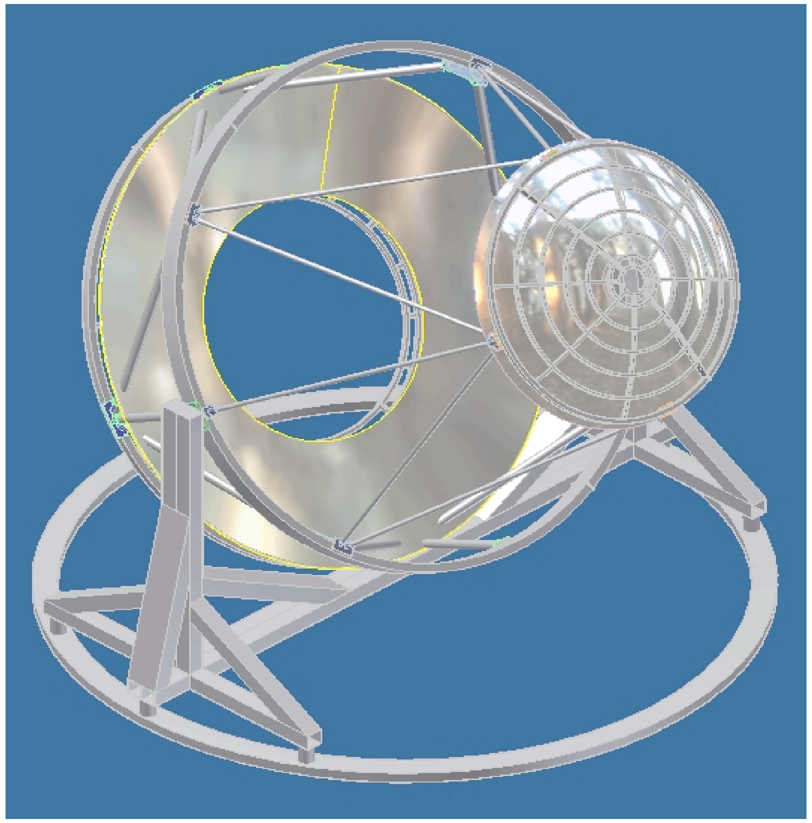


f1.0 Davies-Cotton

S-C offers wide FOV with smaller plate scale than D-C

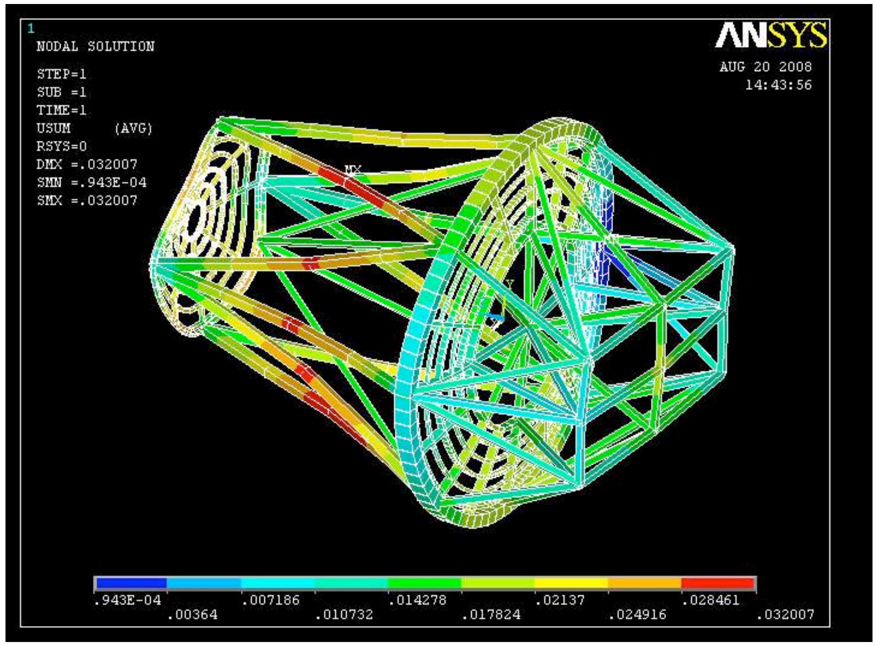
Stringent requirements for primary/ secondary alignment and deflections

Schwarzschild-Couder Telescope Design

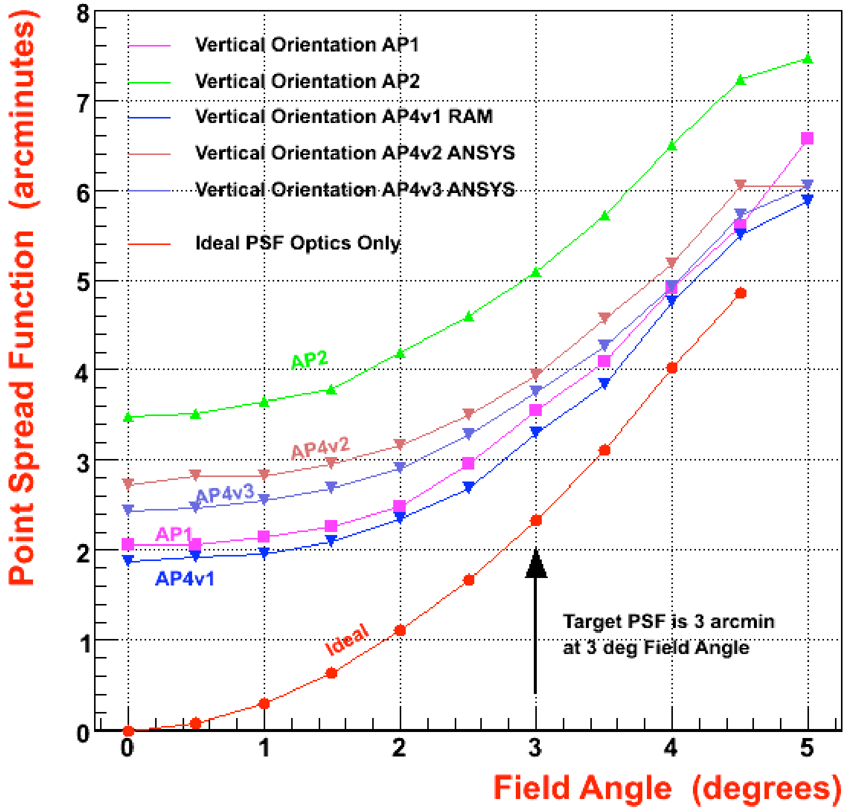


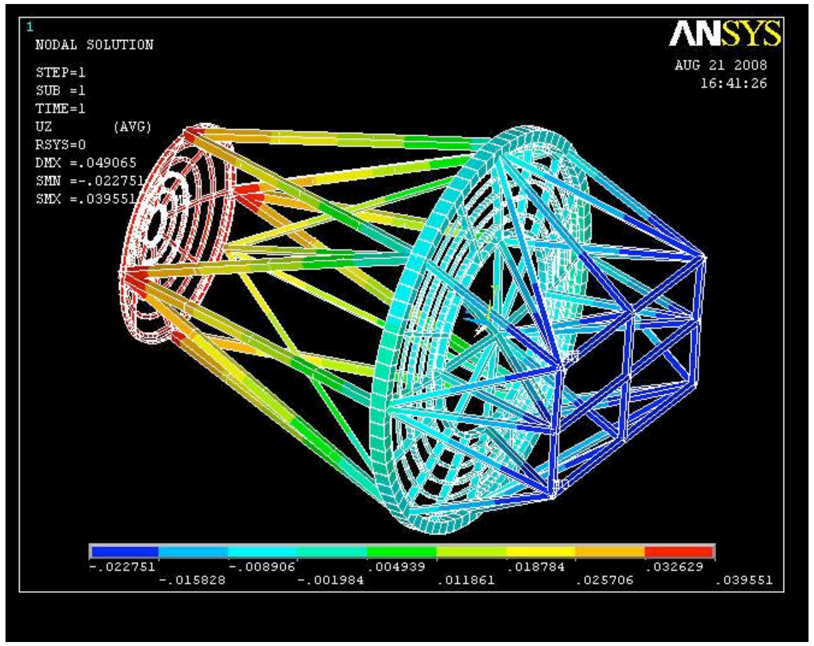
- Complete mechanical/optical design done for 9m S-C including FEA analysis: 2007/8

Modal and dynamic (during positioner rotation) analyses were performed in addition to shown deflections from static and thermal analysis



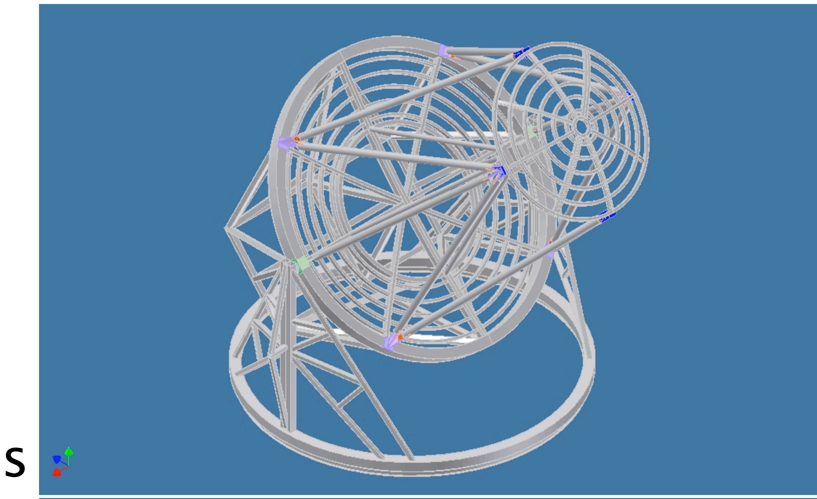
Total deformation in vertical orientation from ANSYS FEA

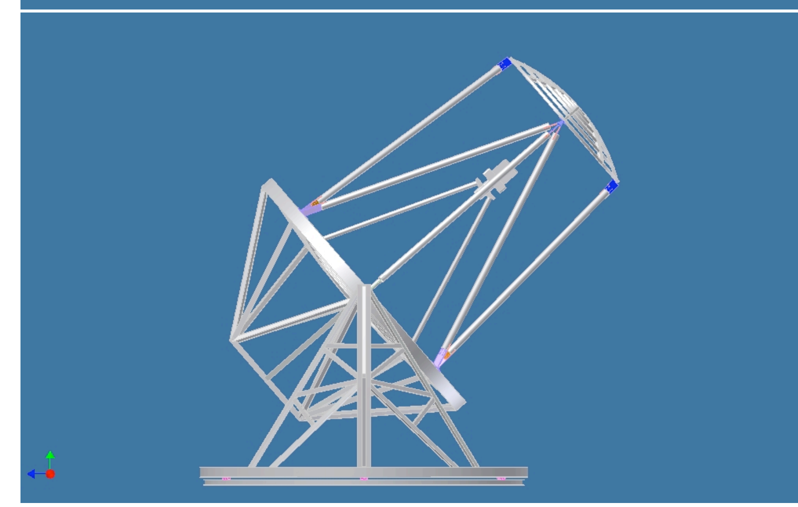




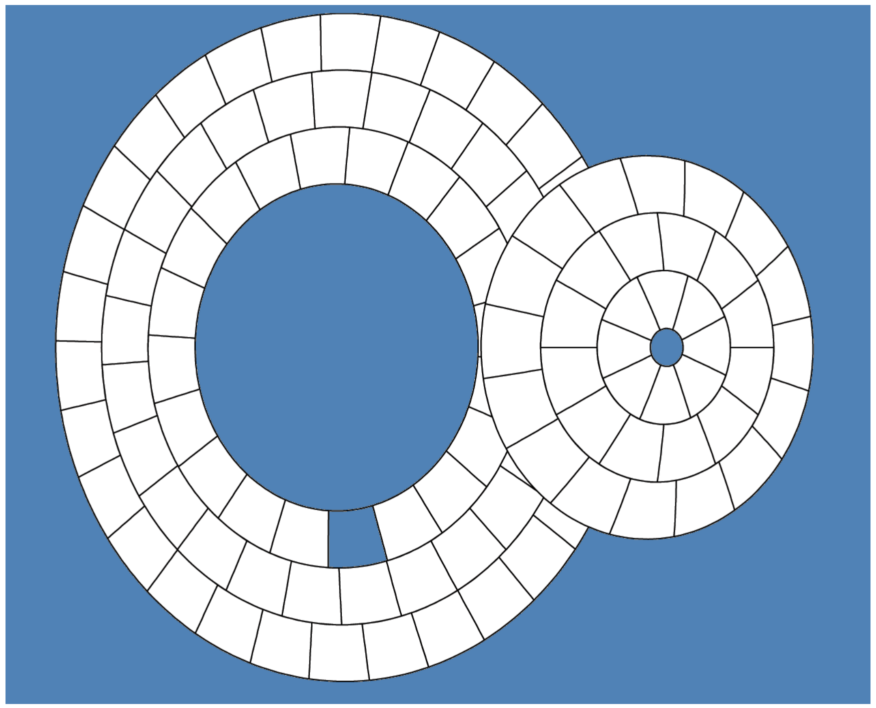
Thermal deformations for ΔT = 10°C

Schwarzschild-Couder Telescope Design -- II





Scale 9m design to 11.5m; complete redesign in future



Primary mirror: 75 ~ $1m^2$ panels
Secondary mirror: 36 ~ $1m^2$ panels
Total: 111 segments

Replication technology (electroforming, glass slumping, Carbon/Graphite Fiber Reinforced Plastic) can be used to reduce costs of manufacturing of aspheric mirrors

Primary diameter: 11.5 m

Central hole: 5.63 m

Secondary diameter: 6.6 m

Focal plane distance: 1.95m (from SM)

Field of View: 8 degrees

Camera diameter: 90 cm

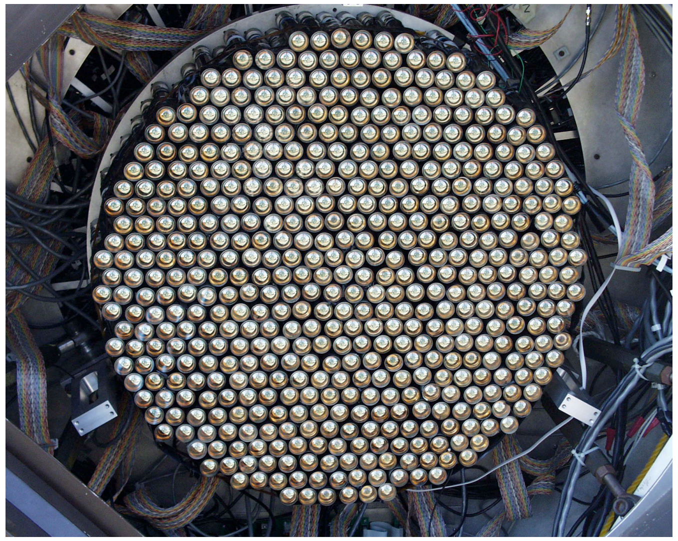
No vignetting to field angle: 3 deg

Effective light collecting area: ~70 m^2

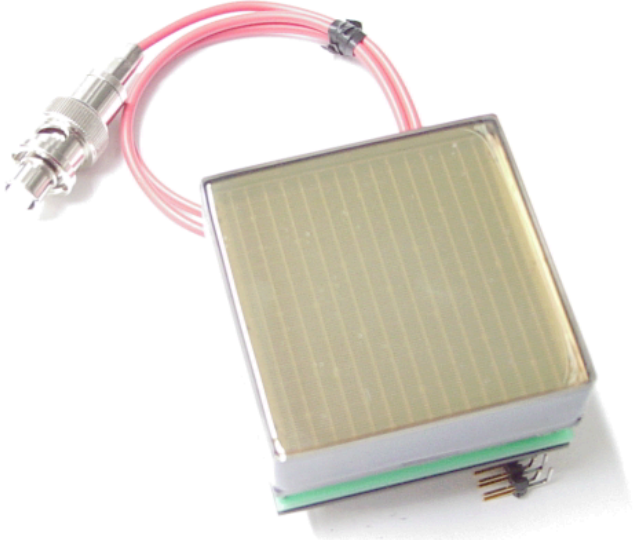
Total mirror area: ~100 m^2

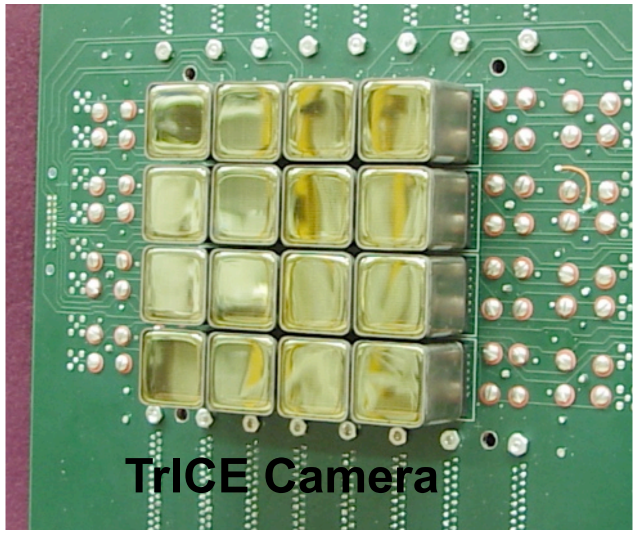
PSF less than: 3 arcmin (within FoV)

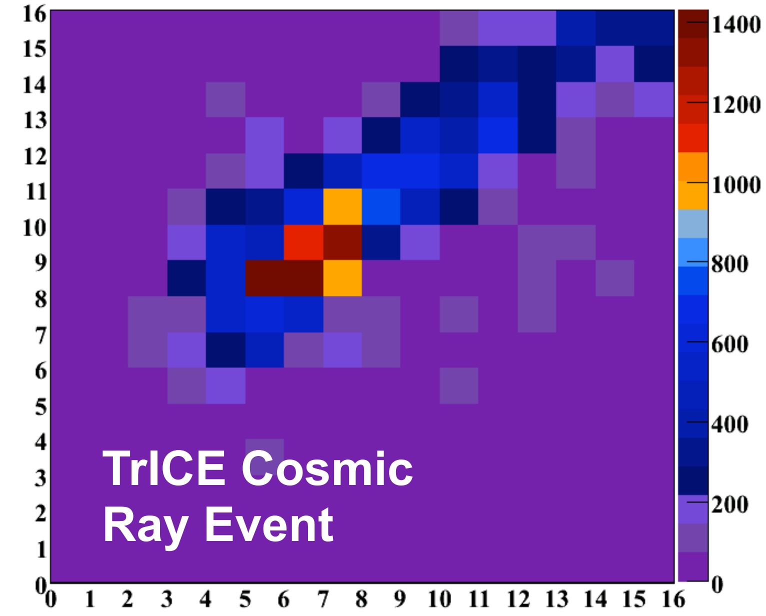
Photodetectors



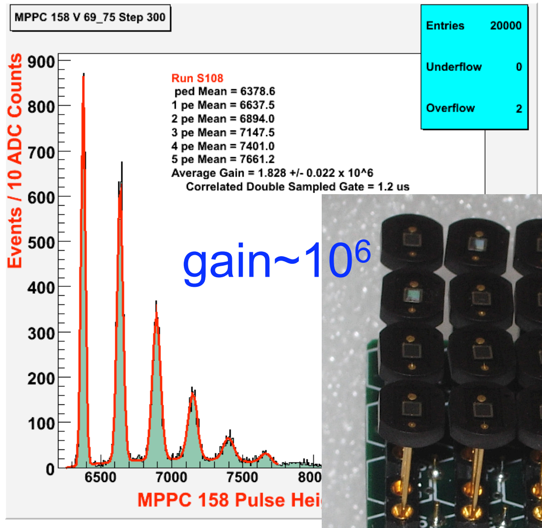
Single Anode PMTs:
standard for current IACT cameras



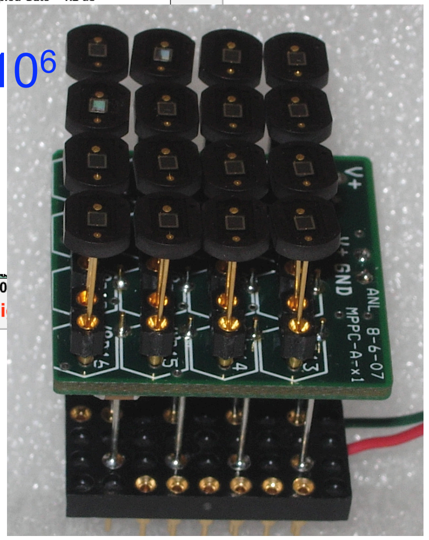




Multi-Anode PMTs (MAPMT):
small pixel size for finer angular resolution
Feasibility demonstrated in TrICE IACT (Argonne, UChicago, Utah)



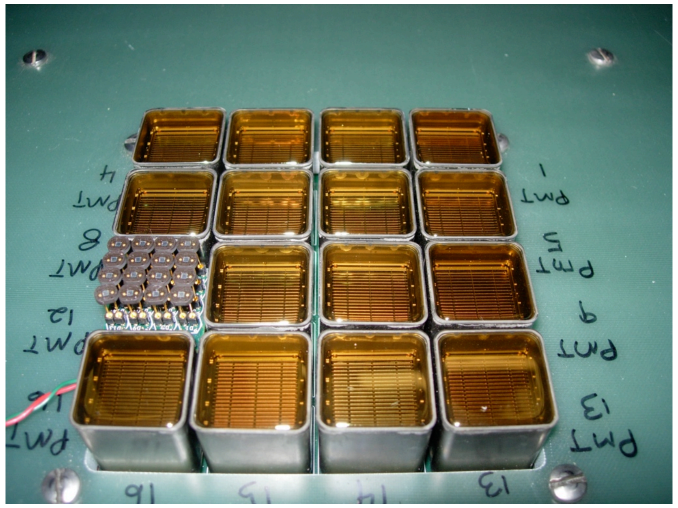
Cherenkov Camera MPPC Array



SiPM

Silicon Photomultipliers:
Advantages:
- low voltage operation
- single pe resolution
- robust

Disadvantages:
- large noise (10s kHz-1MHz)
- crosstalk
- afterpulsing

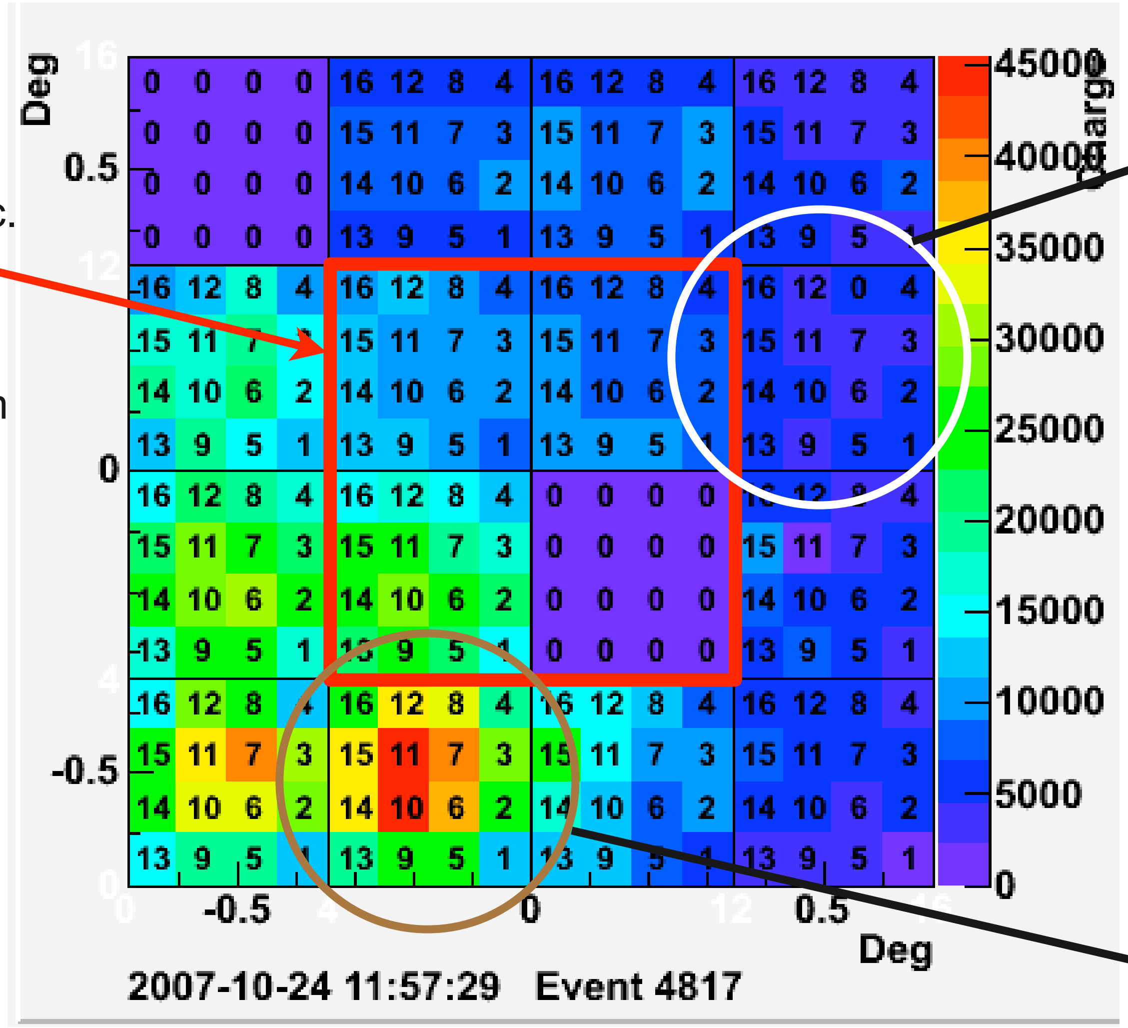


Observation of Cosmic Ray Cherenkov Image with a Multi-Pixel Photon Counter Array

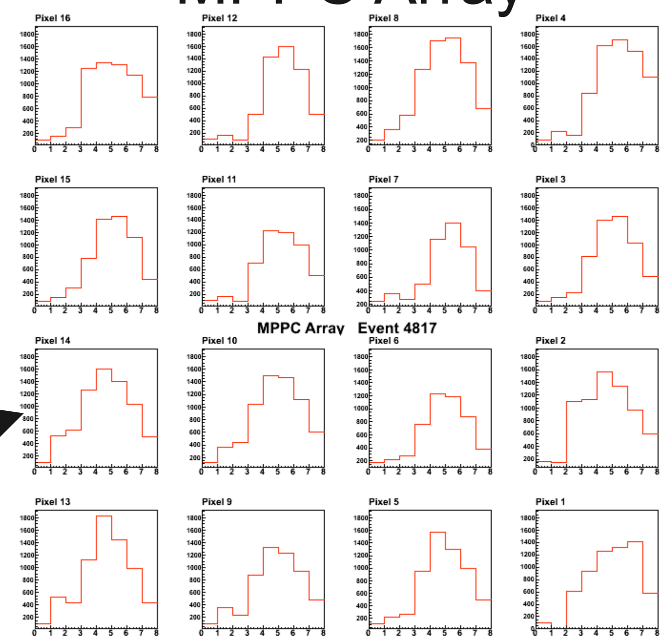
Very Large Pulse Height Event

Sum of time slices 2-6

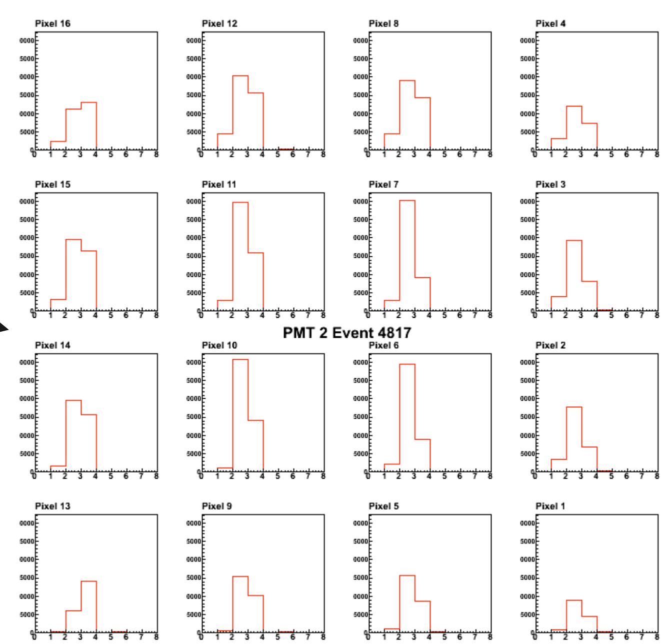
Camera readout triggered by 2-fold coinc. of summed last dynode from 4 central R8900 MAPMTs
(of course, one of readout boards of central tubes (purple) developed problem during LED calibration before data taking).



MPPC Array



*Pulse height distribution by 19 ns time slice for each pixel in R8900 MAPMT or MPPC Array

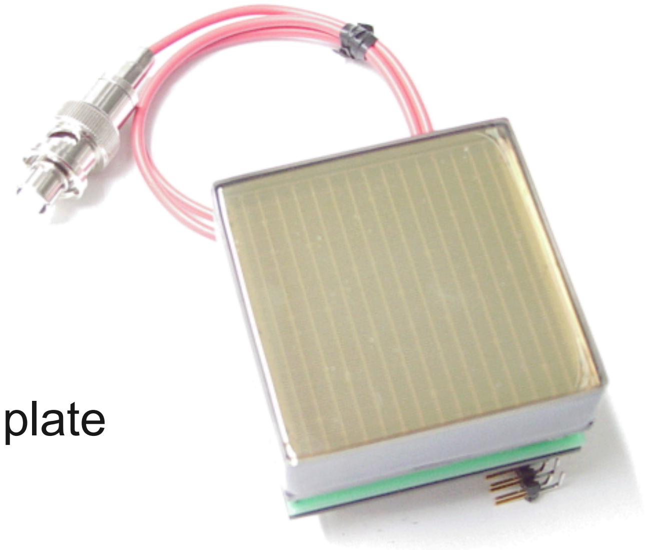


PMT 2

Cosmic Ray Shower imaged on TrICE Telescope camera

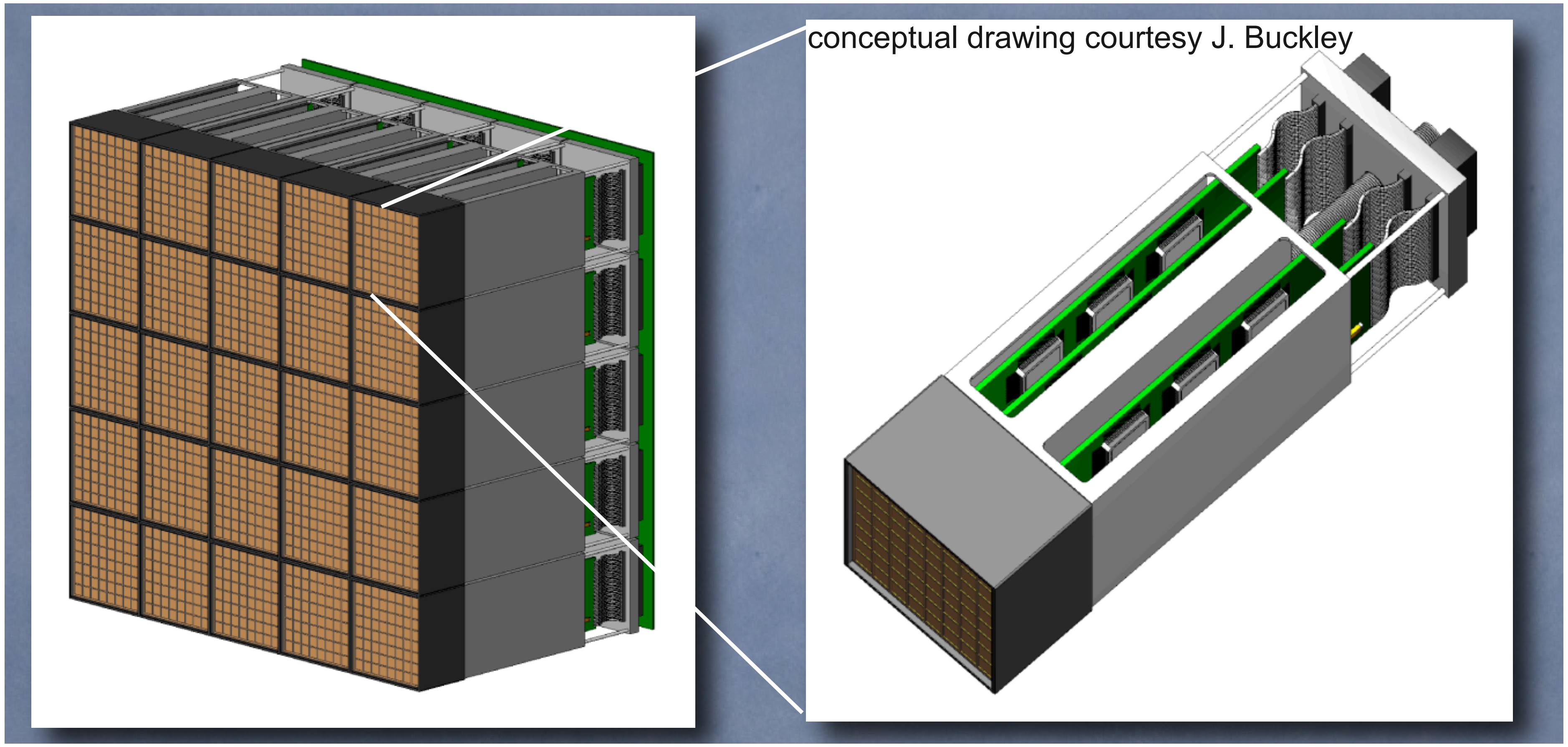
- Camera is 4×4 array of Hamamatsu R8900 MAPMT
  - 6×6mm² pixels
  - Operated at 600V with Gain ~1-2×10⁵
- Replace one R8900 with 4×4 array of MPPCs

Photodetectors - Baseline



Baseline is 64 anode MAPMT:

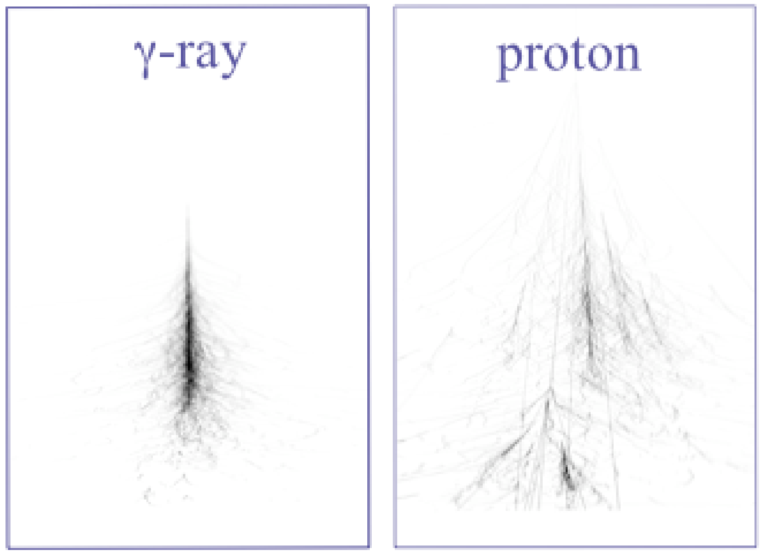
~6×6mm^2 pixels
0.0545° sq / pixel
89% active
Tile camera plane in lego fashion to follow non-planar camera plate

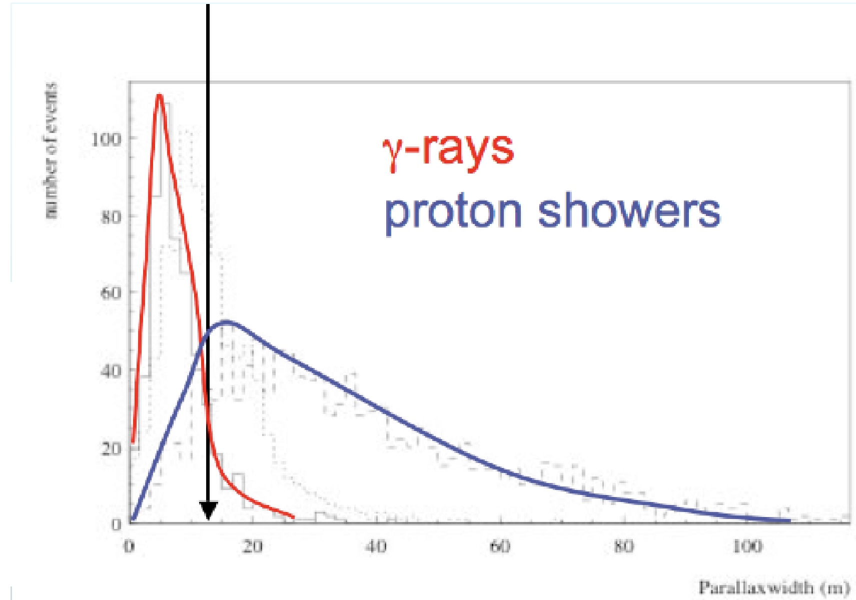


2.2°×2.2° subfield with 1600 0.054° pixels
Subfield has monolithic backplane with trigger electronics, HV control, Gb/s output to DACQ

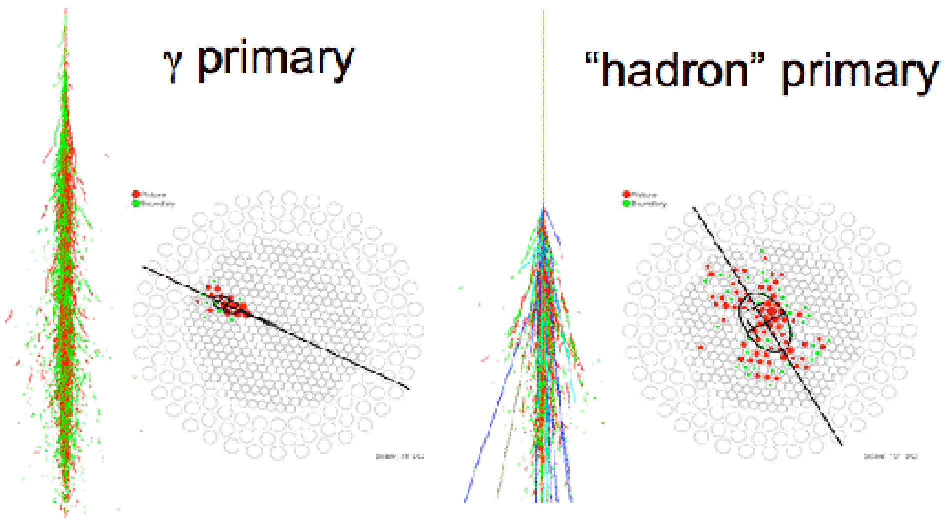
One 64 channel module with 2" MAPMT
Front end electronics located on boards.
Flex cable allows for curved focal plane.
Can tile "lego" fashion to approximate focal plane with 3-4mm stairstepping of tubes.

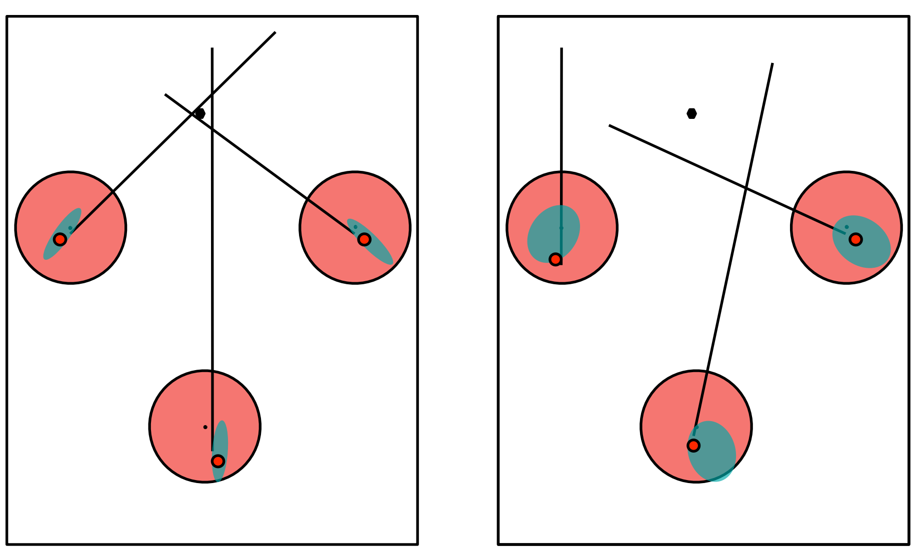
Trigger





Monte Carlo simulation of γ/hadron separation with parallaxwidth.
Simulation used array of (19) 10-meter telescopes spaced 60 meters apart.





Overview:

Use calculation of major axis of ellipse in lowest level trigger

Intersection of axes at array level -- parallactic displacement

Motivation: Lower Energy Threshold/ Bkgd CR Rejection

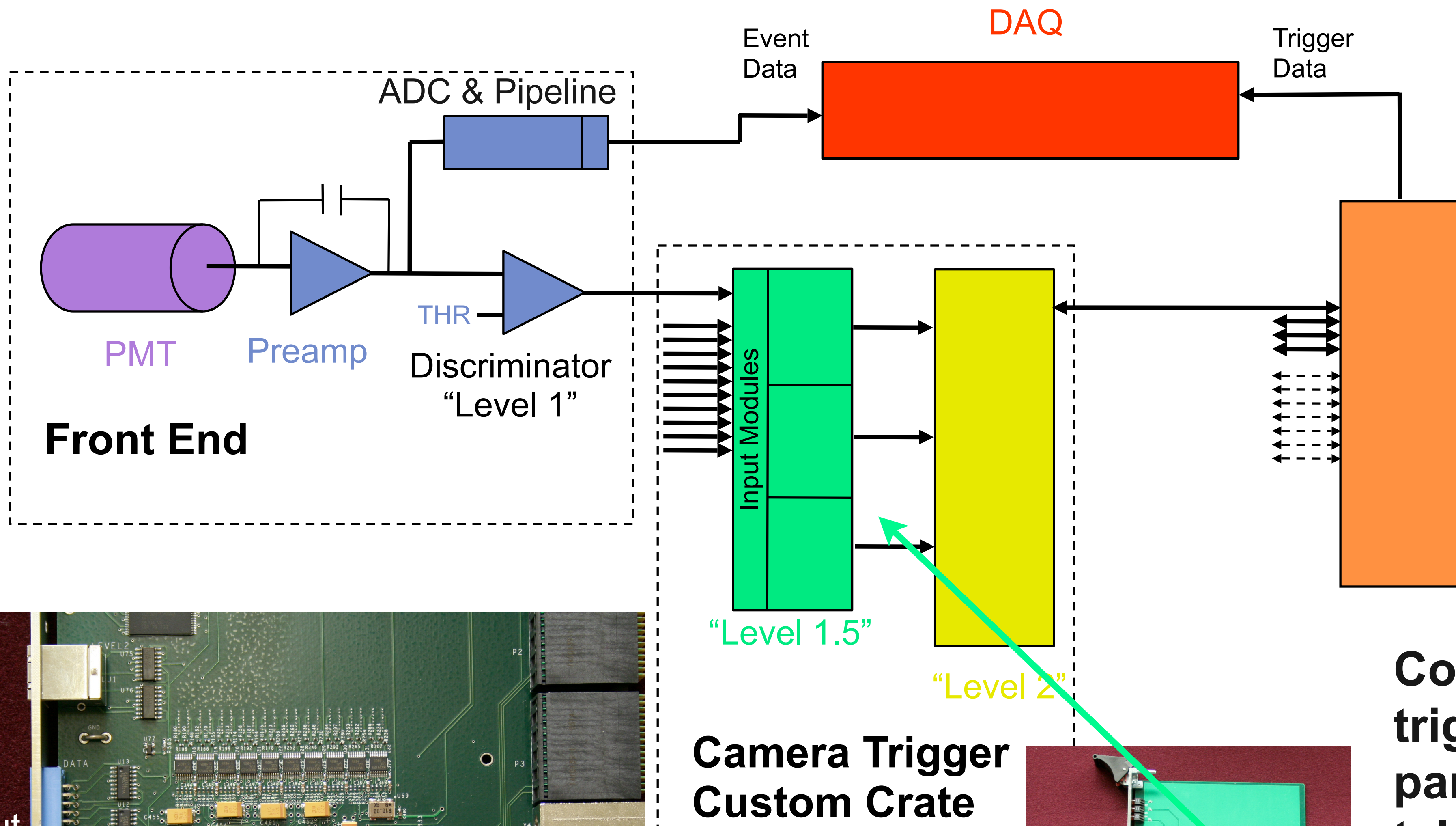
GRB detection
Dark Matter Search
High z Blazars & EBL measure
Pulsars

Implementation:

Fast Topological Trigger
Combine with high Q.E. PMTs

Trigger System Concept

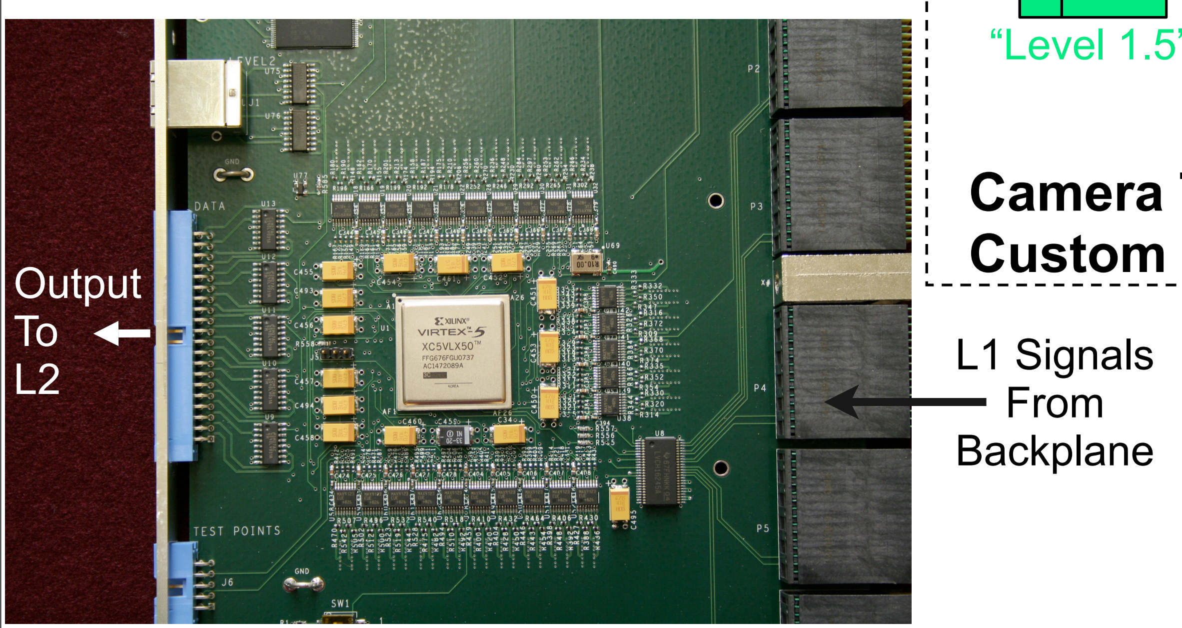
- Multi-Level Trigger System

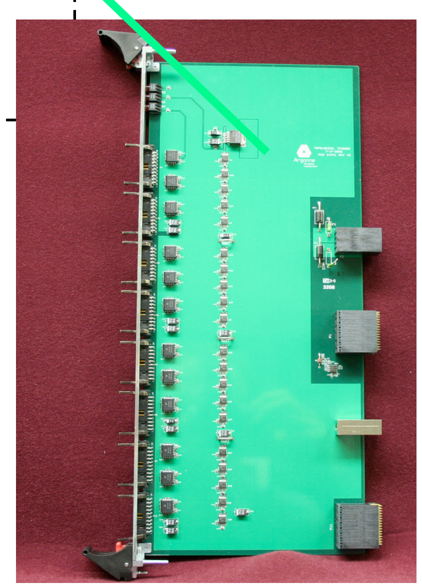


Lvl 1.5:
- 1/region
- receives signals & performs neighbor logic

Lvl 2:
- 1/camera(telescope)
- performs moment analysis

Lvl 3:
- 1 for array
- receives moments & timestamp from Lvl 2
- parallactic analysis
- calculate hold-off from timestamp



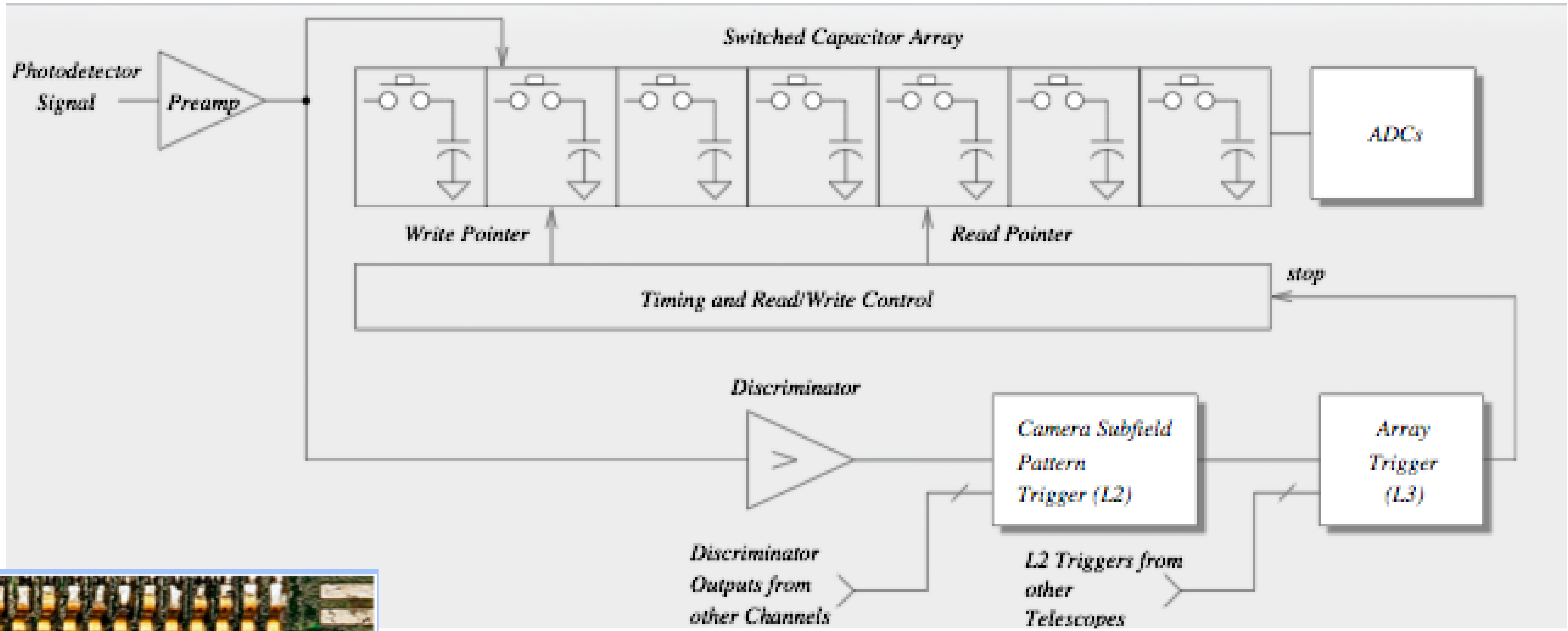


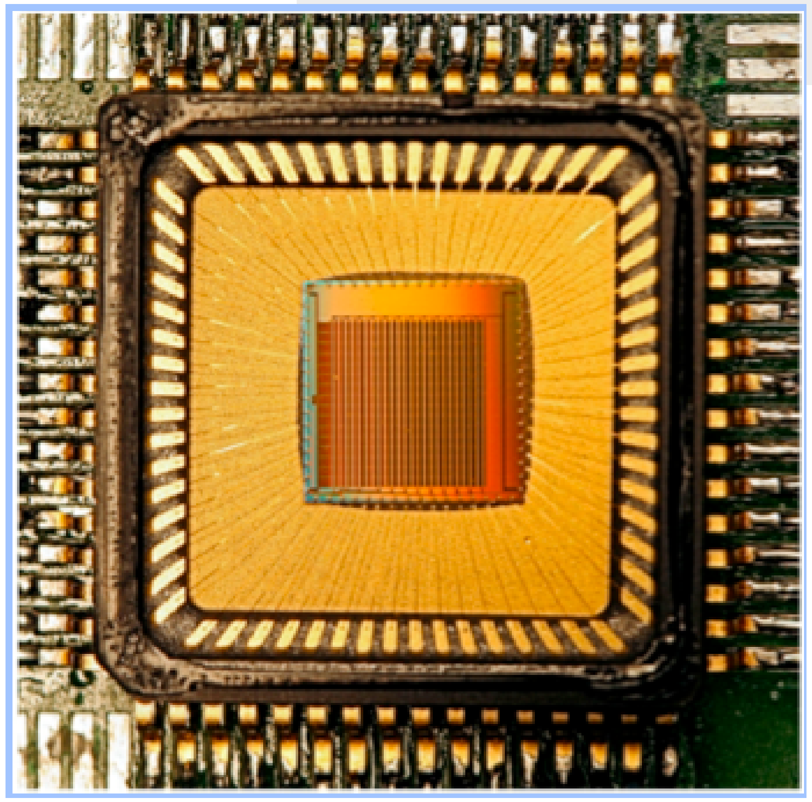
Complete single camera trigger test to be carried out parasitically on one VERITAS telescope this Spring (2009)

Prototype trigger boards in checkout at Argonne

Installation at VERITAS to begin early April.

Readout





Switched Capacitor Array ASIC

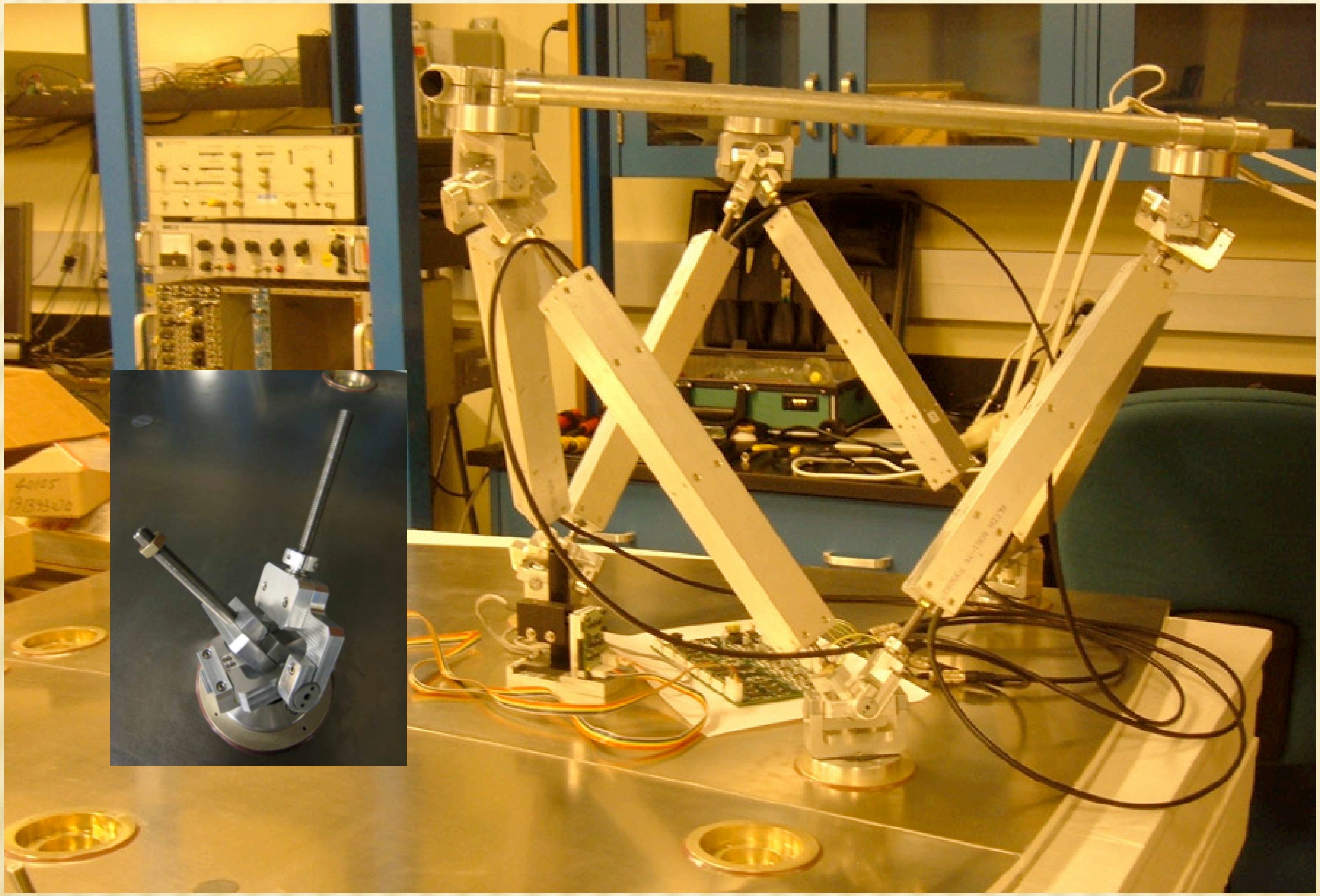
- Digitize in front end; reduce cables from camera
- Gigahertz Sampling; ~8μs latency
- ≥ 8-bit dynamic range
- ~4×10^5 Channels (10^4 pixels/telescope × 36 telescopes)
- Cost: $20-30/ch (target $15/ch) cf. G. Varner for reality check

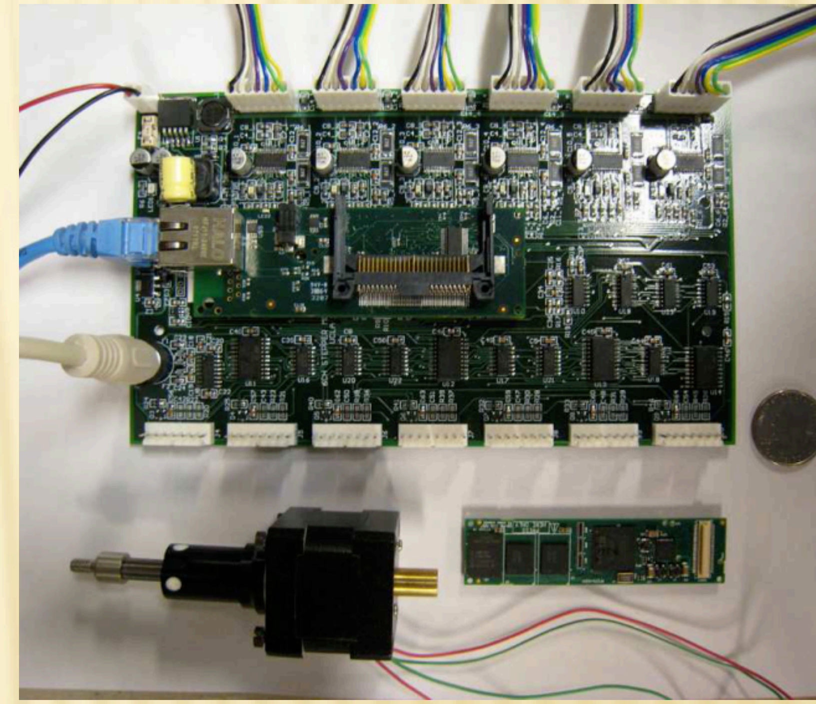
Summary

- **Advanced Gamma-ray Imaging System (AGIS) concept targets a sensitivity increase of order of magnitude compared to present generation IACT arrays**
  - Push limits or discover particle dark matter
  - Study structure of galactic sources
  - Search for TeV counterpart of GRBs
  - EBL and Lorentz Invariance Violation study via AGN (larger Z)
  - Dark accelerators & unexpected new phenomena
- **Design of the Array is maturing with several systems baselined**
  - 36 telescope array of Schwarzschild-Couder instruments
  - MAPMT camera, ASIC readout, topological trigger
  - Site possibilities being explored
- **R&D has been proceeding for past ~2 years and is continuing**
- **Proposals/plans for prototype telescope in next 2 years**
- **Collaboration is established and envisions growing**

Supplemental Material

PROTOTYPING ALIGNMENT SYSTEM (UCLA)





Controller board (embedded computer with OS)

Edge sensor prototype

Prototype Stewart Platform mounted on ALMA mirror
5 degrees of freedom inexpensive joint design

Individual actuators can be positioned with ~1.5 μm
Cost requirements: <2K per hexapod