Studying the Cosmic ν Spectrum

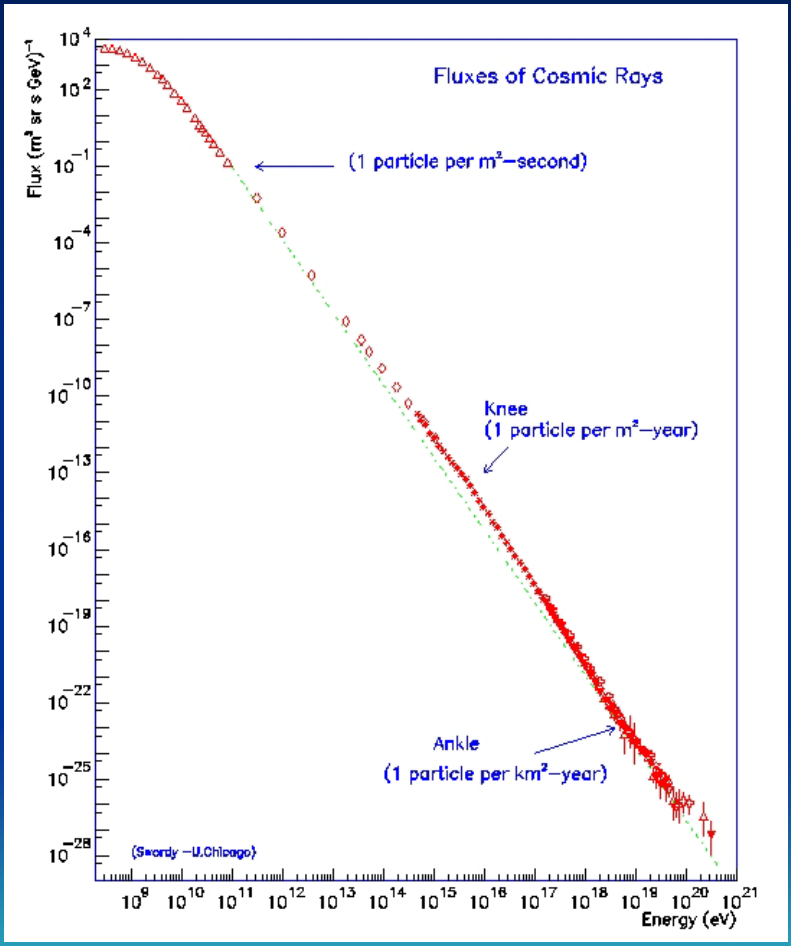
using a modular, expandable detector

TAUWER

Carnegie Mellon, Rome (La Sapienza), Pisa, Bolu, Kars

Cosmic Frontier Question: UHE Cosmic Ray and Connection to Neutrinos

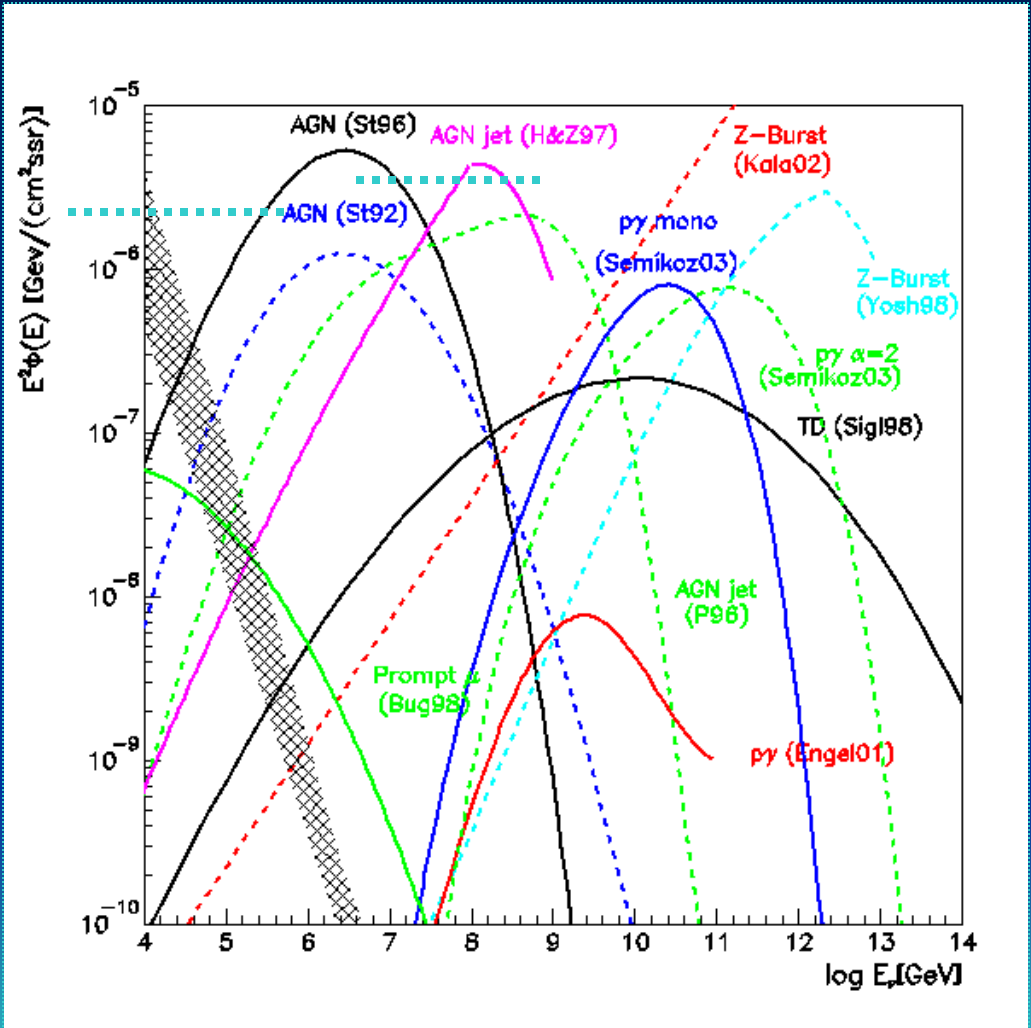
- Sources remain speculative
- Composition is varied - nuclei from H to Fe . Itseems to change with energy.
- Total Energy content of the order of AGN output, but … no known local sources



Comparison of UHECR, UHE γ and UHE ν spectra can identify acceleration mechanism.

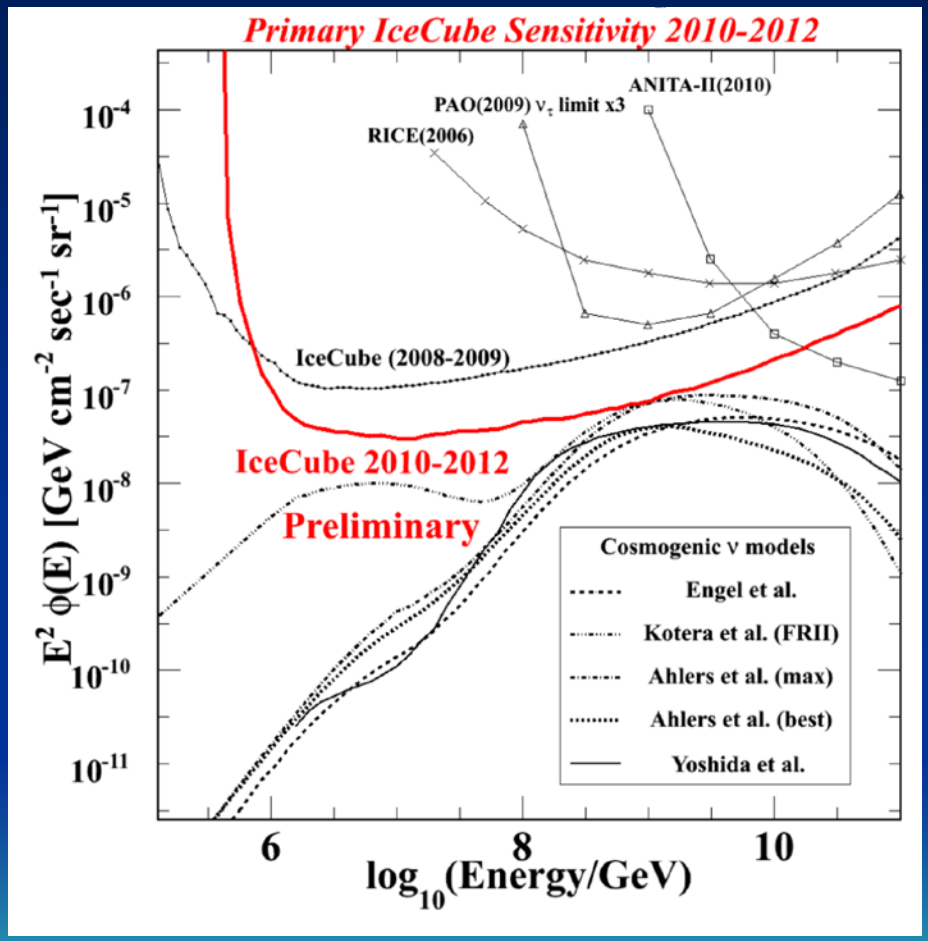
What's the Neutrino Flux?

Before data from Amanda and IceCube imposed experimental constraints, there were *many* ideas, covering decades of ν energy.



Today's Story

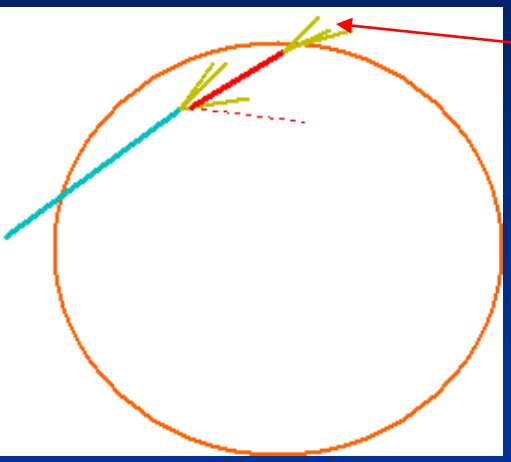
- Spectra are lower – hard to detect UHE events.
- Atmospheric events follow expected curve (hashed line on previous slide)
- Non-atmospheric source possibilities still cover wide possible range of energies and fluences.
- TAUWER objective – to operate where IceCube limit turns up and Anita/ARA-37 is just turning on – 0.1-1.0 EeV



From Neutrino 2012 (Ishihara)

TAUWER – hadronic air shower detector

With ν mixing, incoming ν flux ~ 1:1:1 among flavors



- τ neutrino interactions along a chord can yield lepton to emerge from the earth *before* decaying via hadronic mode.
- Detect hadronic air showers with time-of flight detectors to select *upward-moving particles only.* Sparse-sampling hadron calorimetry

get τ direction and energy from cascade. ν_τ energy inferred on average from cc kinematics

Features of upward-going ν_τ

hadronic-decay τ showers: <u>high multiplicity</u> EM core defines axis location

- Shower emerging from ground ($\Theta > 90^0$) gives unique time of flight signature in counter pair to suppress EAS background.
- Large multiplicity near shower max produces high densities far from shower axis
- Locate in mountain bowl to filter horizontal air showers

Backgrounds:

- Measured background at KIT: 1 μHz, low multiplicity
- Corsika studies indicate background does not look like signal

The TAUWER-I Detector (0.1-1 EeV)

- τ must emerge from rock and decay in air. Probability for nt to interact and t to survive is $P = \int_o^\infty dx\, e^{-x/\Lambda d}/\Lambda_{int}\,(1 - e^{-(L-x)/\Lambda int})$ where x is the distance *from* the earth's surface *to* the point of the neutrino interaction and L is chord length: $L = 2\,R_e\,\sin(\Theta - \pi/2)$

- At high energies Λ_{int} is short and Λ_d is long, so zenith angles are close to 90 degrees. This limits vertical solid angle and also sets vertical size of detector array.

- Air shower development requires minimum of 3 km ($4\,\Lambda_{int}$), maximum of 10 km from τ decay point - sets elevation of array

What Will We See?

- Corsika group adapted code to handle upward-moving particles. We have done extensive simulations (more to be done).

- Run Corsika shower development for 5 hadronic τ decay modes and determine pattern of hit detectors versus τ energy and angles. (not mode sensitive)

- Air showers are electron-rich, define τ intersection point on detector plane. Angles come from timing. Measured average time resolution for TAUWER detectors on EAS events < 1.2 ns.

What's In a TAUWER Detector?

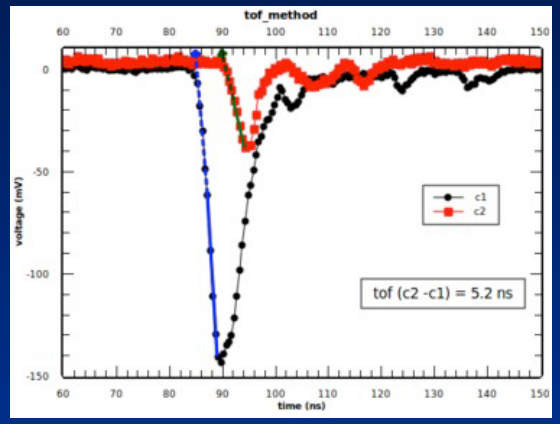
- Simple pair of scintillators with Silicon Photomultiplier readout –
  problem-free operation for 1.5 years at K-G array and over winter at Jungfraujoch High Altitude lab

- For 1.5 m counter separation, measure TOF difference to separate upward (+ 5 ns) from downward (-5 ns) or EAS parallel (0 ns) events

- Confirm timing resolution in Fermilab beam tests(Iori, Russ)

Tile, SiPM and amplifier in light-tight enclosure – one of two units per station, separated by 1.5 m.

Array Tests



Vertical detector orientation
- local coincidence of top and bottom counters
- SiPM, amplifier, DRS4 (2 Gs/s) waveform digitization

- Operated 7 stations in Kaskade-Grande array for 18 months in vertical orientation (0 degree zenith angle)
- Compared TAUWER triggered events with K-G array triggers for vertical EAS events centered in our sector
- Use K-G density analysis to predict number of hit stations – good agreement
- Set arrays horizontal to measure EAS background rate with local trigger

Detector Robustness Verified

- Operated SiPM in extreme temperature ranges (10, -25 C) at Jungfraujoch

- Waveform digitizers (DRS4) , detectors gave high up-time, stable performance in field at KIT for 18 months

- Single-Board computer with Ubuntu reliable

- Serves as working model for whole system development in near future.

- Elements are simple to build, modify, reconfigure. Makes detector readily expandable to adapt to other flux regions.

Conclusions

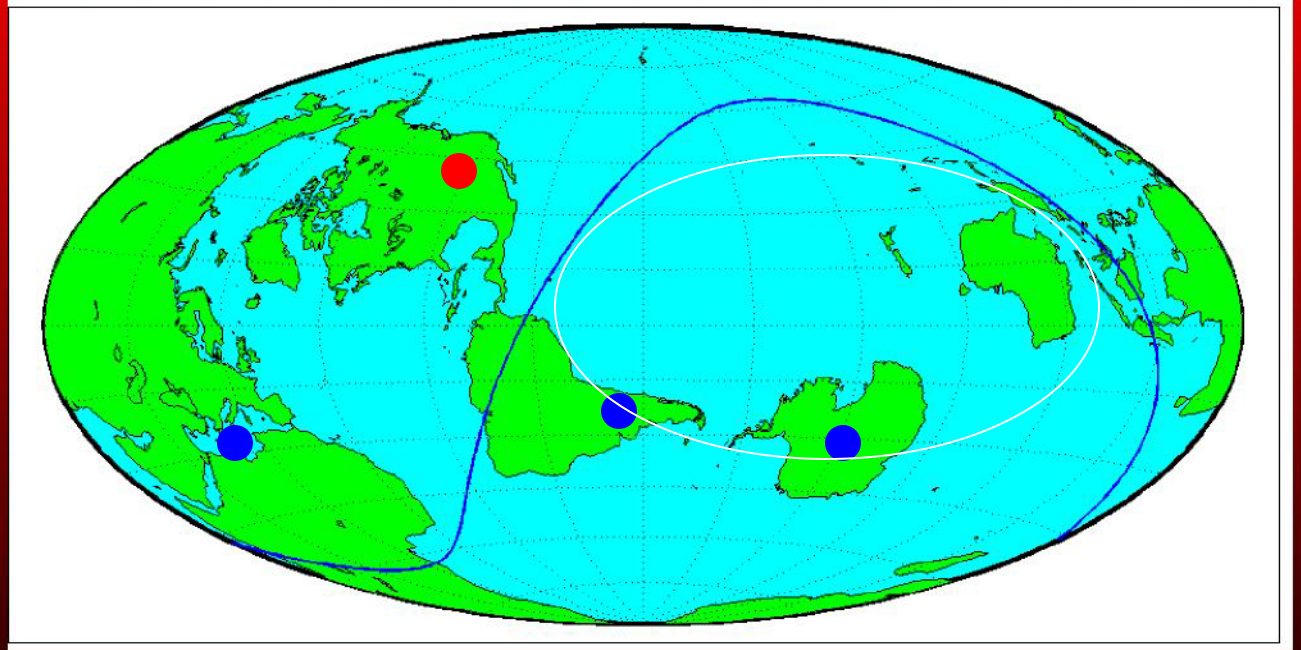
TAUWER uses a vertical array of detectors pointed toward a small area of the earth's surface to detect the hadronic showers from tau decays to hadrons

TAUWER selects energy and zenith angle ranges by redeployment of detector plane and adjustment of detector spacing on the plane

TAUWER is a modest cost, rapidly deployable and *expandable* detector to probe the unknown fluxes of UHE cosmic neutrinos

The test system deployed for 18 months at KIT had > 90% up time and is a working model for the full detector. We welcome new people, new ideas, and are ready to start full-scale design work.

Earth in Galactic Coordinates



Blue line: Equatorial Path
White Circle: below TAUWER horizon