VHE Neutrino Detectability with Ashra-NuTel

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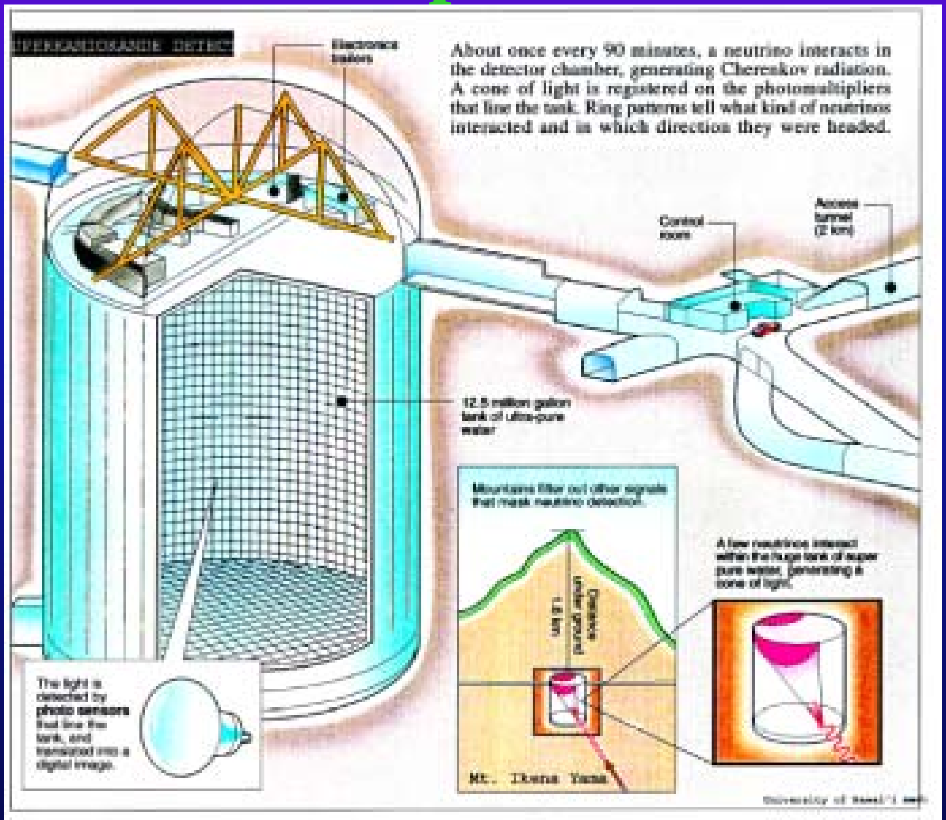
Introduction
Physics Simulation
Detector Simulation
Event Rate
Conclusion

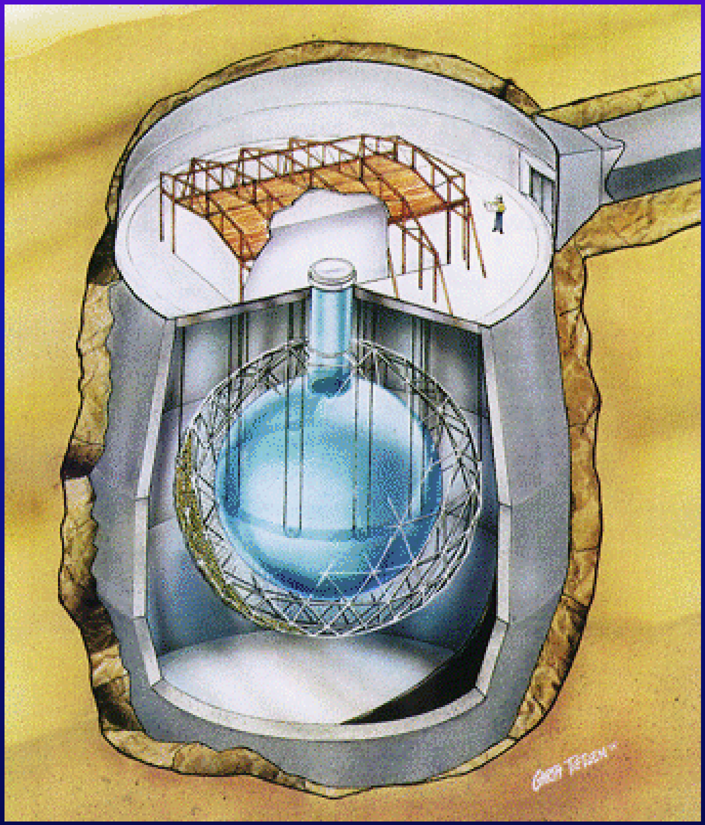
High Energy Physics Group, National Taiwan University

Conventional ν Detectors: Atm/Solar

SuperK



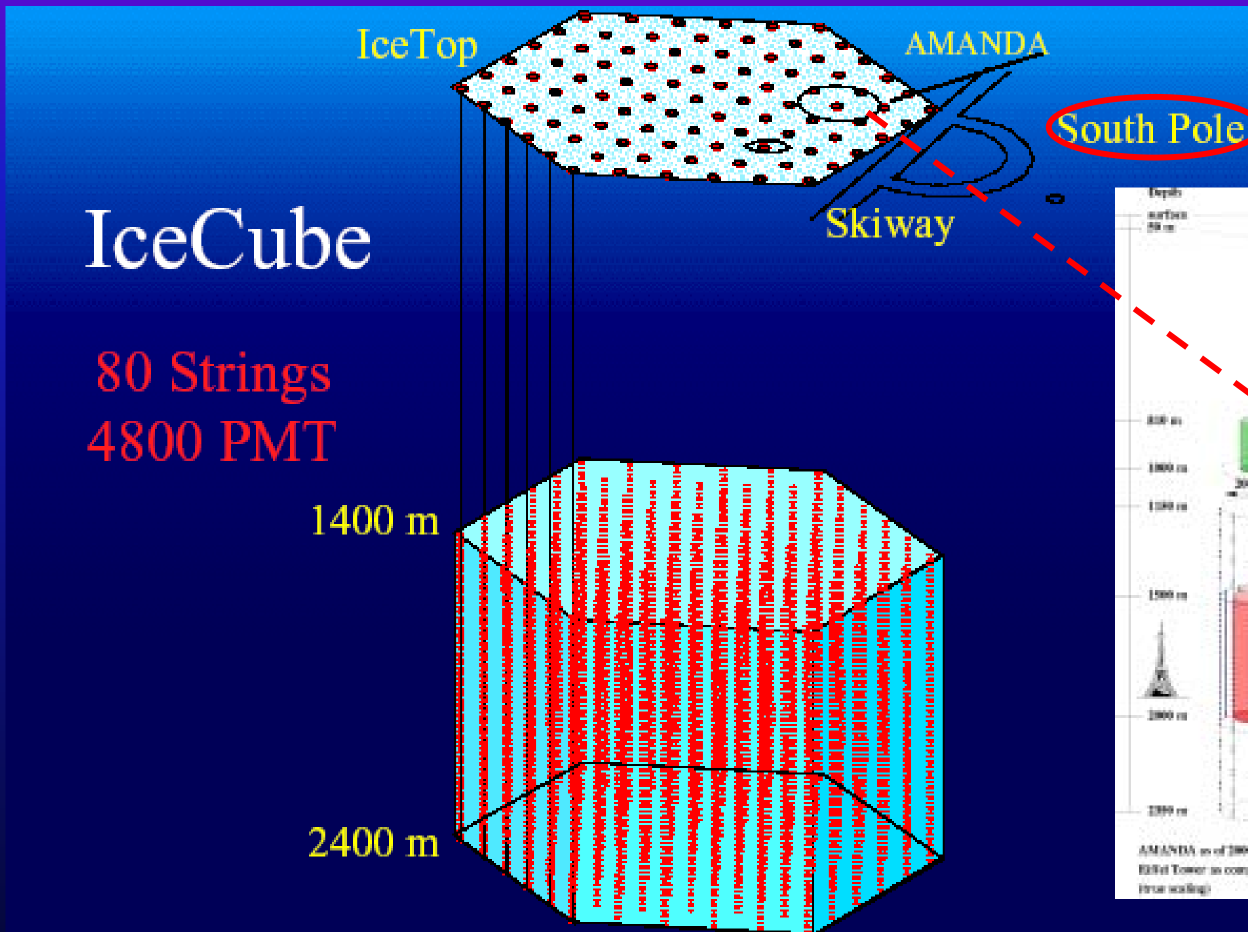
SNO



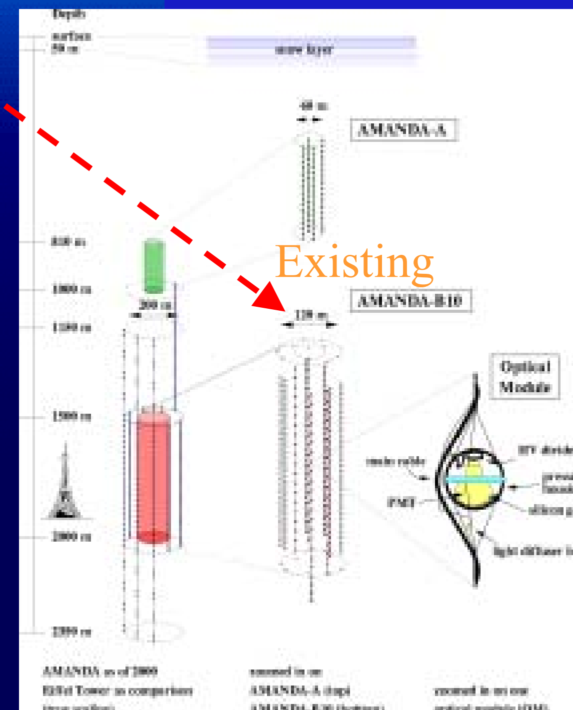
Shield from CR & Atmospheric μ's: Underground → Under Water/Ice
Very Large Target Volume = Detection Volume

solar ν deficit & $\nu_\mu \rightarrow \nu_\tau$

Conventional High Energy ν Detectors

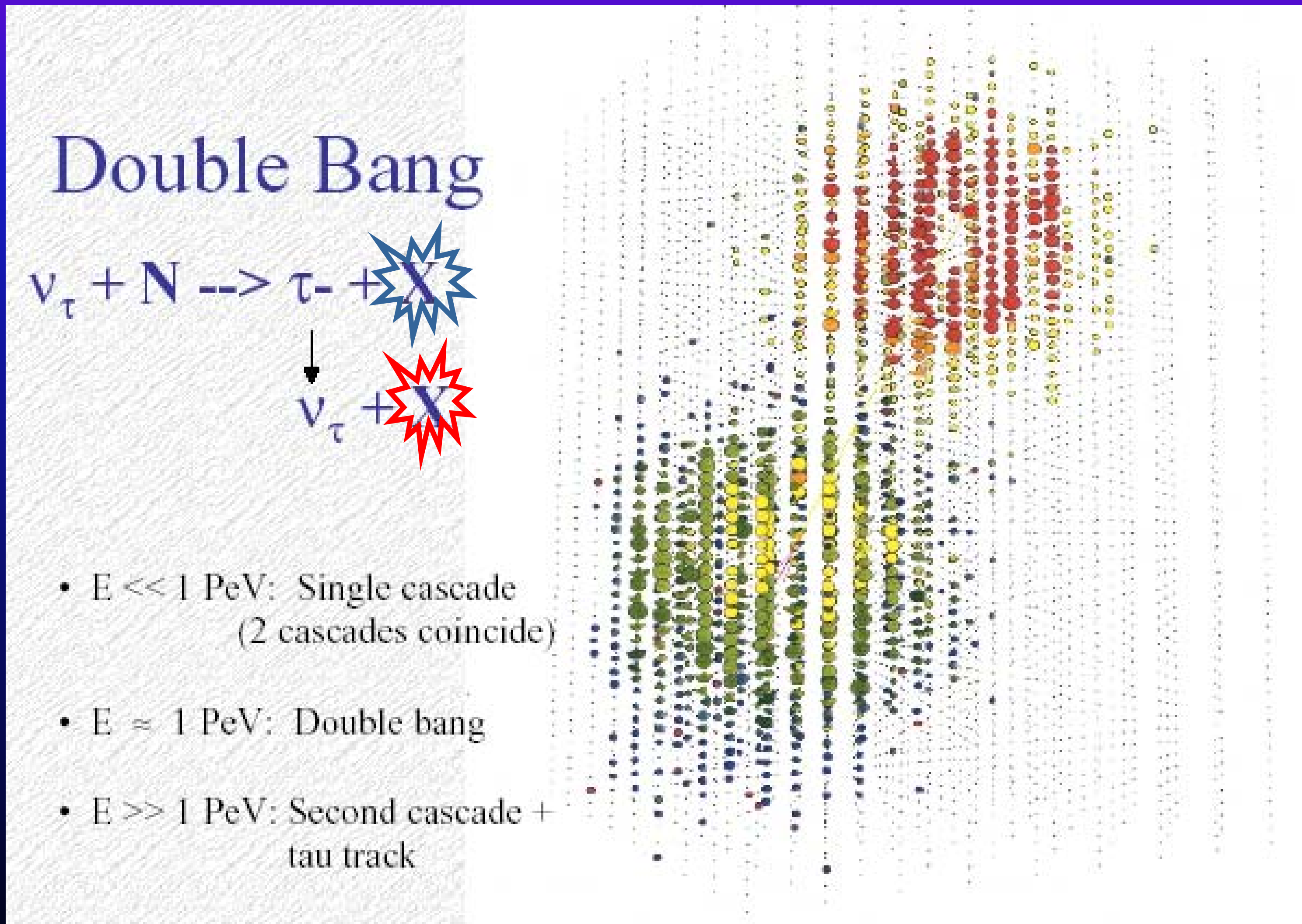


Deployment:
2003 - 2009

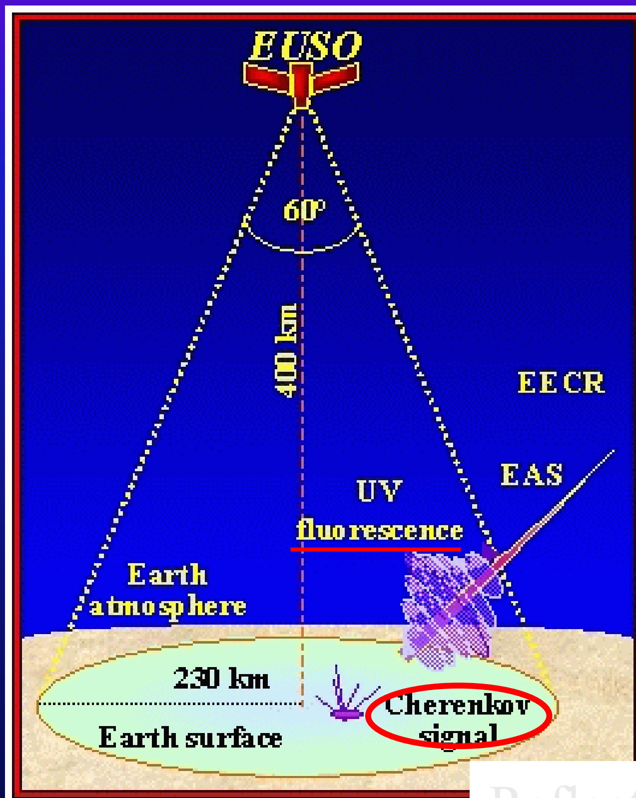


Limited by Target Volume: Maximum Energy ~ 10^{15} eV

IceCube: 1 PeV Limit for ν_τ



UHECR Detectors



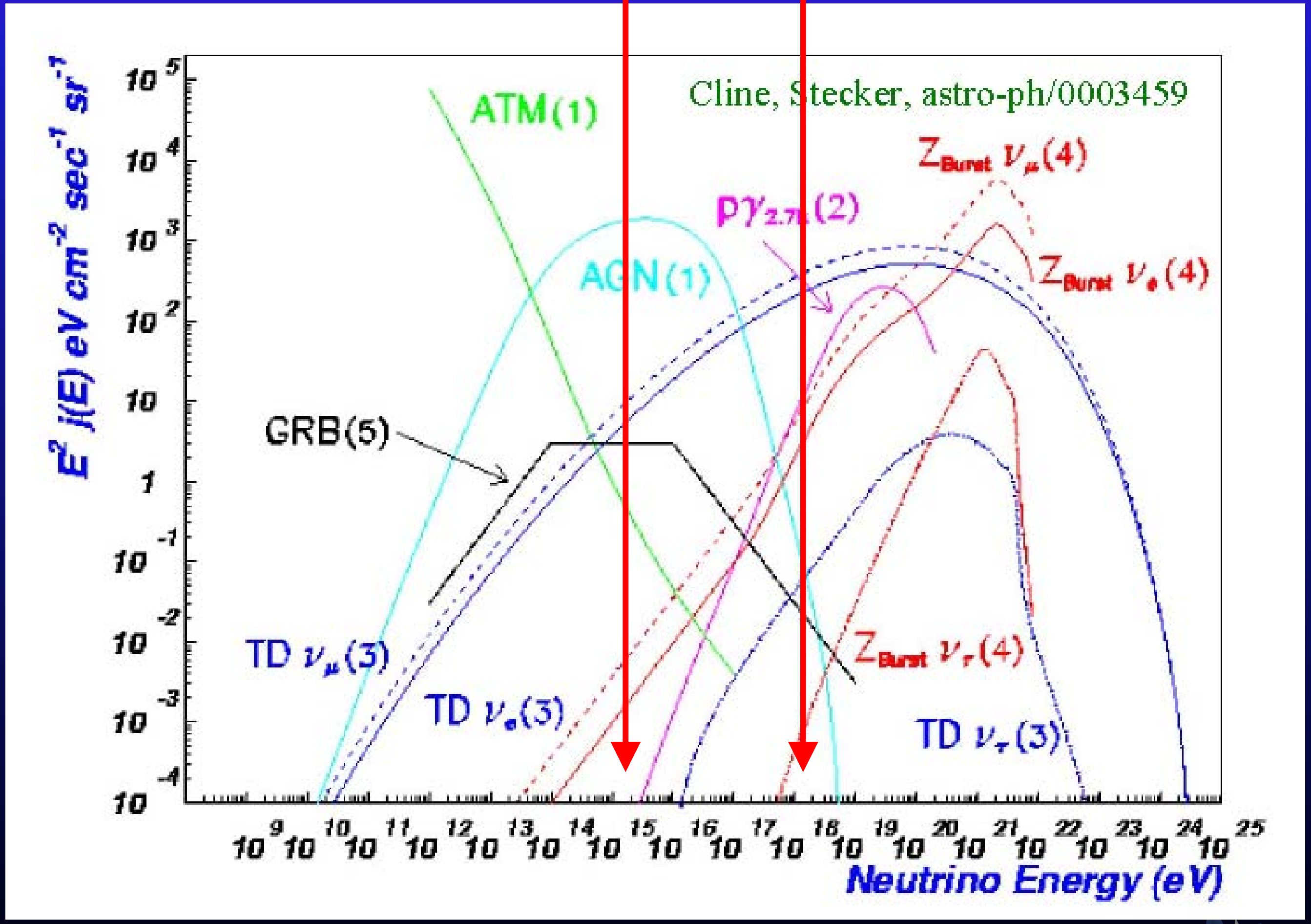
Reflected

Detect ν-induced Air Showers
Conversion Efficiency in Atmosphere Small

Fluorescence → Energy Threshold High > 10^{18} eV

Window of Opportunity

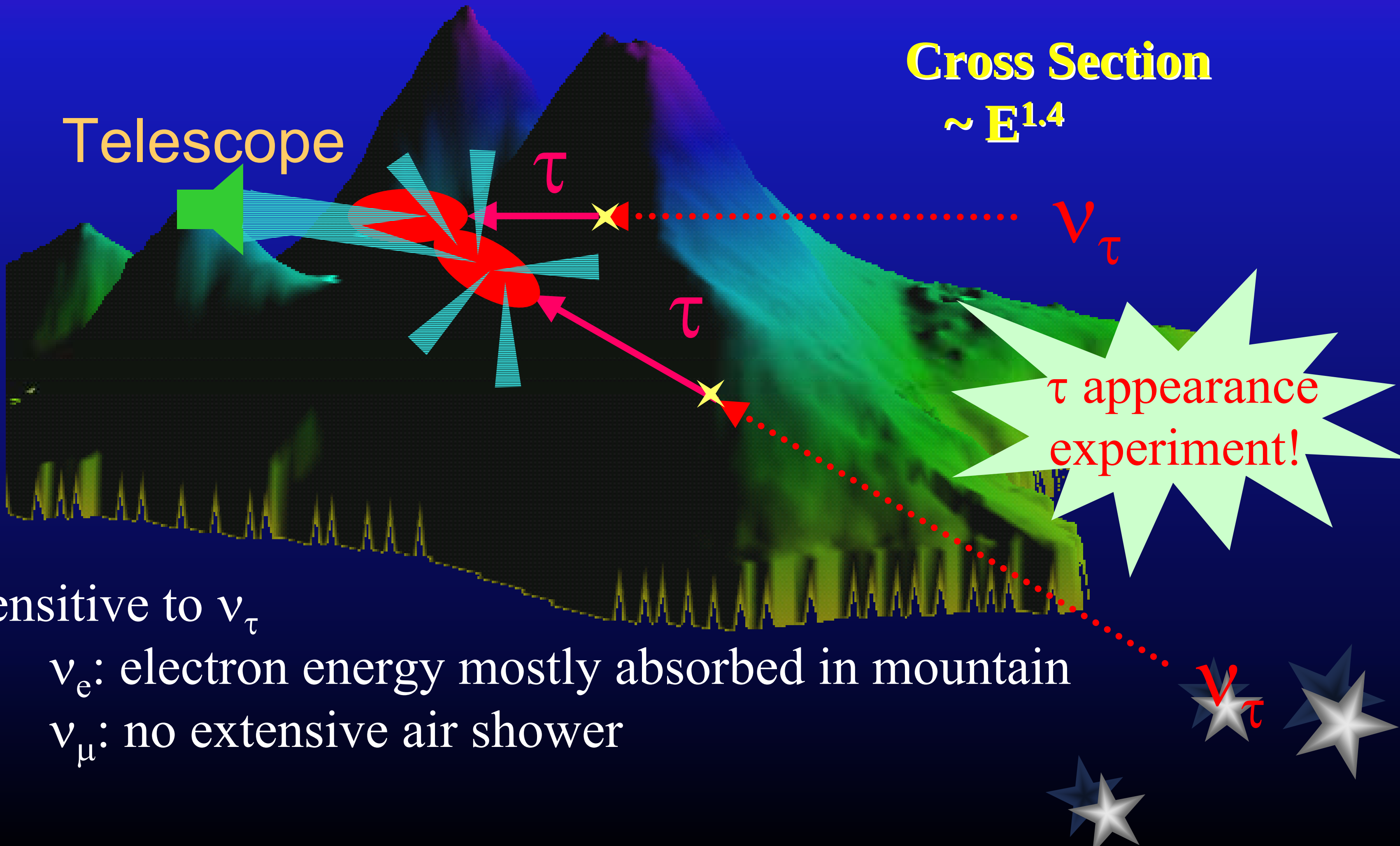
Conventional ν Detector **?** **UHECR ν Detector**



Earth Skimming

Earth Skimming + Mountain Penetrating

Cherenkov vs. fluorescence



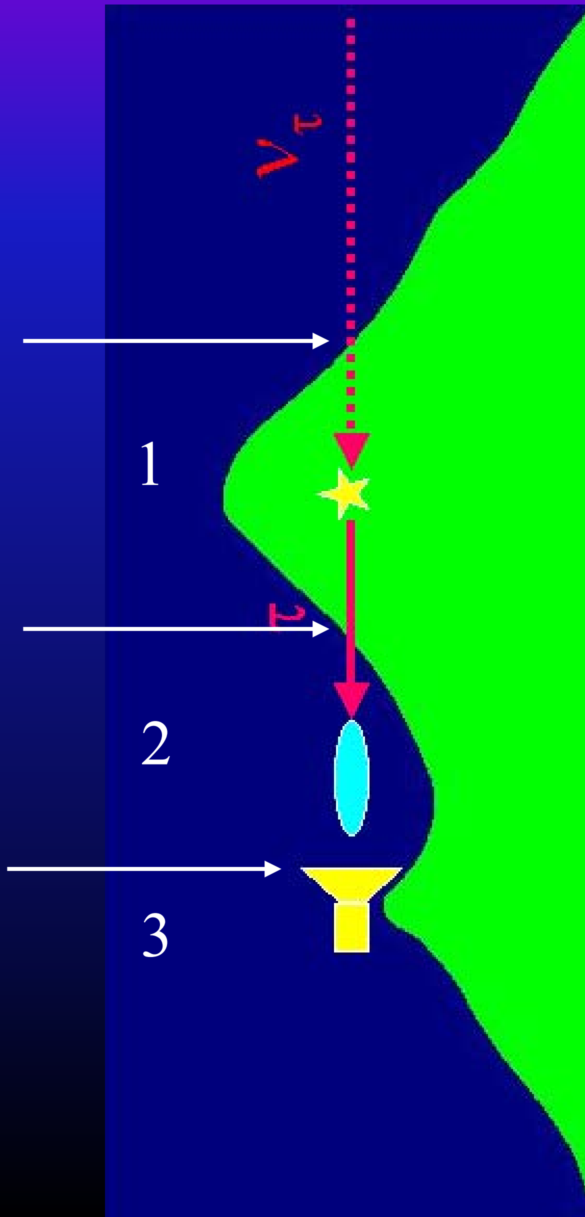
Sensitive to ν_τ

ν_e: electron energy mostly absorbed in mountain

ν_μ: no extensive air shower

Three simulation stages

1. Mountain simulation: $\nu_\tau \rightarrow \tau$
   - ν+N cross-section
   - inelasticity
   - energy loss of tau
2. Air shower simulation: $\tau \rightarrow$ Cerenkov photons
   - τ decay mode
   - CORSIKA detailed air shower simulation vs. fast simulation
3. Detector performance simulation
   - light propagation + Q.E.
   - pixelization for triggers
   - reconstruction



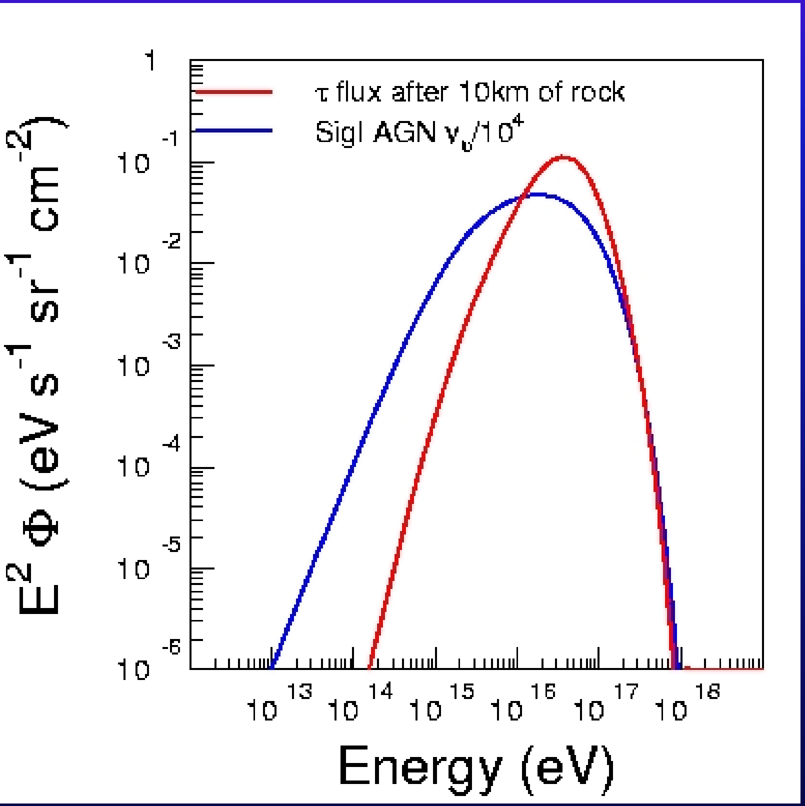
Tau Flux

- Sigl AGN neutrino flux + neutrino-mountain interaction

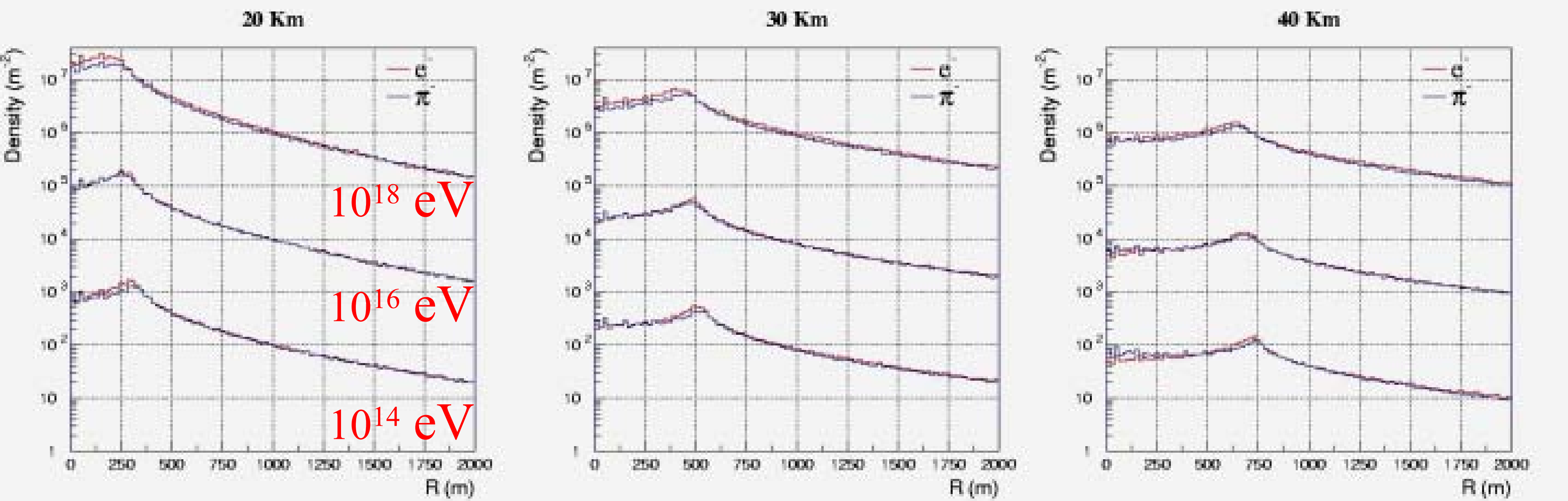
- Fast simulation:
  - single interaction inside target
    - Results from M.A. Huang
- Full-scale transport eq.
  - Consider multiple interactions $\nu_\tau \to \tau \to \nu_\tau \to \tau$ ...
    - Results from G.L. Lin et al.

- Similar results, very small difference at low energy.

  7.5 /km2/sr/yr over 1 PeV-100PeV



Lateral profile of Cerenkov photons for horizontal shower (CORSIKA)

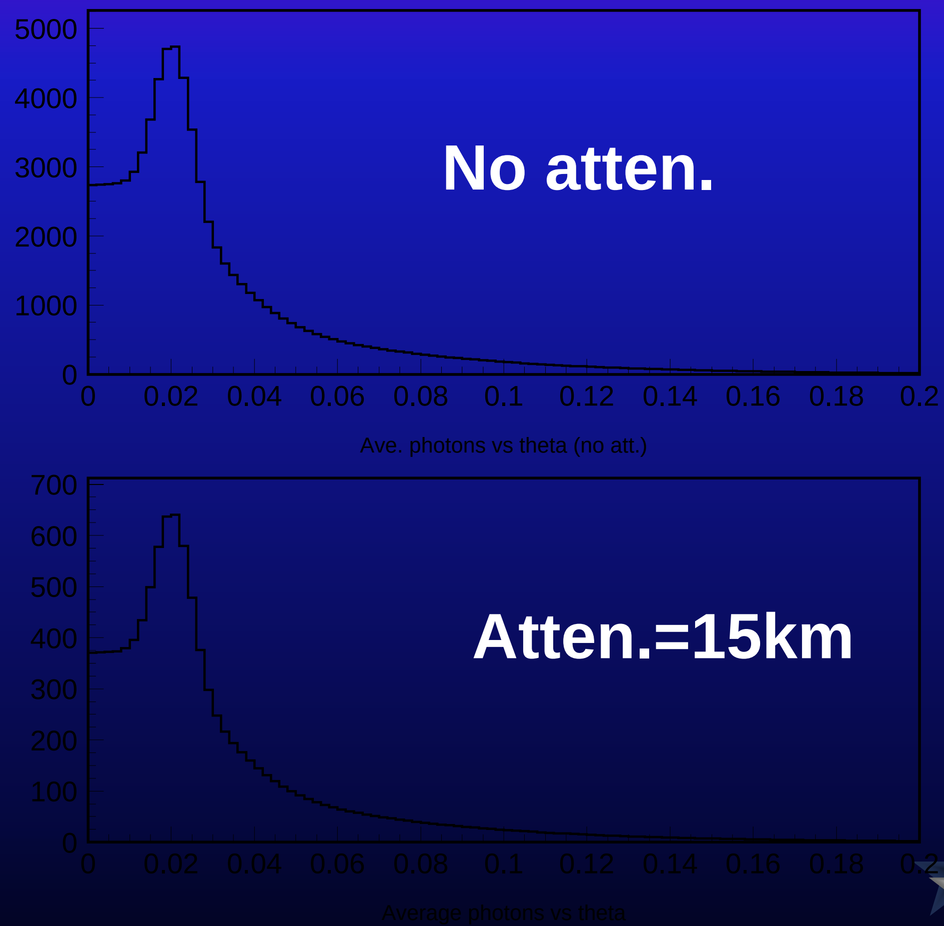


- Similar profile for showers produced by e^- and π^-
- Cerenkov ring distance ~ $(L-R_{max}) \times \mathrm{Tan}\ \theta_c$
- Outside ring, photon density ~ exponential decay
- Detector can trigger far away from Cerenkov ring

Photons numbers vs opening angle

- 1 PeV shower
- Shower core to detector plan 30 km away
- Serious drop with attenuation

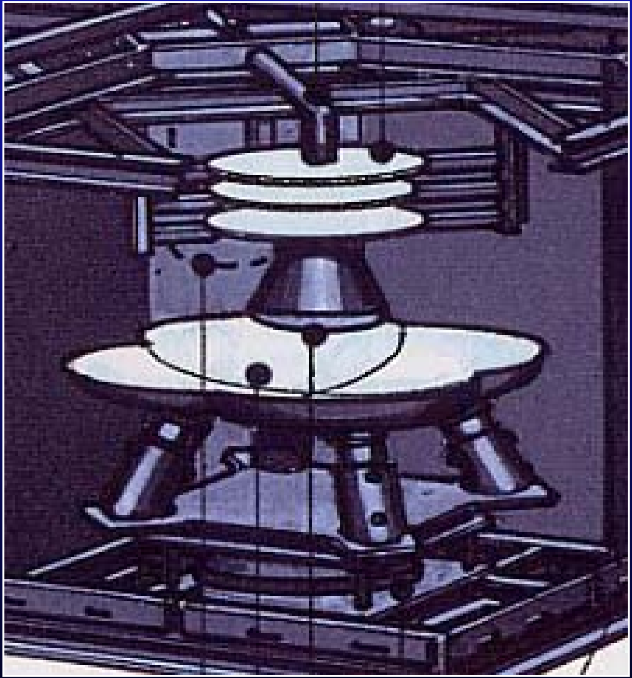
Photon density



Opening angle (radian)

Optics assumptions

- ASHRA Mirror + a simple correction lens
- Multi-Anode Photomultiplier with 0.5^o x 0.5^o pixel span
- Light collection : 1 m^2 aperture, 8^o x 16^o field of view, over all 10% efficiency for $\gamma \rightarrow$ p.e.



The Signal and Background Pattern

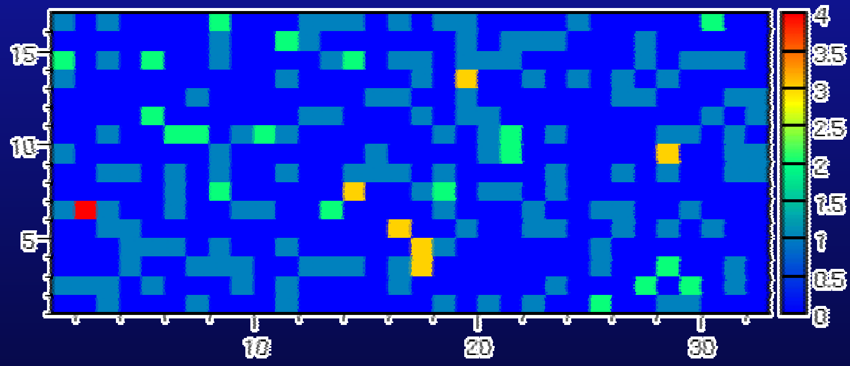
Cherenkov: ns pulse, angular span ~ 1.5 degrees

Night Sky Background (mean)

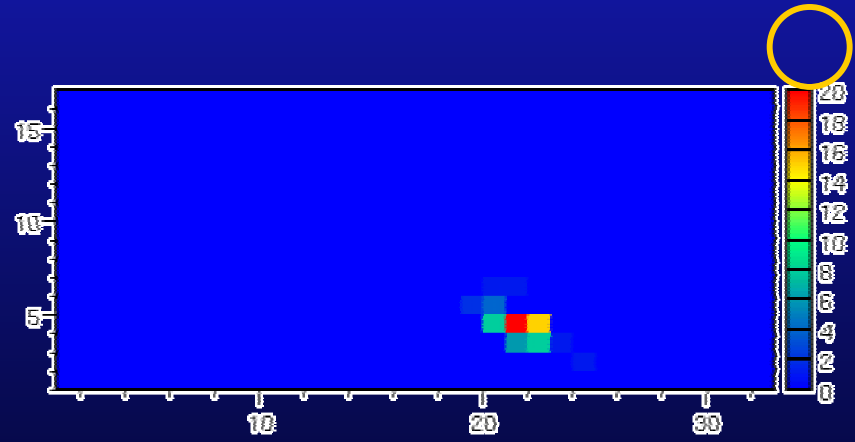
- Measured at Lulin observatory: 2.0 x10^3 ph/ns/m^2/sr
- A magnitude 0 star gives 7.6 ph/m^2/ns in (290,390) nm

Cosmic Ray background very small

Cluster-based trigger algorithm



Random Background with NSB flux



1 km away from a 1 PeV e^- shower

Trigger Configuration

- **Single Pixel Trigger**: One pixel pass energy threshold H

H

- **Duo Trigger**: Two neighbouring pixels pass threshold H

H	H

- **H-L Trigger**: Two neighbouring pixels with one passes high threshold H and the other one passes low threshold L

H	L

- **Sum Trigger**: 1. (3x3) trigger cell
  2. Central pixel pass high threshold H
  Neighbour Npe Sum pass threshold A=n1+n2+…+n8

n1	n2	n3
n8	H	n4
n7	n6	n5

Night Sky Background:

- Npe Follows Poisson distribution: $\mathrm{Prob}(n;\mu) = e^{-\mu} \mu^{n}/n!$,

$\mu = \langle Npe \rangle \;\; \Phi\, t_g\, A\, FOV\, \varepsilon_A\, \varepsilon_q$,

$\Phi = 200/\mathrm{ns}/\mathrm{m}^2/\mathrm{sr}$ $A=1\mathrm{m}^2$ $FOV=0.5^{o}\times0.5^{o}$ $\varepsilon_A=0.5$ $\varepsilon_q=0.2$

$\mu=0.039$ tg=25ns ; $\mu=0.076$ tg=50ns

Range<0.5km: Majority of photon arrives within 25 ns

Most of photons arrives within 50 ns

NSB Trigger Rate

N=10^7MC, (32x32)Pixels

For 10 Hz order NSB trigger rate, the Trigger Configurations are:

25ns

Single Pixel Trigger: H=5

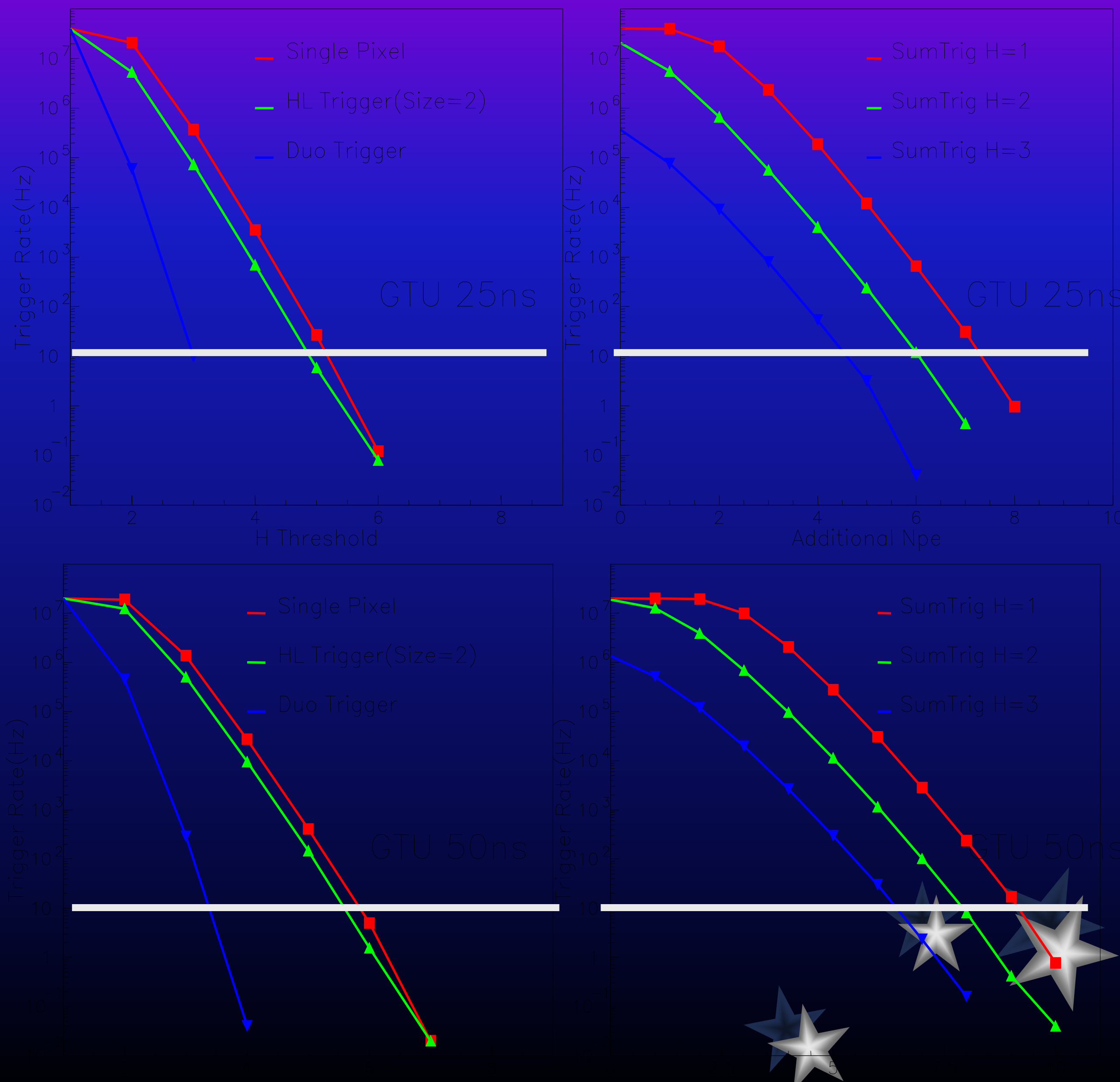
H-L Trigger : (H,L)=(5,1)

Duo Trigger : H=3

Sum Trigger1: (H,A)=(1,7)

Sum Trigger2: (H,A)=(2,6)

8 Npe



50ns

Single Pixel Trigger: H=6

H-L Trigger : (H,L)=(6,1)

Duo Trigger : H=4

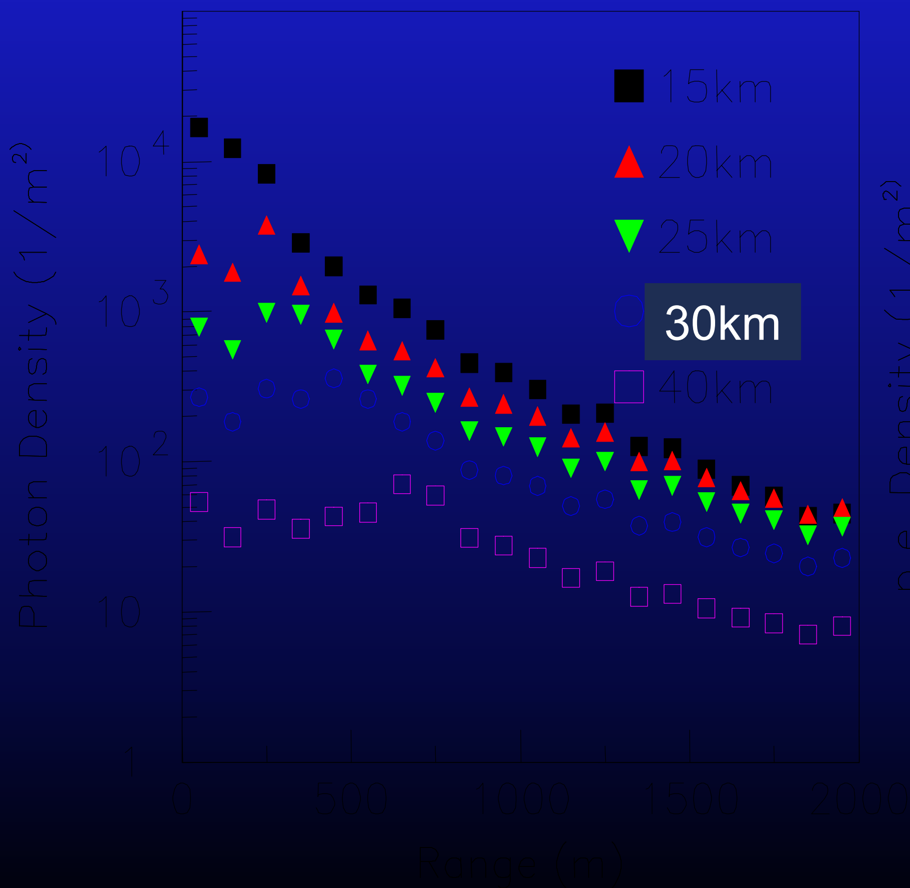
Sum Trigger1: (H,A)=(1,9)

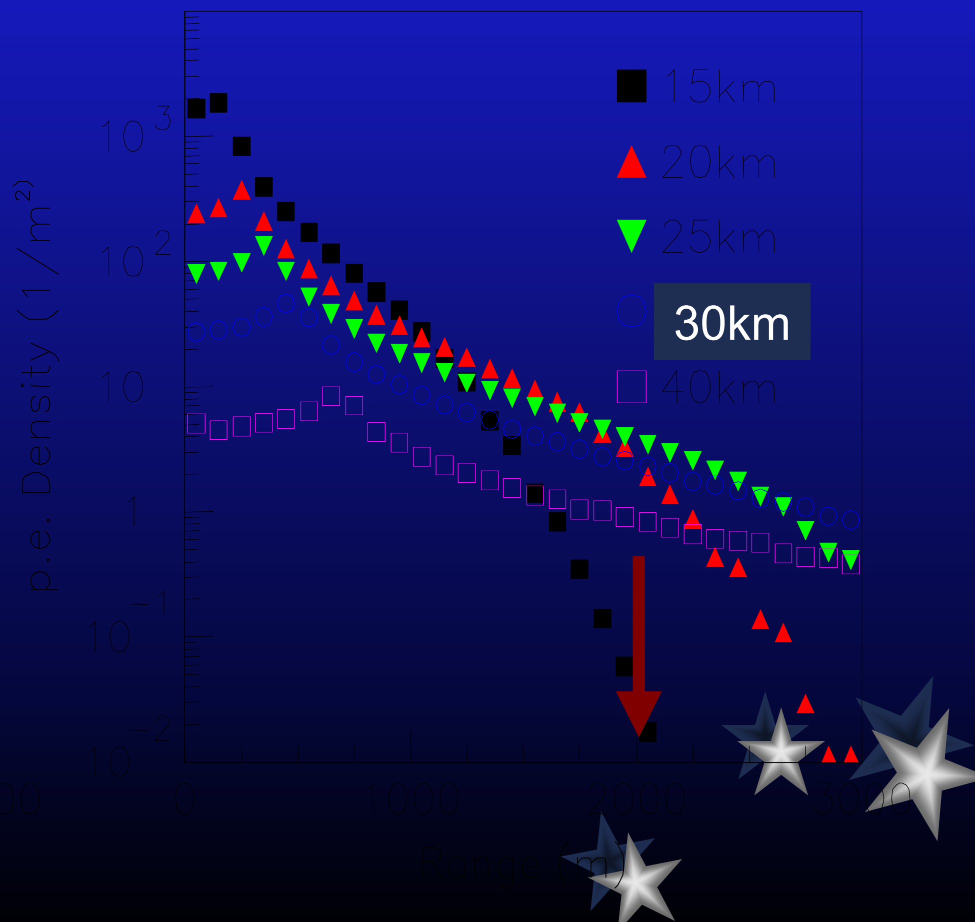
Sum Trigger2: (H,A)=(2,8)

10 Npe

Npe for Electron Shower

The p.e. density loss for range exceeding 2km is due to FOV limitation.





Trigger Efficiency for Electron Shower

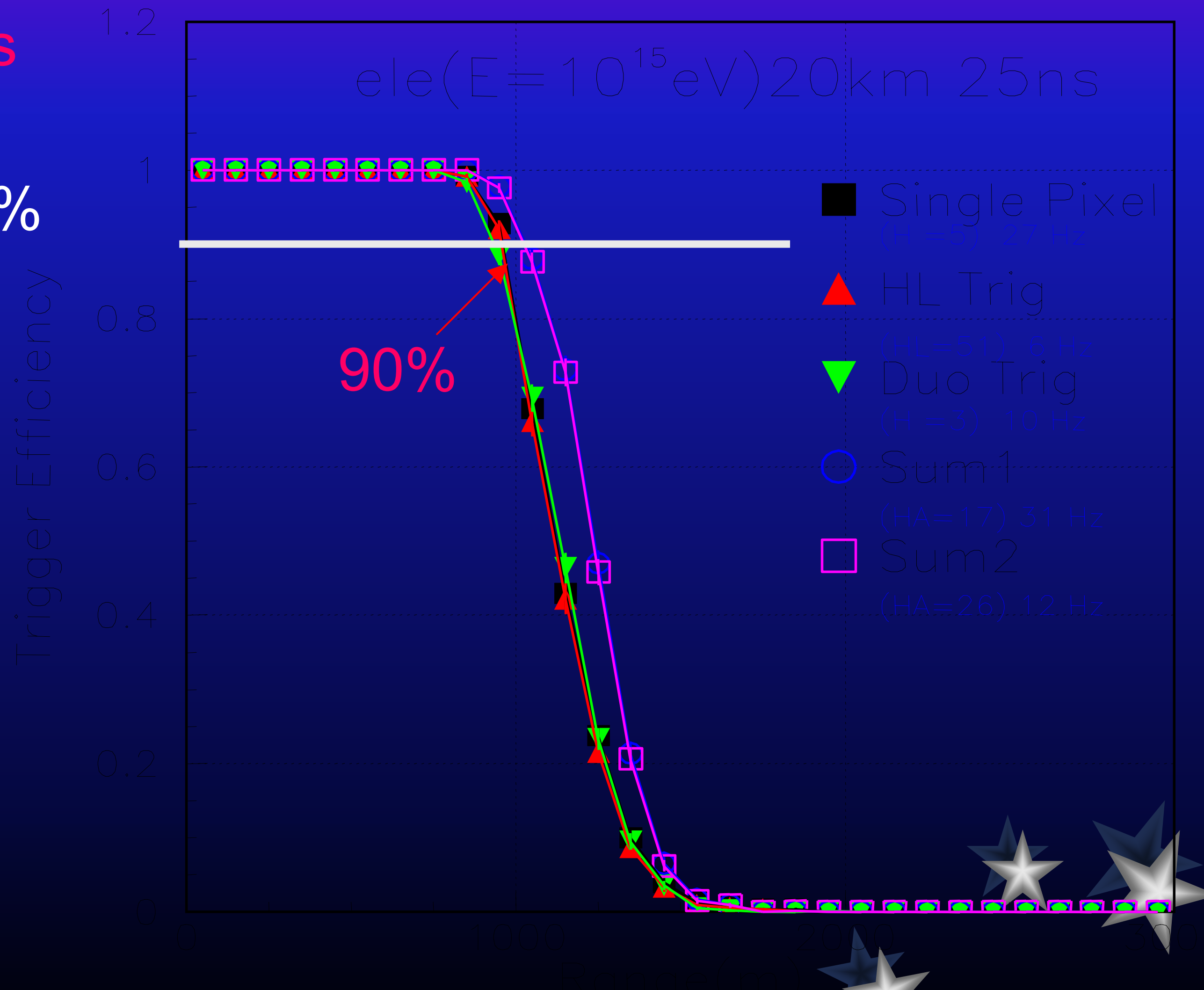
Sum Trigger gives
The largest range

1.1km for ε_{trig}=90%

Sum trigger
are similar

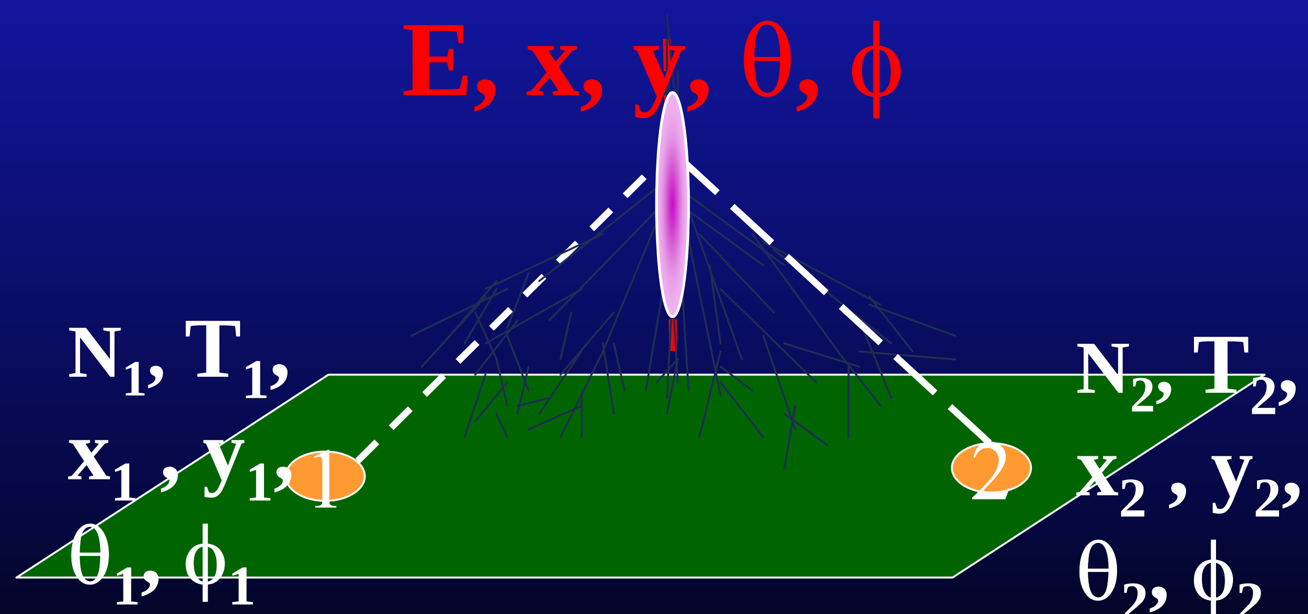
Other Three
triggers
are similar

Conservative
estimation is
200 γneeded



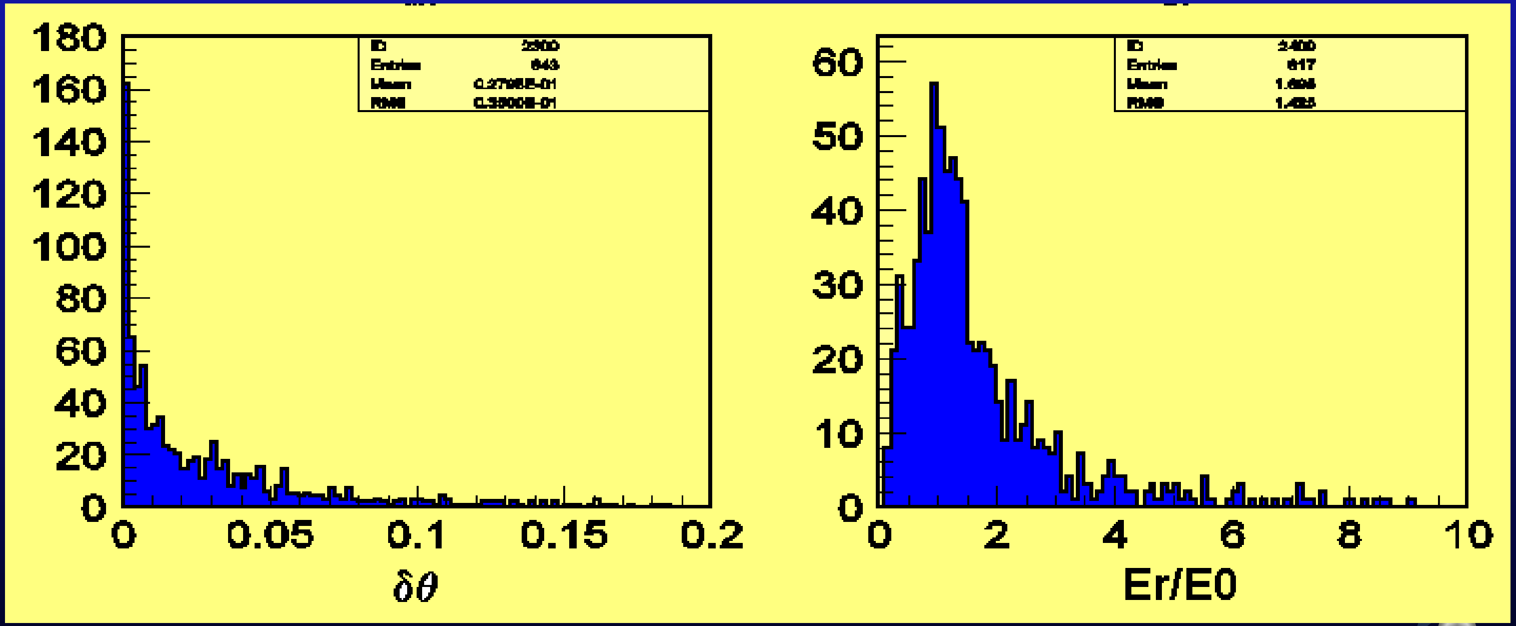
Preliminary Reconstruction

- Reconstruction: Minimize χ^2 for x,y,θ,ϕ, and E
  - Two Detectors Separated by ~ 100m



Possibility for Reconstruction

- Possible to Reconstruct Events
  - Angular Error within 1°
  - Energy Error ~ 40%
  - Reconstruction Efficiency > 90% if triggered



Acceptance Determination

Integration of efficiencies in phase space

$$A_\tau(E) = \int d^2\vec{x}\, d\Omega\, \epsilon_\tau(\vec{x}, \Omega)$$

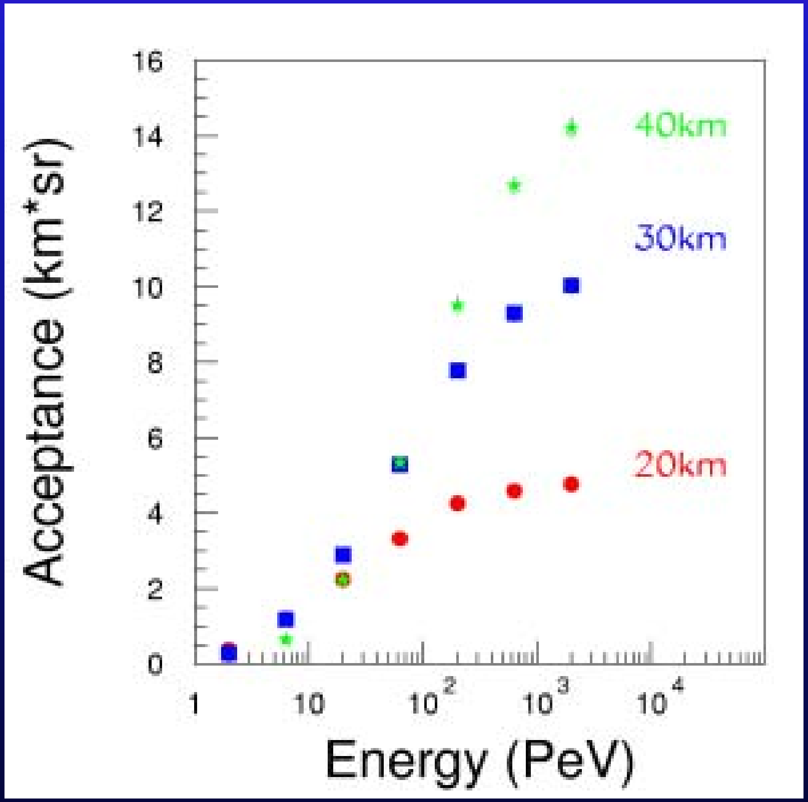
Three independent methods for cross-checking

Method	Efficiency	Integration	Investigator
MIR	Range determined from Simulation	Monte Carlo	Alfred
MIME	Modelled Curve	Monte Carlo	Minzu
NISE	Detailed Simulation	Numerical	Ping

Results are consistent with each other!

Acceptance Curve

Estimated with an idealistic vertical plane mountain surface

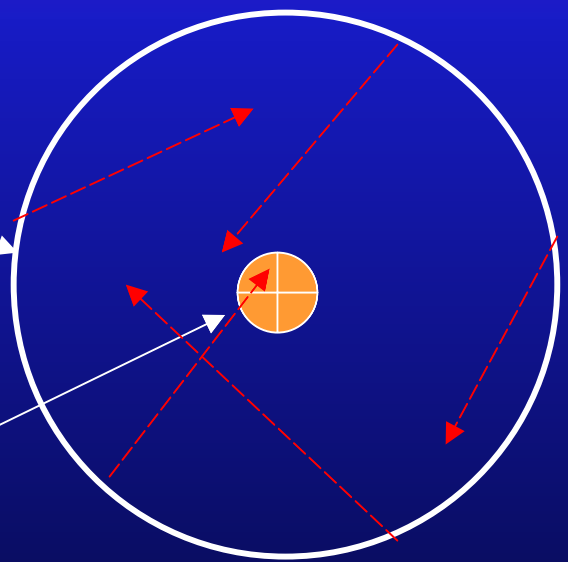


- Acceptance starts at $E_\tau \sim 1$ PeV
- Gradually levels off near 1 EeV (τ decay length = 50 km @ 1 EeV)

MIR Level 1

- Neutrino are generated uniformly and isotropicaly from surface of a sphere 100 km away from detector. All event are facing inward.

- Maximum impact parameter set at 5 km, save those events.

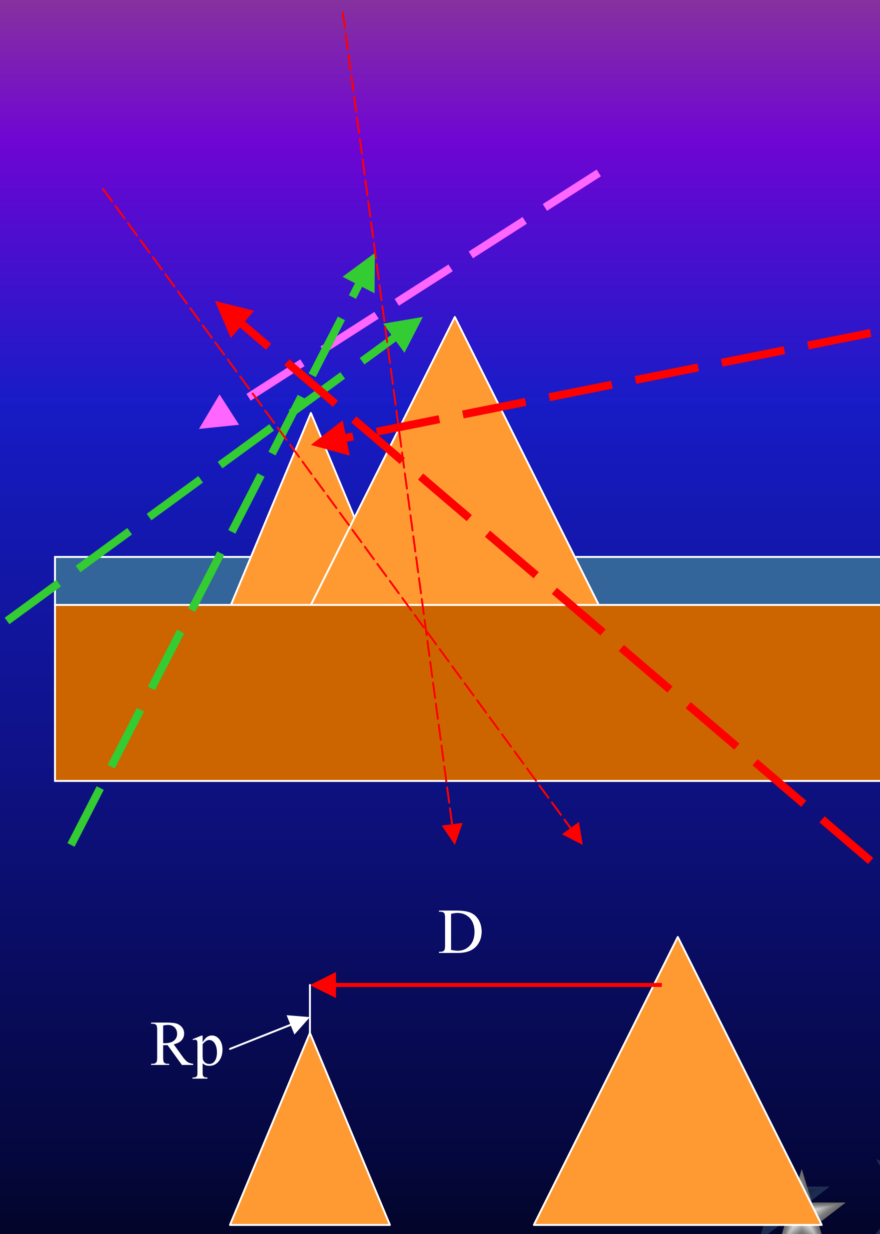


$$A_{tot} = 2\pi \times 4\pi \times 100^2 = 789568.35$$

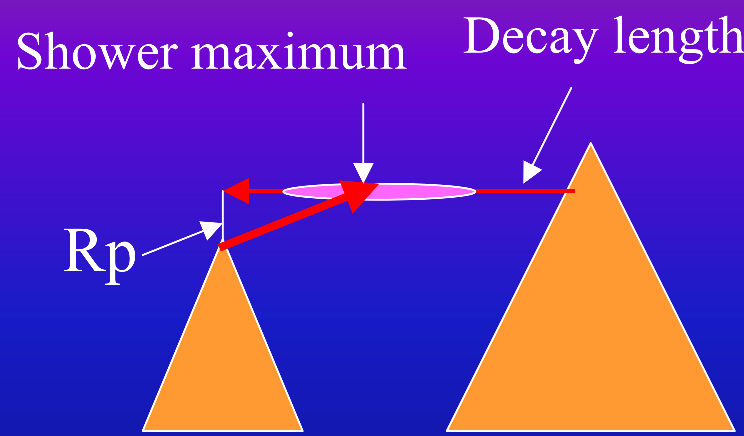
$$A_1 = \frac{N_1}{N_{tot}} \times A_{tot}$$

MIR Level 2

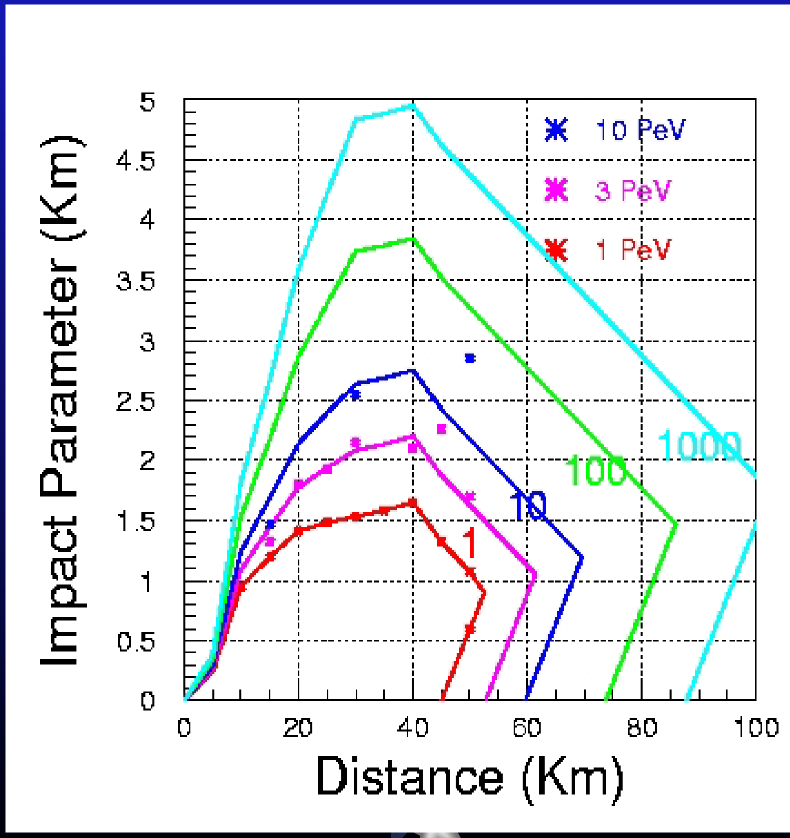
- Add Hawaii Big Island map, select site.
- Propagate neutrinos through the terrains
  - Identify event type according to media before reaching detector: air, sea, rock
  - Find two parameter: Rp and D



MIR Level 3

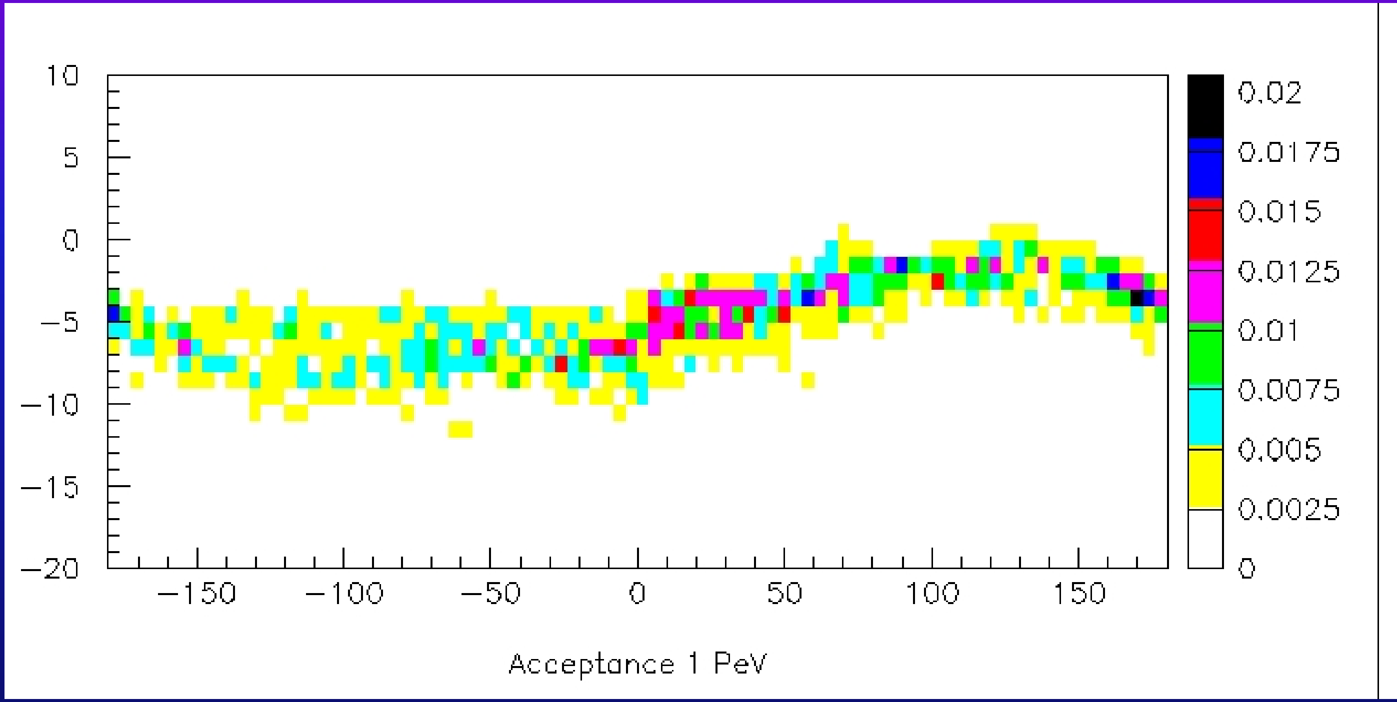


- Loop over energy,
  - Find tau decay position and shower maximum
- Trigger condition:
  - Shower maximum inside field of view
  - Rp and D satisfy condition set by air shower simulation.
  - Altitude of shower maximum must be higher than 1.5 km (To avoid inversion layer, which obscure image of shower.)



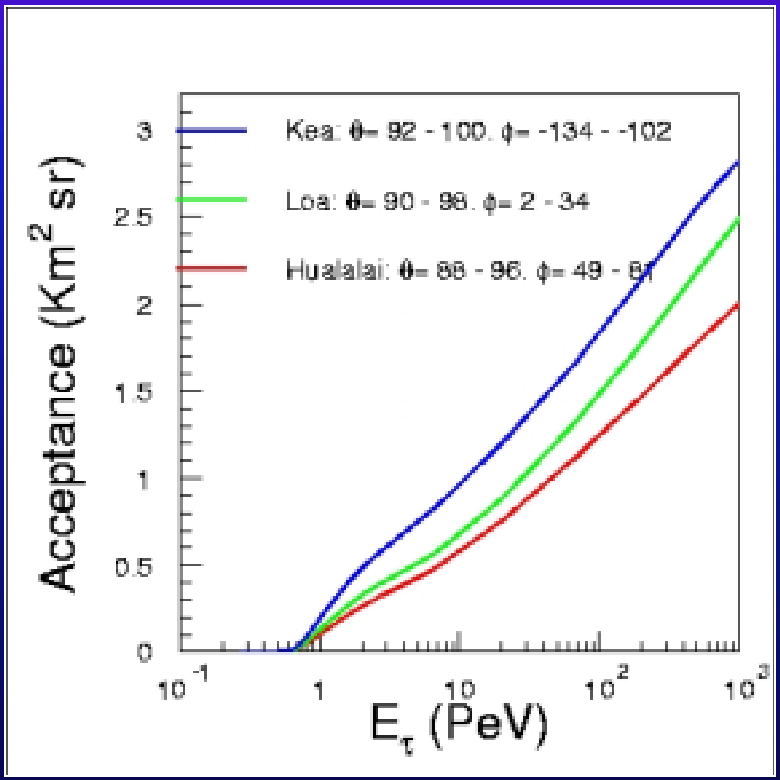
$$A_3 = \frac{N_3}{N_1} \times A_1$$

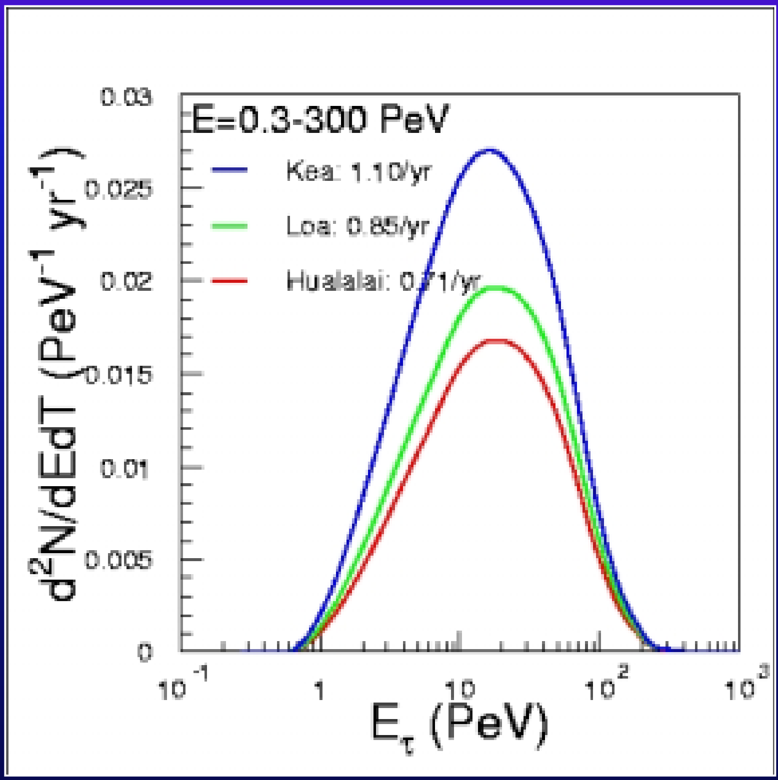
MIR Optimization



- Shower maximum position for triggered events
  - Y: Elevation angle (0 = horizon, zenith=+90)
  - X: geographic azimuth angle (N=0, E=90, S=+-180, W=-90)
  - (X,Y) is the lower-left corner of FOV
- Color code: Acceptance in $4^{\circ}\times 1^{\circ}$ pixels

MIR Event rate





- Use AGN tau flux from J.J.Tseng et al.
- Fold in energy dependence acceptance and maximized FOV

Note that FOV is 8º x 32 º

Best FOV

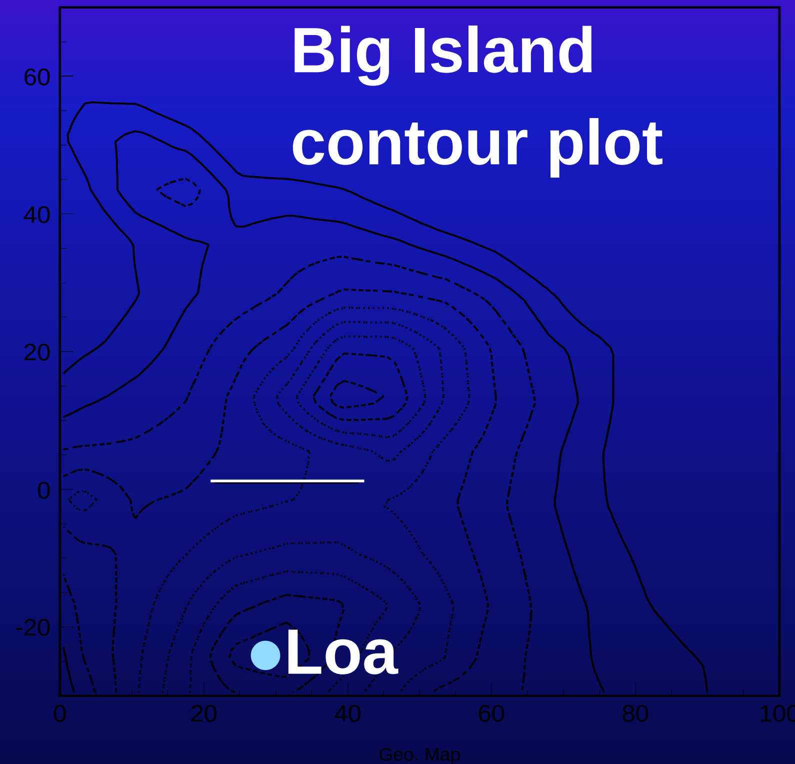
Site	θ	ϕ	Rate (/yr)
Hualalai	88º - 96º	49º - 81º ♤	0.71
Loa	90º - 98º	2º - 34º ♤	0.85
Kea	92 º - 100 º	-134º - 102º ♥	1.10

♤ FOV centered on Kea

♥ FOV centered on Hualalai

MIME

- Put detector on top of Loa
- Pick τ energy
- Pick τ position randomly on a 20 km by 20 km vertical plane located 25 km north of Loa
- Emit τ randomly in 60^{o} cone
- Trace the track to find the exit point of τ
- Find τ decay point
- Assume e/π took away ½ of τ energy and find the shower core position (air density 10^{-3} g/cm^3)
- Make sure shower core is above 1.5 km cloud level



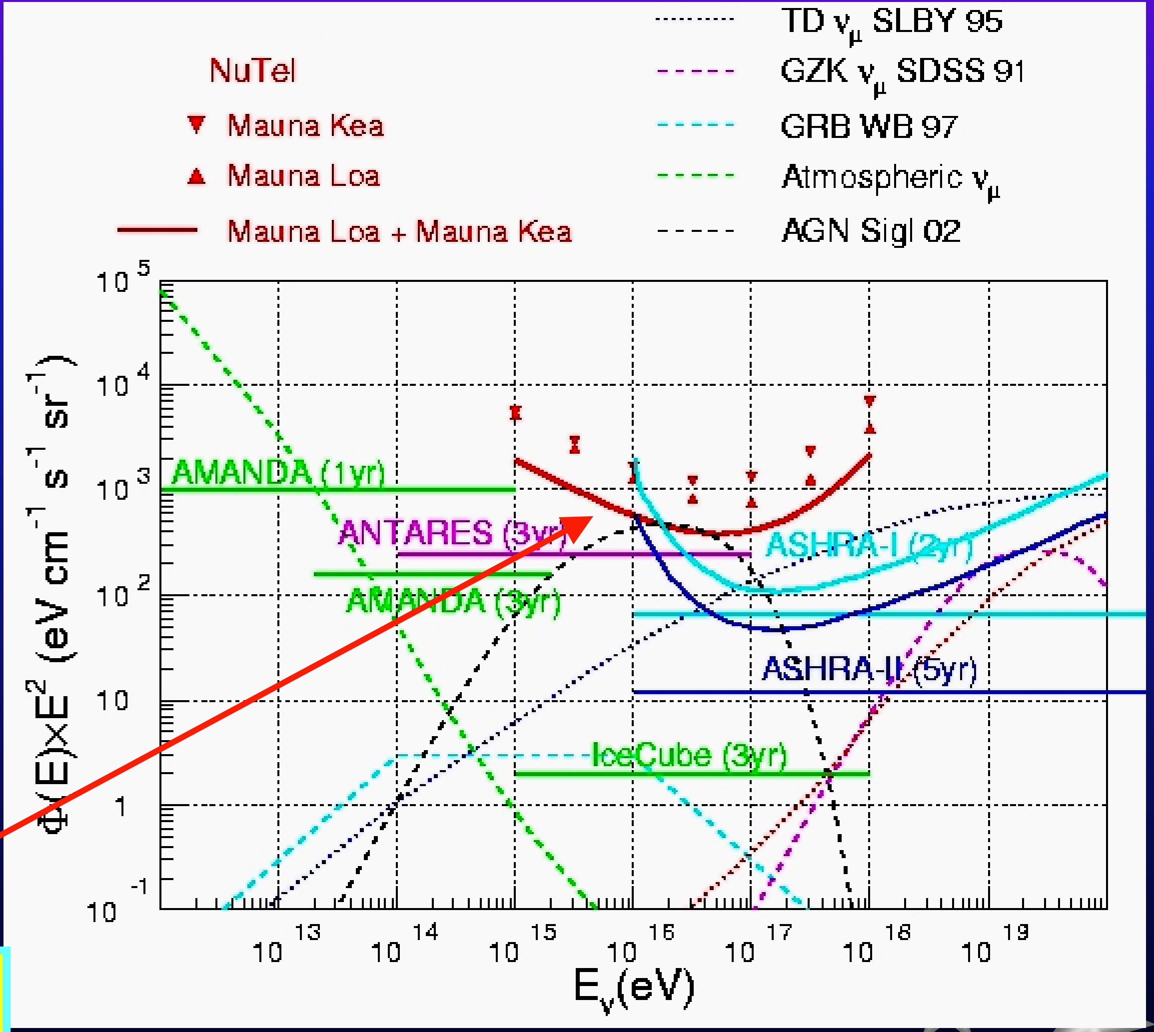
MIME

- Make sure the pathway is clear between τexit point and shower core
- Find the angle and distance between shower core and detector
- Determine the number of photons in the solid angle covered by detector and apply attenuation effect (18 km attenuation length)
- Set the threshold at 200 γ's and check the shower core in the FOV (vertical -8^o-0^o and horizontal -4^o- 12^o)
- Event rate = 7.5 x 400 x π x 0.1(duty) x 0.8(BF) x eff

The obtained rate for Loa is 0.46 per year

Sensitivity

- Sensitivity :
  1 event/year/decade
  of energy
- Great Chance to See ν from
  - AGN
  - TD
  - GC



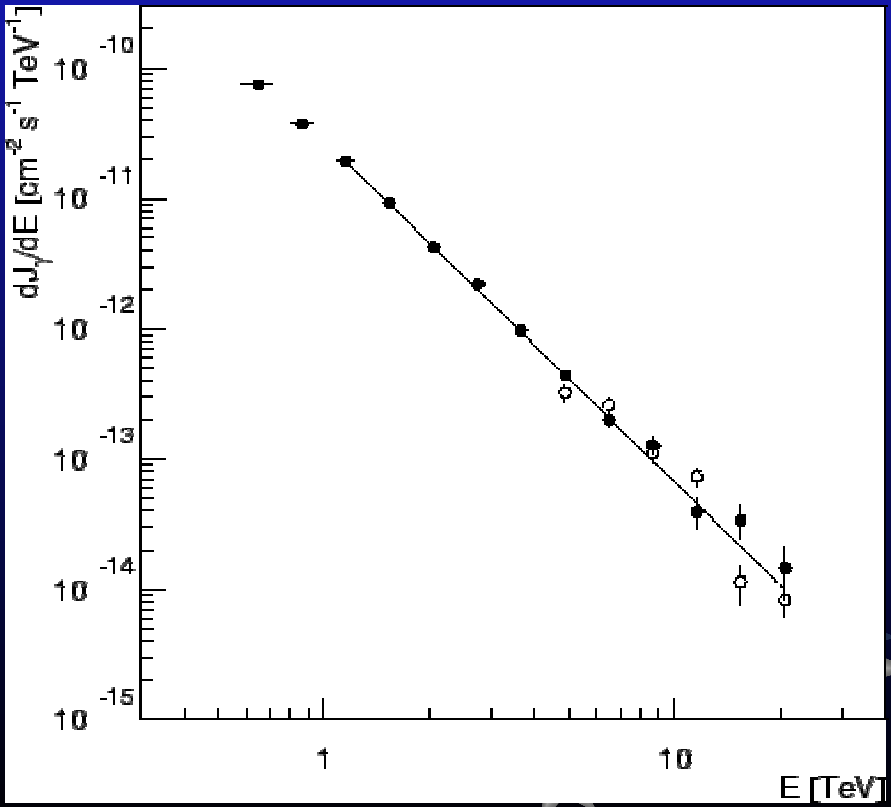
Attenuation is an Issue

Calibration: Pointing

Crab Nebula as the standard candle
Can we see it?

$dJ / dE = 0.28 * (E / 1\,\mathrm{TeV})^{-2.6}\ \mathrm{km}^{-2}\ \mathrm{s}^{-1}\ \mathrm{TeV}^{-1}$

Integrated flux is not small:
$0.3\ /\mathrm{km}^2\ /\mathrm{s}$
Random background > 10 times higher in “stary nights”
Use neutral density filter + tighter trigger

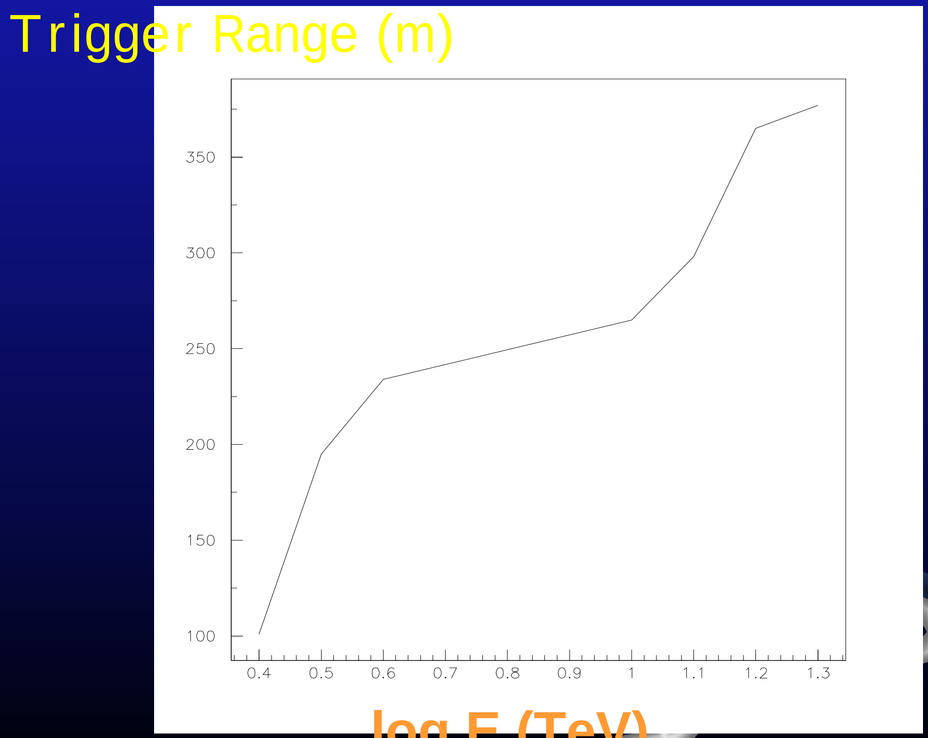


Acceptance to the Crab

- Photon density is high due to high altitude
- Acceptance ~ around O(0.2) km^2 sr
- Rate ~ 6 events/hr (?background)
- Exposure of several nights would be useful

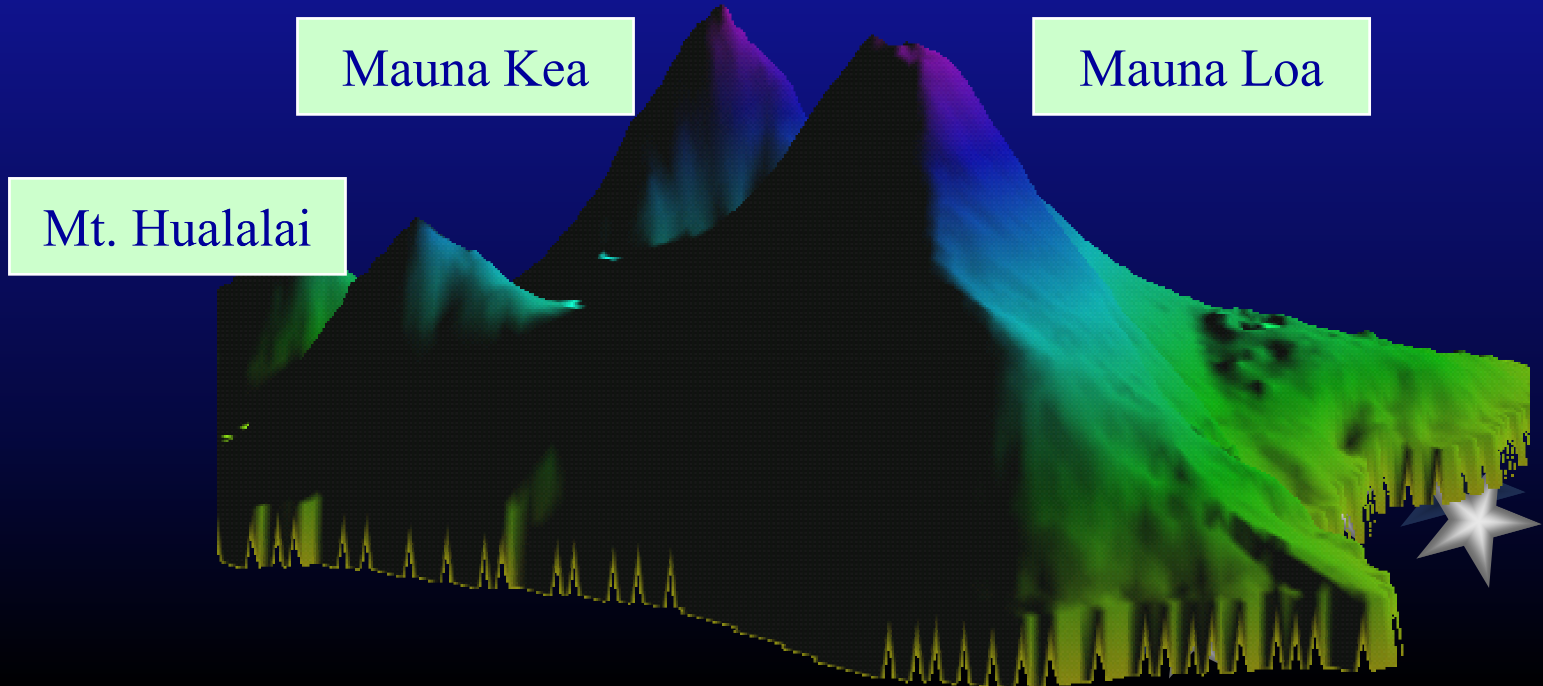
Use starcal to check Crab in FOV and moonless night

Month	Time to Rise
Feb.	13 pm
April	9 am
June	5 am
August	1 am
Oct.	21 pm
Dec.	17 pm



Site

- Original Site: Mt. Hualalai looking at Mauna Loa
  - Good weather condition, less background, GC in FOV
  - No electricity, no water, no communication
- Prototype Site: Mauna Loa looking at Mauna Kea
  - Infrastructure ready, on-site help from CosPA1!
  - No GC observation



Conclusion

- NuTel is the first experiment *dedicated* to Earth skimming / mountaing watching
- The PeV cosmic ν_τ rate is ~ 1 event/year
- The cost is low: O(1) million US dollars to build it
- The time is short: prototype deployment in 2004
- The window of opportunity is good, both in energy and time (uncertainty principle?)

- Ashra is a natural continuation for NuTel
  - Site coincides
  - Physics complimentary
  - Schedule looks promising