CF-6 Summary
Gamma Rays & Neutrinos

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Process

- SLAC Meeting (Thanks to Tom Weiler)
  - 31 talks in 6 sessions
  - Detailed scientific areas for exploration across CF-6
- Call for Whitepapers
  - 10 whitepapers submitted (8 on the arXiv)
  - Broad range of topics covering scientific and experimental program for CF-6
- Generation of Tough Questions
- Minneapolis Meeting
  - CF-6/2 Joint session on future experiments
  - CF-6/IF Nu5 joint session on neutrino experiments

Questions and Issues

Nature provides sources of VHE (100 GeV-100 TeV) gamma rays

1) How are particles accelerated to such energies?
2) How can we use these particle beams to probe fundamental physics?

The astrophysics and fundamental physics are entangled.

We must understand 1 to get at the fundamental physics.
(or have methods for controlling systematic errors resulting from our lack of understanding of 1)

The Fundamental Physics

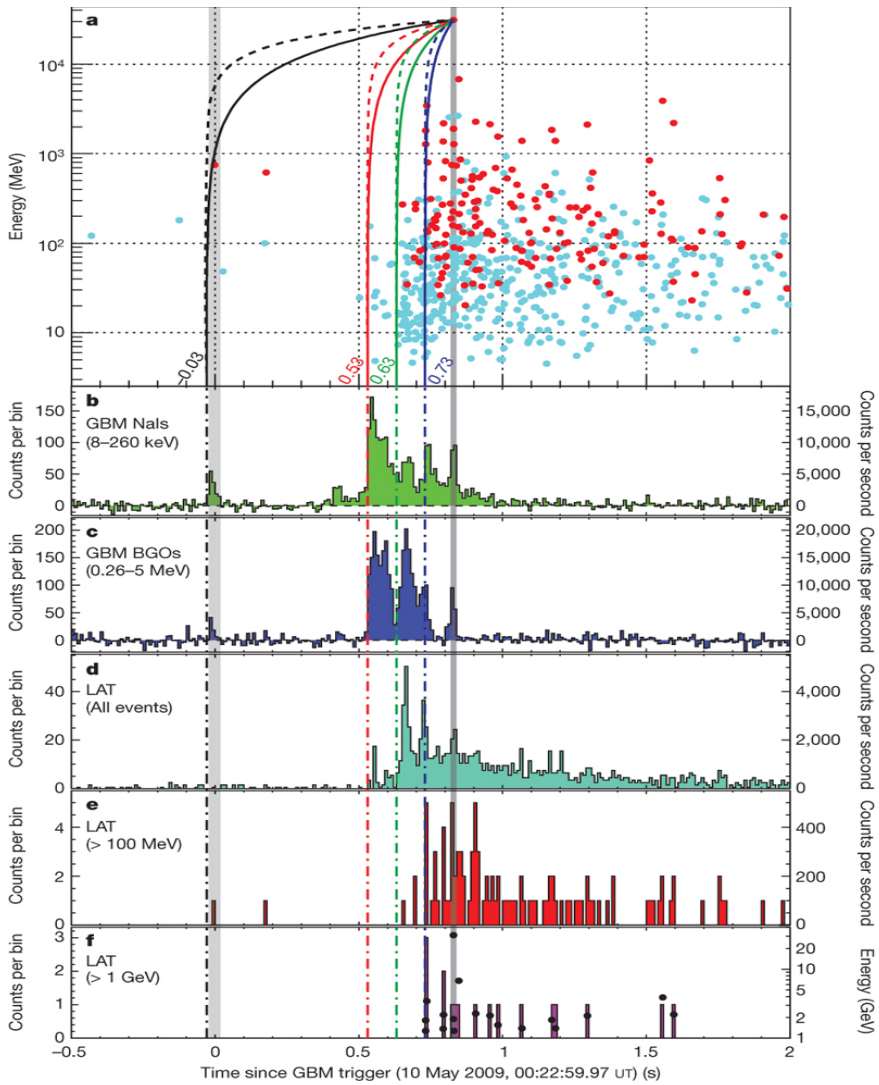
- Indirect WIMP Dark matter (see CF-2 for discussion). Indirect detection has unique capabilities
  - ***Sensitivity to high mass wimps***
  - ***Understanding cosmological evolution of dark matter***
- Non-WIMP Dark Matter
  - Axions (***unique region of parameter space***)
  - ***Q-Balls*** (unique direct detection techniques using CGN experiments)
  - Primordial black holes (*unique sensitivity to final phase of evaporation*)
- Fundamental Symmetries
  - ***Lorentz Invariance*** (window into physics at the Planck scale)
- Cross Sections and new physics
  - ***JEM-EUSO 300 TeV C-M energy of collisions (already hints of non-standard interactions at Auger)***
  - ***High-Energy neutrino cross sections sensitive to extra dimensions***
- Neutrino mass hierarchy
  - Supernova neutrinos (LBNE)
  - Atmospheric neutrinos (PINGU)

Lorentz Invariance Violation

- Vacuum dispersion relation for photons
- Energy dependent speed of light
- Physics at Planck scale
  - Quantum Gravity
  - String Theory
- Can not directly probe this energy scale

$$\frac{\mathrm{v}(p)}{c} = 1 + \zeta_1 \left(\frac{p}{E_{LIV}} \right) + \zeta_2 \left(\frac{p}{E_{LIV}} \right)^2 \qquad \Delta t \approx \frac{1}{\zeta_n} \left(\frac{\Delta E}{E_{LIV}} \right)^n \frac{L}{c}$$

Testing LIV with Gamma-Ray Bursts



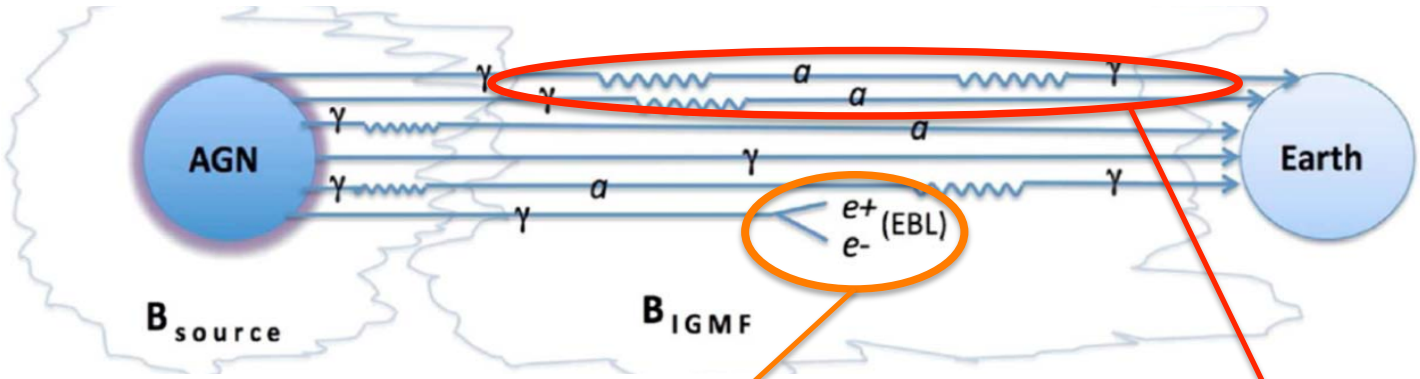
- GRB 090510
- Z = 0.9
- Timescale < 1 sec
- **E^1_{LIV}>1.5x10^{19} GeV**
- E^2_{LIV}>3x10^{10} GeV
- Background: Source effects – energy dependent acceleration times

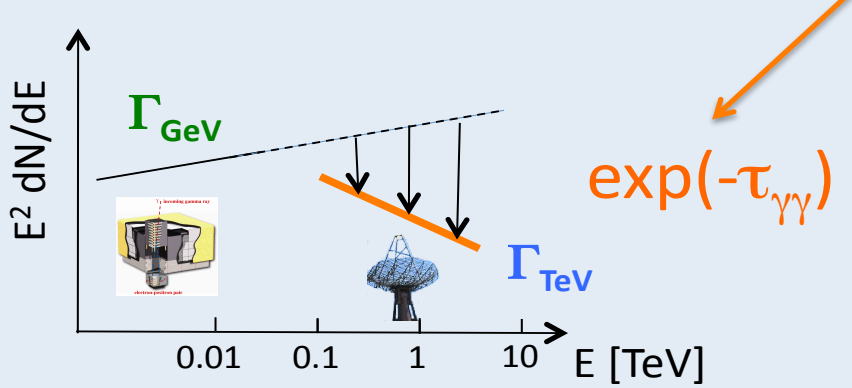
From N. Otte, SLAC meeting

Axion-like Particles

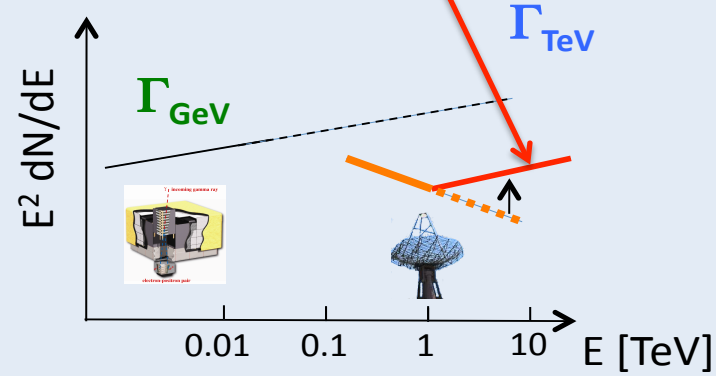
- Axions (CF-3)
  - Solve the strong CP problem
  - Dark matter candidate
- Axion-like particles: coupling and mass not related ($g_{a\gamma} \neq 1/m_a$)
- Extragalactic background light (EBL) leads to energy dependent absorption of VHE gamma rays ($E_{TeV} \sim 0.9\lambda_{\mu m}$)
- Expected spectrum = Intrinsic AGN spectrum + EBL absorption
  - search for deviations from measured spectrum
  - Too little absorption indication of gamma-alp mixing or UHECR production at AGN + secondary gamma-ray cascades in CMB
  - VHE variability (>1 TeV) of distant AGN (> 0.15) will resolve UHECR vs ALP debate

Signatures from the EBL & ALP





- Absorption of primary γ-rays by diffuse EBL
- spectra soften
- effect increases with distance (redshift z)

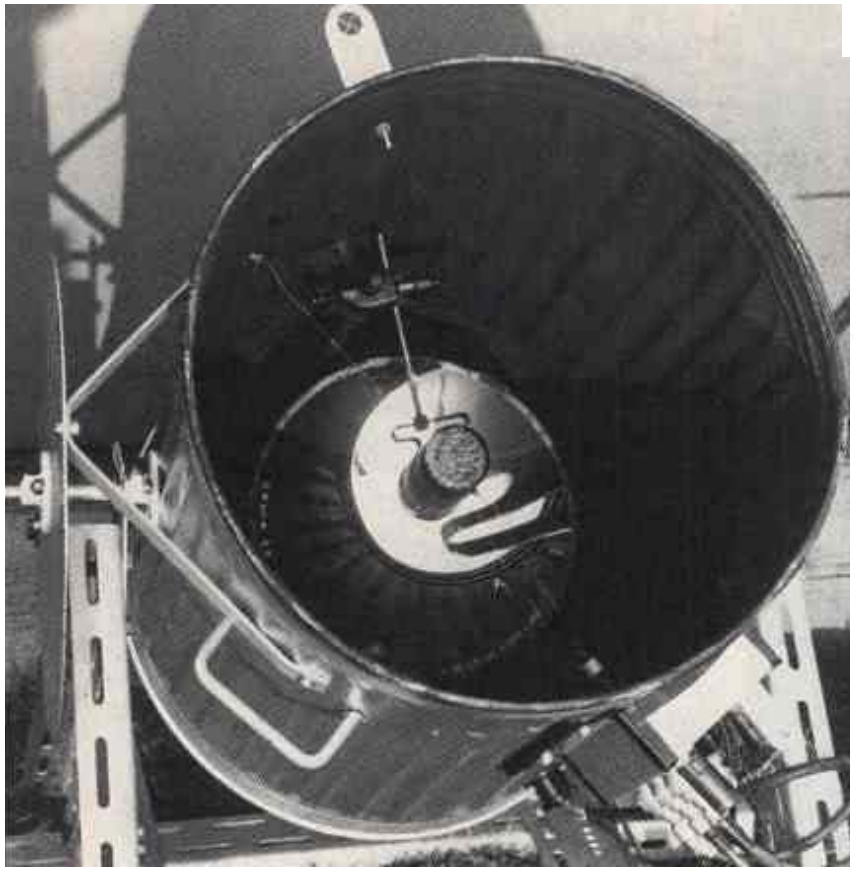


- component arises from **secondary γ-rays** generated by ALP-photon mixing
- spectra harden – characteristic energy
- **but spectral rise** may **not** be unique!

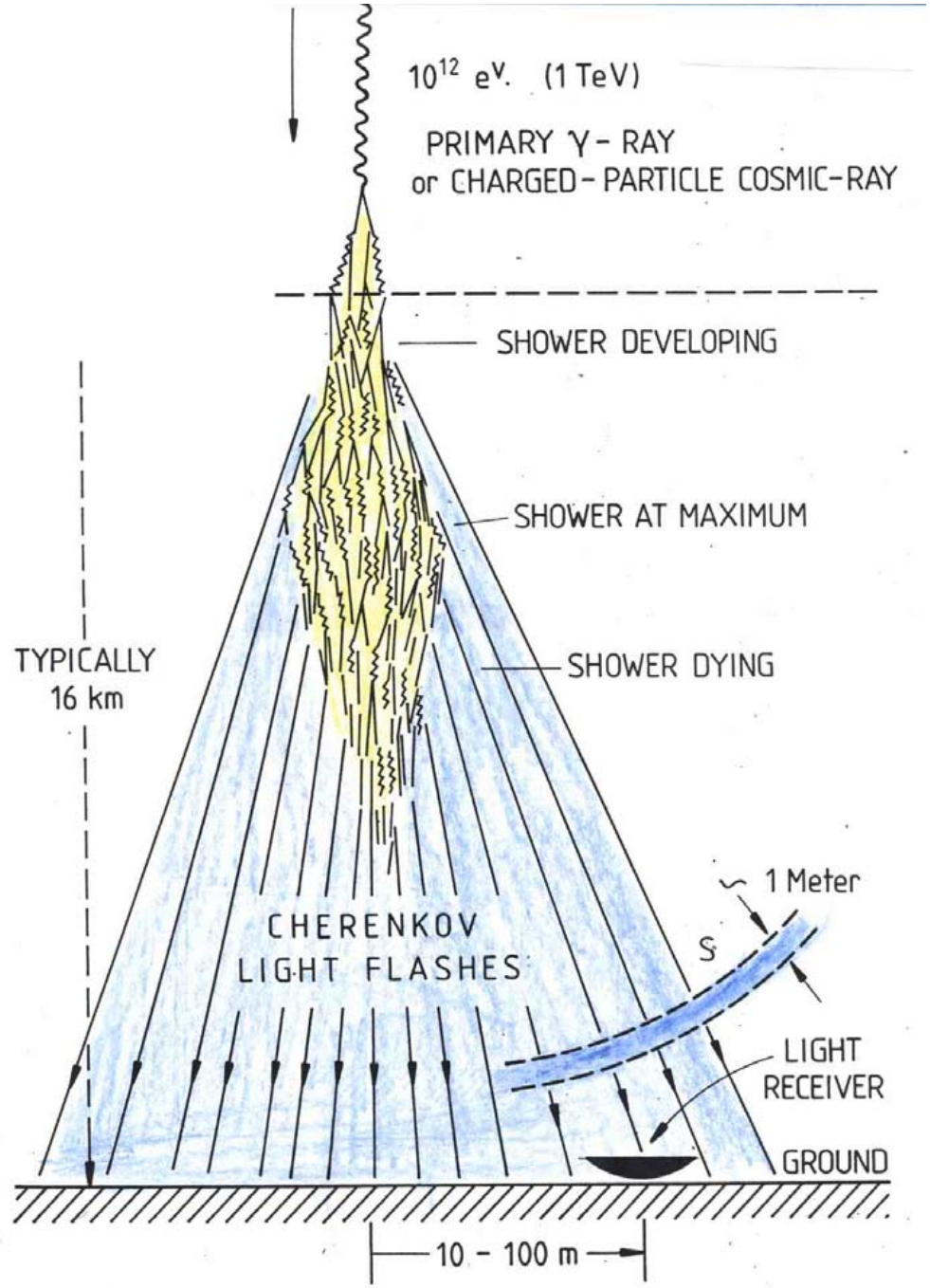
From Krennrich (SLAC meeting)

Physics	Technique	Background	Solution
Axions	AGN spectra	Intrinsic spectra EBL level UHECR production of secondary gammas	Many AGN large redshift range, precision spectra (100 MeV->TeV) particle acceleration Variability EBL knowledge
LIV	AGN/GRB timing	Acceleration mechanism	Many sources large redshift range particle acceleration
Primordial Black Holes	Short burst search	Gamma-Ray Bursts	Precision spectra and time evolution
Q-Balls	Direct Detection	N/A	N/A
Particle Acceleration	Multi-wavelength		Precision multi-λ spectra Variability Multi-messenger?

Detection of VHE Gamma Rays



1951 Galbraith & Jelley
Phototube in garbage can!



Modern VHE Gamma-Ray Instruments

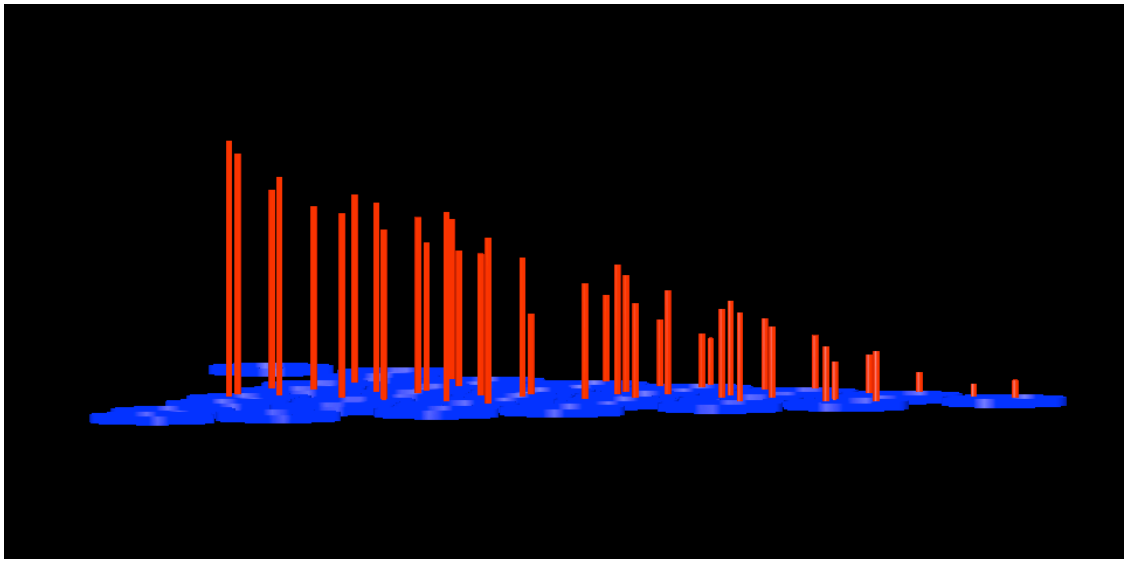
VERITAS: Pointed high sensitivity instrument

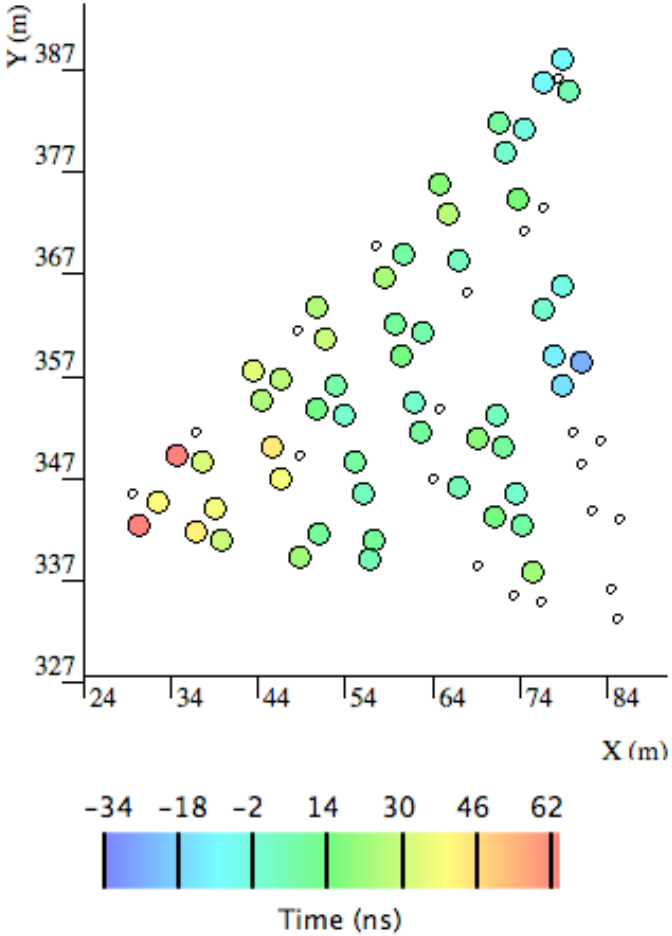
HAWC: All-sky instrument

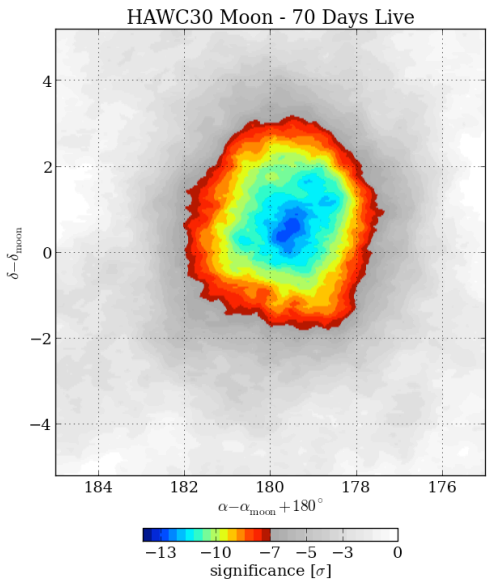
HAWC

- All-sky VHE observatory 100 GeV – 100 TeV
- 15x sensitivity of previous all-sly instrument (Milagro)
- Continuous 24/7 operations (>95% duty cycle)
- Observe every source in 8sr every day
- Science Strengths
  - Transient phenomena (GRB, AGN, XRBs)
  - Large & extended sources (diffuse emission, PWN)
  - Highest energies
  - High mass WIMPs, Q-Balls, Primordial Black Holes
  - Multi-wavelength studies of many sources
  - Alert for VERITAS (~same longitude) and other IACTs
- Begin operations with 100 tanks yesterday
- 250 tanks complete in 8/2014

HAWC-30 Completed Sept 2012



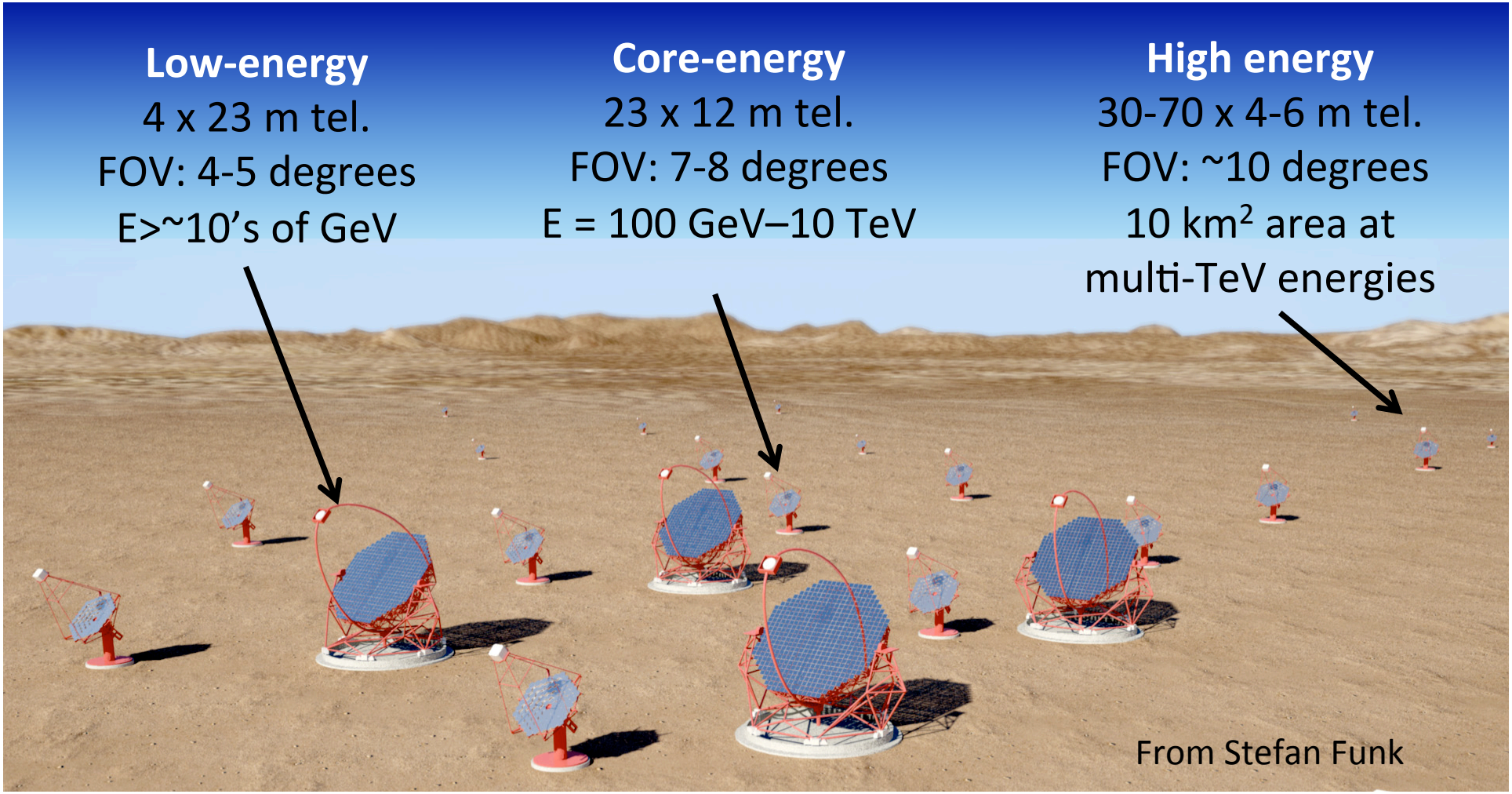




HAWC 30 Events and
Observation of cosmic-ray shadow of
Moon with 70 days of data

From B. Dingus

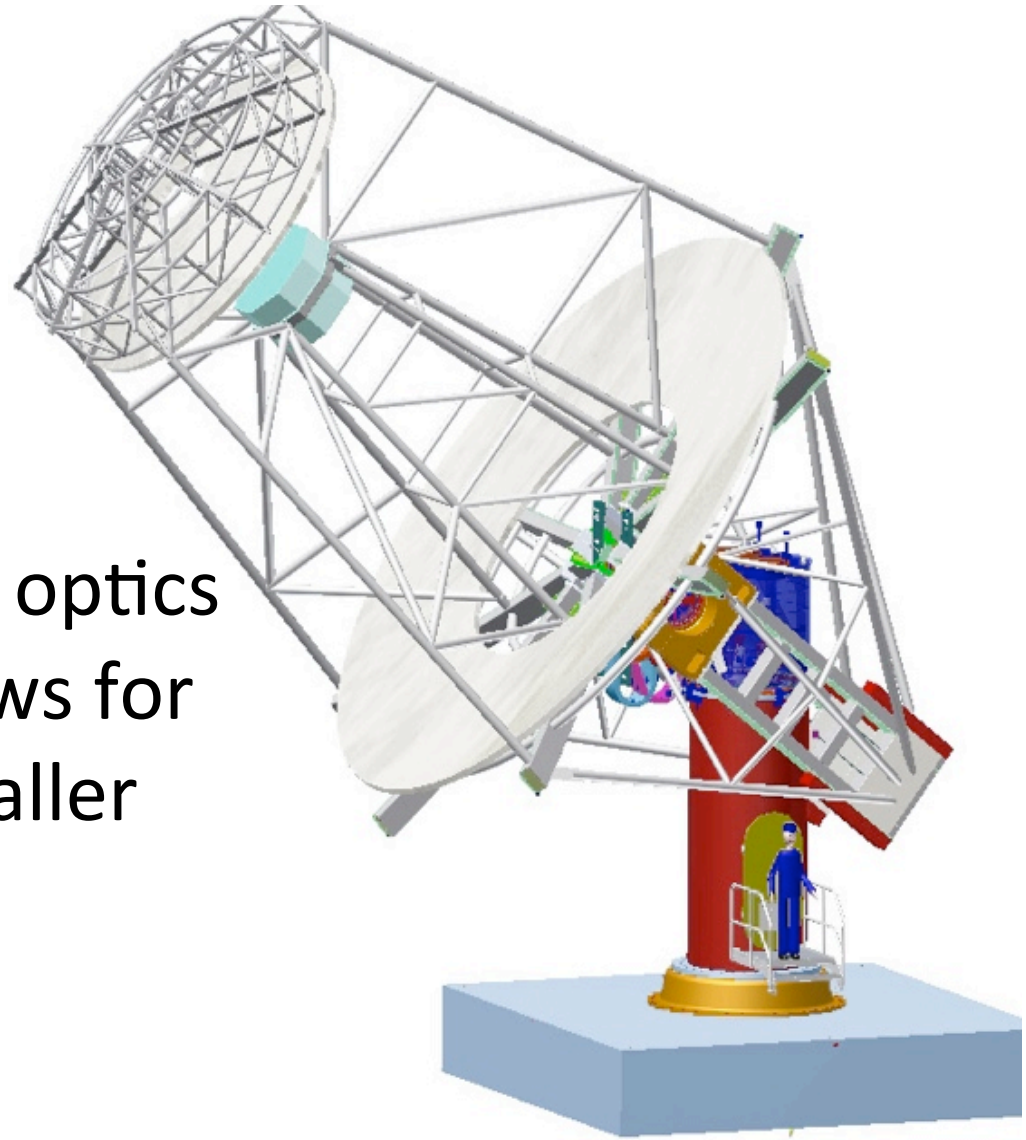
CTA



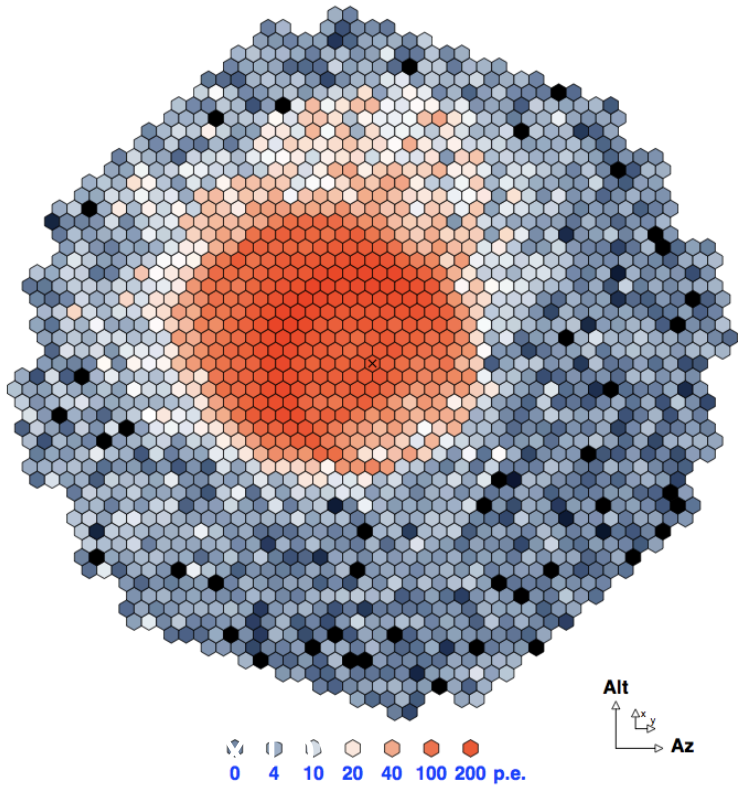
~10x sensitivity of current IACTs

U.S. Contribution to CTA

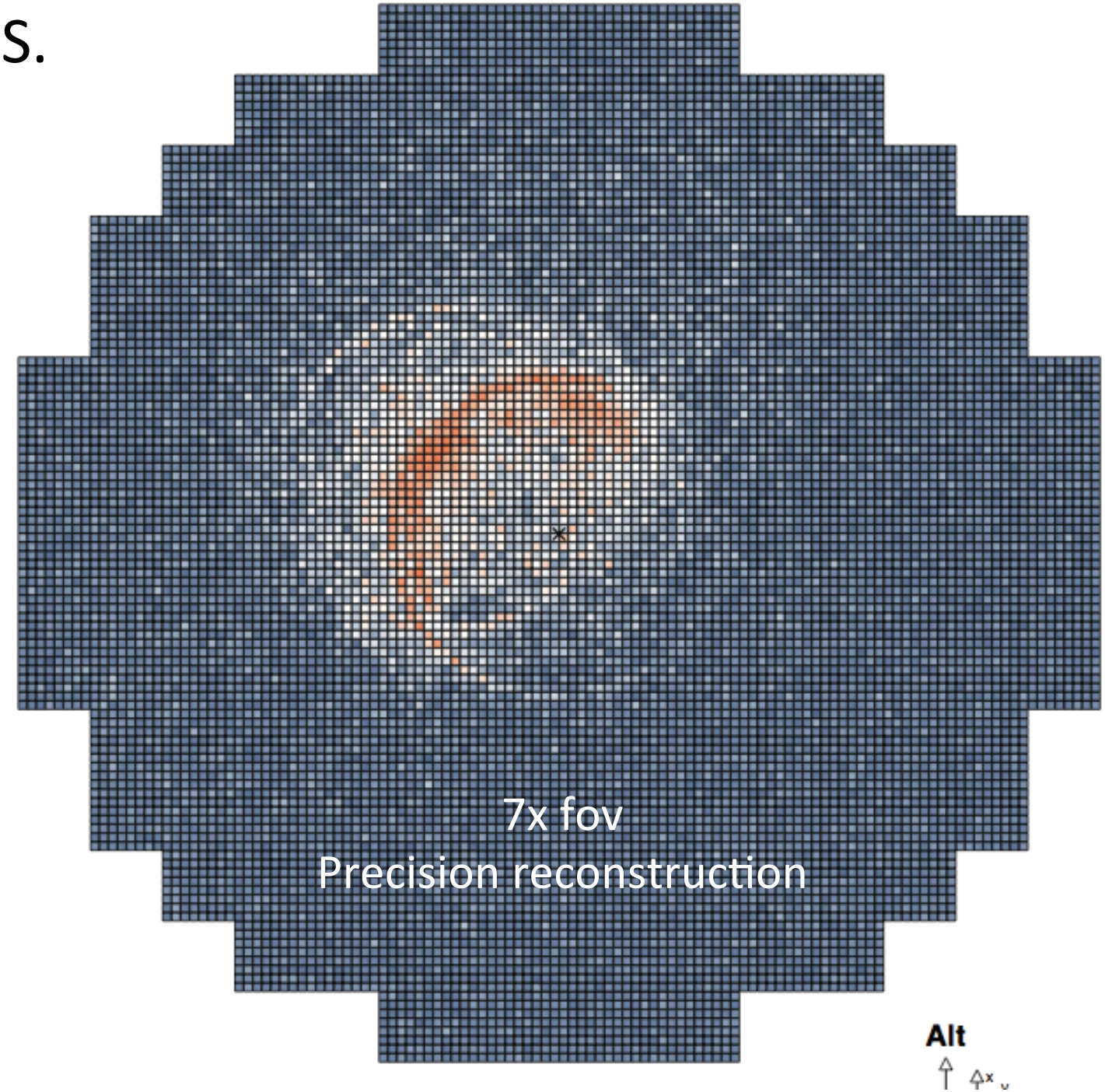
- 23 mid-sized systems (double)
- Schwarzschild-Couder optics
- Secondary mirror allows for larger fov (7x) and smaller plate scale



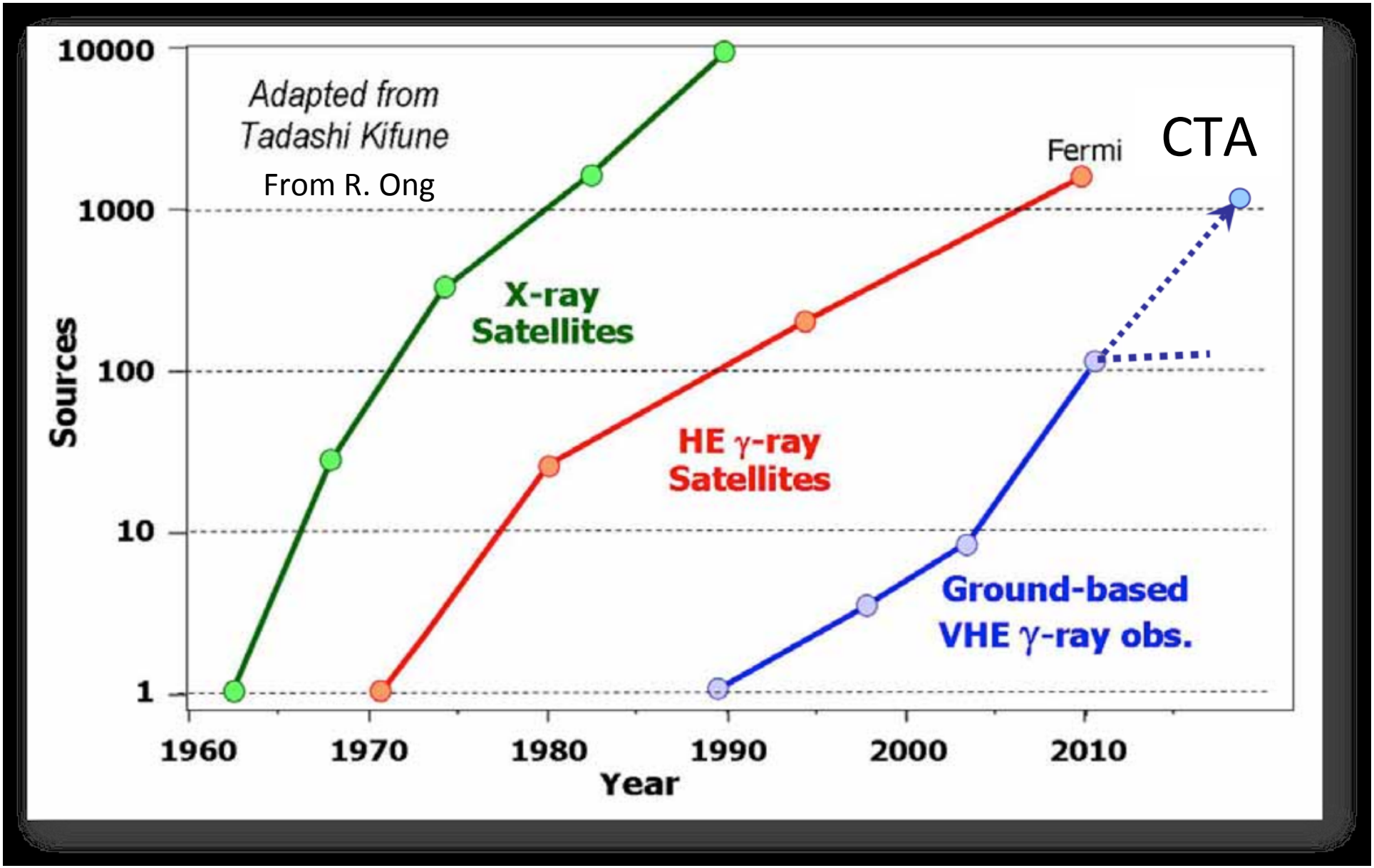
CTA Baseline: Proton image in mid-size telescopes



CTA-U.S.



Progress in Gamma Rays

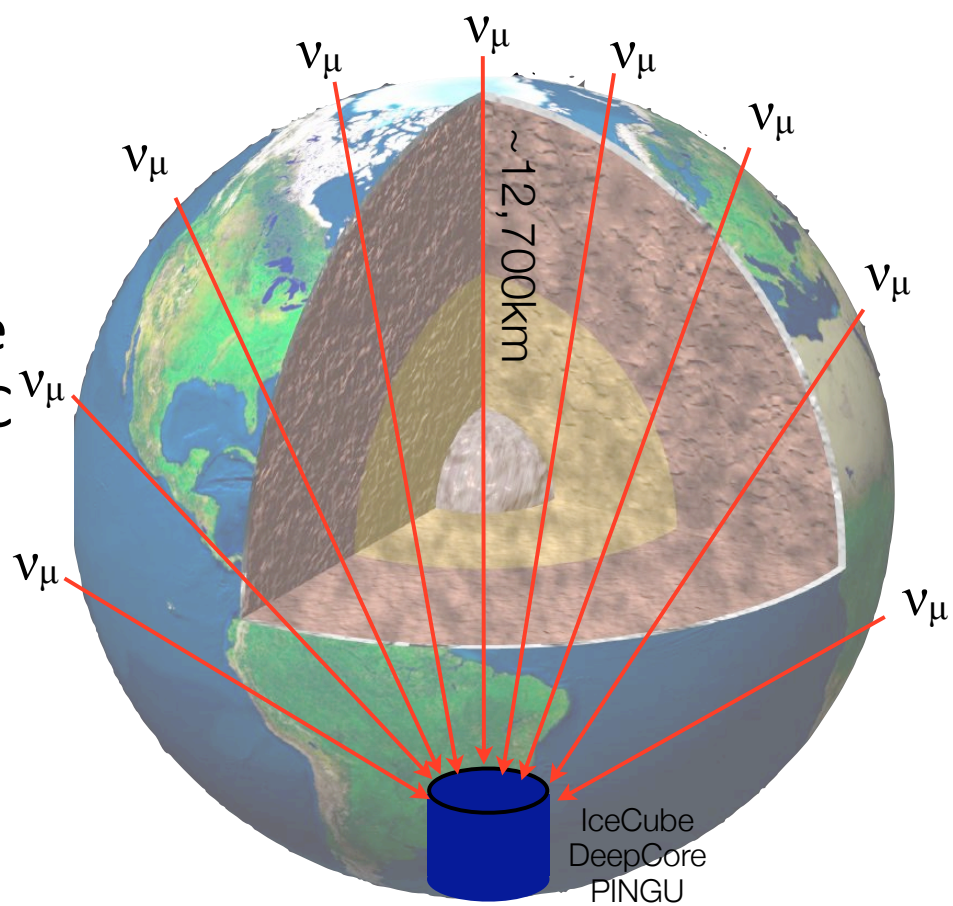


Neutrino Mass Hierarchy

- Mass hierarchy and CPV leading outstanding issues in neutrino physics (leptogenesis)
- Long baseline accelerator experiments are one approach
- Supernova and atmospheric neutrinos can also be sued to determine the mass hierarchy

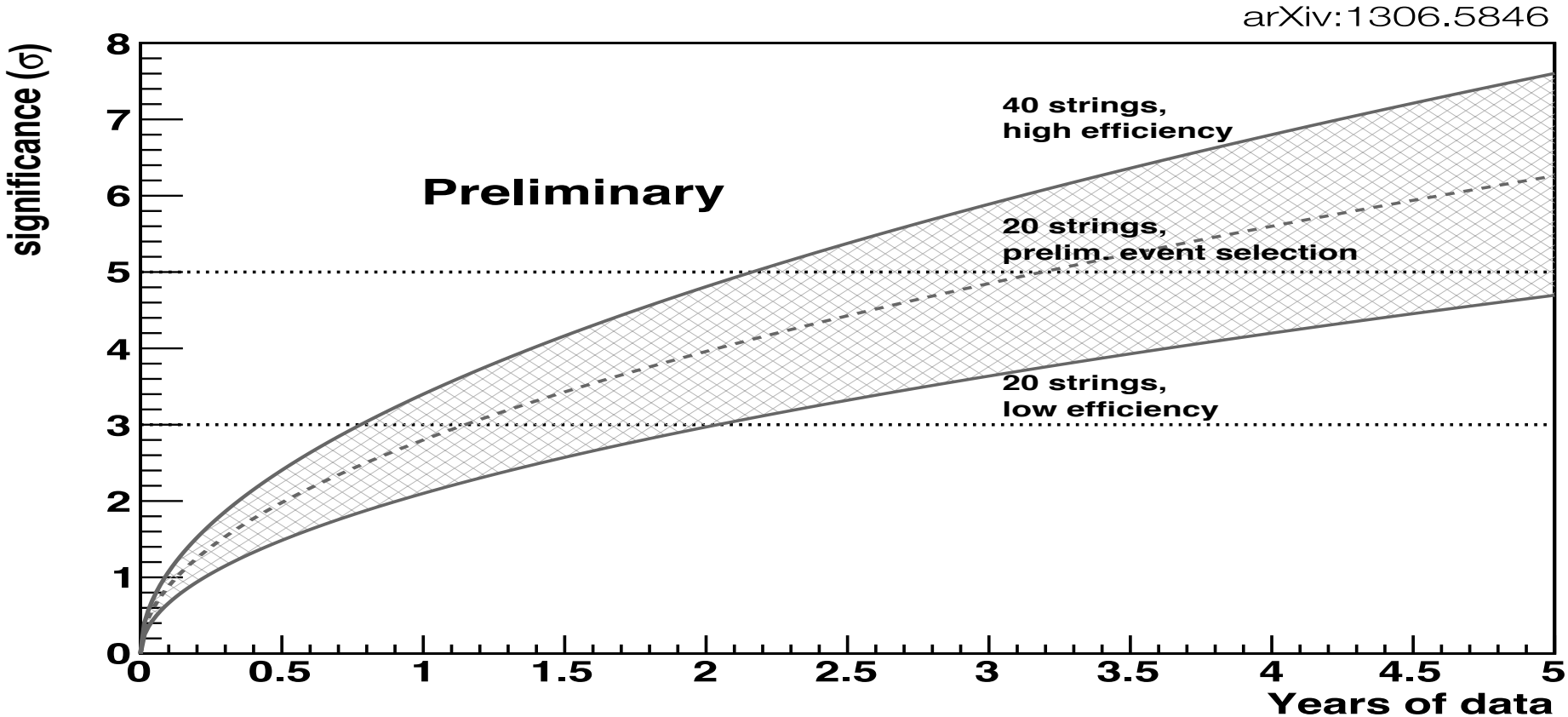
PINGU

- Atmospheric neutrinos provide many values of L and E
- Very large baselines for probing matter effects (~12,700 km)
- Add ~40 strings inside DeepCore
- 20-25m string spacing (73 for DC and 125 for IC)
- Cost ~$60M



PINGU

- ν_μ disappearance experiment
- 5-20 GeV energy range



Summary

- We are entering an era of precision VHE gamma-ray astrophysics
  - Unprecedented angular and energy resolution
  - Unprecedented sensitivity (1000-fold increase 1990)
  - Huge energy range (100 MeV – 100 TeV)
  - Large number of sources (and source classes)
  - Will enable understanding of astrophysical processes
- Extraction of fundamental physics possible with future instruments (operated simultaneously)
  - Fermi, HAWC, VERITAS → CTA
- Neutrino mass hierarchy possible with SN neutrinos (LBNE) and/or atmospheric neutrinos (PINGU)