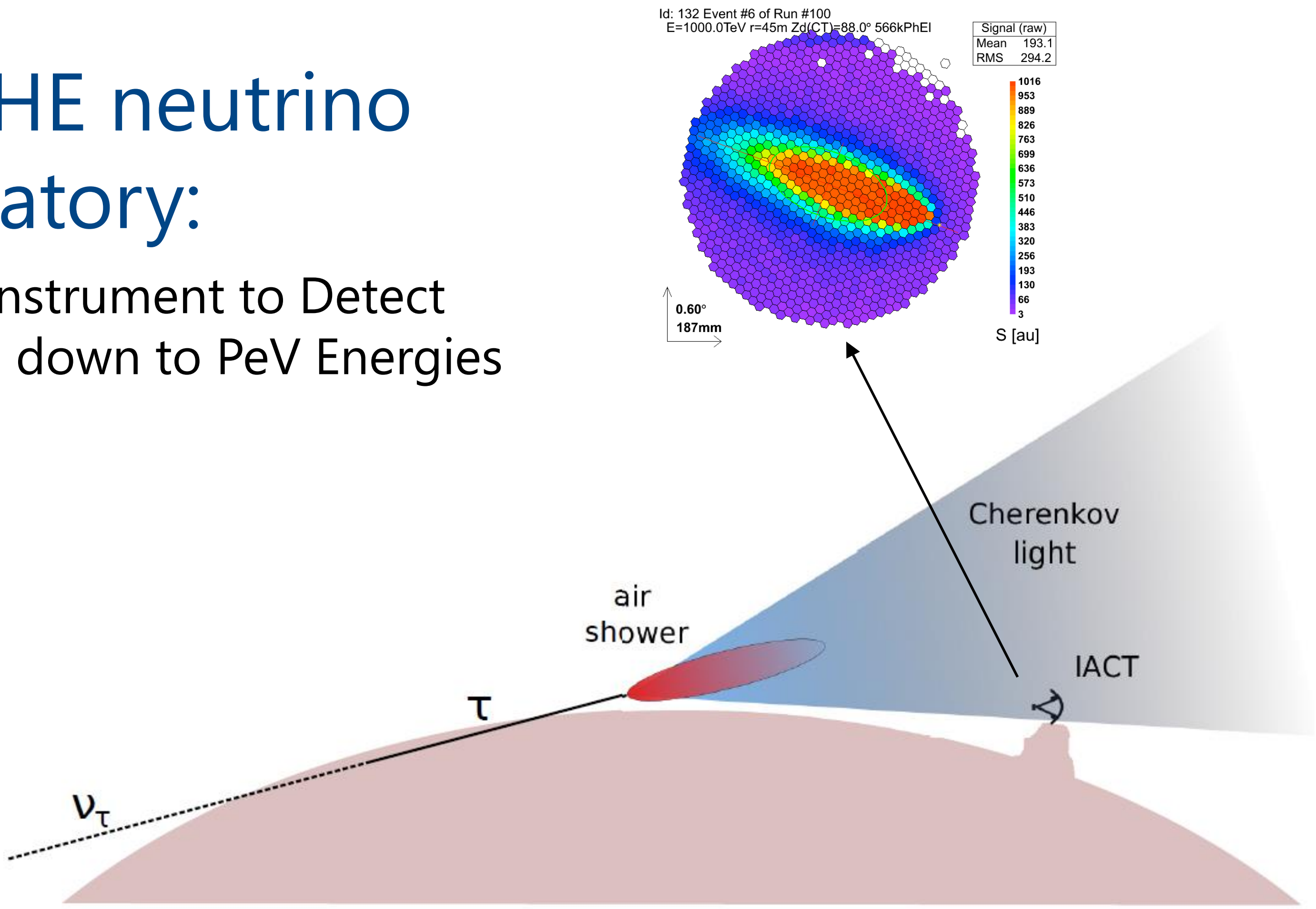
The Trinity VHE neutrino observatory:

An Air-Shower Imaging Instrument to Detect Ultrahigh-Energy Neutrinos down to PeV Energies

Phys. Rev. D 99, 083012 (2019)
Astro2020 white paper arXiv:1907.08727
ICRC 2019 arXiv:1907.08732

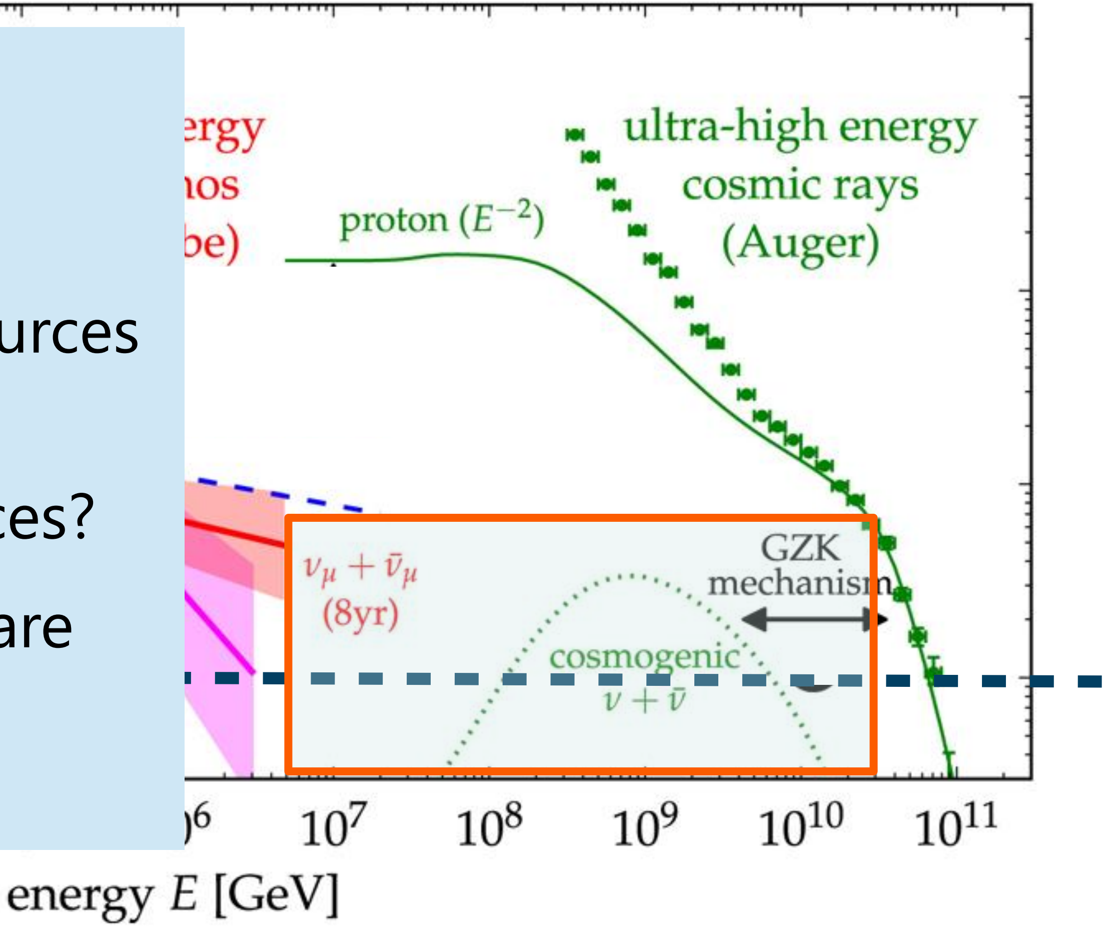
Georgia Tech
University of Utah
Durham University, UK
University of Padova, IT
University of Bari, IT
University of Perugia, IT



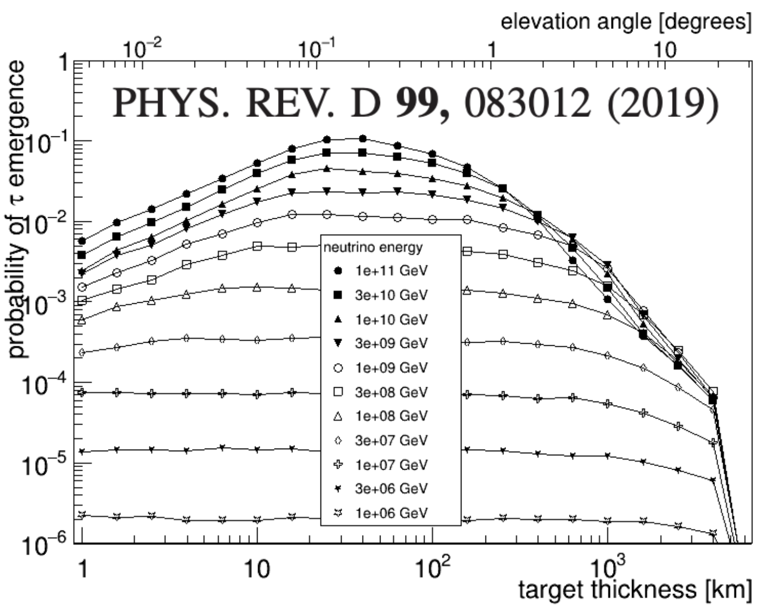
Dave Kieda (University of Utah) for the Trinity Collaboration

The Ultra-High Energy Neutrino Window

- What are the sources of the astrophysical neutrinos?
- What is the composition of UHECRs and how do their sources evolve?
- Are GRBs UHE neutrino sources?
- Are there steady sources we are missing?
- Probing BSM physics.



Optical Neutrino Detection Technique

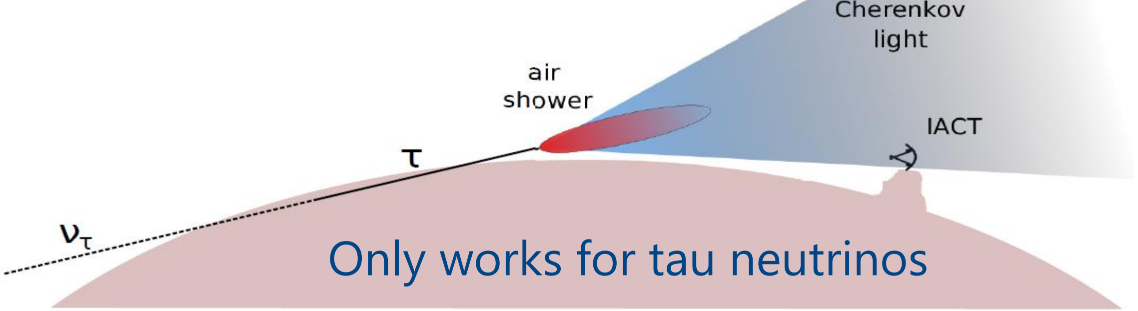


10^6-10^{10} GeV UHE nu-tau, when crossing 1-100 km of rock have significant **probability of emerge as tau-lepton**

- The emerging UHE tauons can generate e.m. atmospheric (sub)showers

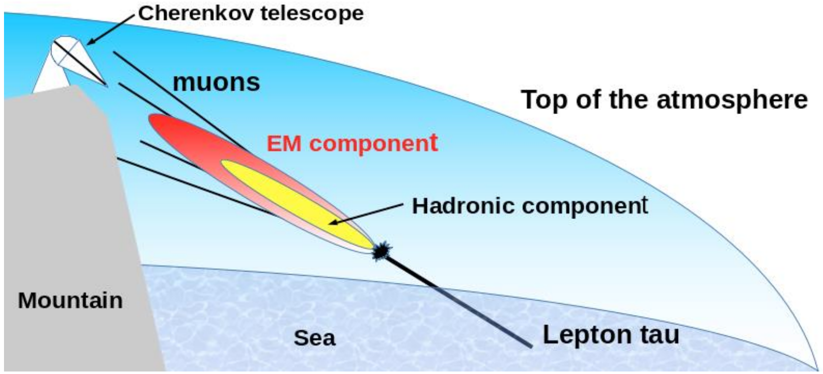
Decay	Secondaries	Probability	Air-shower
$\tau \to \mu^- \bar{\nu}_\mu \nu_\tau$	μ^-	17.4%	weak showers
$\tau \to e^- \bar{\nu}_e \nu_\tau$	e^-	17.8%	1 Electromagnetic
$\tau \to \pi^- \nu_\tau$	π^-	11.8%	1 Hadronic
$\tau \to \pi^- \pi^0 \nu_\tau$	$\pi^-, \pi^0 \to 2\gamma$	25.8%	1 Hadronic, 2 Electromagnetic
$\tau \to \pi^- 2\pi^0 \nu_\tau$	$\pi^-, 2\pi^0 \to 4\gamma$	10.79%	1 Hadronic, 4 Electromagnetic
$\tau \to \pi^- 3\pi^0 \nu_\tau$	$\pi^-, 3\pi^0 \to 6\gamma$	1.23%	1 Hadronic, 6 Electromagnetic
$\tau \to \pi^- \pi^- \pi^+ \nu_\tau$	$2\pi^-, \pi^+$	10%	3 Hadronic
$\tau \to \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$	$2\pi^-, \pi^+, \pi^0 \to 2\gamma$	5.18%	3 Hadronic, 2 Electromagnetic

- **Imaging Cherenkov telescopes (IACT)** record image of air shower →

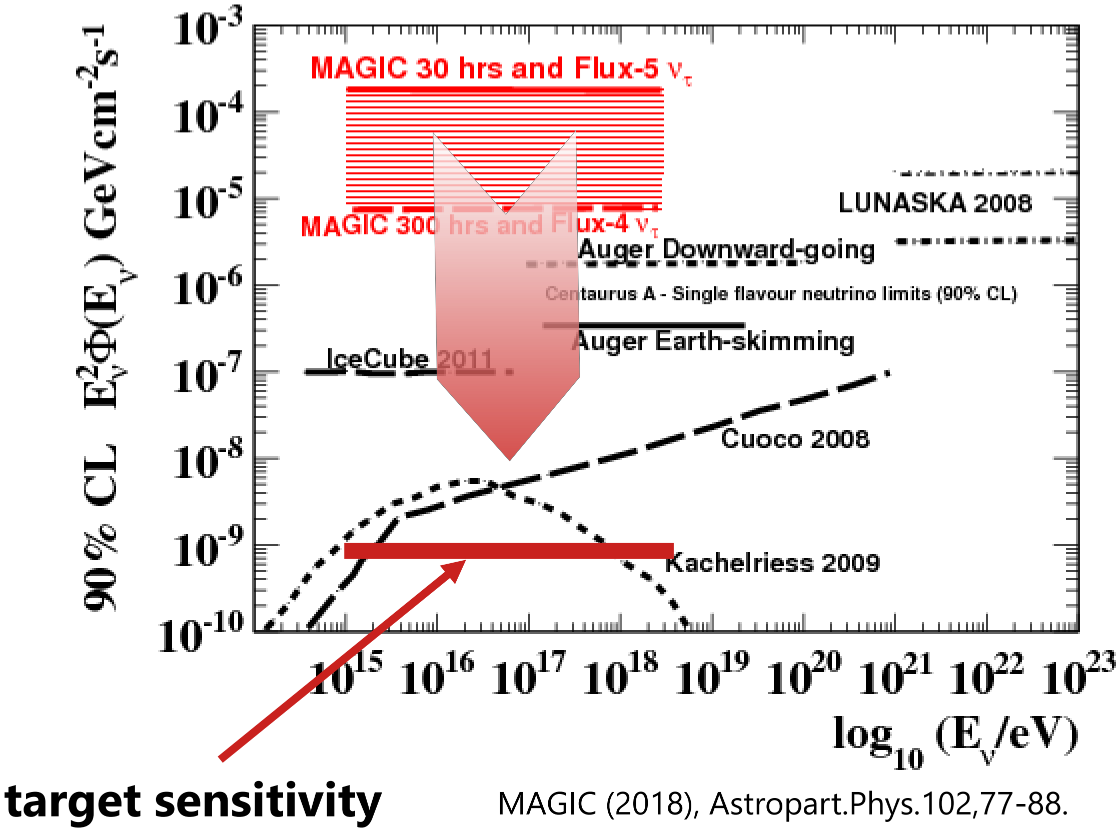


Only works for tau neutrinos

UHE-Neutrino Searches with MAGIC



MAGIC telescopes



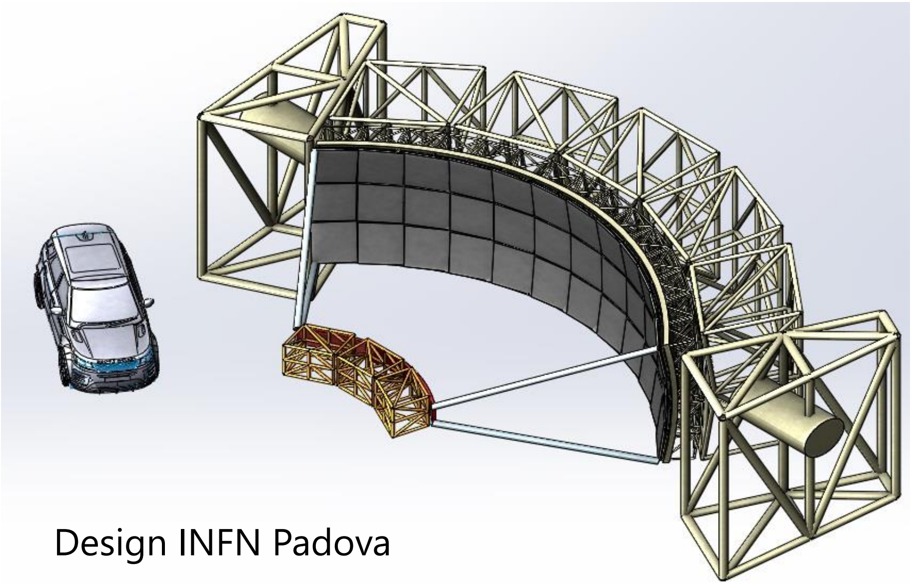
MAGIC (2018), Astropart.Phys.102,77-88.


PREF
+031.69168° / -110.88498° 8436ft 13:15:52
MAIL
POSITION - ALTITUDE - TIME
MAP
LOG
MAGIC
FoV
1° veto
region
4° signal region
HORIZON
+00.8°
ANGLE
ELEVATION
-01.9°
ANGLE
-05
00
+05
AZIMUTH - BEARING
301° N59W 5351mils TRUE
ZERO
A-B
CAL
W
300
330
LENS
1.0X
S

The Trinity Telescope Design

Based on J. Cortina et al., Astrop. Physics 72 (2016) 46

- **FoV 5° X 60°.**
- 5.6 m focal length.
- 68 m^2 mirror area → **16 m^2** in any direction.
- 0.3° optical PSF.
- 3,300 pixel camera.
- 20 mm Winston cones coupled to **9 mm SiPMs**.
- Thin-glass replica mirror technology ~$2k/$m^2$.
- Implementation based on MAGIC structure.
- Rotates in elevation.
- $170k for one telescope.
- $330k for one camera.
- Full Trinity Observatory employs arrays of multiple telescopes/multiple sites



Design INFN Padova

Astro 2020 APC White Paper arXiv:1907.08727

Suitable sites for Trinity with existing infrastructure:
Frisco Peak, UT; Hawaii; Canary Islands La Palma and Tenerife

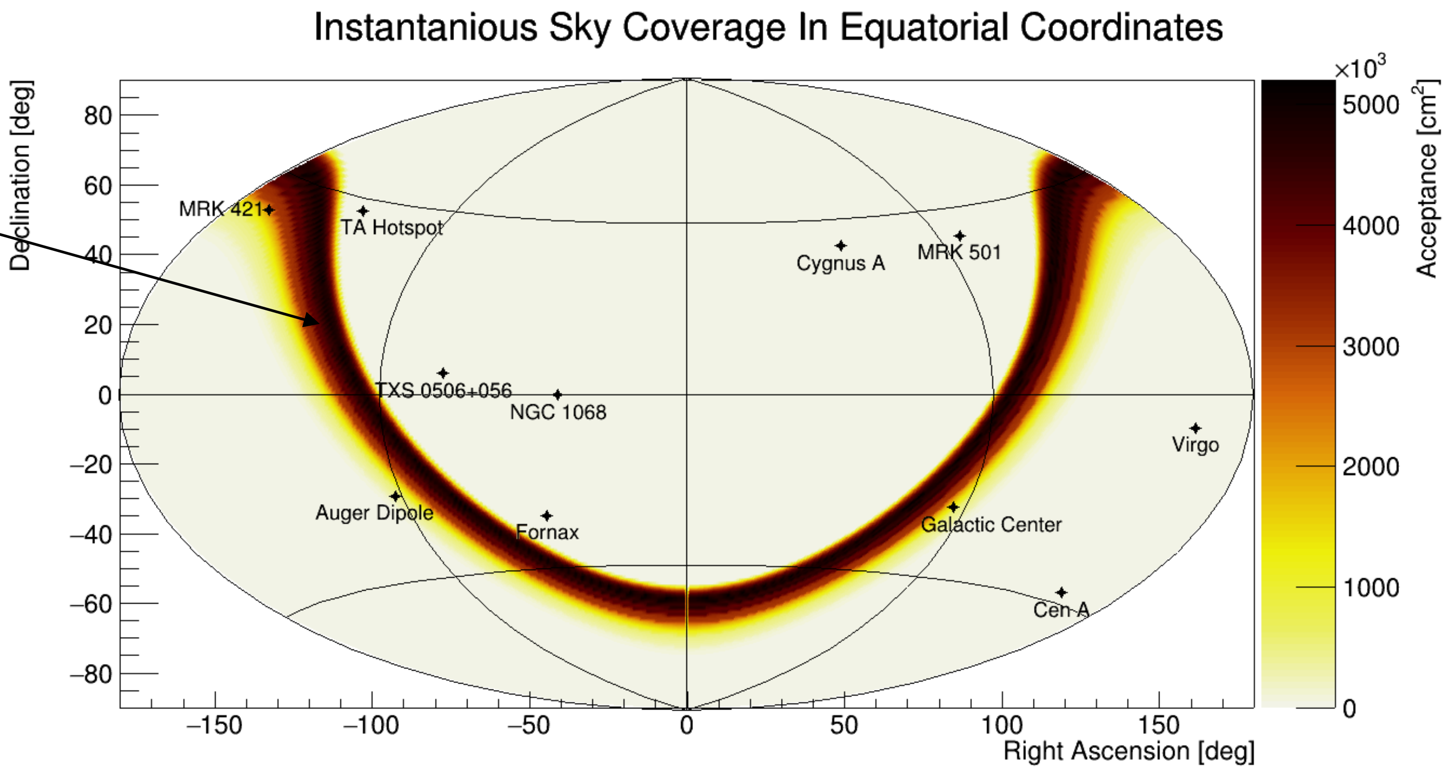
Instantaneous Sky Coverage (One Site)

15° wide band
→ 13% of sky

~50% of the sky observed
every night

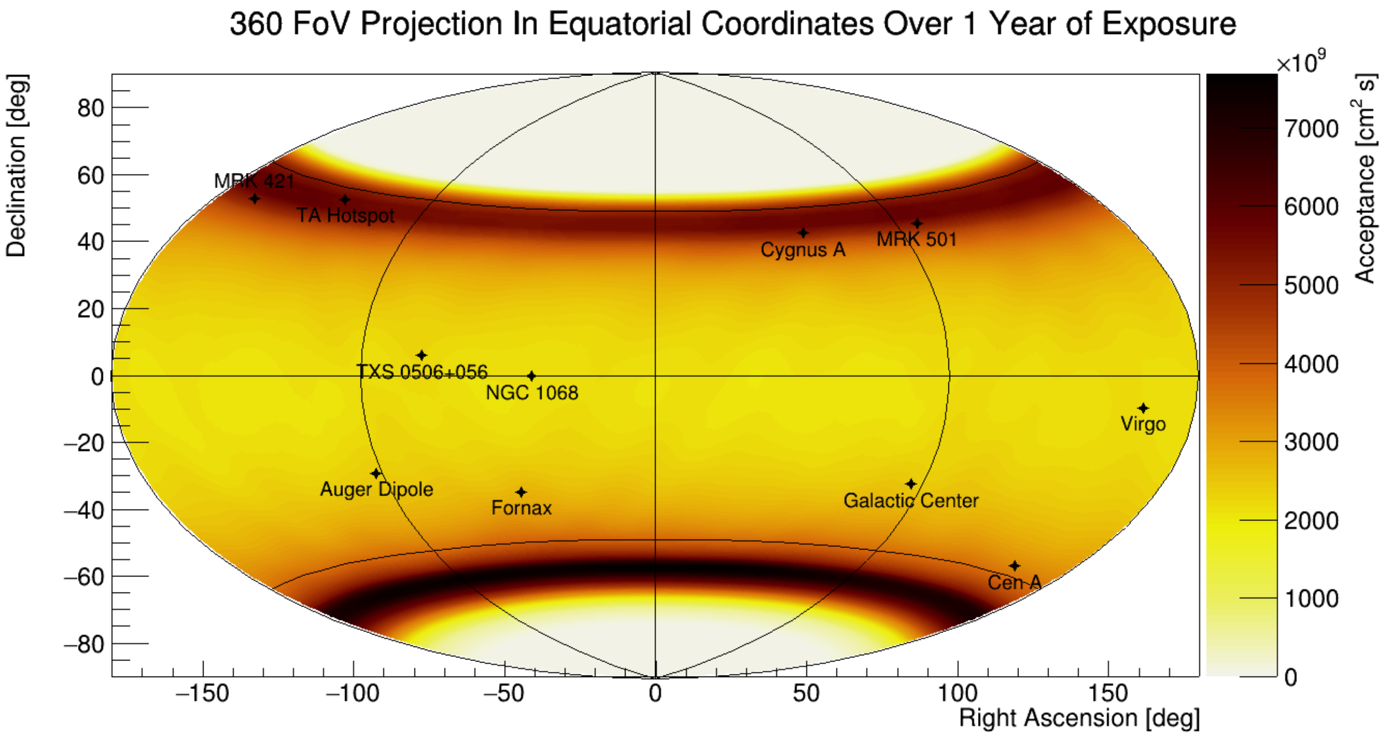
Nightly exposure per source
1-2 hours

Expect several 10 GRBs per year to go off in FoV



Sky Coverage (One Year, One Site)

Annual point source sensitivity: 1...5 $\cdot 10^{-5}$ GeV cm^{-2} s^{-1} @ 10^8 GeV



- Trinity has much of the same sky coverage as all major EM and GW multi-messenger instruments.
- Trinity observes 50% of the sky every night.

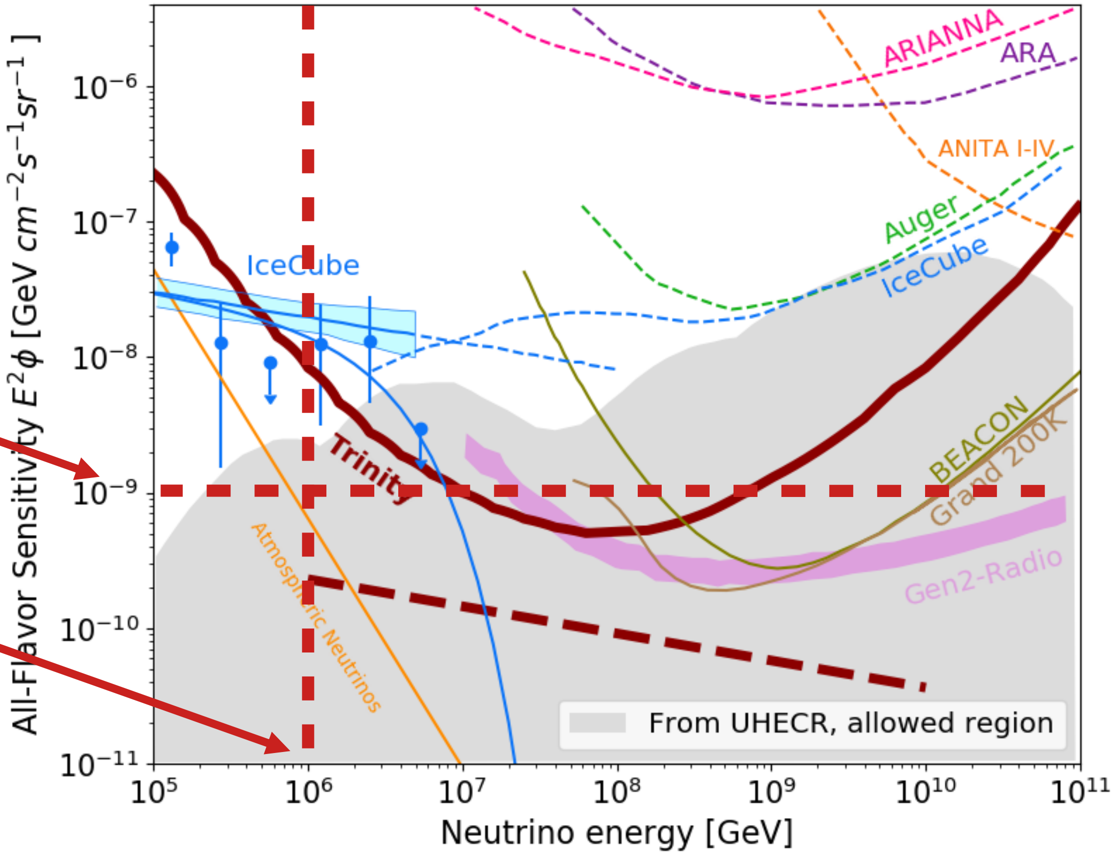
Expected Performance

18 telescopes at three sites

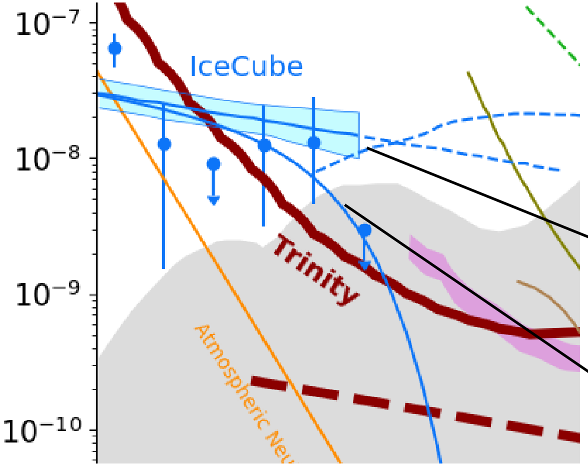
10 year observation

Target sensitivity

PeV threshold



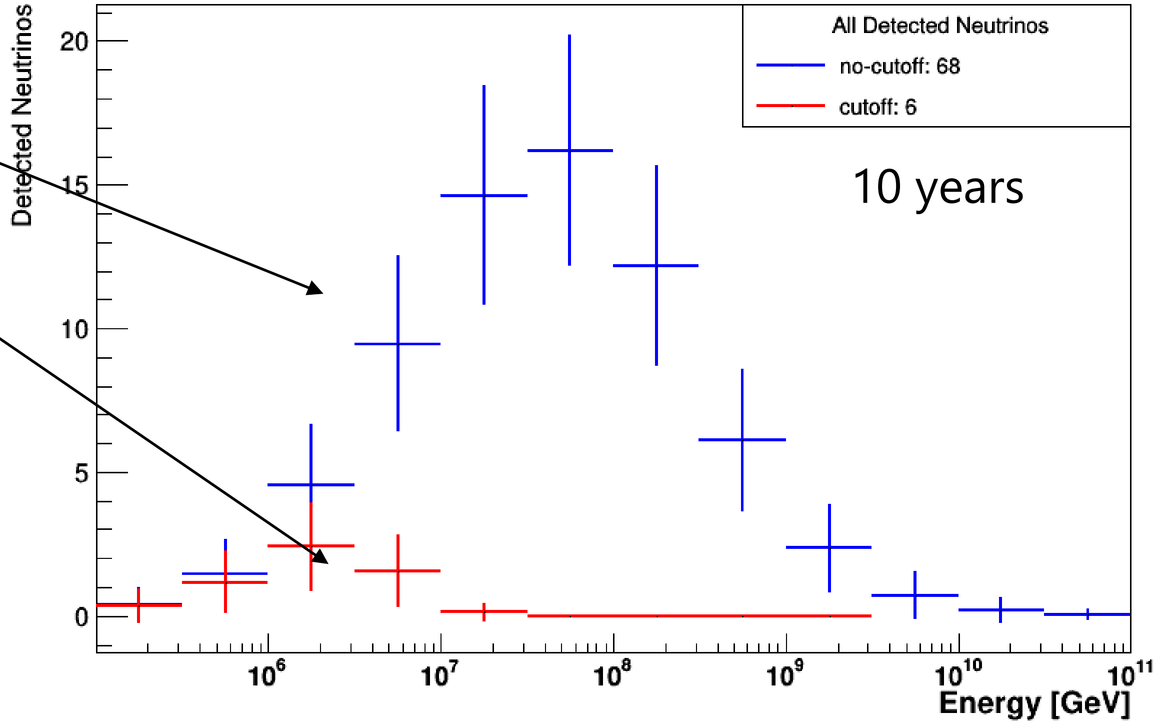
Astrophysical-Neutrinos with Trinity



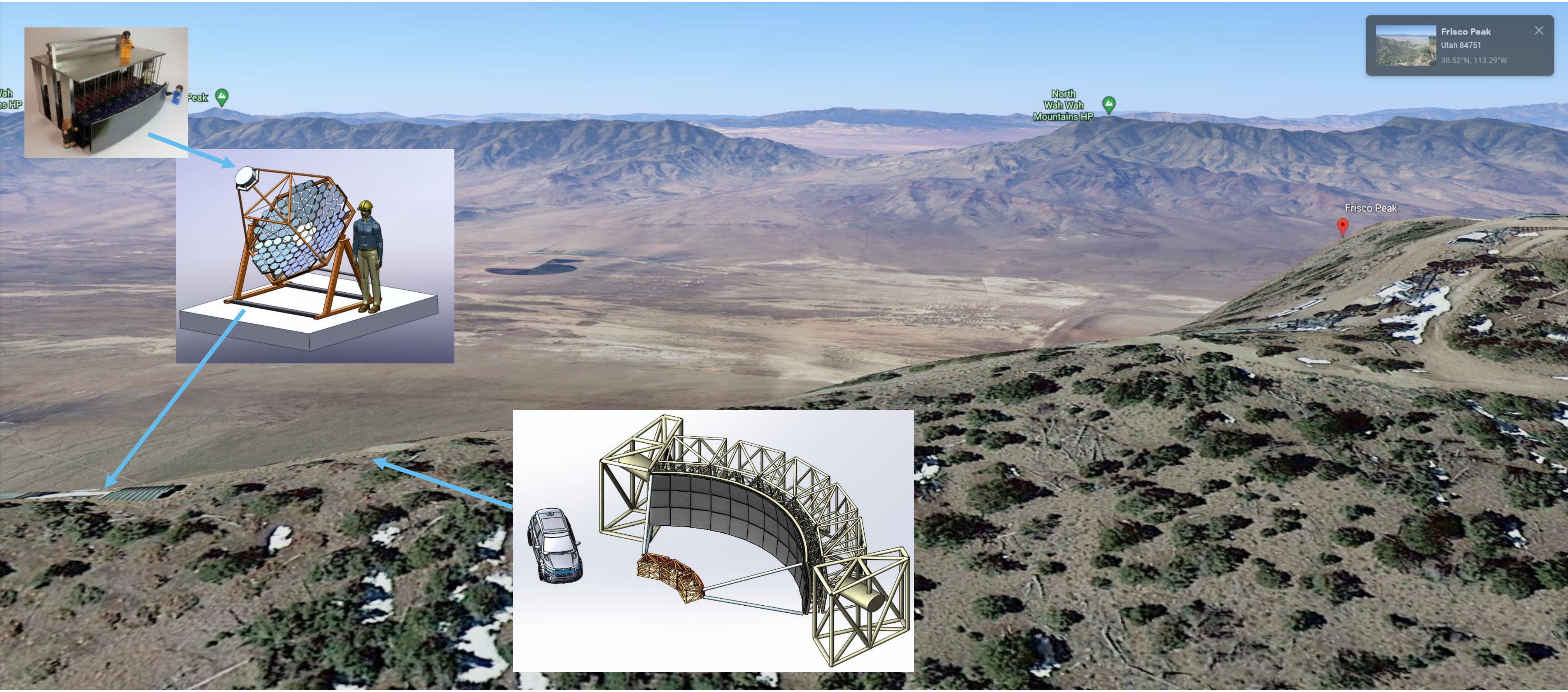
Pure tau-neutrino sample

Sources must turn off but where?

→ Need a low energy threshold

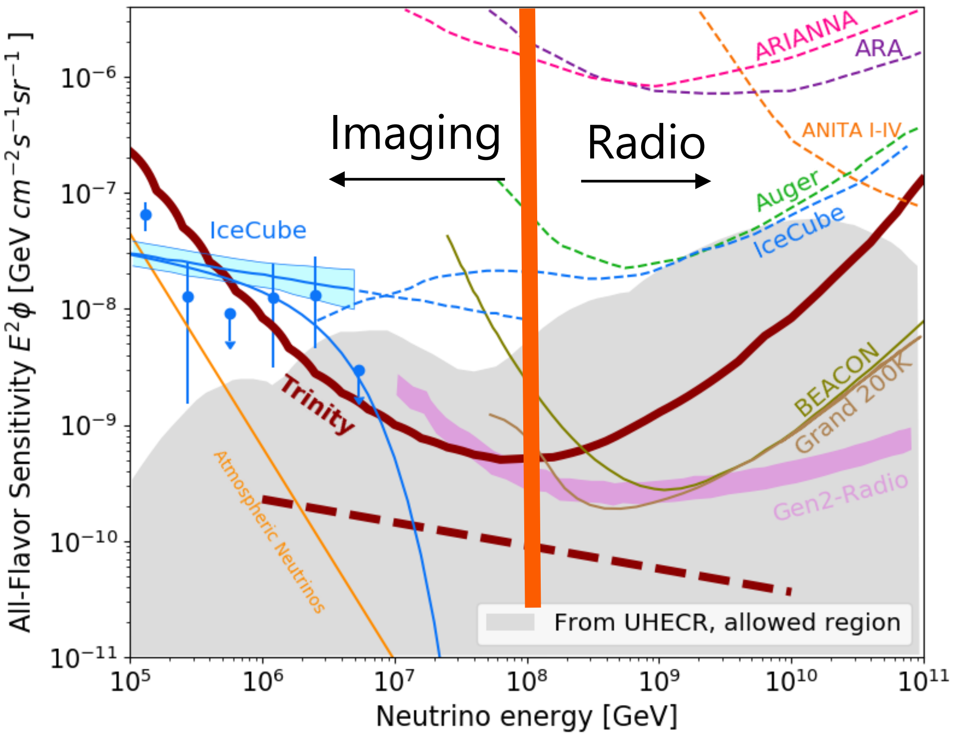


Trinity Prototype Telescopes @ Frisco Peak, Utah, USA



Take-Away Points and Remarks

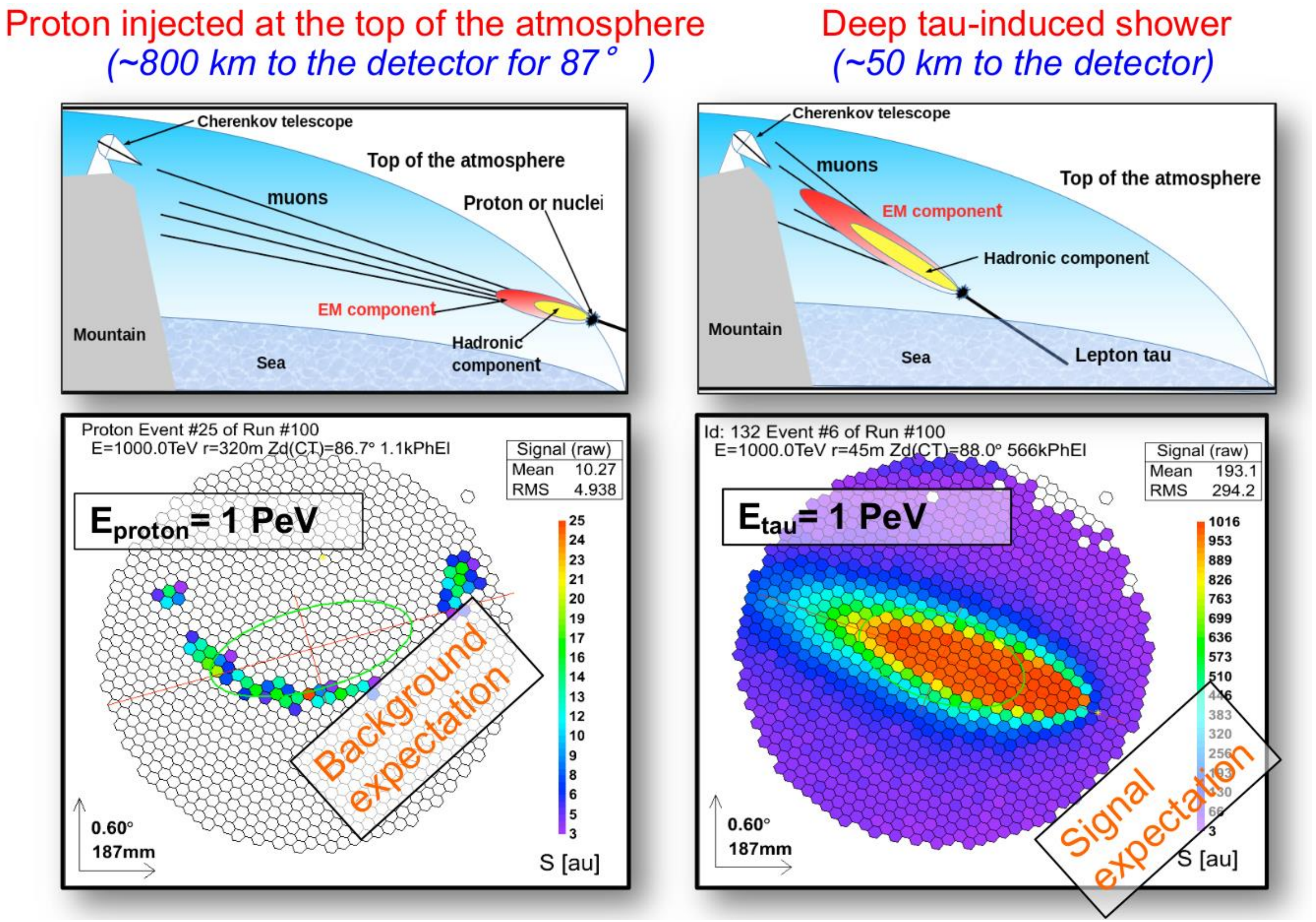
- Trinity is the lowest threshold UHE-instrument in the market.
- Trinity and radio UHE-detectors complement each other.
- The technique is thoroughly tried and tested → WYSIWYG.
- Overlap with astrophysical-neutrino flux → guaranteed signal.
- Highest sensitivity where peak of cosmogenic-neutrino flux is expected
- Pure tau-neutrino sample from $5x10^5$ GeV to 10^{10} GeV → fundamental physics.
- The source density in the non-thermal universe decreases rapidly with energy → a low energy threshold yields more science.



Status

- Frisco Peak Site: BLM permit in process
- Prototype Trinity Optics: in fabrication
- Site preparation & installation 2022-2023 (?)

Backup



Slide from Dariusz Gora (MAGIC)

Trinity: An Optimized PeV Threshold UHE-Neutrino Detector

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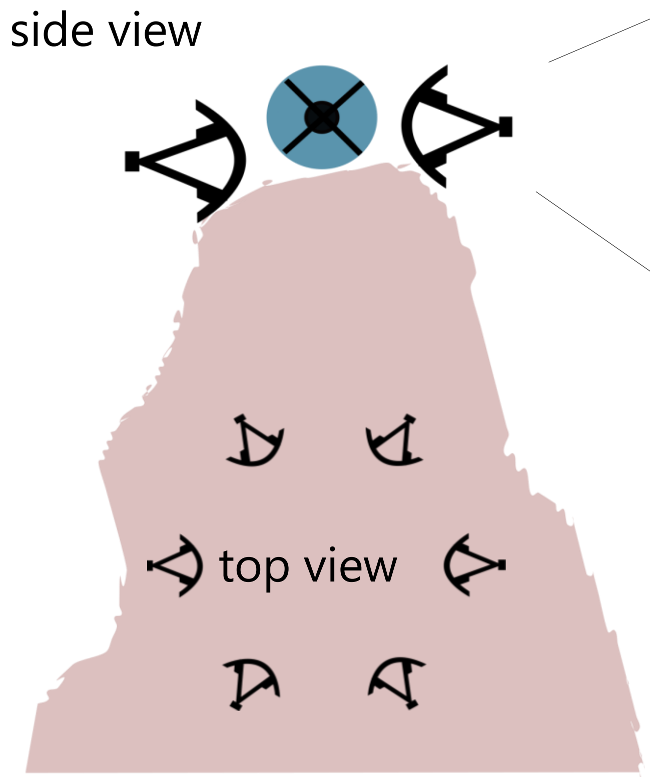
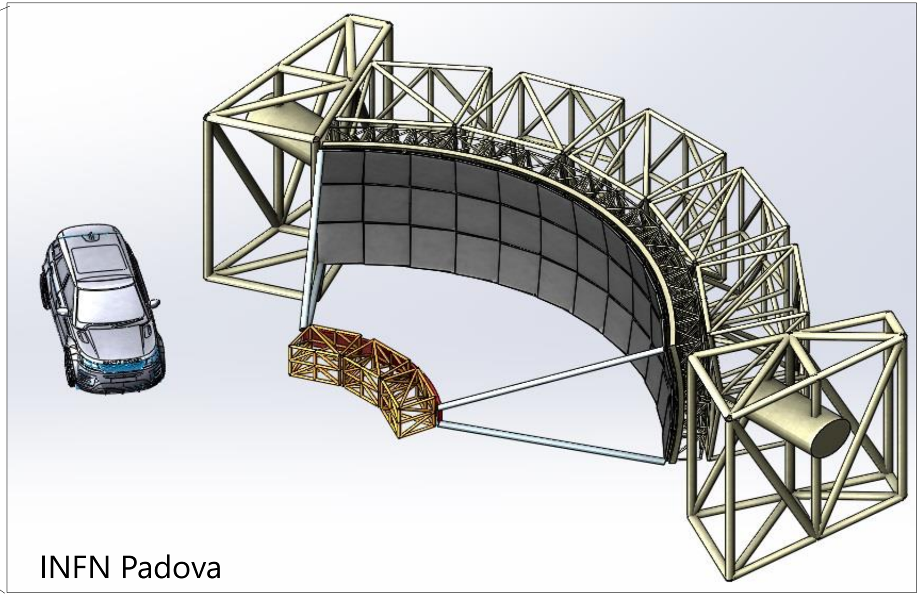


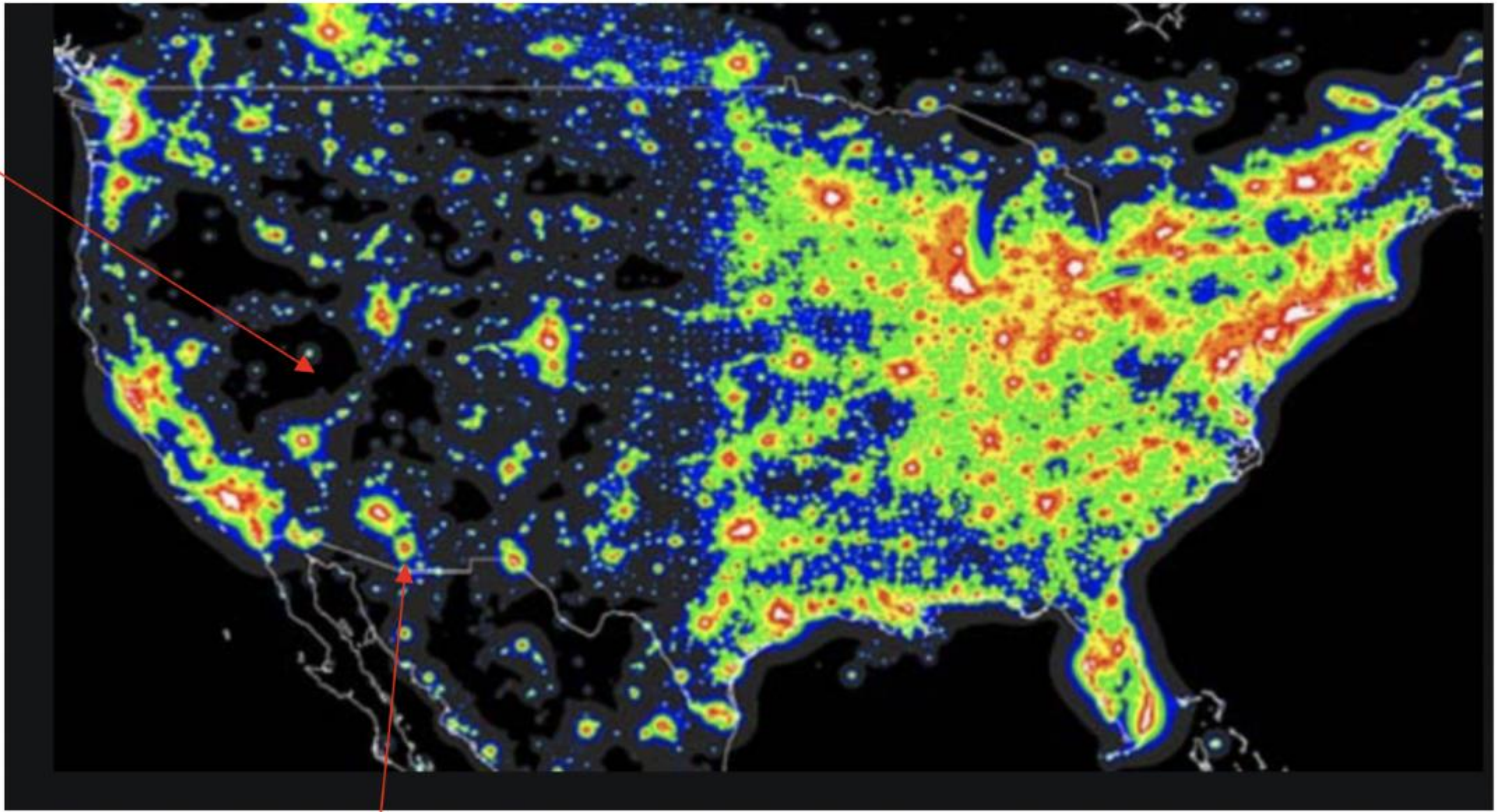


Suitable sites for Trinity with existing infrastructure:

Frisco Peak, UT; Hawaii; Canary Islands La Palma and Tenerife

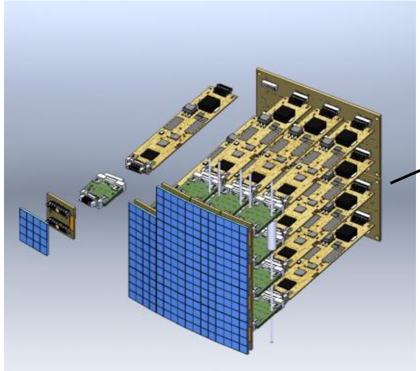
Site

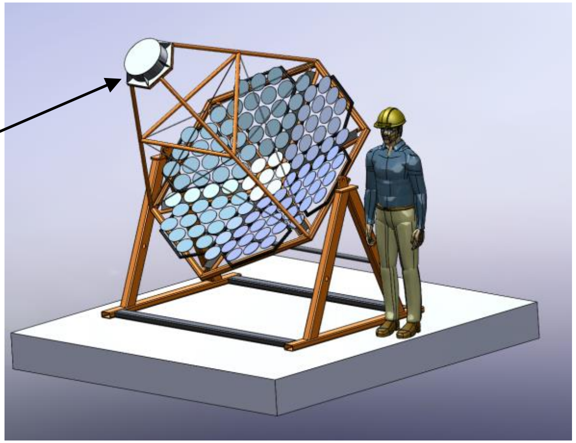
- Needs to oversee a remote area.
- Modest light contamination is ok.
  - Images happen on <100ns timescales.
- Ashra Site; BEACON Test site; Frisco Peak, UT, La Palma, …



Trinity Demonstrator @ Frisco Peak

- Validate Trinity's telescope configuration
- Long-term stability of technologies
- Study background sources





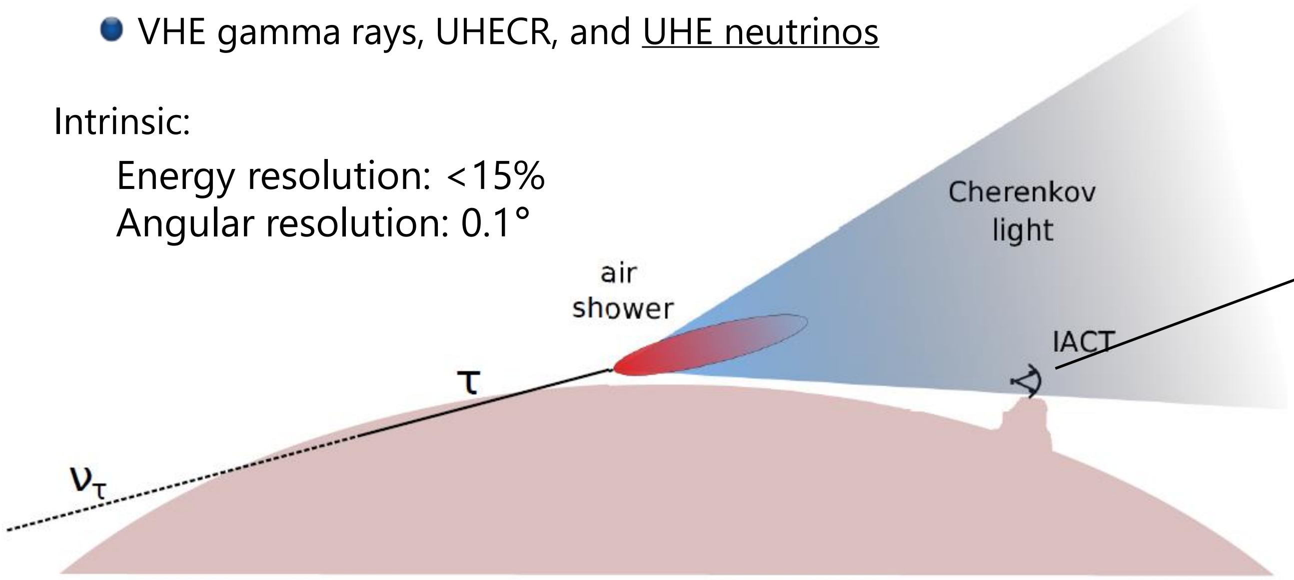
1 m^2 prototype

Air-Shower Imaging and Earth-Skimming Tau Neutrinos

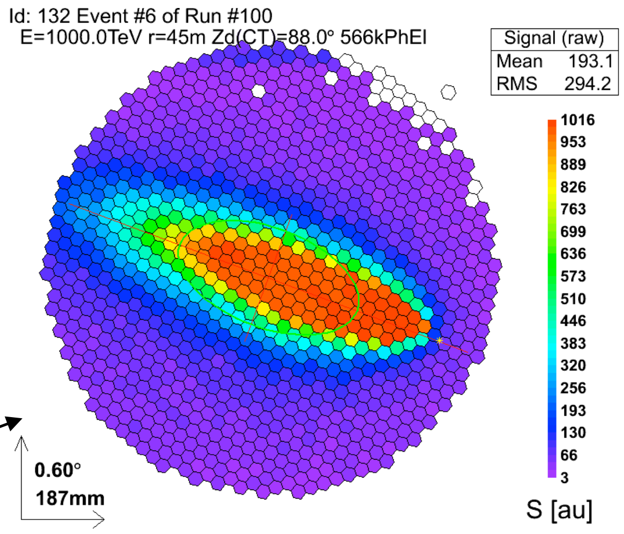
- A proven technique for
  - VHE gamma rays, UHECR, and UHE neutrinos

Intrinsic:

Energy resolution: <15%
Angular resolution: 0.1°



Simulated 1 PeV tau shower image

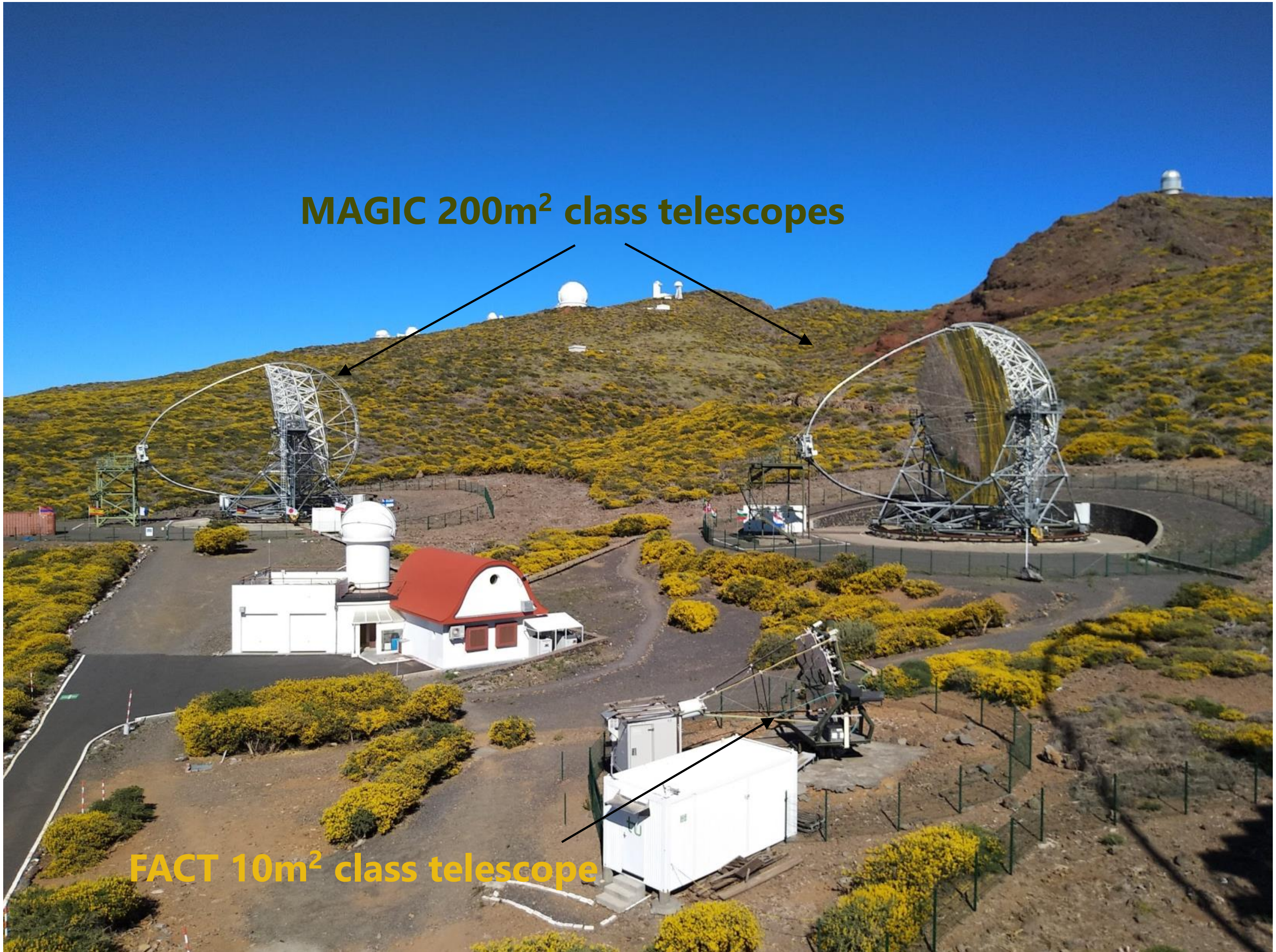


credit: MAGIC

Concept has been shown to work for UHE-neutrino observations:

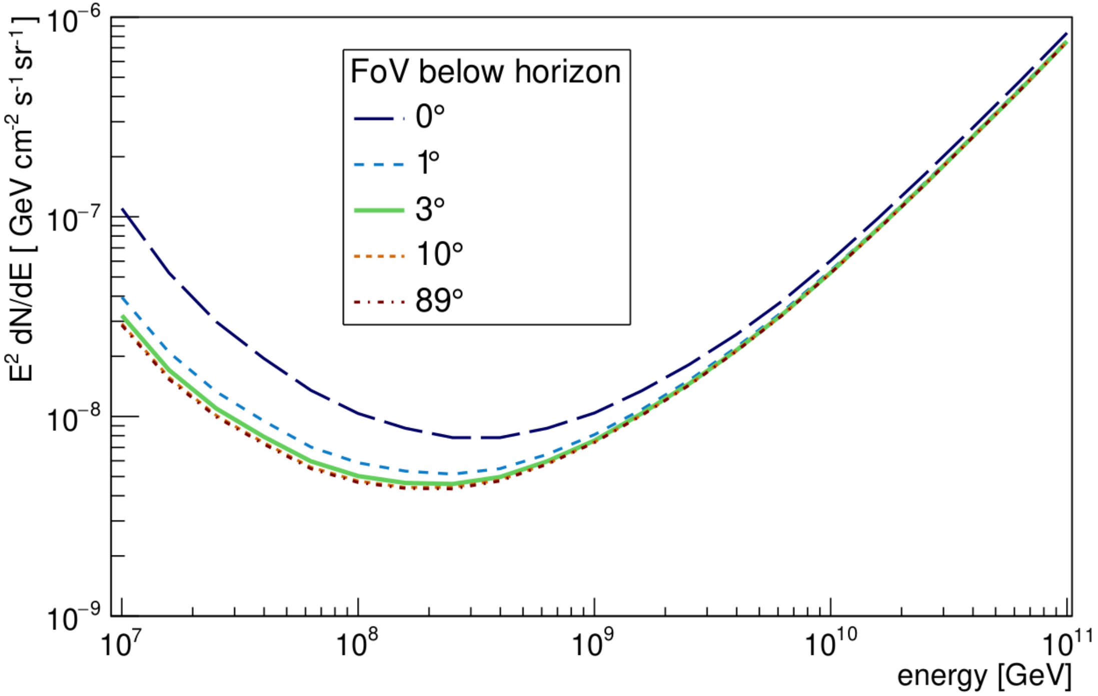
e.g. MAGIC (2018), Astropart.Phys.102,77-88.

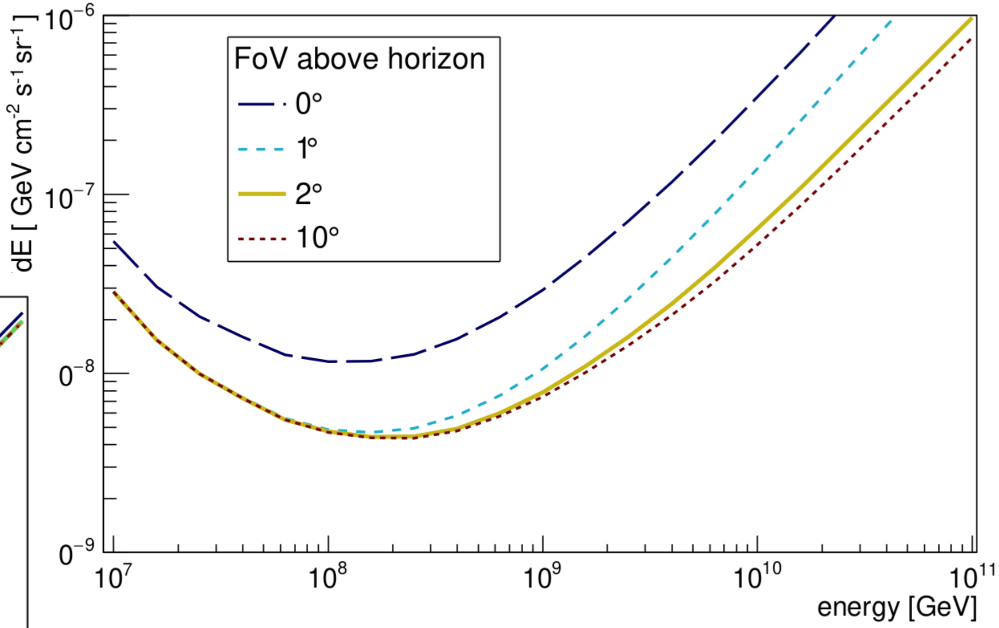
Ashra-1 PoS(ICRC2019)970



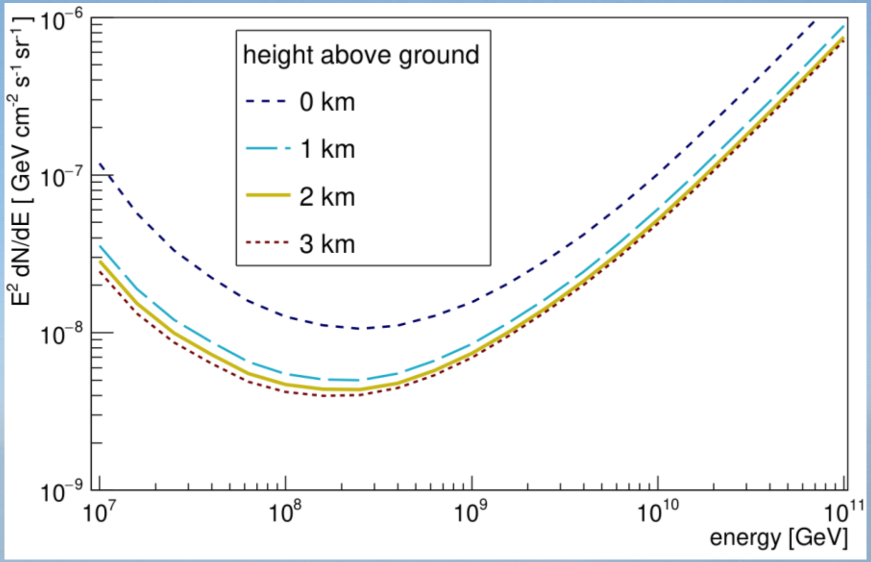
MAGIC 200m² class telescopes
FACT 10m² class telescope

Compact Field-of-View





Keeping out of the Haze



Compact Telescopes

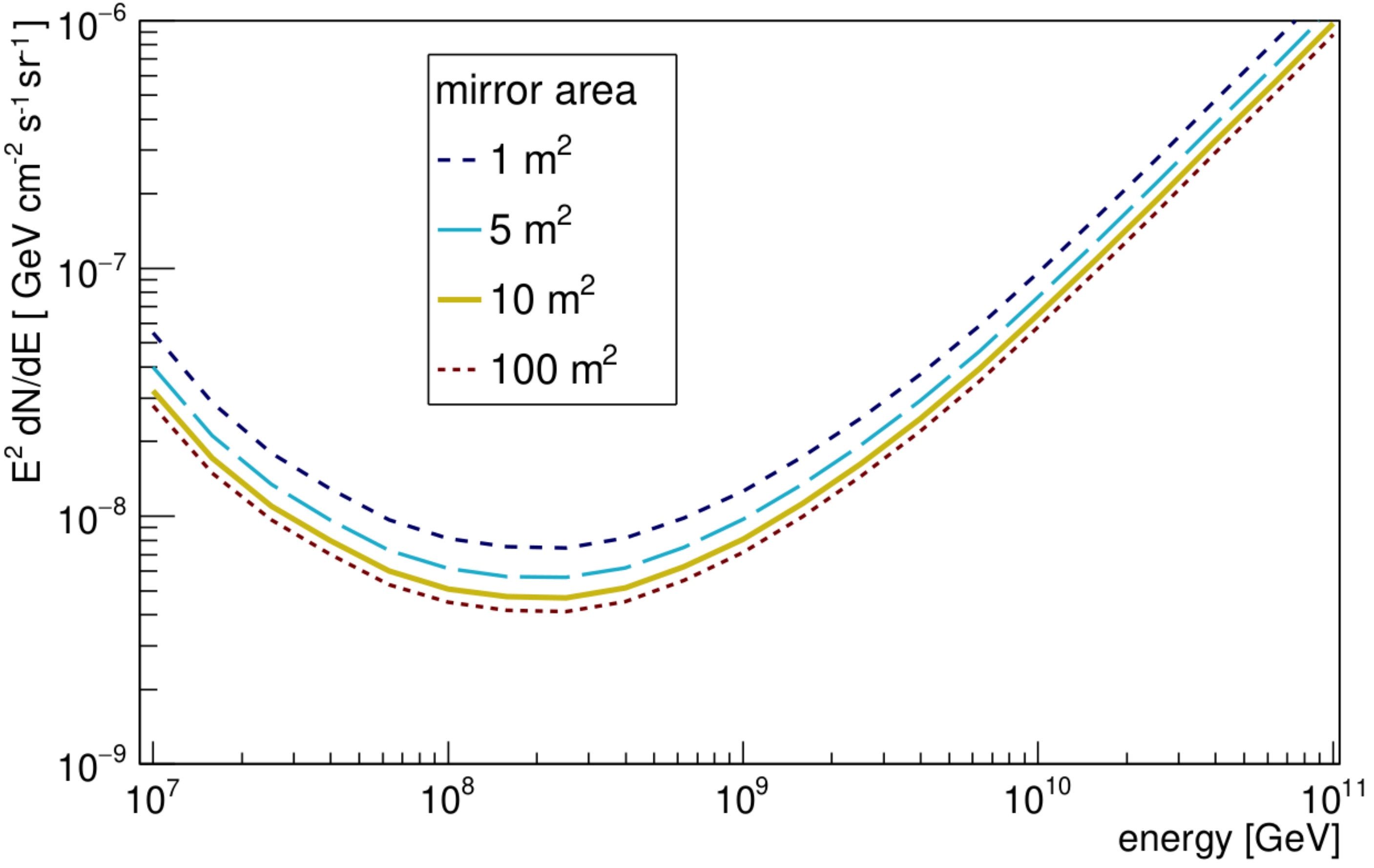
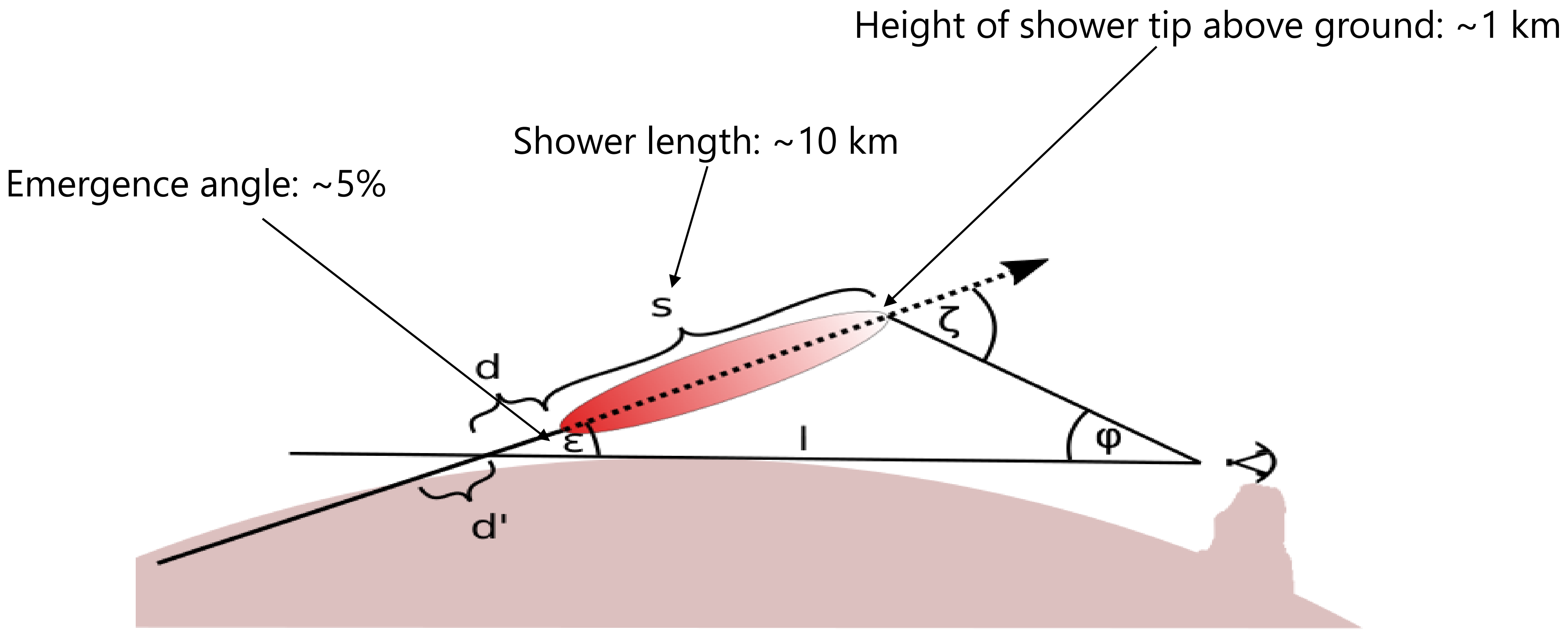
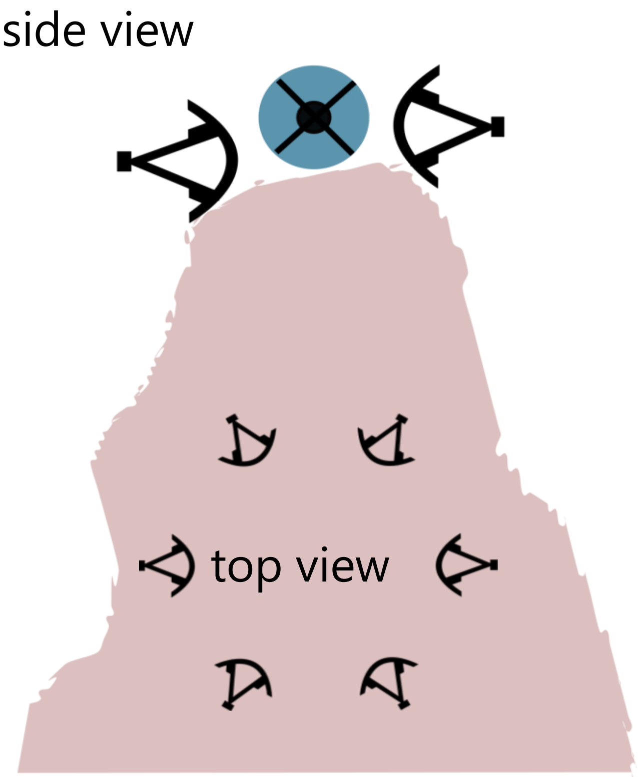


Image Containment



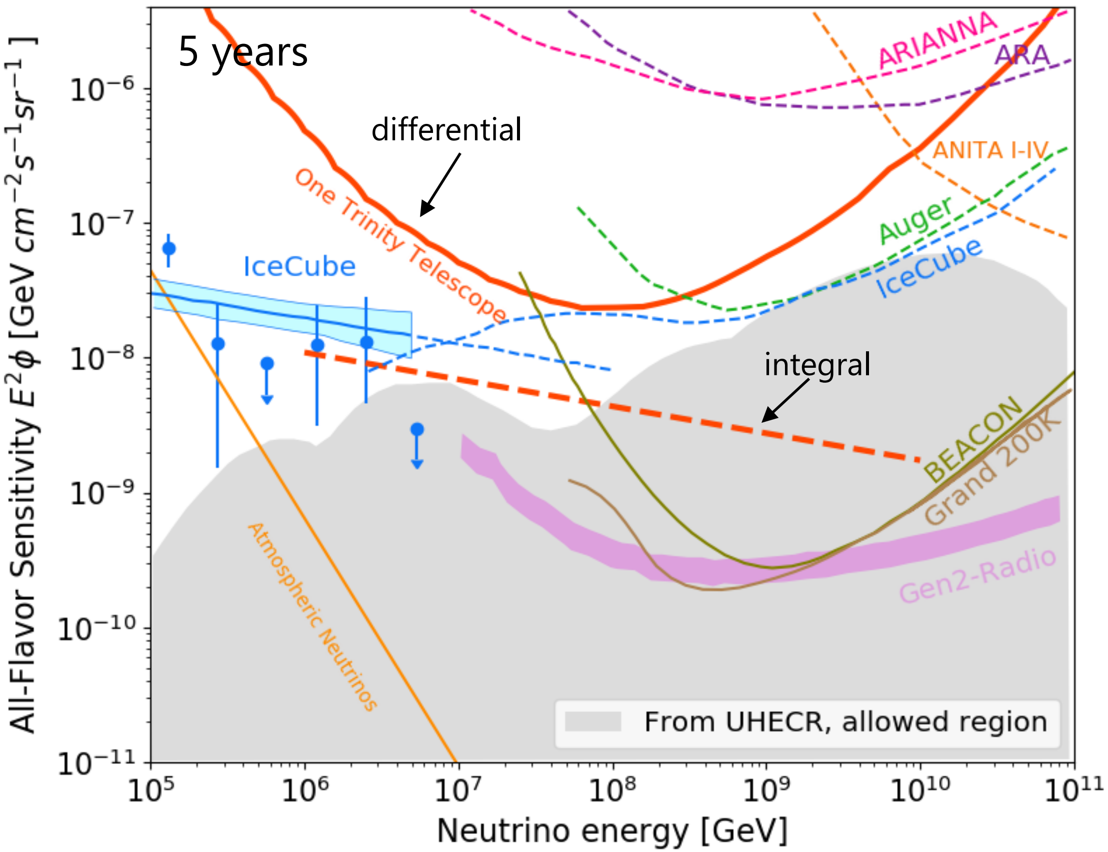
Trinity: An Optimized PeV Threshold UHE-Neutrino Detector



- 2 km above ground
- 360° azimuthal acceptance (six 60° FoV telescopes)
- Three sites (18 telescopes)
- 10 m^2 effective mirror area
- 3° FoV above horizon, 2° FoV below horizon
- 0.3° angular resolution
- Silicon photomultipliers instead of bialkali photomultipliers
- $15 M (telescopes + infrastructure)

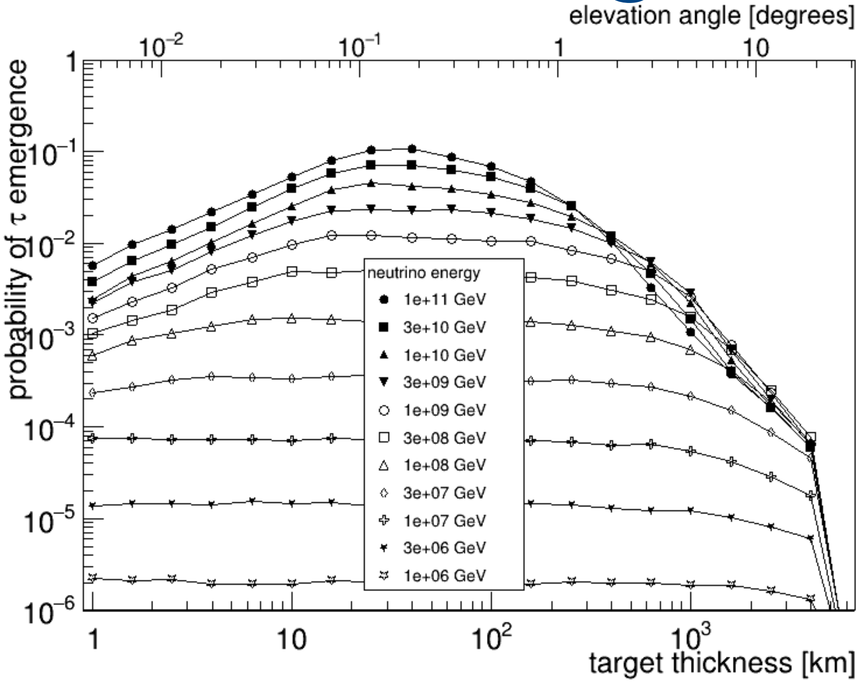
Suitable sites for Trinity with existing infrastructure:
Frisco Peak, UT; Hawaii; Canary Islands La Palma and Tenerife

Trinity: Single-Telescope Sensitivity



A single telescope will detect astrophysical neutrinos provided the spectrum does not cut off.

Earth-Skimming Technique



Probability if ν conversion and emergence of τ from ground

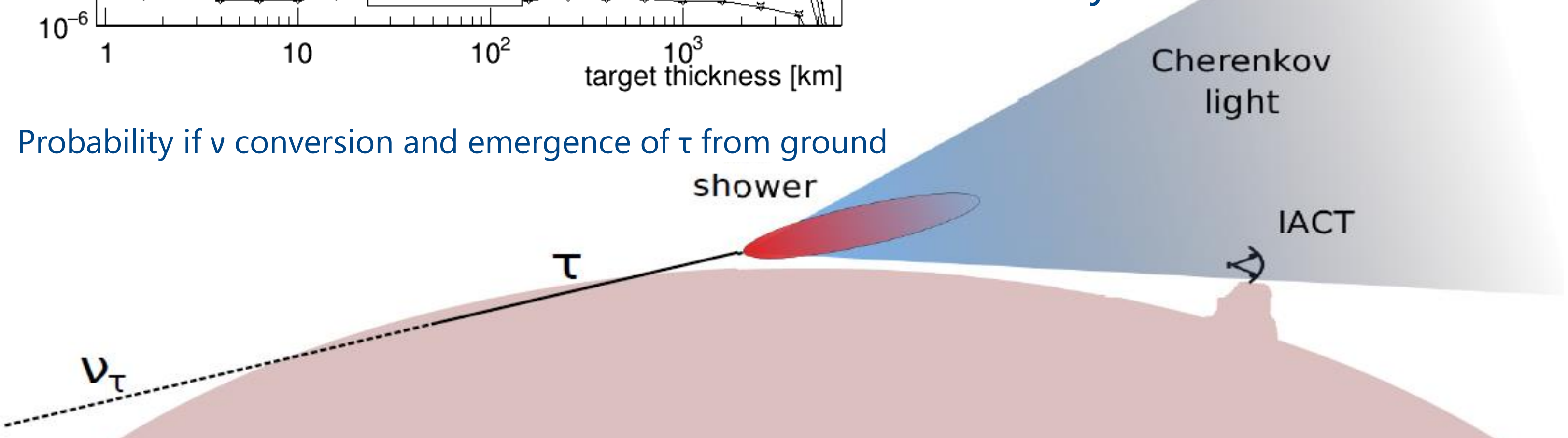
Limiting factors above 10^8 GeV:

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

Limiting factors below 10^8 GeV:

τ decay length: $49km \times \frac{E_\tau}{10^9 GeV}$ <1 km

Only works for tau neutrinos



Science with UHE Neutrinos

- What are the sources of the astrophysical neutrinos?
- What is the composition of UHECRs and how do their sources evolve?
- Are GRBs UHE neutrino sources?
- Are there steady sources we are missing?
- Probing BSM physics.

Require: All sky survey, > 10 PeV sensitivity, large field of view, sensitivity to neutrino flavors