# Trinity

## An air-shower imaging instrument to detect ultra-high energy neutrinos with the Earth skimming technique


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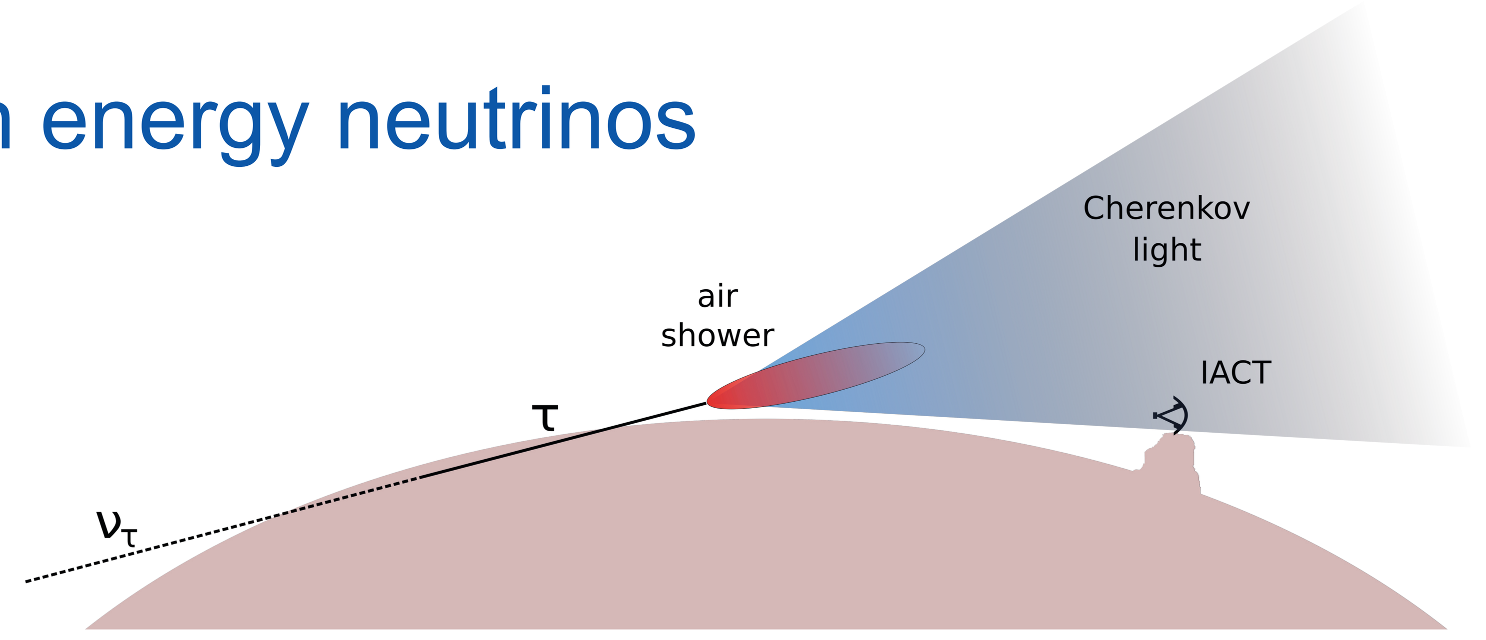
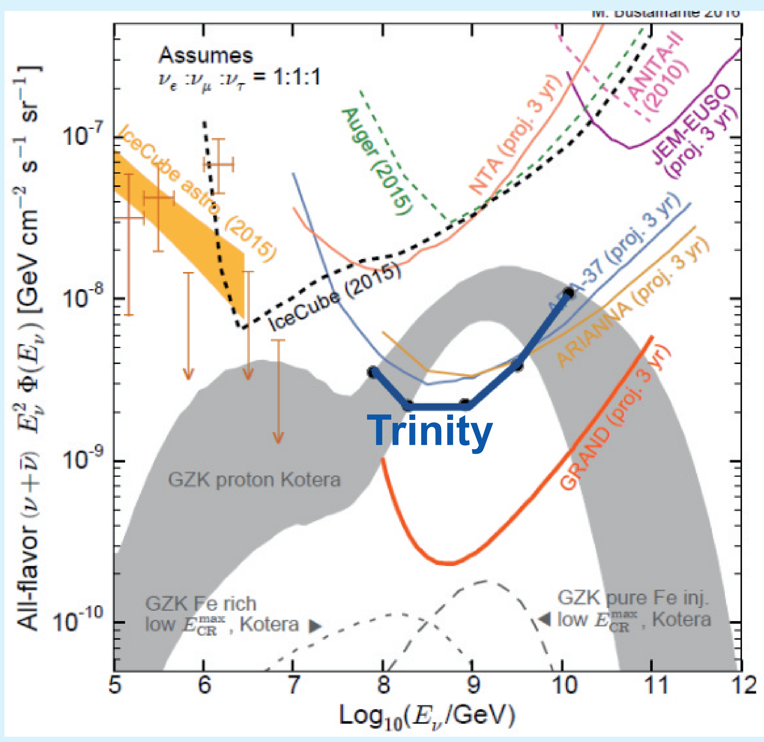
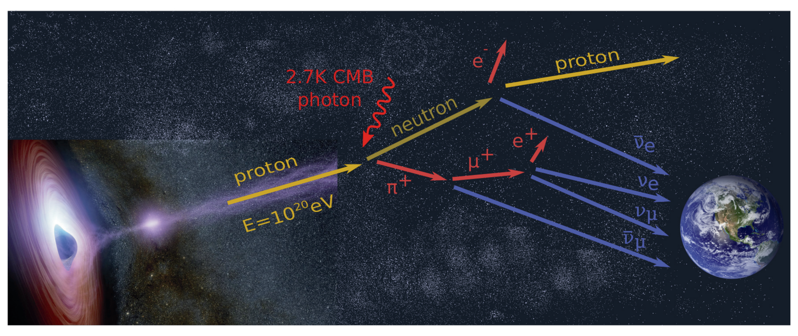



## Summary


- A modest air-shower imaging system can achieve competitive sensitivity to ultra-high energy (>$10^8$ GeV) neutrinos.
- Gamma-ray Cherenkov telescopes like MAGIC and VERITAS and fluorescence detectors like AUGER-FD, HiRes, and Telescope Array have shown that the technique works.
- Recent advances in Silicon photomultipliers and the availability of low cost digitization systems make Trinity feasible.


## Science Cases

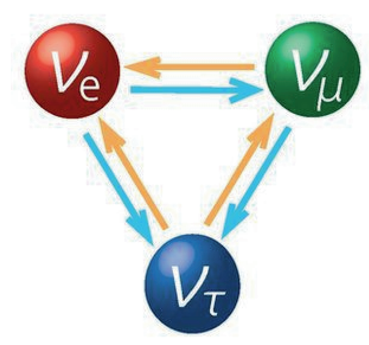



**Composition of ultra-high energy cosmic rays**
- UHE neutrions are produced through interaction of UHECR with CMB photons
- Protons produce more UHE neutrinos (GZK mechanism)
- Heavy elements produce fewer UHE neutrinos (photodisintegration)

**Astrophysical Neutrinos**

Extension of IceCube detected astrophysical neutrino flux to higher energies
- Spectral shape and flux levels help identify and exclude source classes
- Possible detection of sources

**Neutrino flavor mixing at ultra-high energies (>$10^8$ GeV)**
- Comparison of fluxes measured by techniques sensitive to different flavors (Earth-skimming is only sensitive to tau neutrinos)



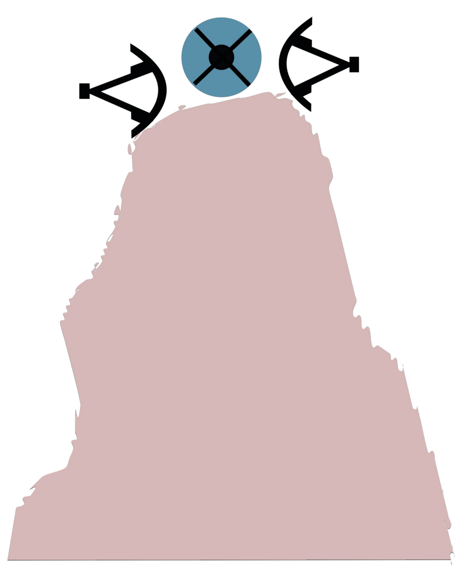

## Study Objective

**Can an air-shower imaging system deliver compatitive sensitivity to ultra-high energy neutrinos?**

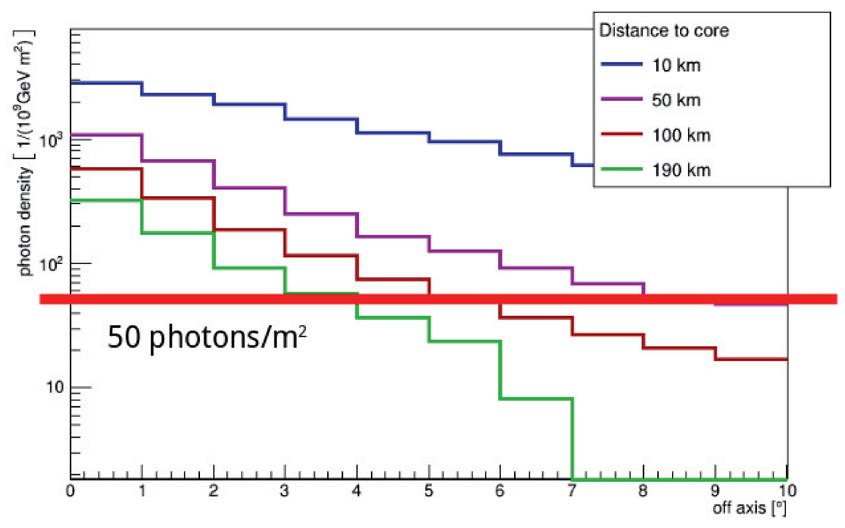
## Detector Configuration

System of wide field-of-view Cherenkov telescopes
- 360° coverage in azimuth
- 5° field of view in the vertical
- positioned 1-2 km above ground
- unobstructed view of the horizon
- 1 m$^2$ light collection area in any direction
- minimum signal to trigger 50 photons

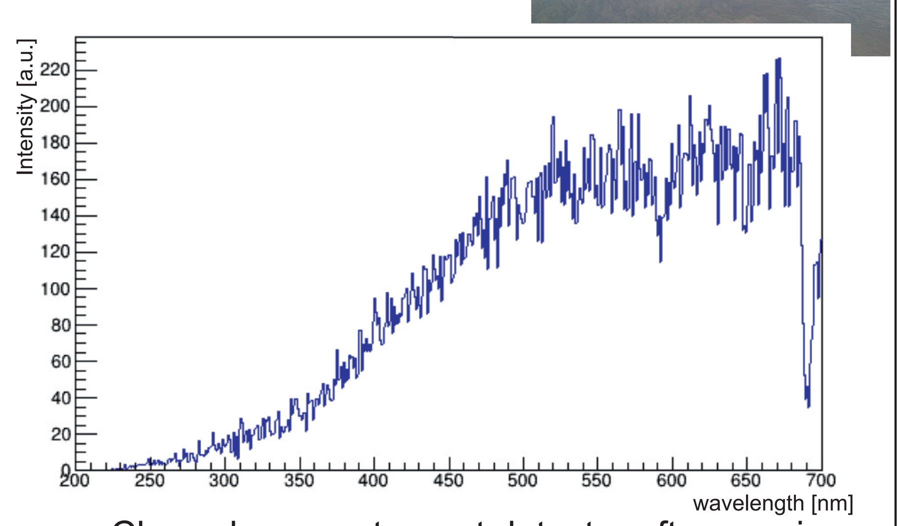
The studied configuration has not been optimized.



## Cherenkov Intensity at the Detector




Photon intensity after absorption for different distances to the air shower

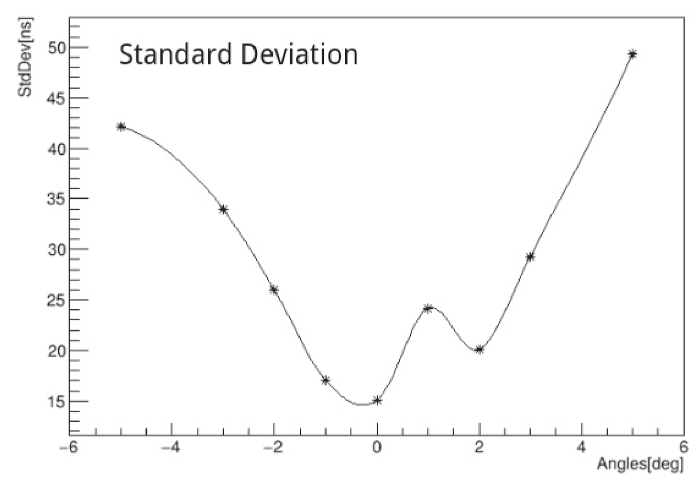



Cherenkov spectrum at detector after passing through 190 km of atmosphere

## Photon Arrival-Time Distribution

- Shower started 1.5 km above ground
- 88° zenith angle
- Distance to detector 100 km

10 ns to 40 ns spread requires only modest sampling speed of readout of 100 MS/s

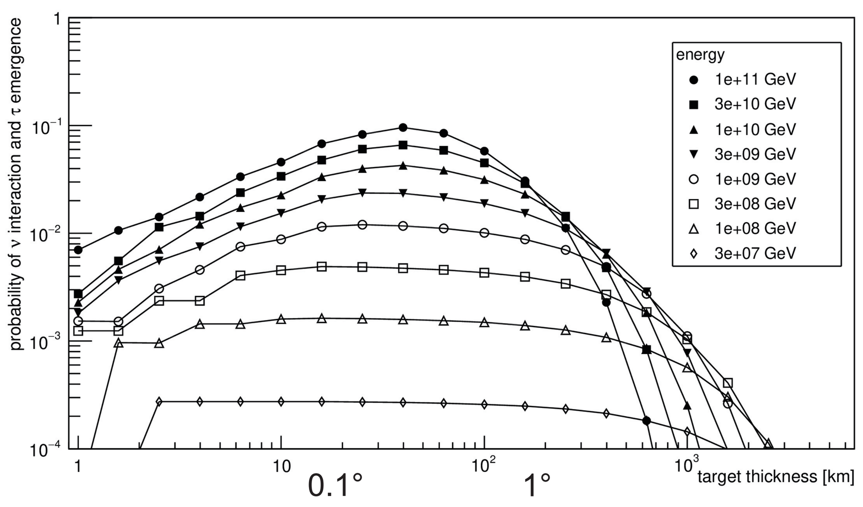


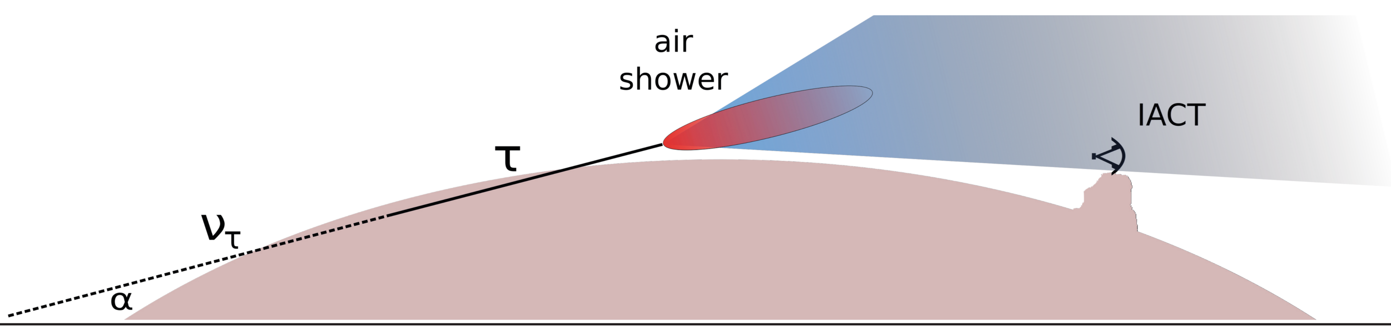

## Vertical Acceptance

Determined by neutrino interaction length and tau decay length

Useful target thickness for rock (ρ = 2.65 g/cm$^3$) ~10 ... ~200 km

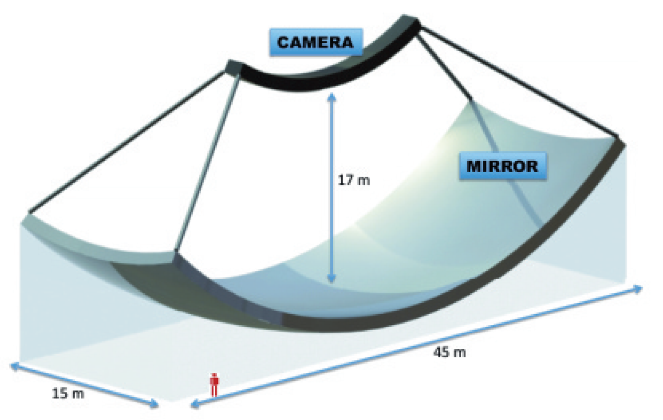
**Range of neutrino angle of incidence alpha = ~0.1° to ~1°**




## Optics

- 5° x 60° field of view
- D=1.2 m, f=1.2 m, f/D=1
- Mirror surface: 1.2 m x 2.5 m
- 90% containment: 0.42°
- plate scale factor: 20.9 mm/deg
- Camera size: 105 mm x 1254 mm = 0.13 m$^2$
- Pixel size: 6 mm x 6 mm, 0.3° diameter → 3622 pixel
- Light concentrator: factor 4 → sensor size 3 x 3 mm$^2$




A transit imaging atmospheric Cherenkov telescope to survey half of the very high energy γ-ray sky
J. Cortina, R. López-Coto, A. Moralejo
Astropart.Phys. 72 (2016) 46-54

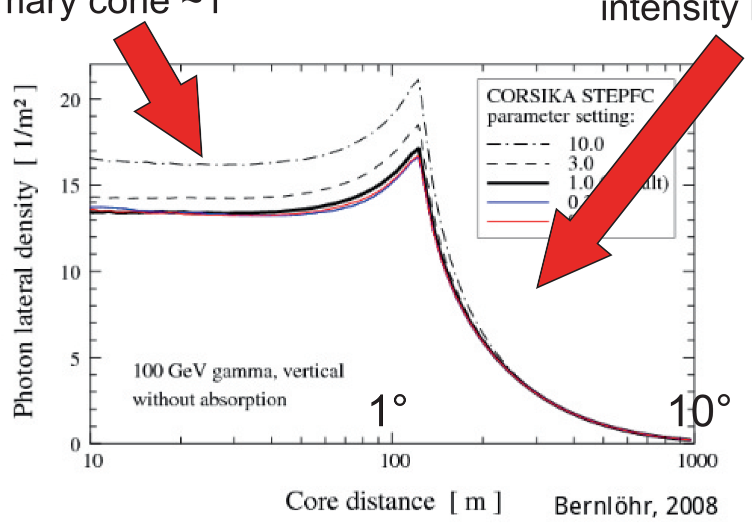
## Off-Axis Shower Imaging

How far off-axis can an UHE air-shower be imaged?

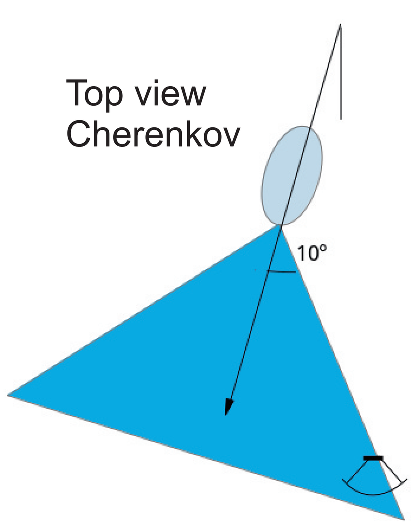
**Cherenkov Emission**

Constant Intensity within primary cone ~1°

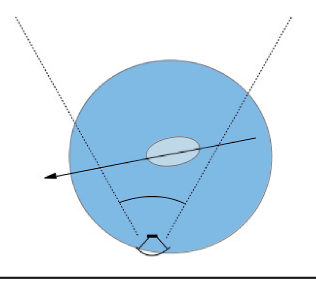
Exponential decaying intensity beyond 1°




High absolute Cherenkov intensity allows to image showers far into tails.

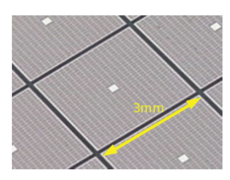


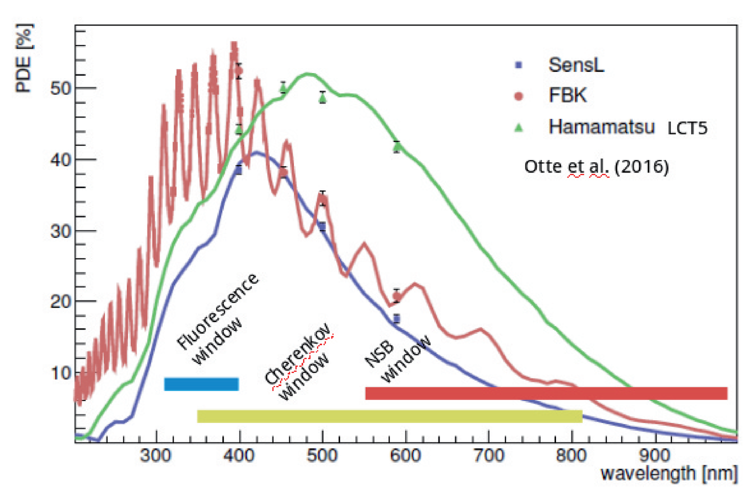

**Fluorescence Emission**
- Isotropic = 360° viewing angle
- Detectable if shower develops within several 10 km of detector




## Silicon Photomultipliers

- Mature photosensor technology
- Available in sizes 3 mm x 3 mm to 6 mm x 6 mm
- Sensitive in the right wavelength range
- Optical Crosstalk of 1% - 6% does not limit performance
- Dark-count rate of 50 kHz/mm$^2$ is below ambient photon background
- Can observe in bright moonlight -> 20% duty cycle






## Signal Chain

- SiPM with light concentrator
- ASIC (e.g. MUSIC) for bias control, shaping and amplification
- Sampling with 100 MS/s FADC, 8-bit resolution
- Alternative option for digitization:
AGET chip: a 100 MS/s, 512 cell switch capacitor array