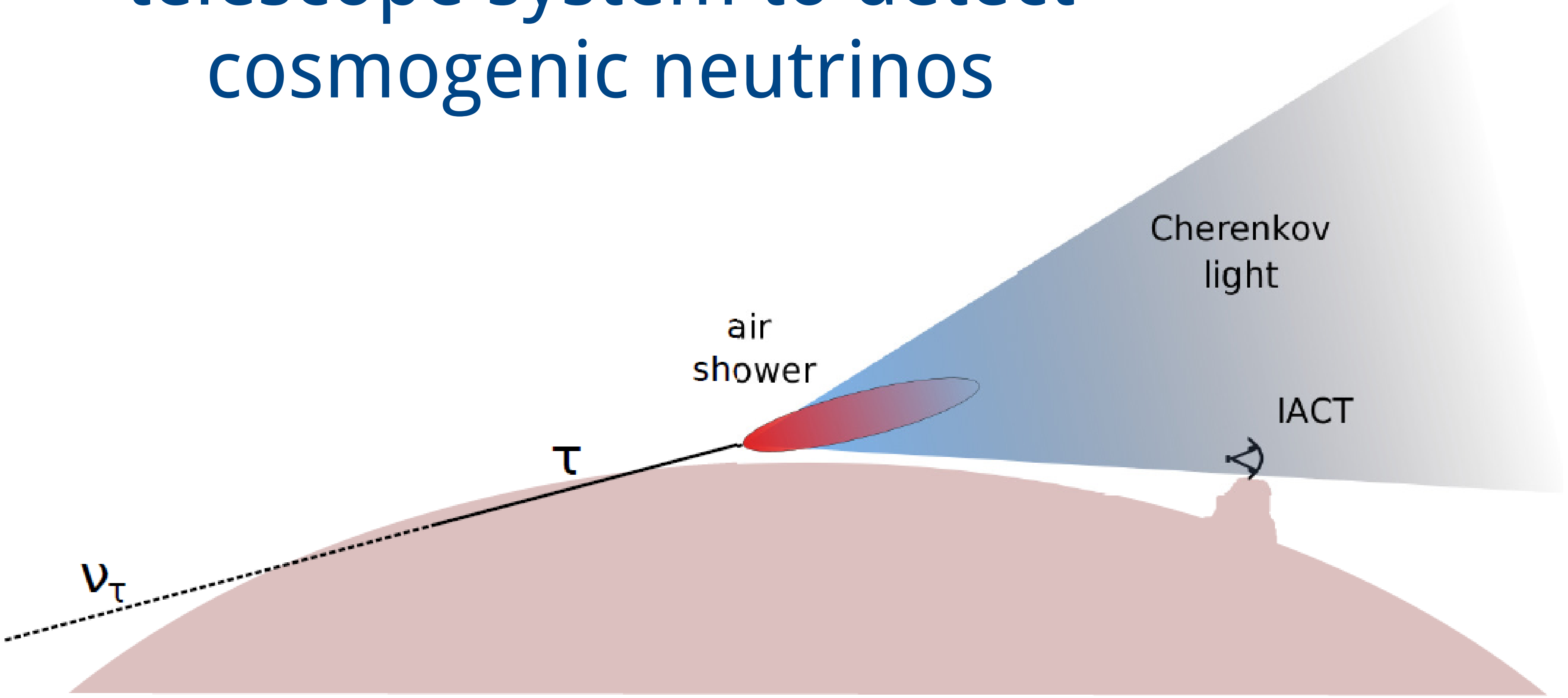
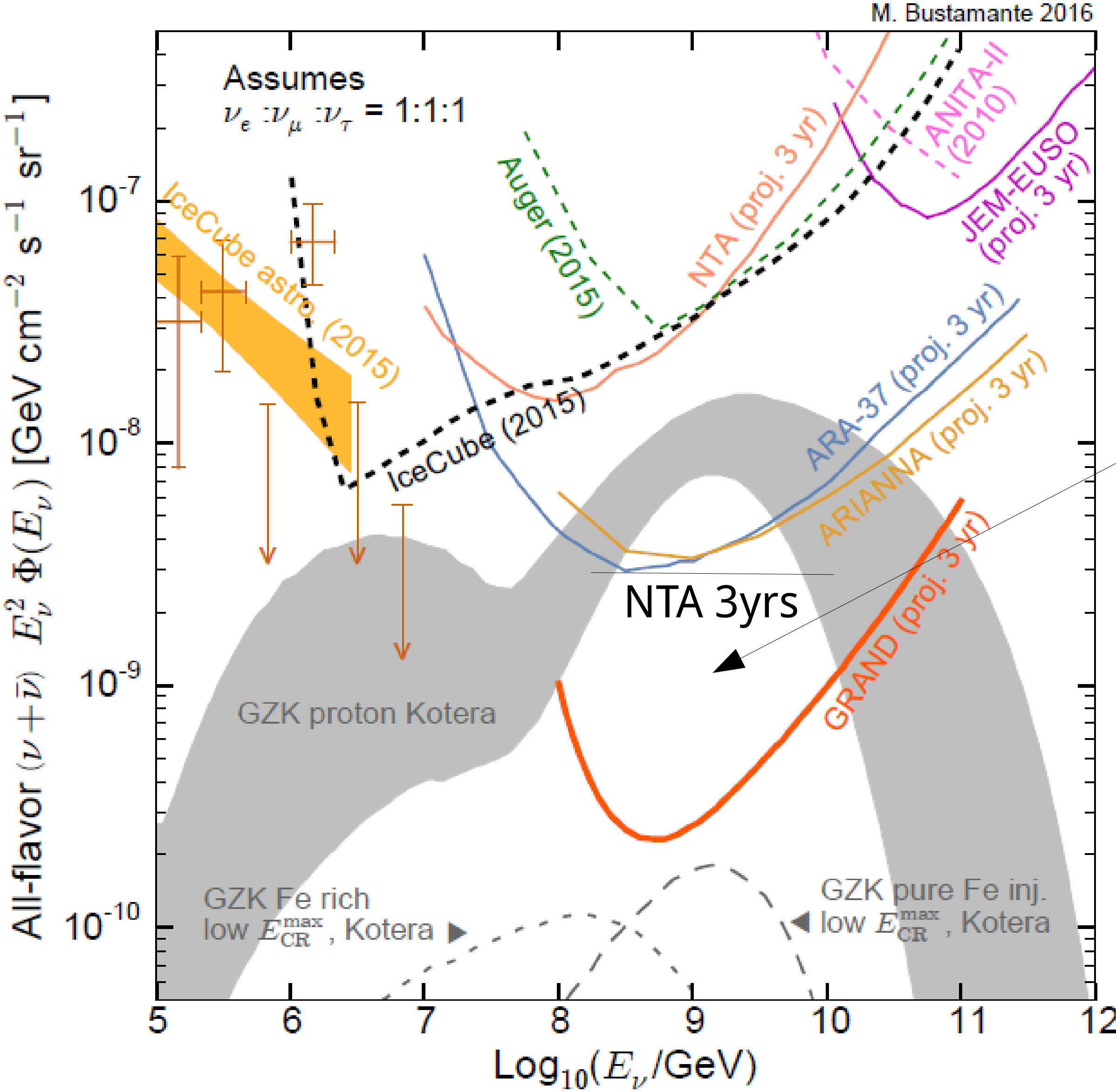
Trinity
A Cherenkov/fluorescence telescope system to detect cosmogenic neutrinos



Nepomuk Otte

School of Physics
&
Center for Relativistic Astrophysics



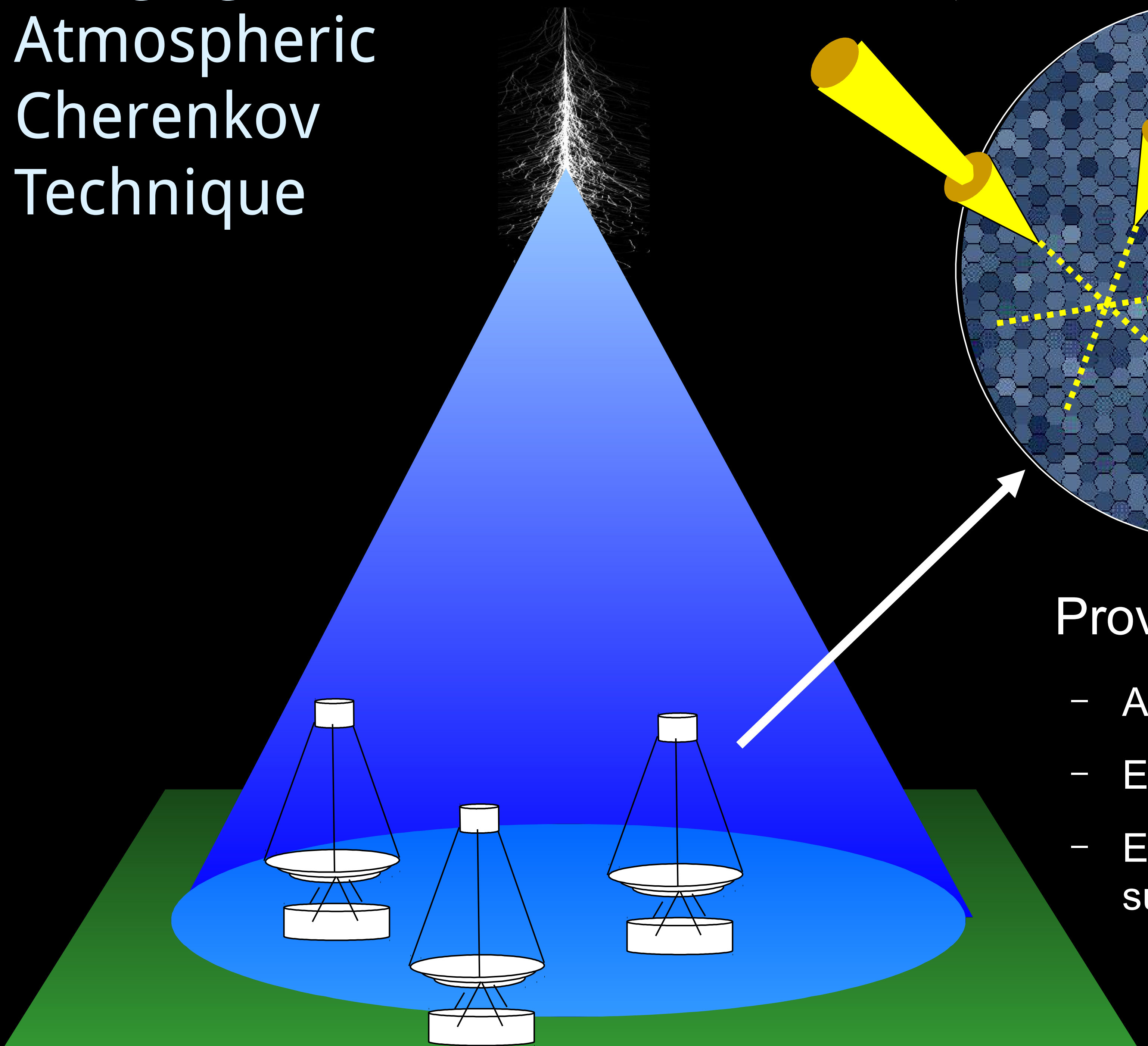
Target sensitivity

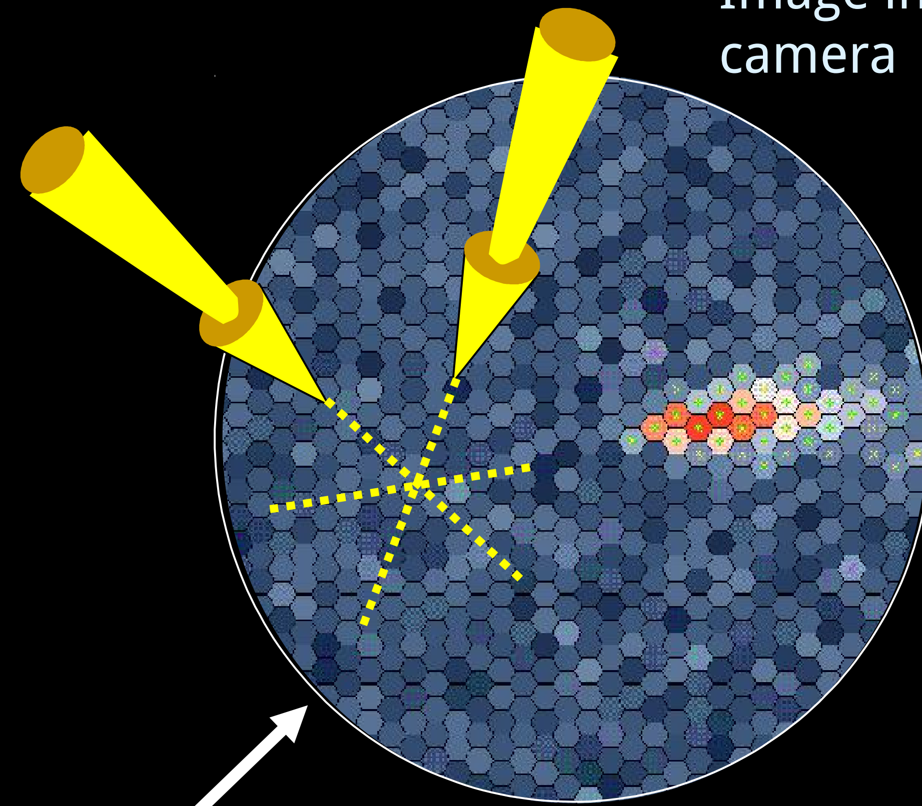
10^{-9} GeV/s/cm^2/sr

Science Motivation:

- **What is the composition of UHECR?**
- **Extension of IceCube detected ν flux to 10^9 GeV?**
- **Test of fundamental physics**

Imaging Atmospheric Cherenkov Technique



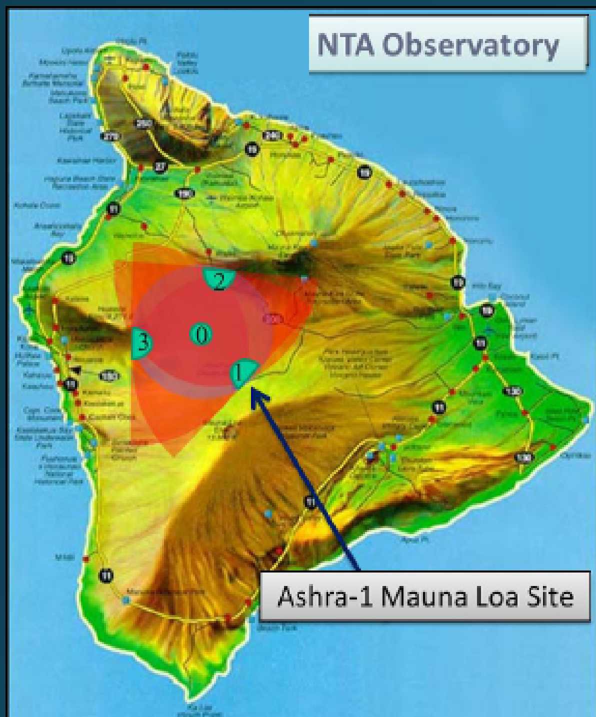


Proven Technique

- Angular resolution <0.1°
- Energy resolution 10%
- Excellent background suppression

NTA Baseline Design

Ashra-1 Light Collector



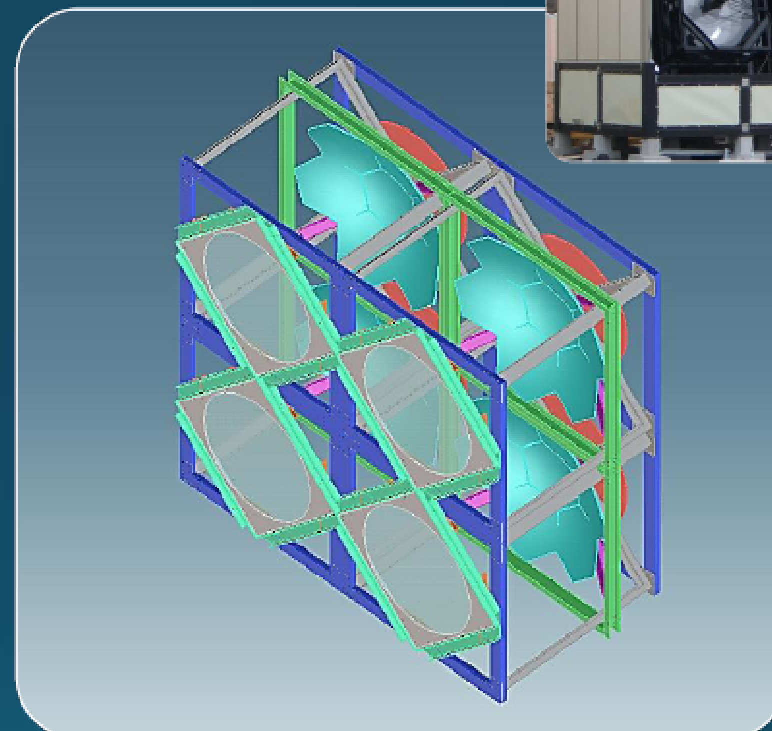


Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

Site ID	Location	X [km]	Y [km]	Z [km]	FOV [sr]
Site0	Center	0.000	0.00	2.03	π
Site1	Mauna Loa	9.91	-10.47	3.29	$\pi/2$
Site2	Mauna Kea	4.12	13.82	1.70	$\pi/2$
Site3	Hualalai	-14.02	-3.35	1.54	$\pi/2$

$\Rightarrow$ Concept:
Ashra-1 x 1.5 scaled-up
+ same trigger & readout

Light Collector (LC)
Optics with φ1.5m pupil
FOV 28° = focal sphere φ50cm

Detector Unit (DU)
4 LCs watching same FOV
Superimposed 4 images
$\Rightarrow$ **Effective pupil = φ3m**

12 DU's per π coverage

~1000km^2 stereo

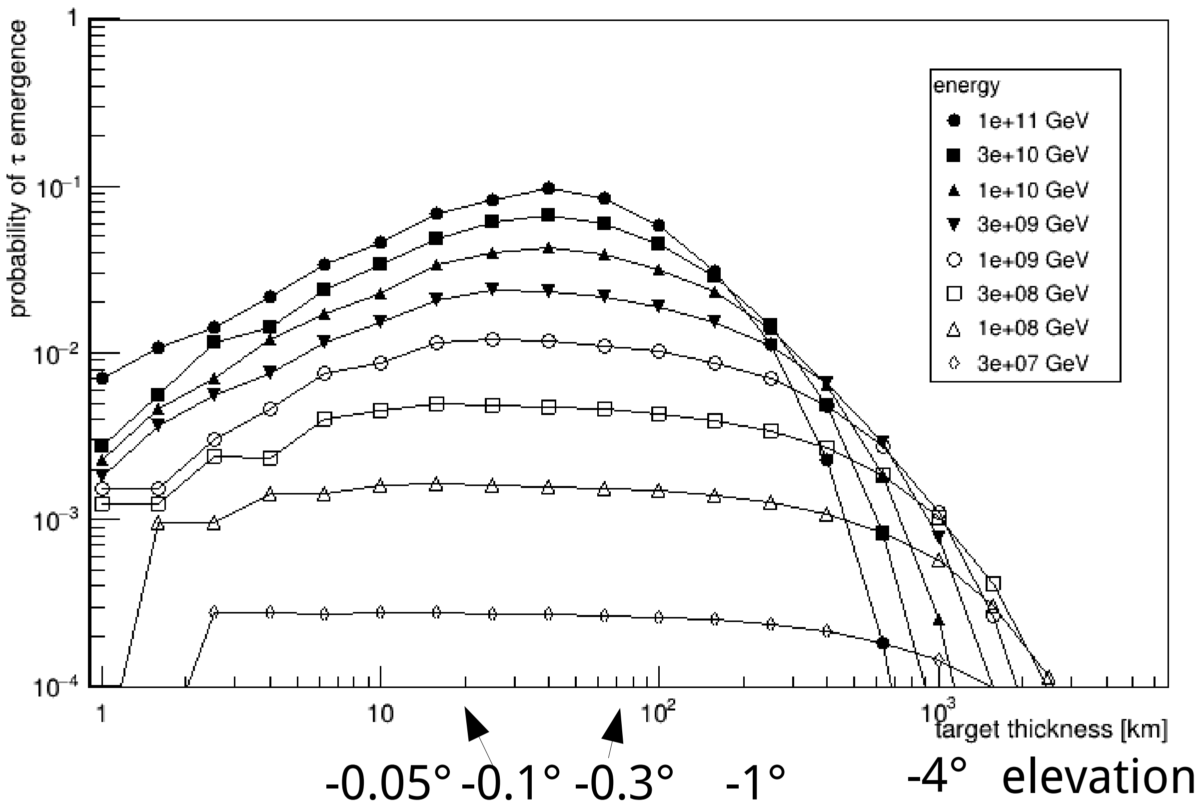
Need at least 30 DU's for Coverage

Trinity

- **Cherenkov/fluorescence telescope system**
  - 1-2 km above ground
  - 360 degrees azimuthal acceptance
  - 1 m^2 effective mirror area

- **Sensitivity determined by:**
  - Shower physics
    - Neutrino/tau physics (vertical acceptance)
    - Light emission pattern (azimuthal acceptance)
  - Instrument (event reconstruction)
    - Image intensity (energy threshold)
    - Image resolution (angular resolution / background suppression)

Probability for τ Emergence



Probability for ν conversion and emergence of τ from ground

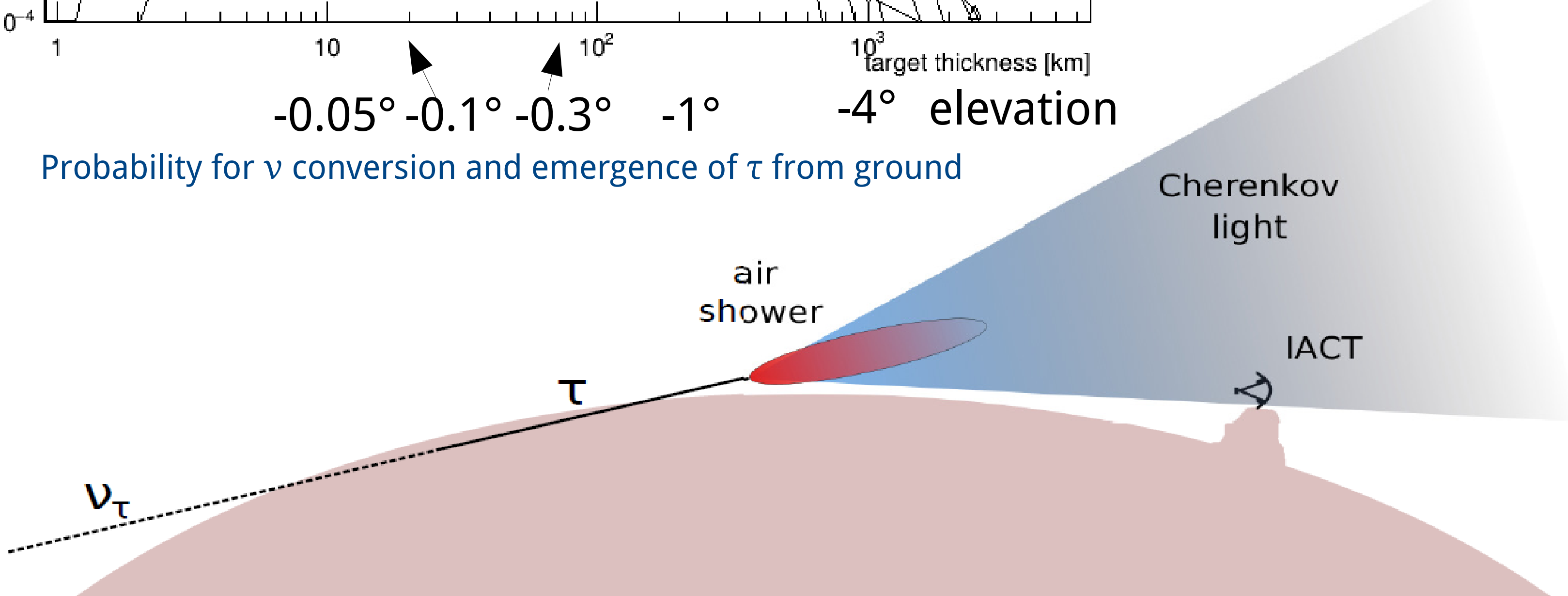
Target material:
Rock with ρ = 2.65 g/cm^3

Works best for:

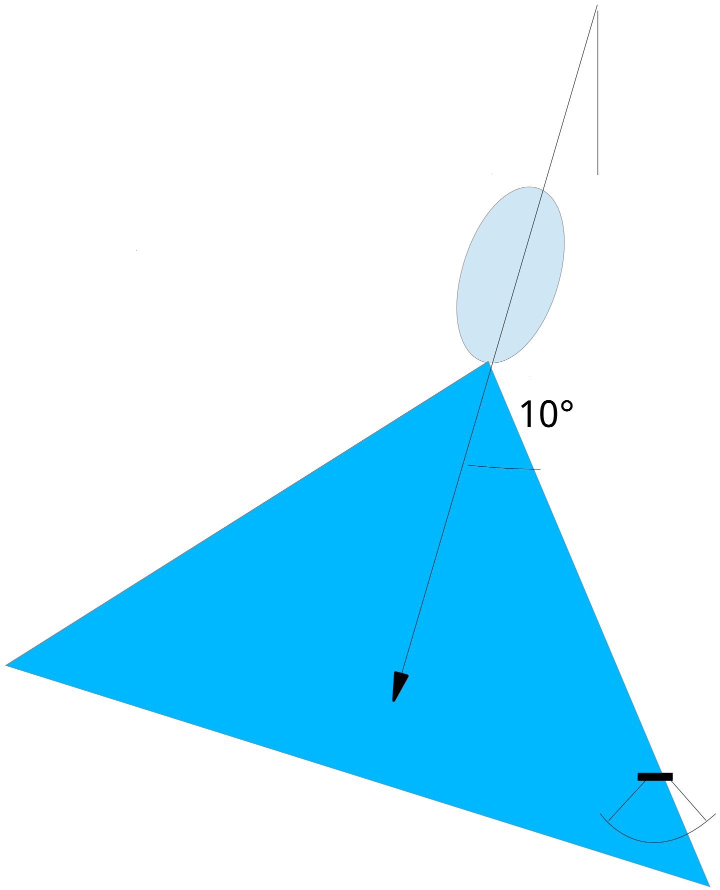
- **>10^8 GeV**
- ~50 km target

Limiting factors:

- Target to thin: ν does not convert
- Target to thick: τ does not make it out



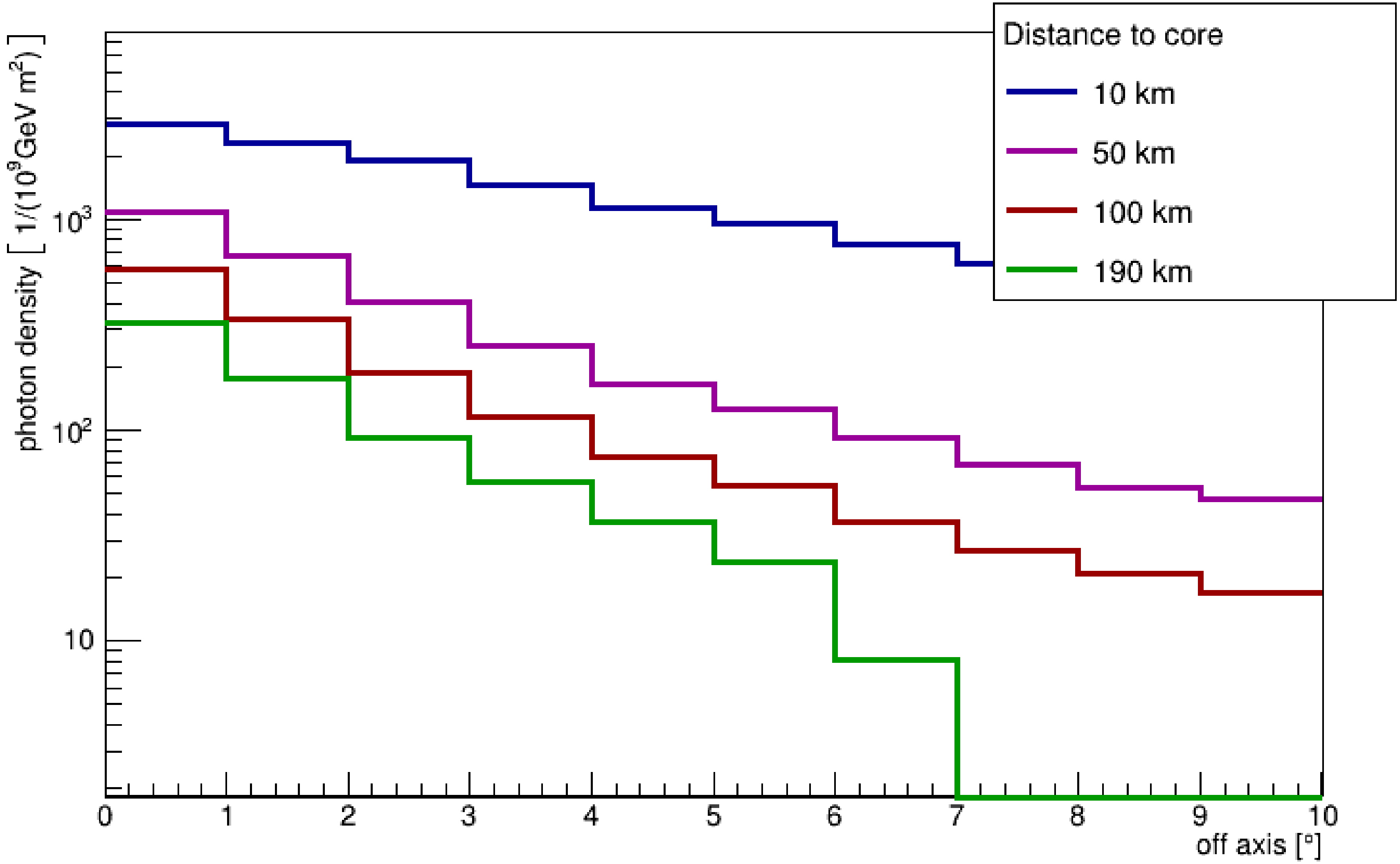
Azimuthal Acceptance



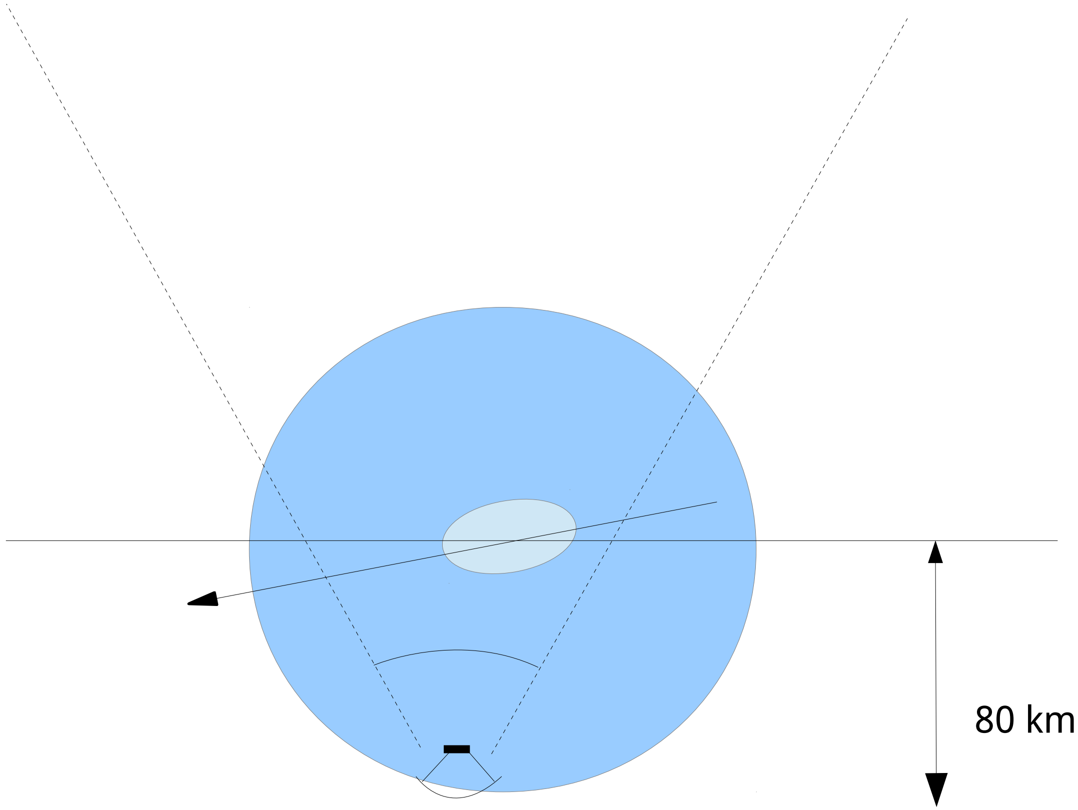
Lots of Cherenkov light scattered outside of primary 1° cone

Atmospheric Absorption

Radial Cherenkov Intensity Distribution



The Top View: Fluorescence

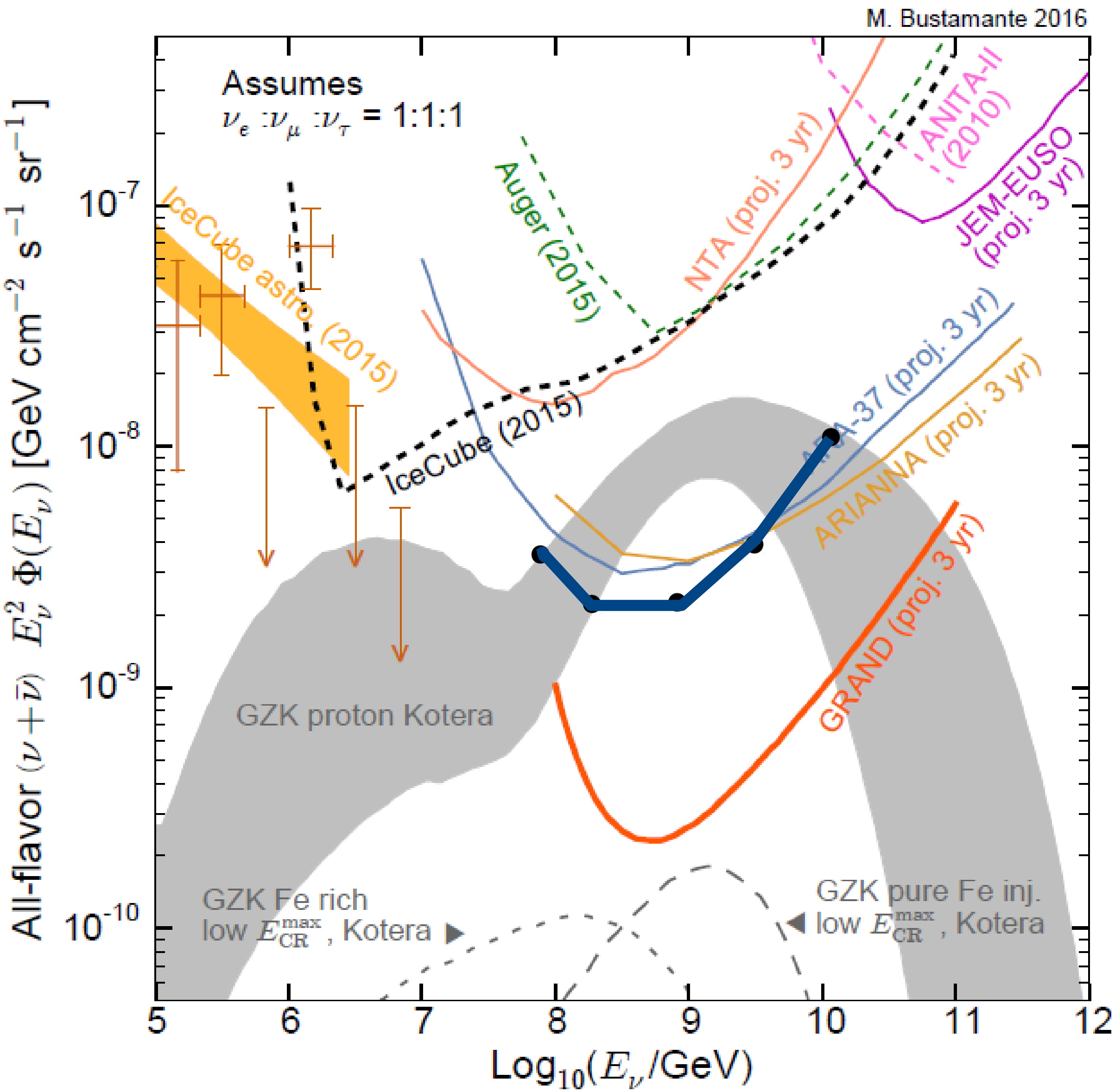


Azimuth acceptance: ~360°

Yield: 30 photons / MeV

Keilhauer et al. 2012

For 10^9 GeV τ:
~200 photons per m^2 in telescope
if shower is 80 km away



Detection threshold 1 neutrino
In 3 years
25% duty cycle

Uncertain by a factor of two

Detector Design Requirements

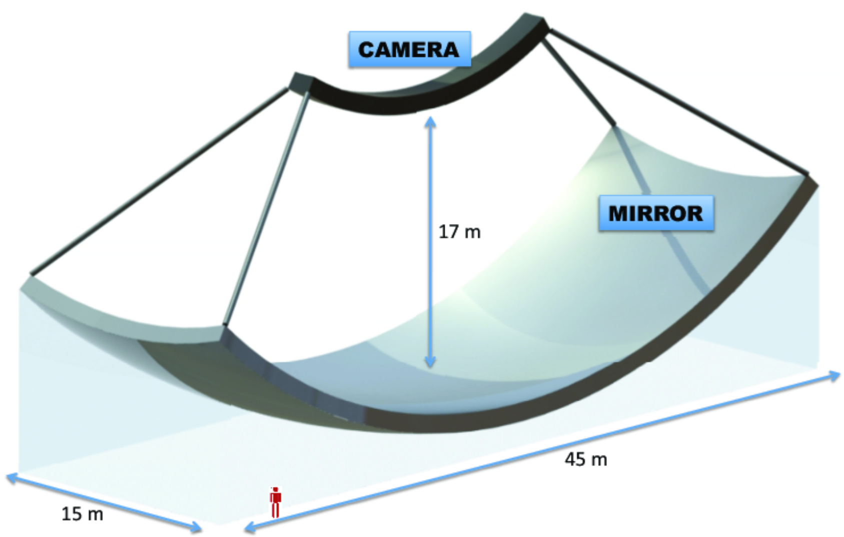
- 360° azimuthal FoV and 5° vertical FoV
- 1m^2 effective mirror area
- Minimum 0.3° angular resolution
  → >10 pixel per image
- Signal sampling speed 100 MS/s
- Single photoelectron resolution

Machete

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



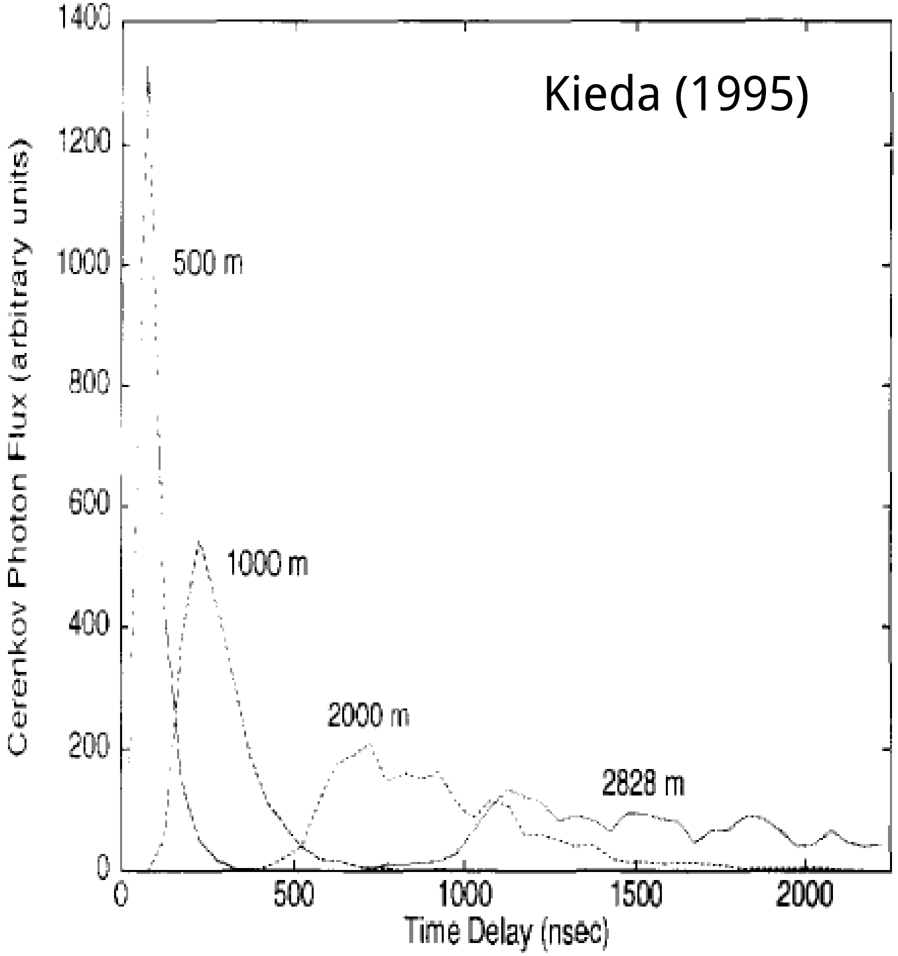
FOV of 5 × 60 sq deg

Scaled down to 1m² mirror:

- D=1.2 m, f=1.2 m, f/D=1
- **Mirror surface**: 1.2m x 2.5 m
- **90% containment**: 0.42°
- **plate scale factor**: 20.9 mm/deg
- **Camera size**: 104.5 x 1254 mm^2 = 0.13 m^2
- **Pixel size**: 6 x 6 mm^2, 0.3° diameter → 3622 pixel
- **Light concentrator**: factor 4
  → sensor size 3x3mm^2 (SiPMs)

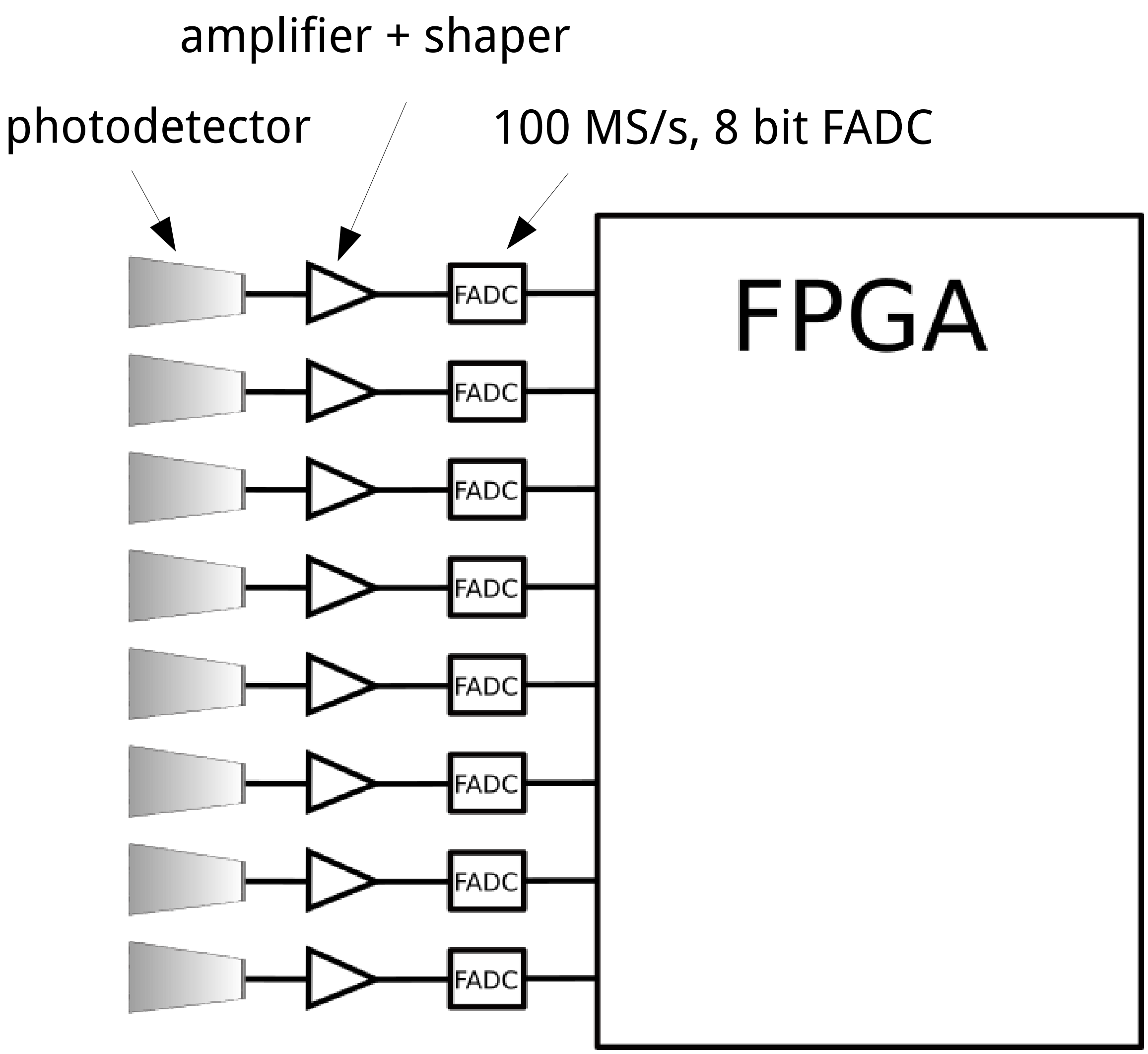
Costs per station (optics only): ~$50,000

Data Acquisition Requirements



- Photon arrival times spread out to ~10 μs
  → "slow" 100MS/s DAQ sufficient
- NSB: 36mm^2 pixel record about
  → 4 photon / 1 μs
- Single pe signal stretched to 100 ns

Signal Chain



- SiPMs as photodetectors
  - 3x3 mm^2 sensor + light concentrator
- Continuous sampling with 100 MS/s
- Signal processing and trigger in FPGA
  - Allows flexible trigger schemes using time and amplitude information

Cost per channel ~$100

Back on the Envelope Cost Estimate

6 Detector stations for 360° FoV:

- 22,000 pixel * $100/channel (sensor + readout) = $2.2M
- Optics ~$400k
- Infrastructure ~$400k

$3M total + R&D costs ~$500k

Next Steps

PREF
+031.69168° / -110.88498° 8436ft 13:15:52
POSITION - ALTITUDE - TIME
MAP
HORIZON
+00.8°
ANGLE
ELEVATION
-01.9°
ANGLE
00
+05
AZIMUTH - BEARING
301° N59W 5351mils TRUE
ZERO
A-B
CAL
W
300
330
LENS
1.0X
S

Conclusions

- A dedicated Cherenkov/fluorescence instrument can deliver a sensitivity comparable to ARA/ARIANA
- Costs fit into a $5M MRI
- Technique is proven and well established in VHE gamma rays
  - Very good angular resolution and energy reconstruction

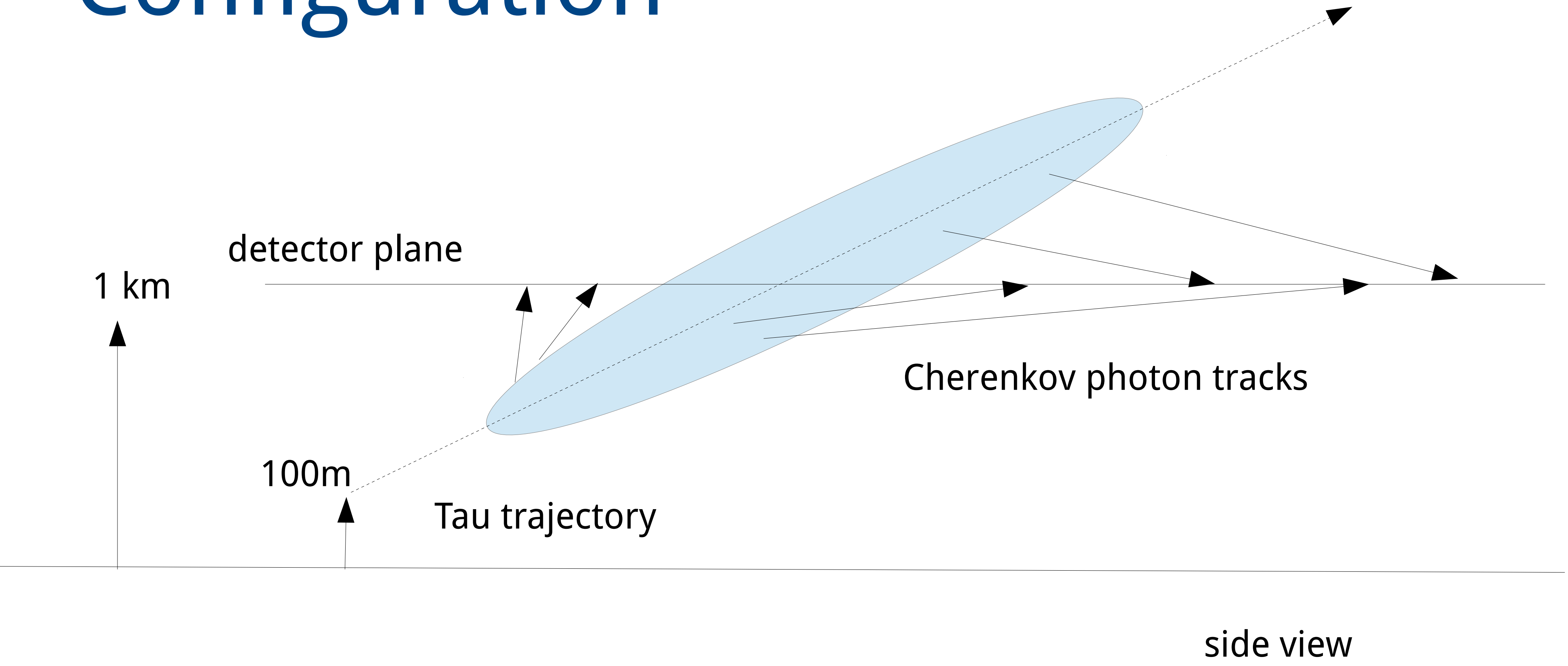
- Open issues need to be addressed with a small prototype
  - Background photon rates
  - Cosmic Ray background
  - Signal extraction and triggering
    - Advanced methods can significantly improve sensitivity and lower energy threshold
  - Data analysis: How well can up-going showers separated from down-going ones

Backup

Air Shower Simulations

- With CORSIKA 7.56 modified to do Cherenkov emission for upward going particles (credit to D. Heck)
- Curved atmosphere with changing index of refraction
- VERITAS atmospheric attenuation models generated with modtran
- Restrict simulations to gammas
  - first interaction always the same (100m above ground)
  - pure em-shower no hadronic component, which widens Cherenkov footprint
- No LPM effect (important above 10^7 GeV), which makes shower longer

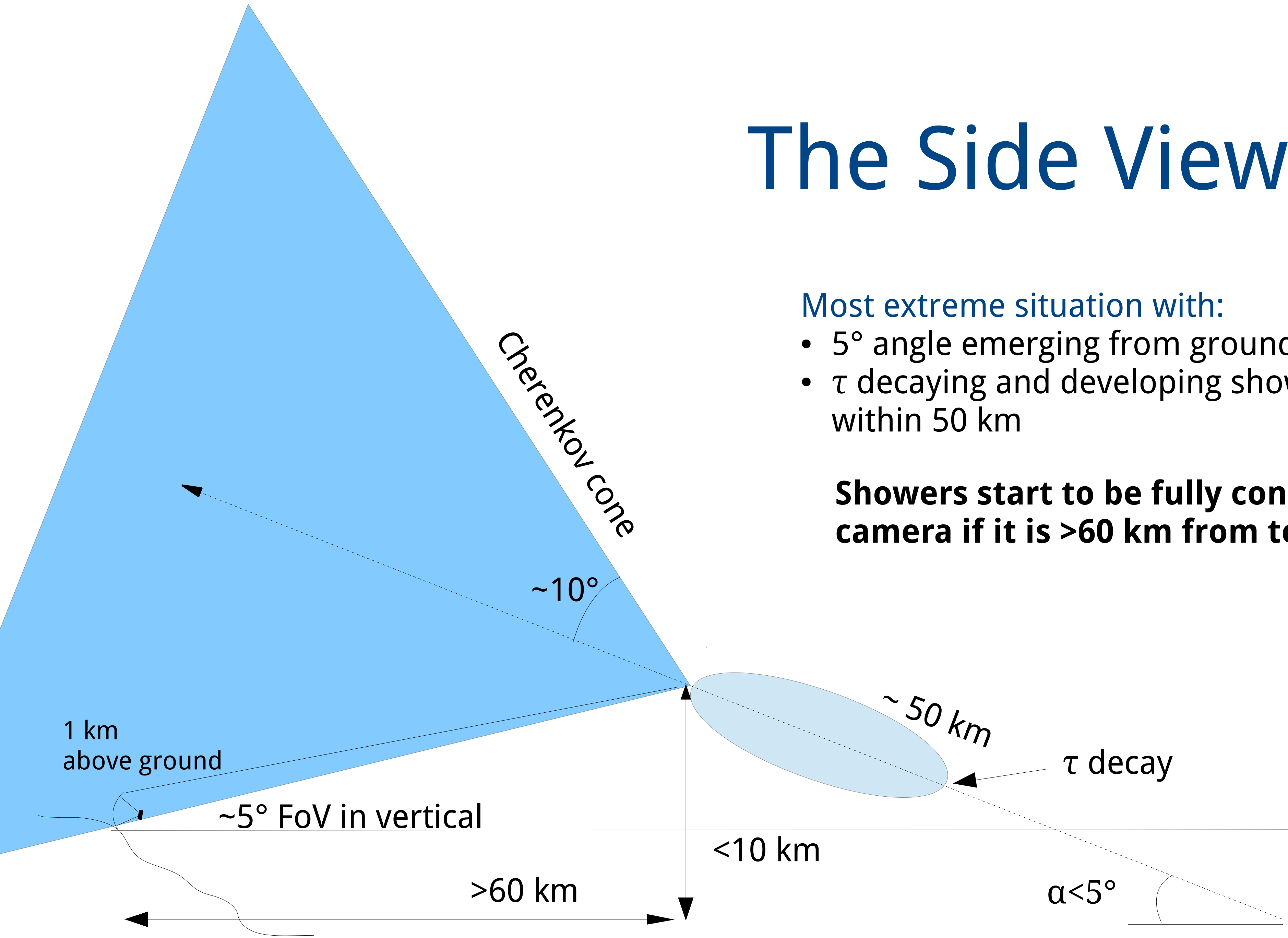
Simulated Detector Configuration



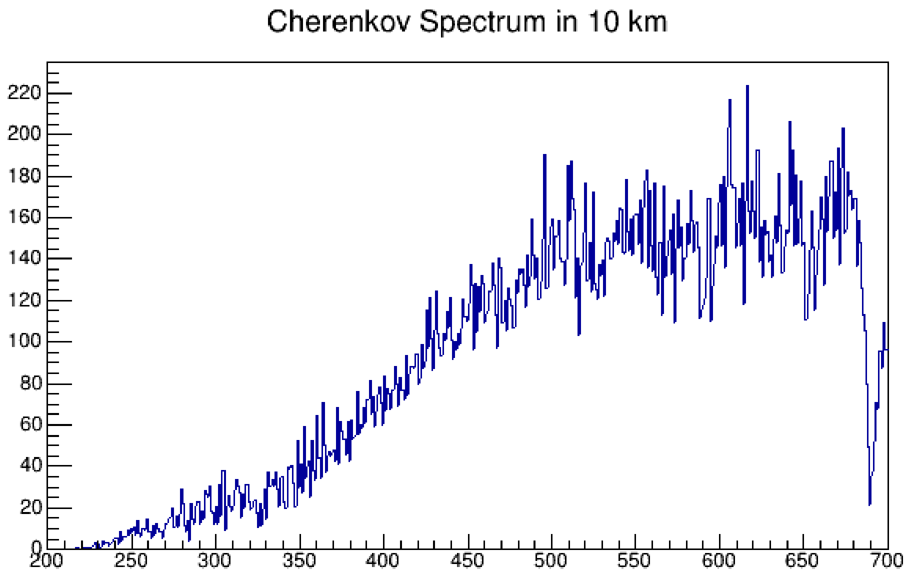
The Side View

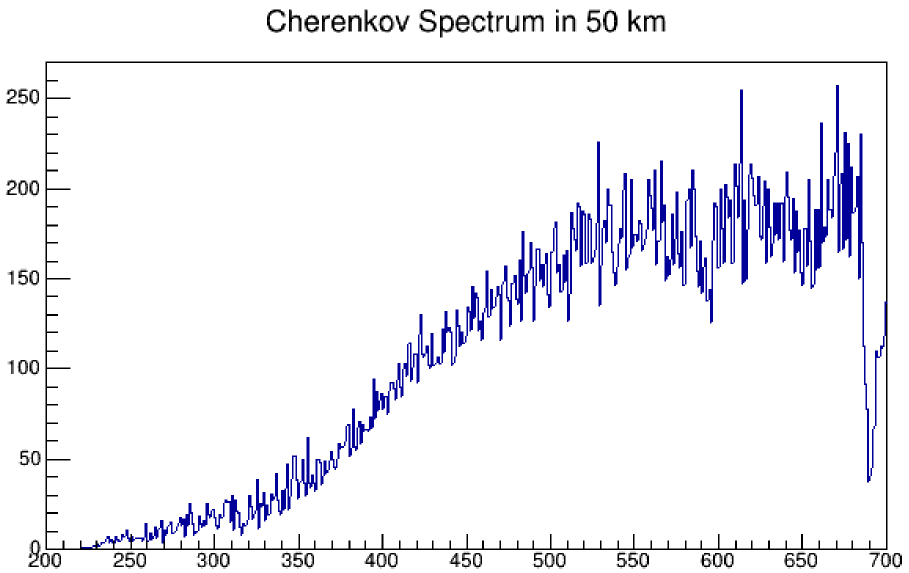
Most extreme situation with:
- 5° angle emerging from ground
- τ decaying and developing shower within 50 km

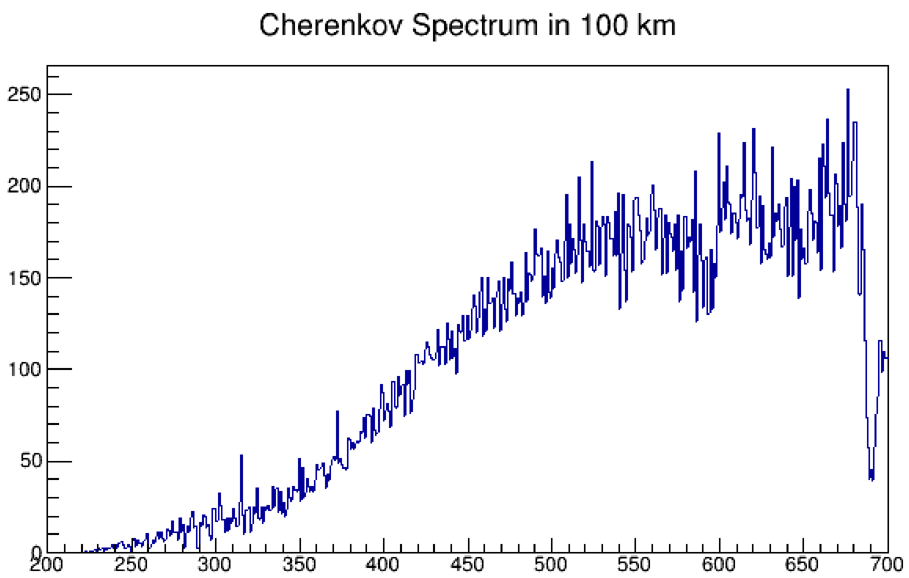
Showers start to be fully contained in camera if it is >60 km from telescope

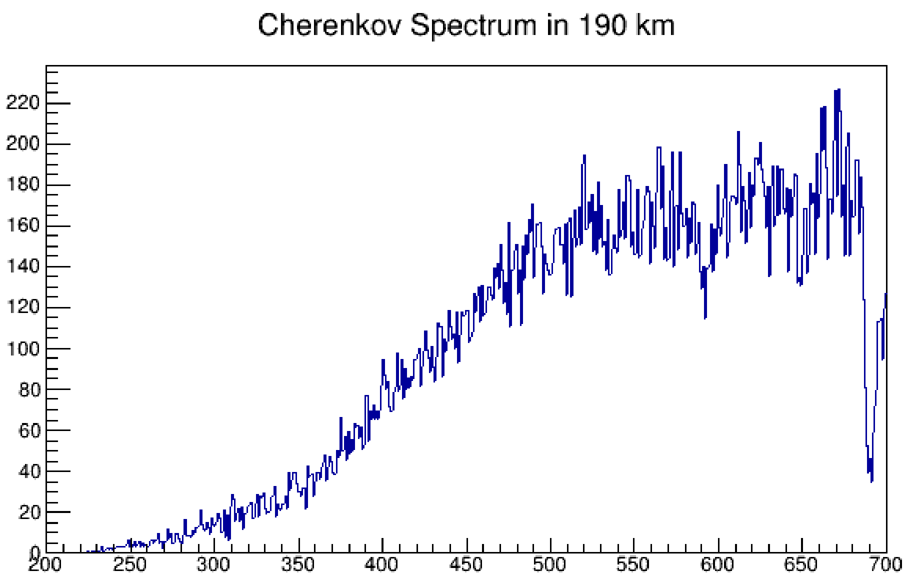


Cherenkov Spectrum









Comparison Cherenkov and Fluorescence

	Cherenkov	Fluorescence
Azimuthal acceptance	~20°	~360°
Elevation acceptance	~5°	~5°
Area on ground	120,000m^2	20,000m^2

~3 time sensitivity of Cherenkov

Prototype Site

IOTA site on Kitt Peak, AZ