# Towards Survey of Astronomical $\nu_\tau$ Sources

Neutrino Telescope Array (NTA)

George W.S. Hou (侯維恕)
National Taiwan University

July 24 @ EPS-HEP2015, Wien

National Taiwan University

# Towards Survey of Astronomical $\nu_\tau$ Sources

I. Intro: Towards $\nu$-Astronomy

II. Earth-Skimming $\nu_\tau$ Method

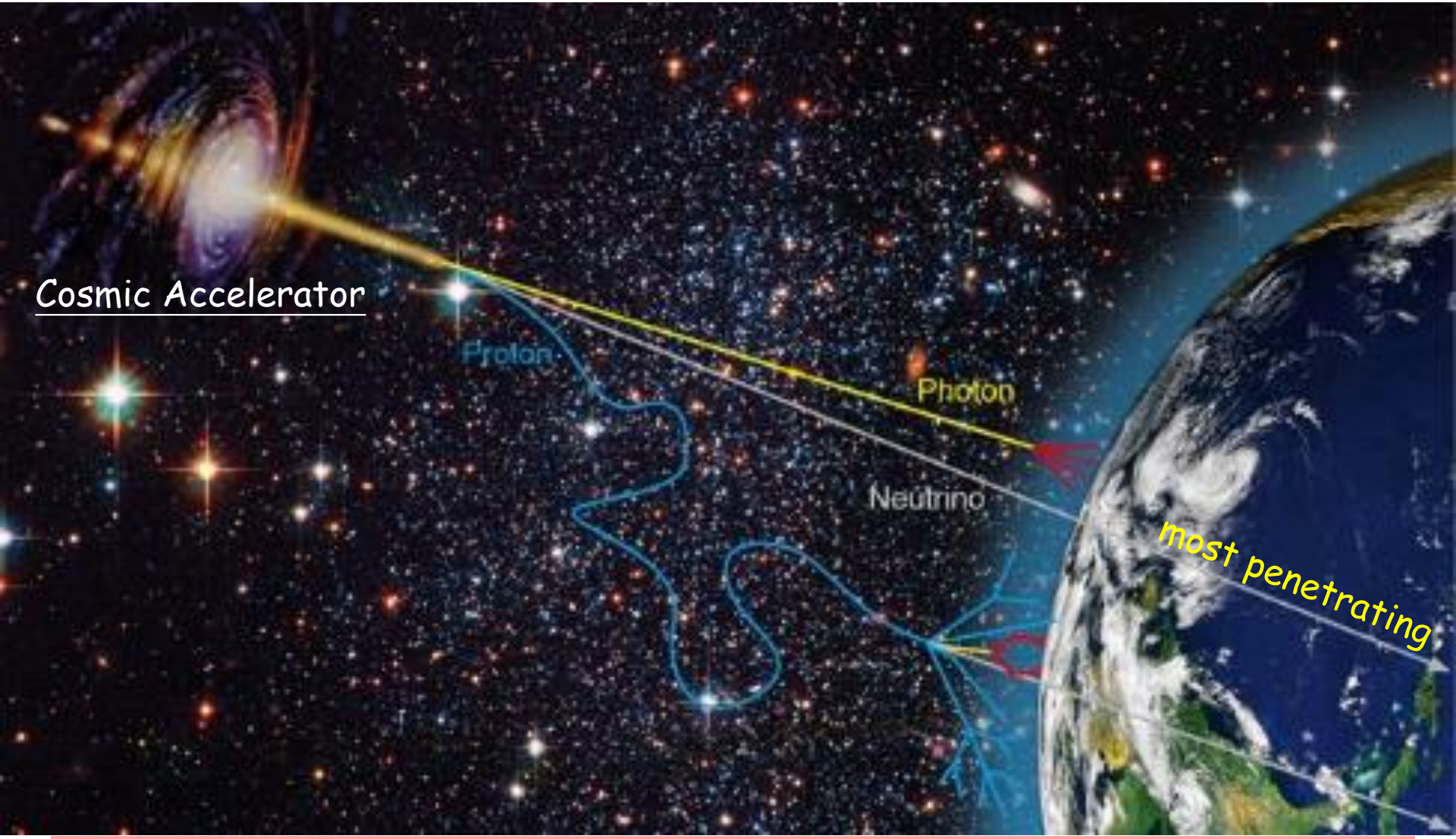
III. Ashra-1 & 1st Search for GRB $\nu_\tau$

IV. Neutrino Telescope Array (NTA)

* Site Plan
* Pointing Accuracy
* Performance & Sensitivity

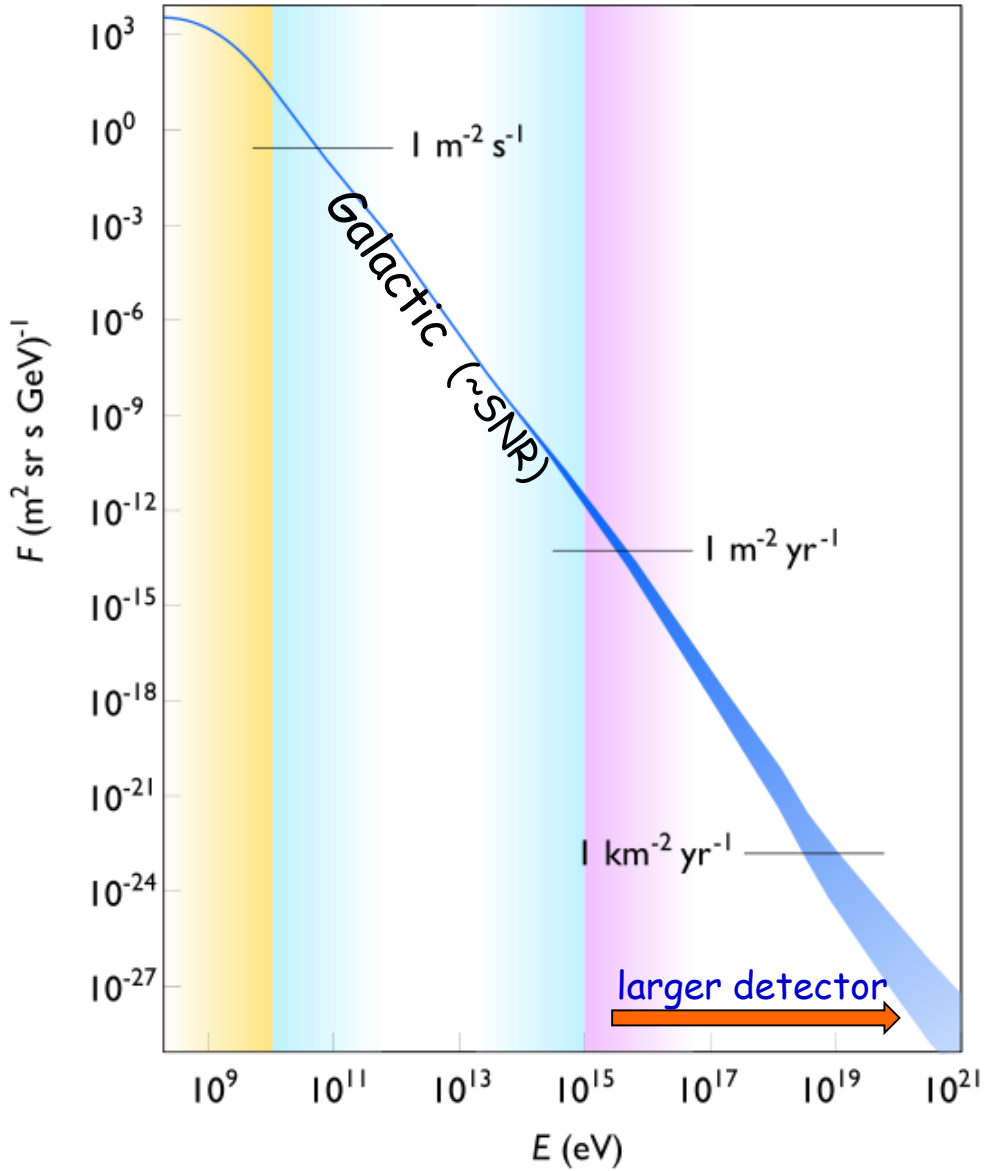
V. Towards a New Collaboration

# I. Intro: Towards ν-Astronomy

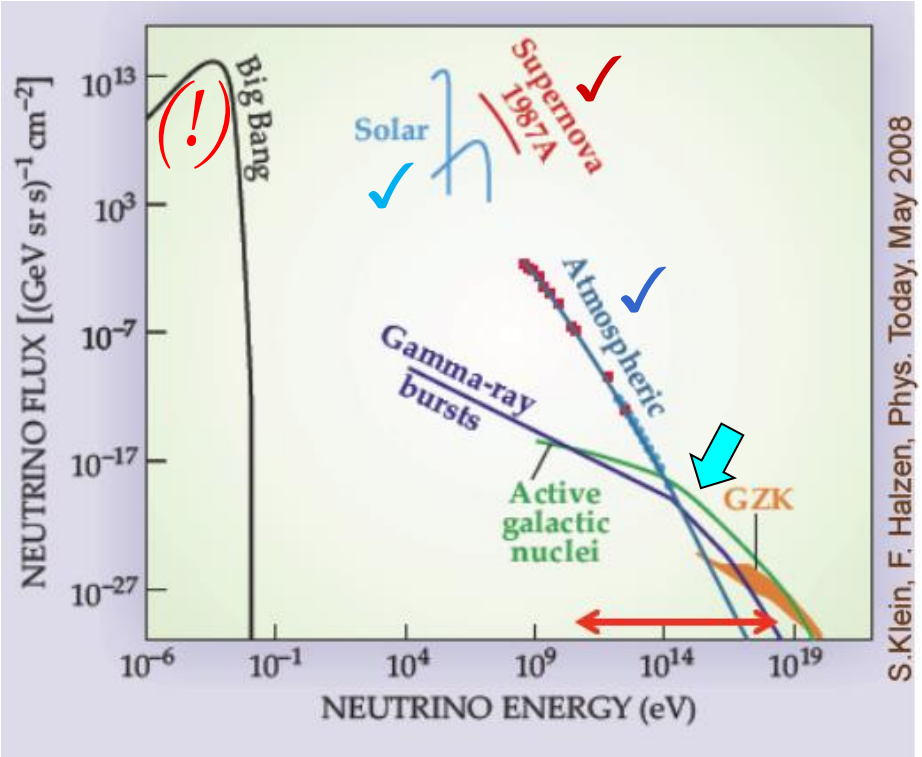



Neutrinos, chargeless and weakly interacting, point back to far away sources.

# Cosmic Ray Flux




# Neutrino Flux



Ernie

$E$ = 1.1 PeV, $\theta$ = 23º

Bert

$E$ = 1.0 PeV, $\theta$ = 62º

Big Bird

$E$ = 2.0 PeV, $\theta$ = 34º

What if one had better Sensitivity and accurate Pointing Info?

# Window of Opportunity

Still Survives

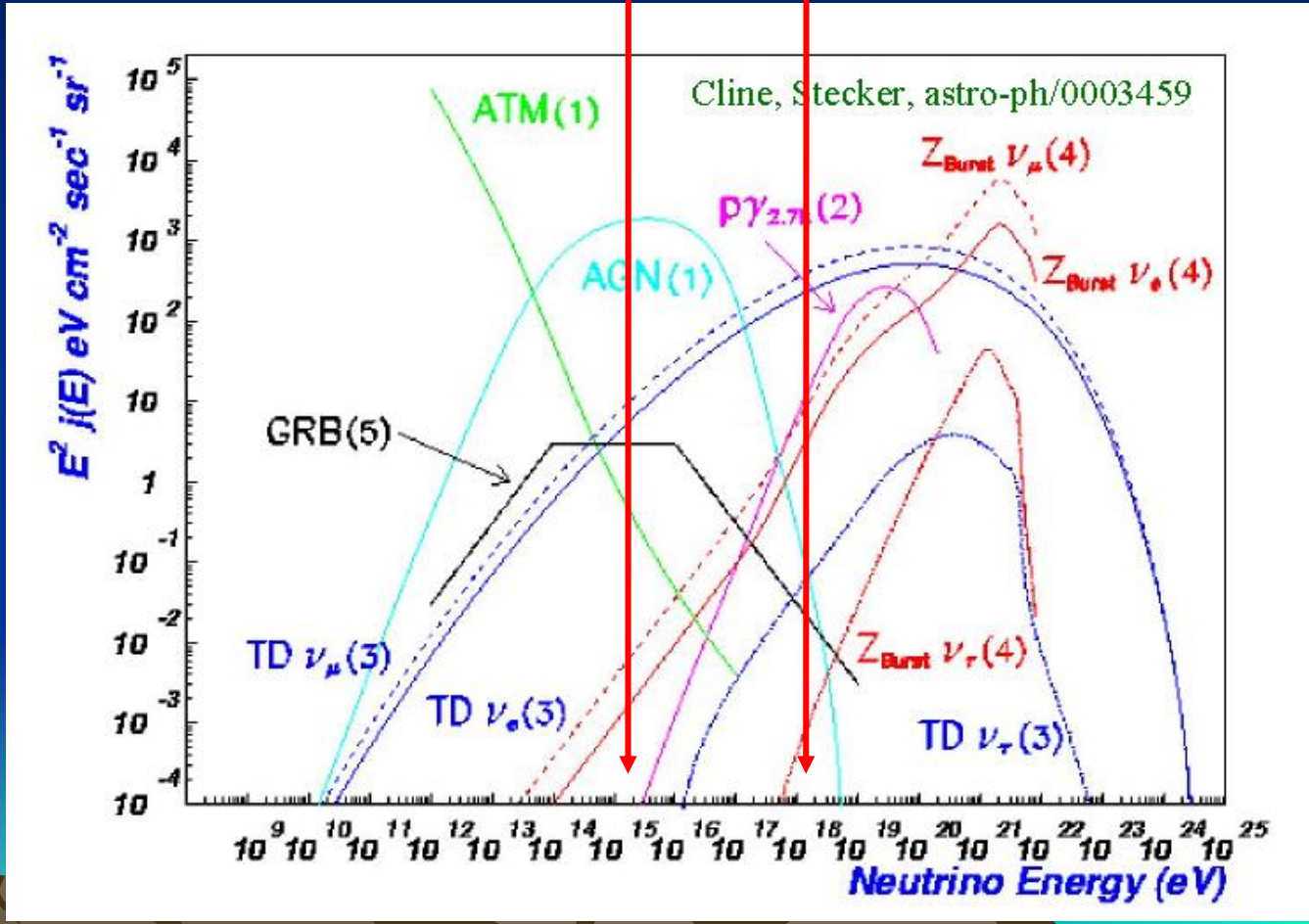
IceCube

**Conventional ν Detector**

**?**

**UHECR ν Detector**

Auger

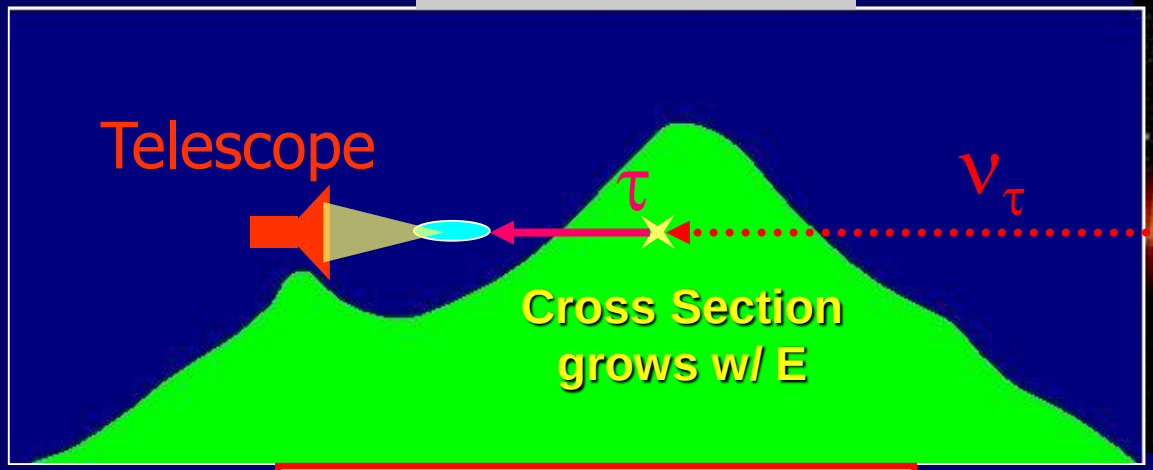



a plot I first used ~ 2002

# Detection Mechanism

## II. Earth-Skimming $\nu_\tau$ Method

*$\tau$ Appearance!*




$\nu_\mu$ $\nu_\tau$

$\theta_{23}$ ~ max. mix.

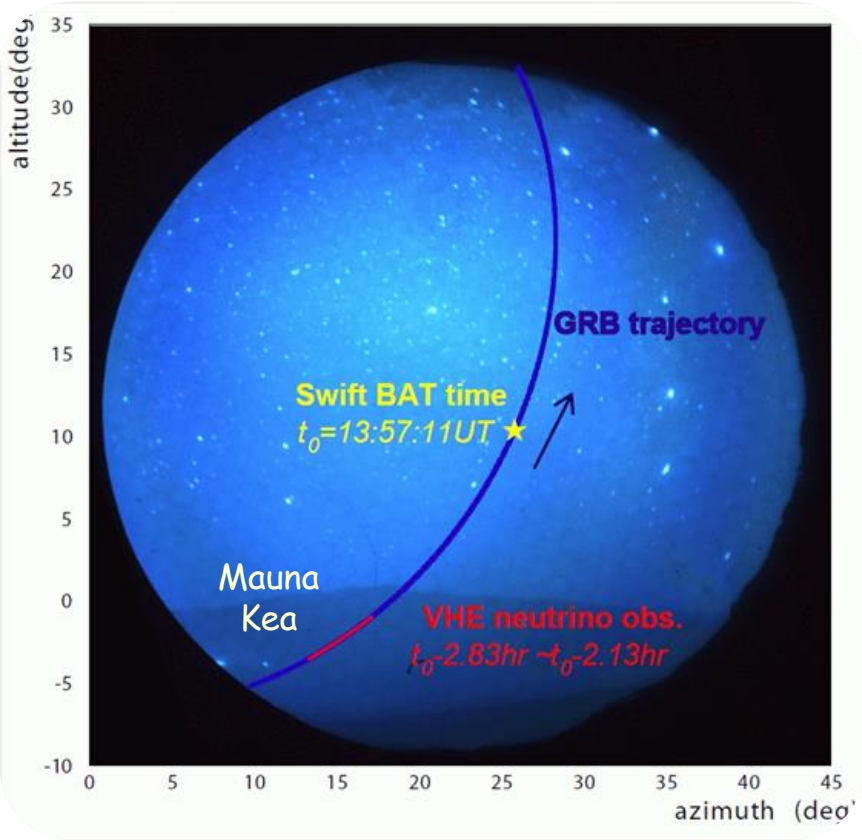
**$\tau$ *Decay*: Air Shower**
**→ ns Cherenkov**

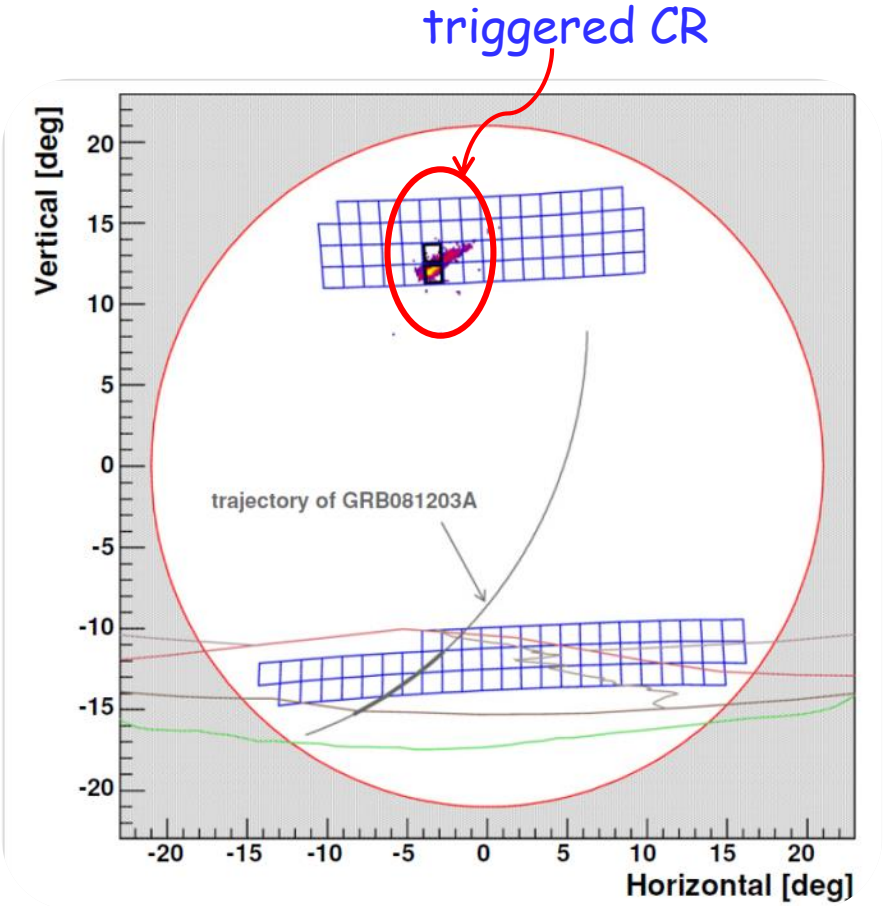
$\nu_e$: electron energy mostly absorbed in mountain
$\nu_\mu$: no extensive air shower

"My" NuTel Effort

# III. Ashra-1 & 1st Search for GRB $\nu_\tau$

GRB081209A




Swift GRB Alert during Ashra-1 Commissioning

First Check for PeV-EeV Tau Neutrino from a GRB

Y. Aita et al., ApJ 736 (2011) L12

# Ashra-1: 1st Search for GRB $\nu_\tau$

The Astrophysical Journal Letters, 736:L12 (5pp), 2011 July 20 doi:10.1088/2041-8205/736/1/L12
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## OBSERVATIONAL SEARCH FOR PeV–EeV TAU NEUTRINO FROM GRB081203A

Y. Aita[1], T. Aoki[1], Y. Asaoka[1], T. Chonan[1], M. Jobashi[1], M. Masuda[1], Y. Morimoto[1], K. Noda[1], M. Sasaki[1], J. Asoh[2], N. Ishikawa[2], S. Ogawa[2], J. G. Learned[3], S. Matsuno[3], S. Olsen[3], P.-M. Binder[4], J. Hamilton[4], N. Sugiyama[5], and Y. Watanabe[6]
(Ashra-1 Collaboration)
[1] Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan; asaoka@icrr.u-tokyo.ac.jp, sasakim@icrr.u-tokyo.ac.jp
[2] Department of Physics, Toho University, Funabashi, Chiba 274-8510, Japan
[3] Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, HI 96822, USA
[4] Department of Physics and Astronomy, University of Hawaii at Hilo, Hilo, HI 96720-4091, USA
[5] Department of Physics and Astrophysics, Nagoya University, Nagoya, Aichi 464-8601, Japan
[6] Department of Engineering, Kanagawa University, Yokohama, Kanagawa 221-8686, Japan
*Received 2011 April 29; accepted 2011 June 10; published 2011 June 28*

I'm not an author.

### ABSTRACT

We report the first observational search for tau neutrinos ($\nu_\tau$) from gamma-ray bursts (GRBs) using one of the Ashra light collectors. The Earth-skimming $\nu_\tau$ technique of imaging Cherenkov $\tau$ showers was applied as a detection method. We set stringent upper limits on the $\nu_\tau$ fluence in PeV–EeV region for 3780 s (between 2.83 and 1.78 hr before) and another 3780 s (between 21.2 and 22.2 hr after) surrounding GRB081203A triggered by the *Swift* satellite. This first search for PeV–EeV $\nu_\tau$ complements other experiments in energy range and methodology, and suggests the prologue of "multi-particle astronomy" with a precise determination of time and location.

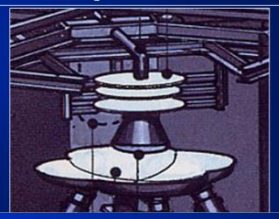
Will be discussed further at ICRC2015

# Ashra-1

(Courtesy Makoto Sasaki)

## Progress of Optics

- TA … Davies-Cotton
  - FOV ~ 16° / Telescope
  - Focal spot size ~ 0.3°
- ASHRA … Baker-Nunn
  - FOV ~ 50° / Telescope
  - Focal spot size ~ 0.01°



## Progress of Imaging Device

- TA … PMT+ADC
  - 16 × 16 = 256 pixels/tele.
  - Pixel res. ~ 1°
  - 256 outputs / 256 pixels
- ASHRA … IIT+SS-Imager
  - 3K × 3K~10M pixels/tele.
  - Pixel res. ~ 0.015° (=1')
  - 4 outputs / 10M pixel

## New Eye for Particle Universe

**Key Technology:**

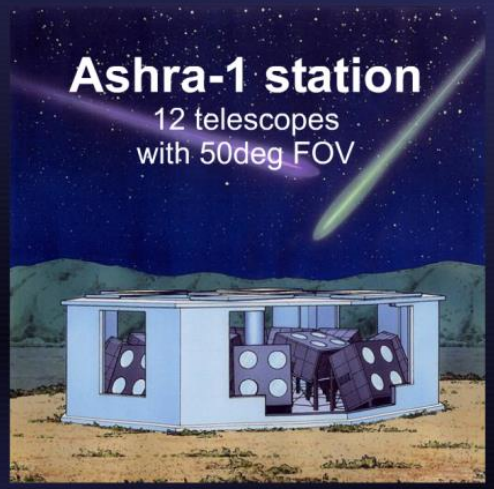
9M-pixel CMOS sensor covering 50deg FOV

**Leading Features:**

All-sky Survey
=> Discovery Potential

1arcmin directional accuracy
=> Source ID

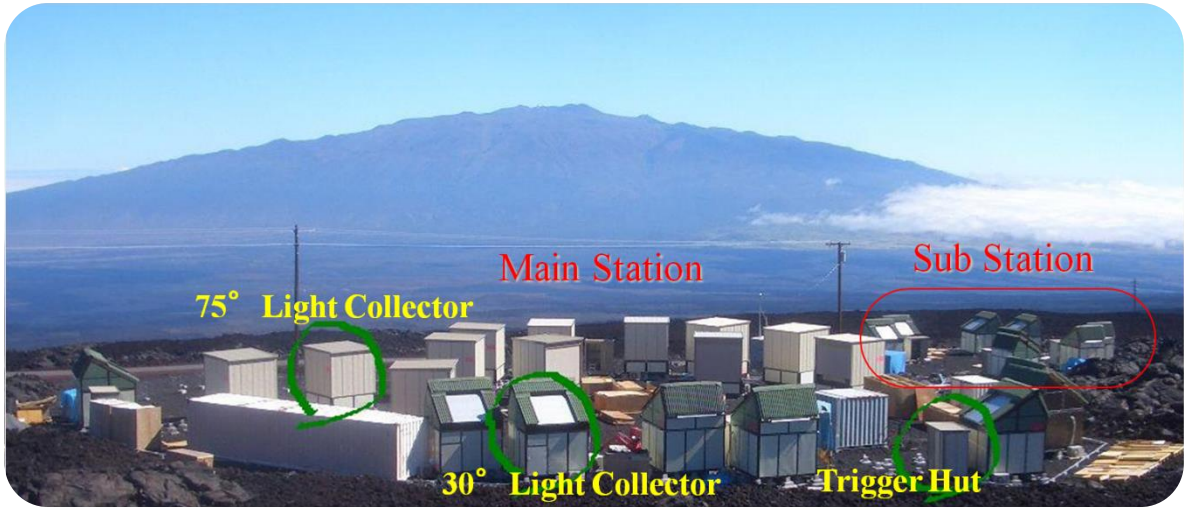
Simultaneous Detection for Cerenkov & Fluorescence
=> Physics ID




Pioneer Experiment for VHE Particle Astronomy: Ashra-1

# Ashra-1

Ashra Observational Site: Mauna Loa




3300 m a.s.l., 35 km from MK

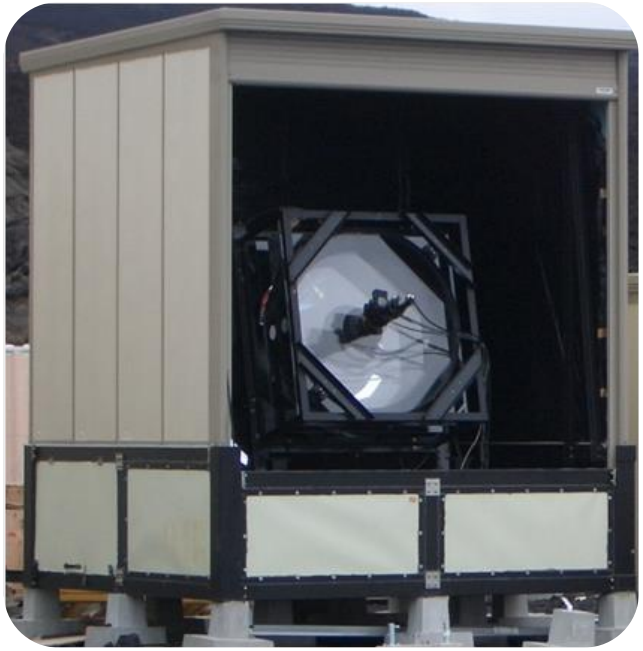
77% mono, 27% stereo

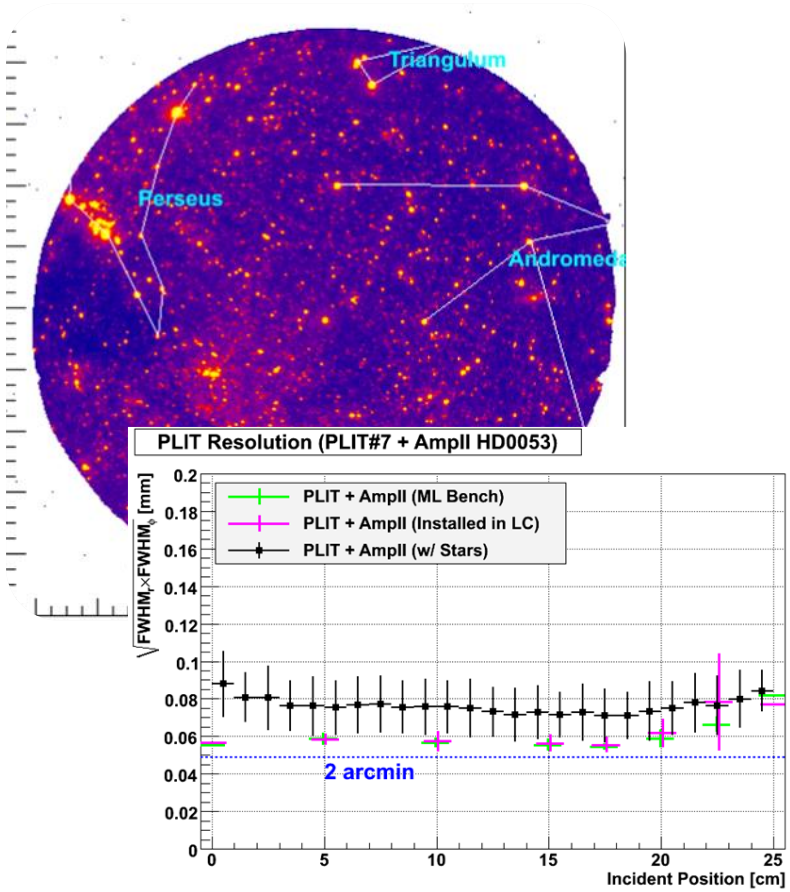
2~3 arcmin image

Nice Coverage and Precision as Particle Monitor

# Ashra-1: Wide field Optics

Ashra-1 Light Collector






Total Resolution: ~3 arcmin image in 42° FOV

Can cover Mauna Kea surface at 35 km distance

# Ashra-1 Pipeline Trigger & Readout

demonstrated

Same Fine Image to Multiple Triggers

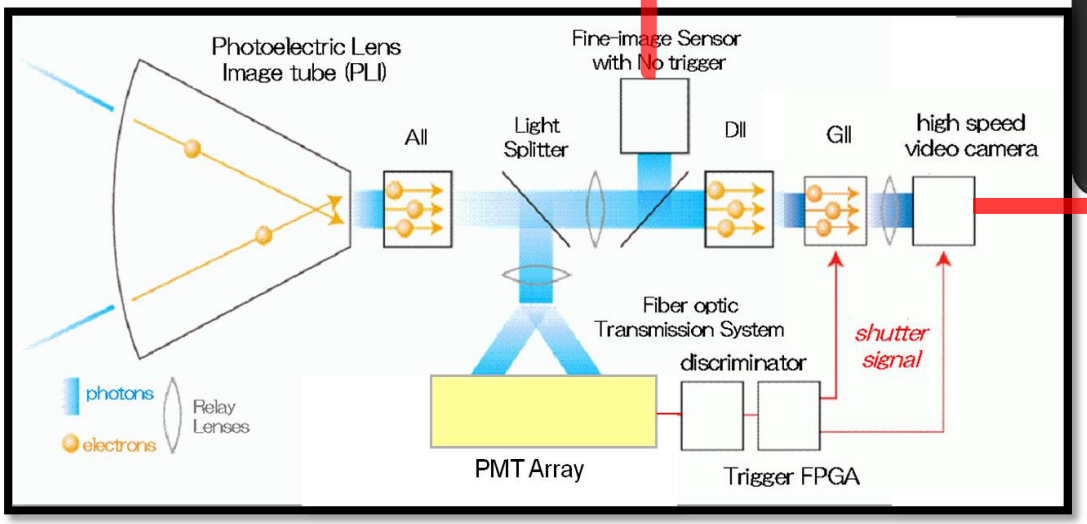
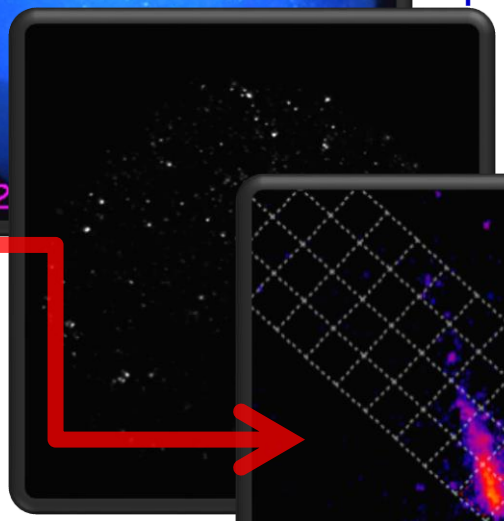
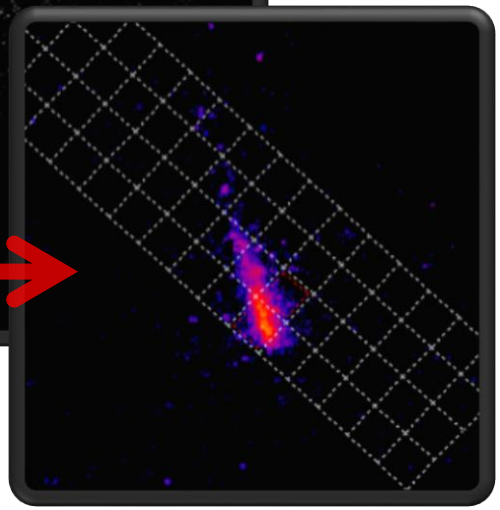



Photo-electric Image Pipeline (PIP)

Optical 4s



BG 200ns



CR 200ns

Multi-Messenger Approach with
One Detector System

High Pixelation w/ CMOS → Fine Resolution

**1st imaging air-shower with self-trigger**

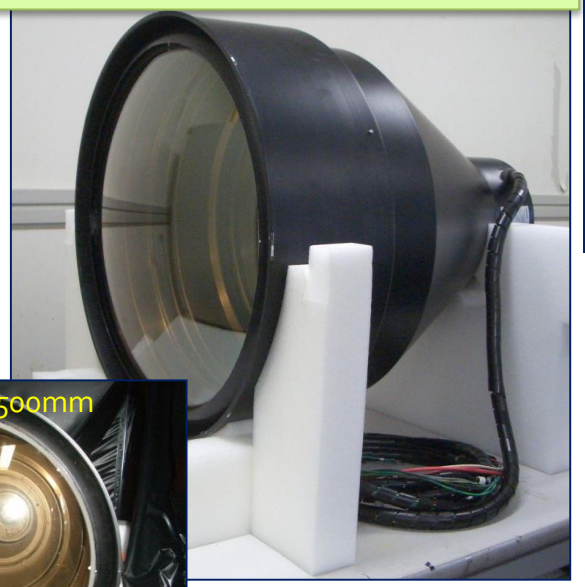
# Imaging Tube + CMOS (video camera)

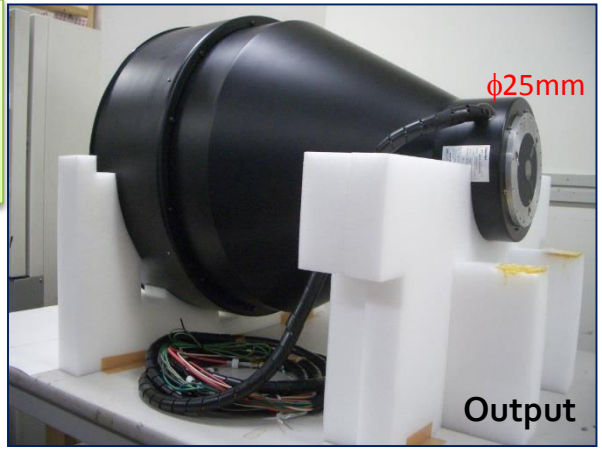
## 20” Photoelectric Lens Imaging Tube (PLI)

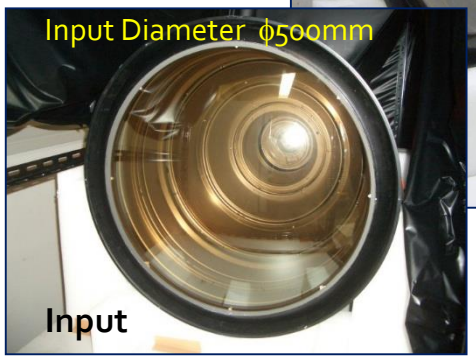
**Large:** World largest I.I.

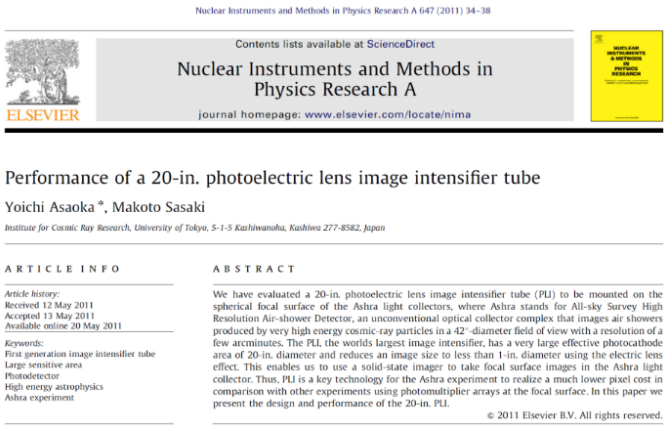
**Fine:** FWHM = 40-60μm @output window

**Stable:** No performance degradation for 3.5 years





Nuclear Instruments and Methods in Physics Research A 647 (2011) 34–38

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Performance of a 20-in. photoelectric lens image intensifier tube

Yoichi Asaoka *, Makoto Sasaki

Institute for Cosmic Ray Research, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa 277-8582, Japan

ARTICLE INFO

*Article history:*
Received 12 May 2011
Accepted 13 May 2011
Available online 20 May 2011

*Keywords:*
First generation image intensifier tube
Large sensitive area
Photodetector
High energy astrophysics
Ashra experiment

ABSTRACT

We have evaluated a 20-in. photoelectric lens image intensifier tube (PLI) to be mounted on the spherical focal surface of the Ashra light collectors, where Ashra stands for All-sky Survey High Resolution Air-shower Detector, an unconventional optical collector complex that images air showers produced by very high energy cosmic-ray particles in a 42°-diameter field of view with a resolution of a few arcminutes. The PLI, the worlds largest image intensifier, has a very large effective photocathode area of 20-in. diameter and reduces an image size to less than 1-in. diameter using the electric lens effect. This enables us to use a solid-state imager to take focal surface images in the Ashra light collector. Thus, PLI is a key technology for the Ashra experiment to realize a much lower pixel cost in comparison with other experiments using photomultiplier arrays at the focal surface. In this paper we present the design and performance of the 20-in. PLI.

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**Y.Asaoka, M.Sasaki NIMA 647 (2011) 34**

High Pixelation w/ CMOS → Fine Resolution

Improved QE and Precision

# IV. Neutrino Telescope Array (NTA)

## The Clear Discovery and Identification of Non-thermal Hadronic Process in the Universe

## Air Shower Imaging Detector for Neutrinos

**Neutrino Telescope Array Letter of Intent:**

**A Large Array of High Resolution Imaging Atmospheric Cherenkov and Fluorescence Detectors for Survey of Air Showers from Cosmic Tau Neutrinos in the PeV-EeV Energy Range**

Makoto Sasaki[1], George Wei-Shu Hou[2]

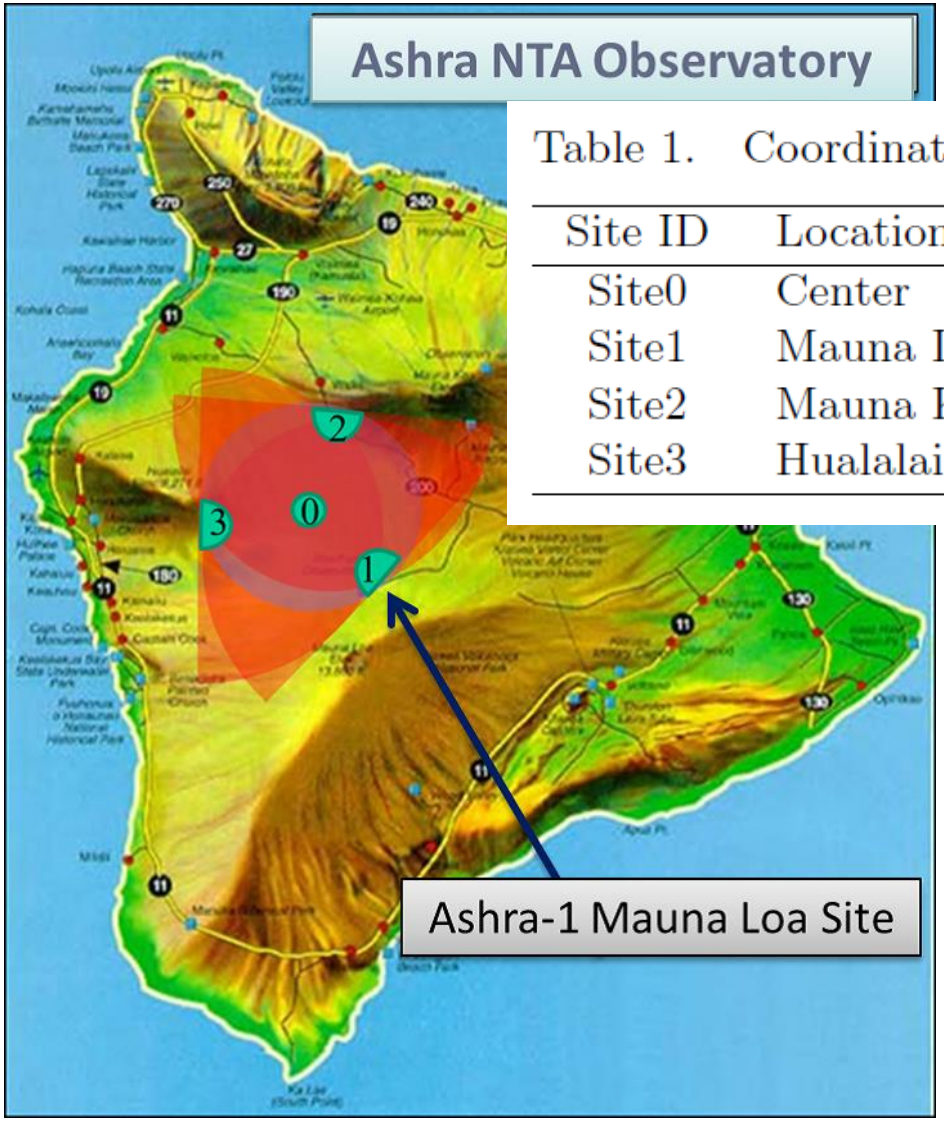
[1] *Institute for Cosmic Ray Research, The University of Tokyo, Kashiwa, Chiba 277-8582, Japan*
[2] *Department of Physics, National Taiwan University, Taipei 10617, Taiwan*
* *E-mail: sasakim@icrr.u-tokyo.ac.jp, wshou@phys.ntu.edu.tw*

LoI at Hand

1408.6244v2

Towards ICRC2015 (The Hague) & Beyond

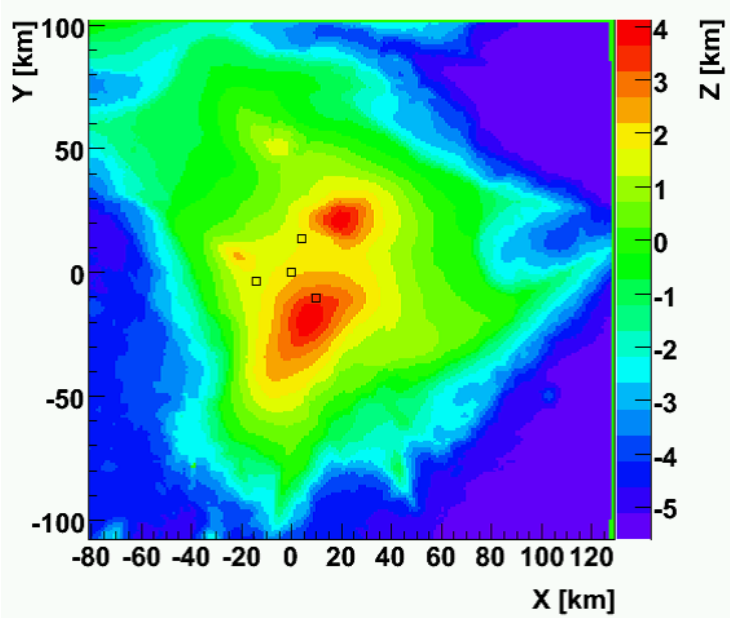
# NTA Site Plan



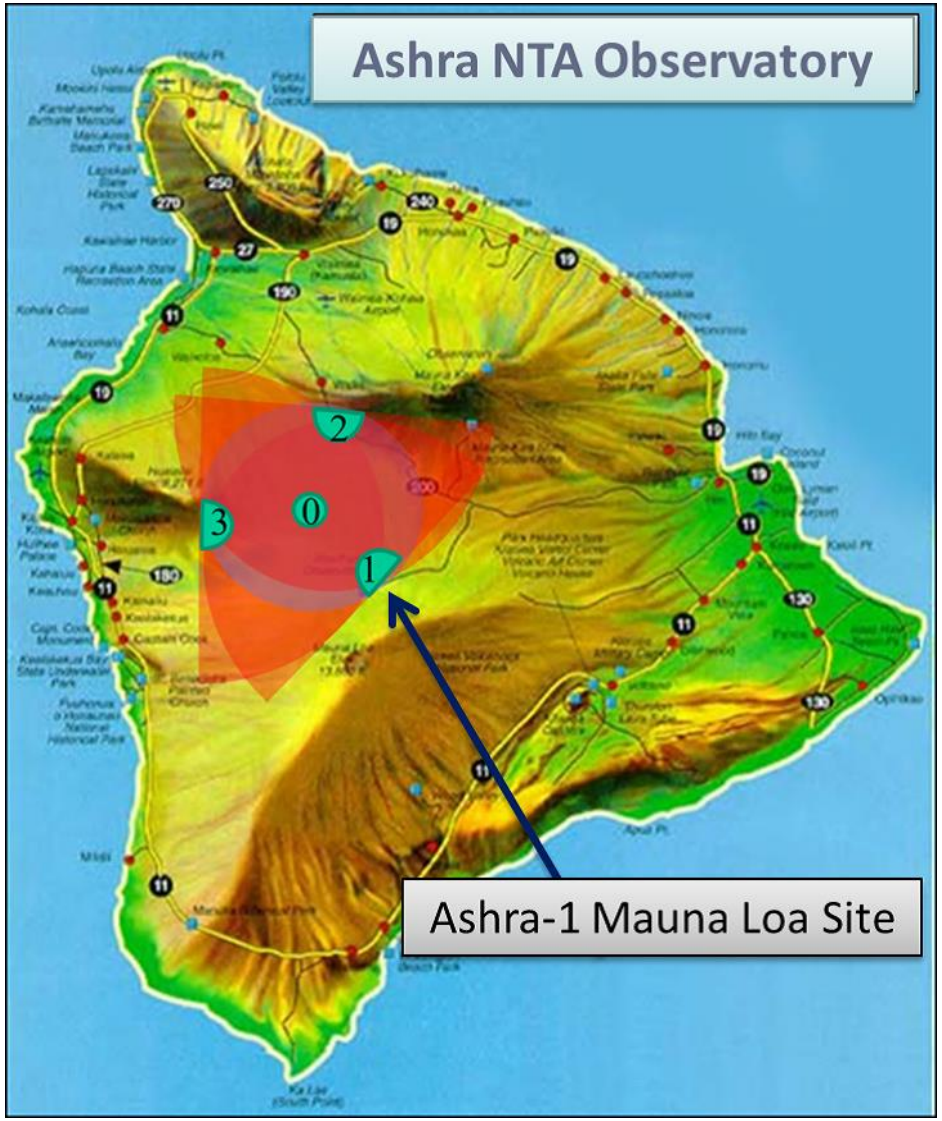

(LOI at Hand)

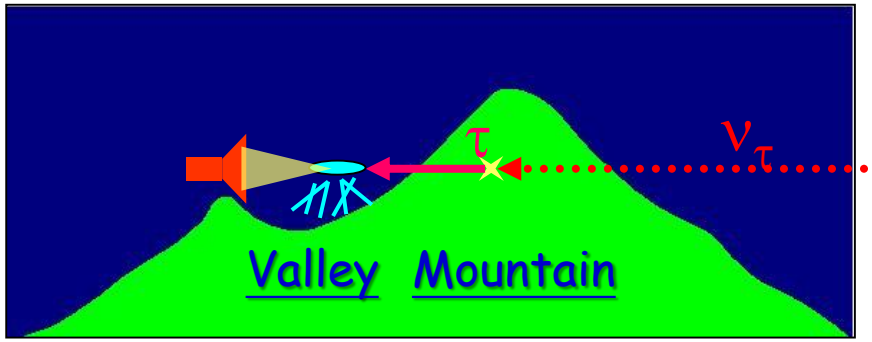
Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

| Site ID | Location | X [km] | Y [km] | Z [km] | FOV [sr] |
|---|---|---|---|---|---|
| Site0 | Center | 0.000 | 0.00 | 2.03 | $\pi$ |
| 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 | $\pi/2$ |



# NTA "Charm"

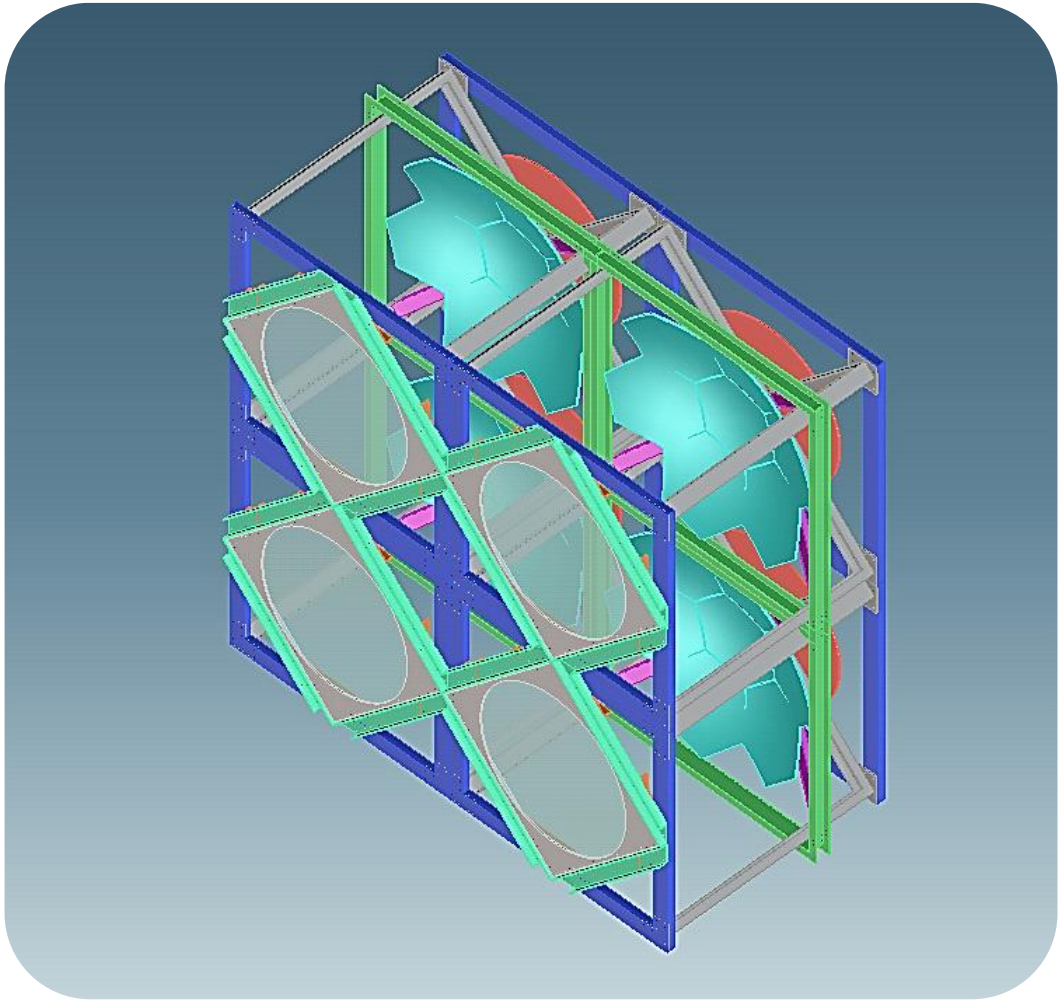



Separation of
**Conversion** vs **Shower**

- Huge **Target** Mass
  **(> 100 km$^3$-weq)**
- Huge **Atmos.** Mass
  (area **> 1000 km$^2$**)
- Mountains **Shield** BG

# NTA Dector Unit (DU)



12 DU's per π coverage

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

Detector Unit (DU)
4 LCs watching same FOV
Superimposed 4 images
⇒ Effective pupil size = ϕ3m

Need at least 30 DU's for Coverage

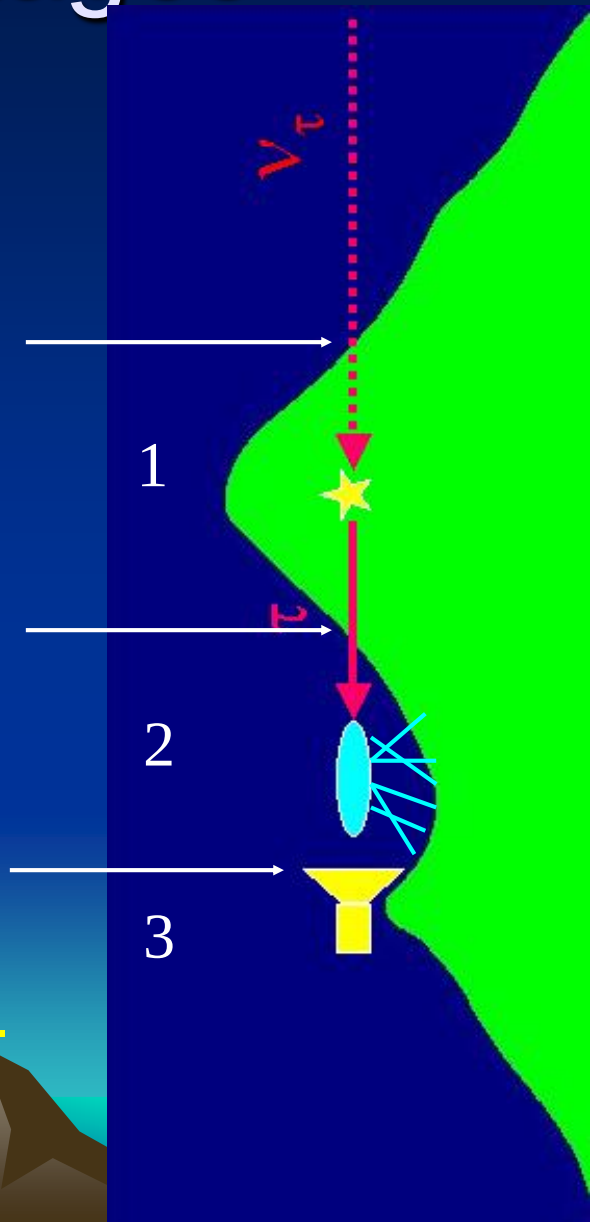
¥¥¥¥

⇒ Concept:
Ashra-1 x 1.5 scaled-up + same trigger & readout

# Three simulation stages

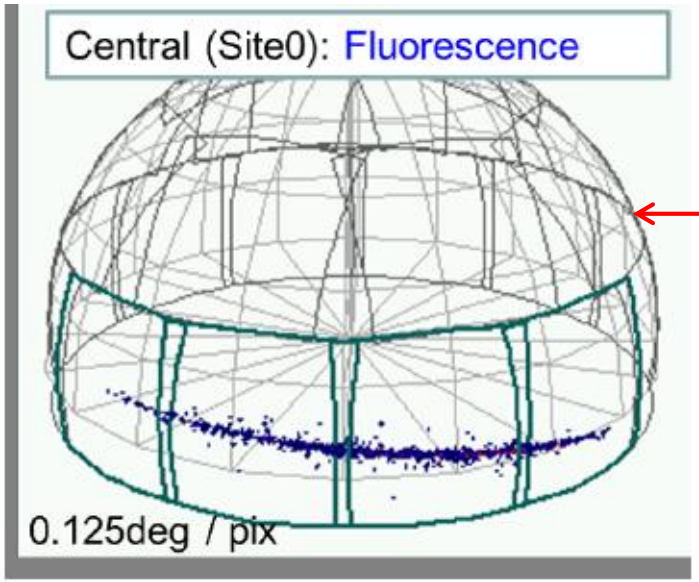
1. Mountain simulation: $\nu_\tau \rightarrow \tau$
   - $\nu$+N cross-section
   - inelasticity
   - energy loss of tau
2. Air shower simulation:
   $\tau \rightarrow$ Cherenkov photons / fluorescence
   - $\tau$ decay mode
   - CORSIKA detailed air shower simulation vs. fast simulation
3. Detector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

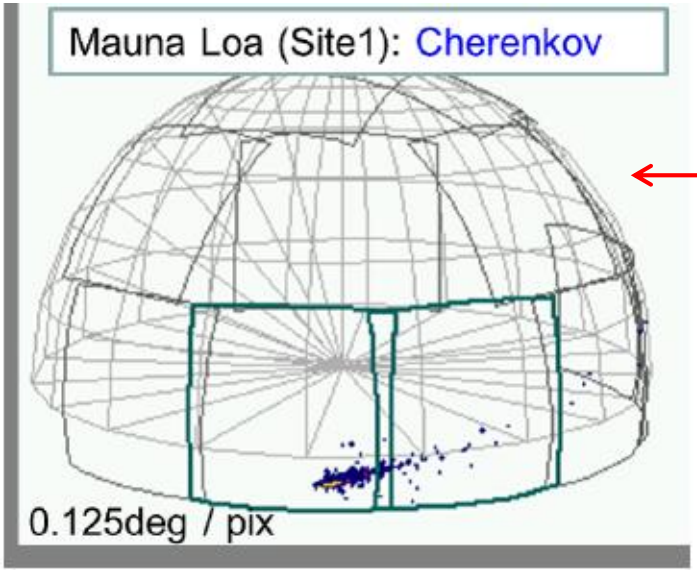
sophisticated "Ashra-1" det.

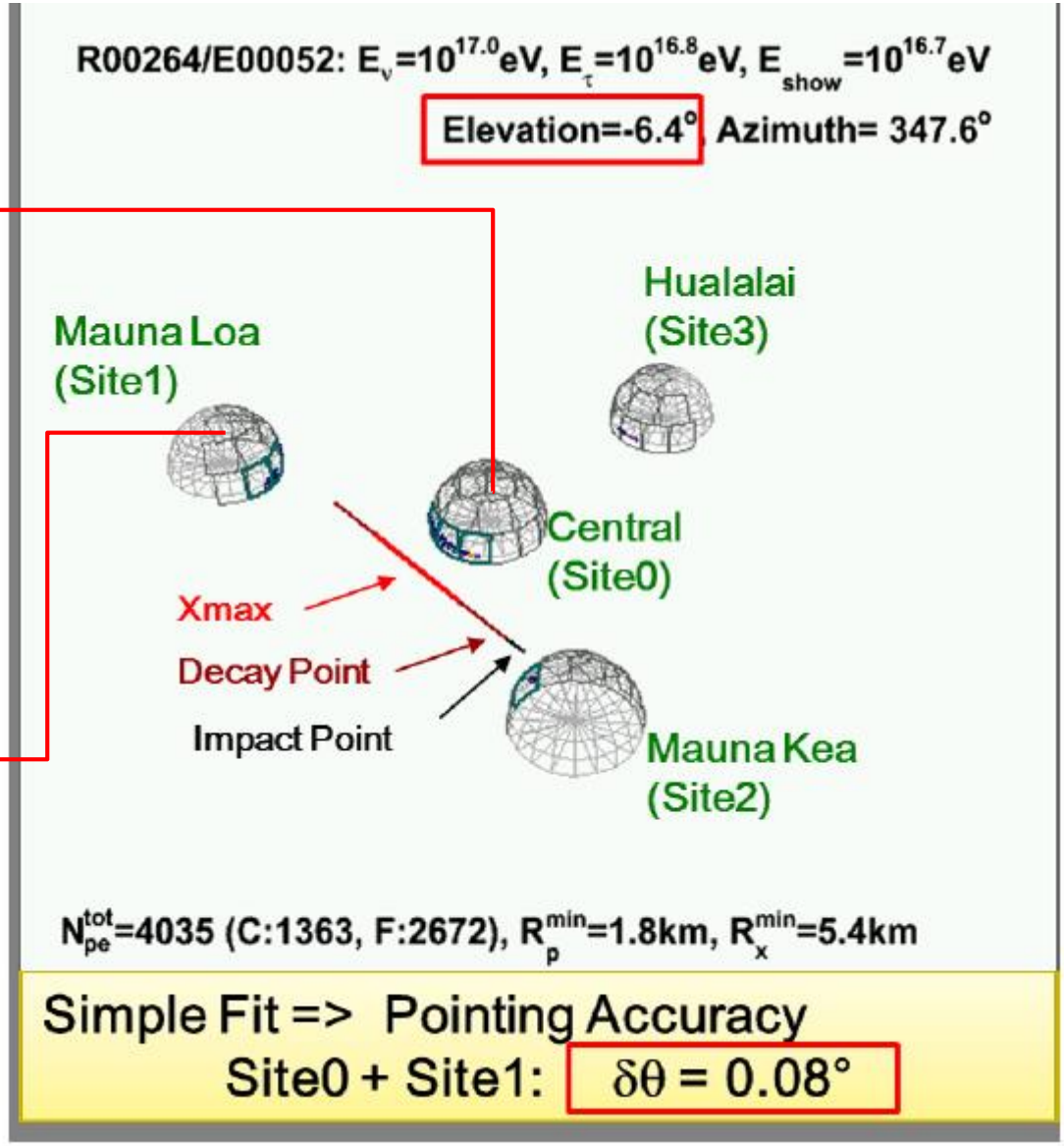



**LOI at hand** (submitted to PTEP)

# NTA Simulated Event: 0.1° Pointing



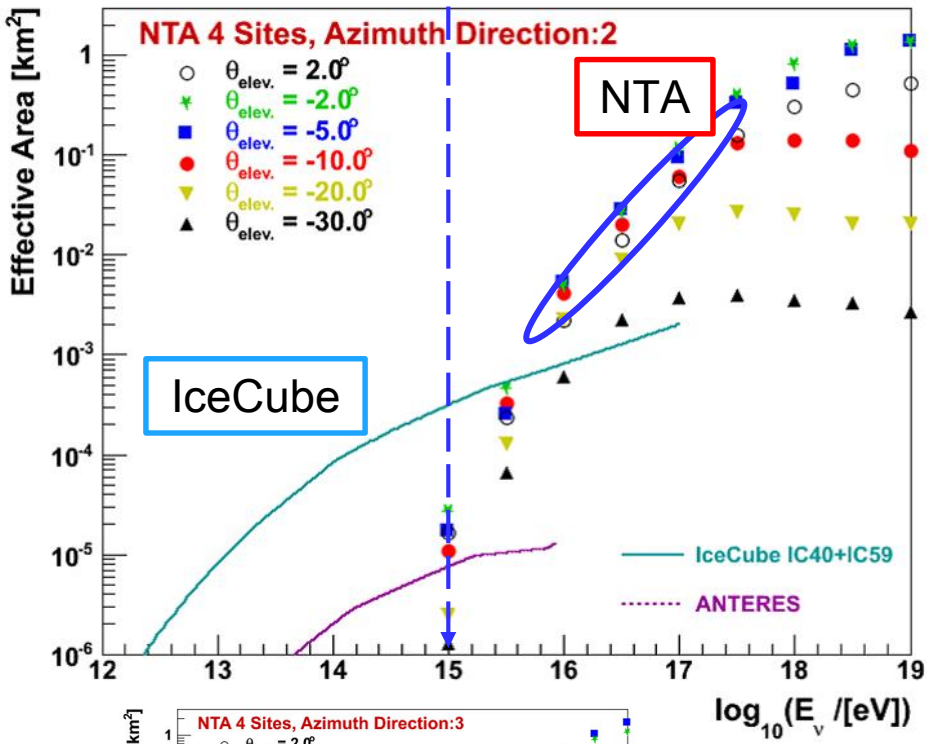



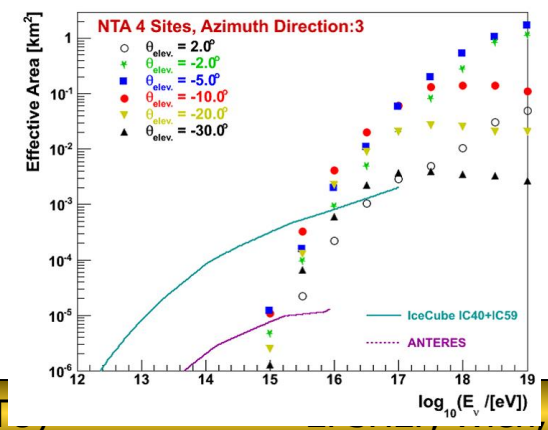



# Acceptance: Air & Tau vs Water & Muon

1. We use the $\nu_\tau$ distribution from CTEQ4 [14], inelasticity parameter from [13], and parameterize energy loss in Earth by [12, 15].
2. We use $\tau$ decay from TAUOLA and air-shower generation of Gaisser-Hillas + NKG [16].
3. For detector simulation, we incorporate light collection and throughput with simplified triggering logic. Event reconstruction is not yet implemented.

Point source, arrival dir. Mauna Loa




dir. Hualalai

**Assumed FOV**

| | |
|---|---|
| LC: | 32° X 32° |
| Trigger Pixel: | 0.5° X 0.5° |
| Sensor Pixel: | 0.125° X 0.125° |

trigger conditions:

- Number of detected photoelectrons per LC > 61.
- S/N estimated in track-associated 4 pixels × 64 pixels box (air-shower track included) > 4 [17].

Ernie

$E$ = 1.1 PeV, $\theta$ = 23º

Bert

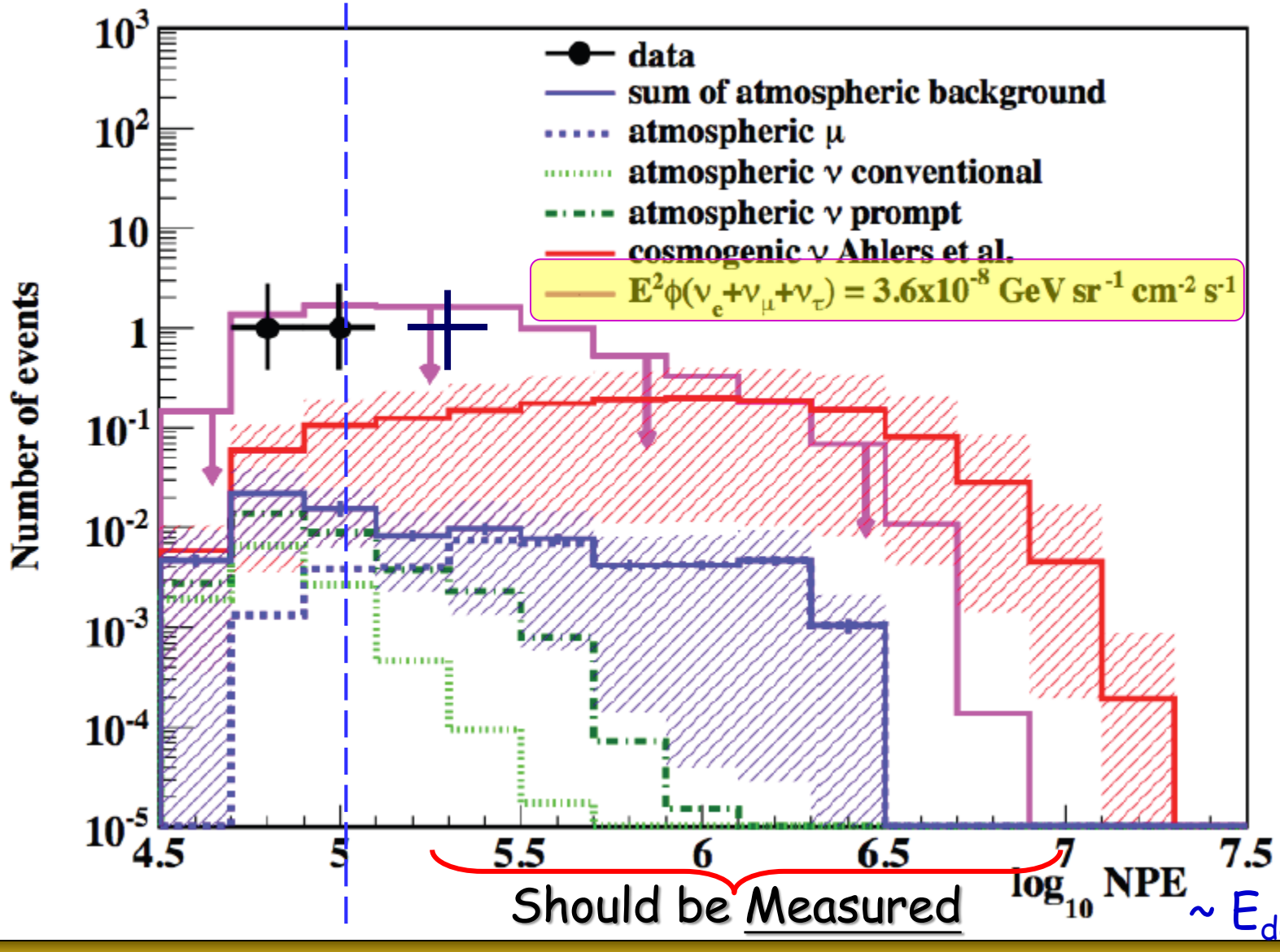
$E$ = 1.0 PeV, $\theta$ = 62º

Big Bird

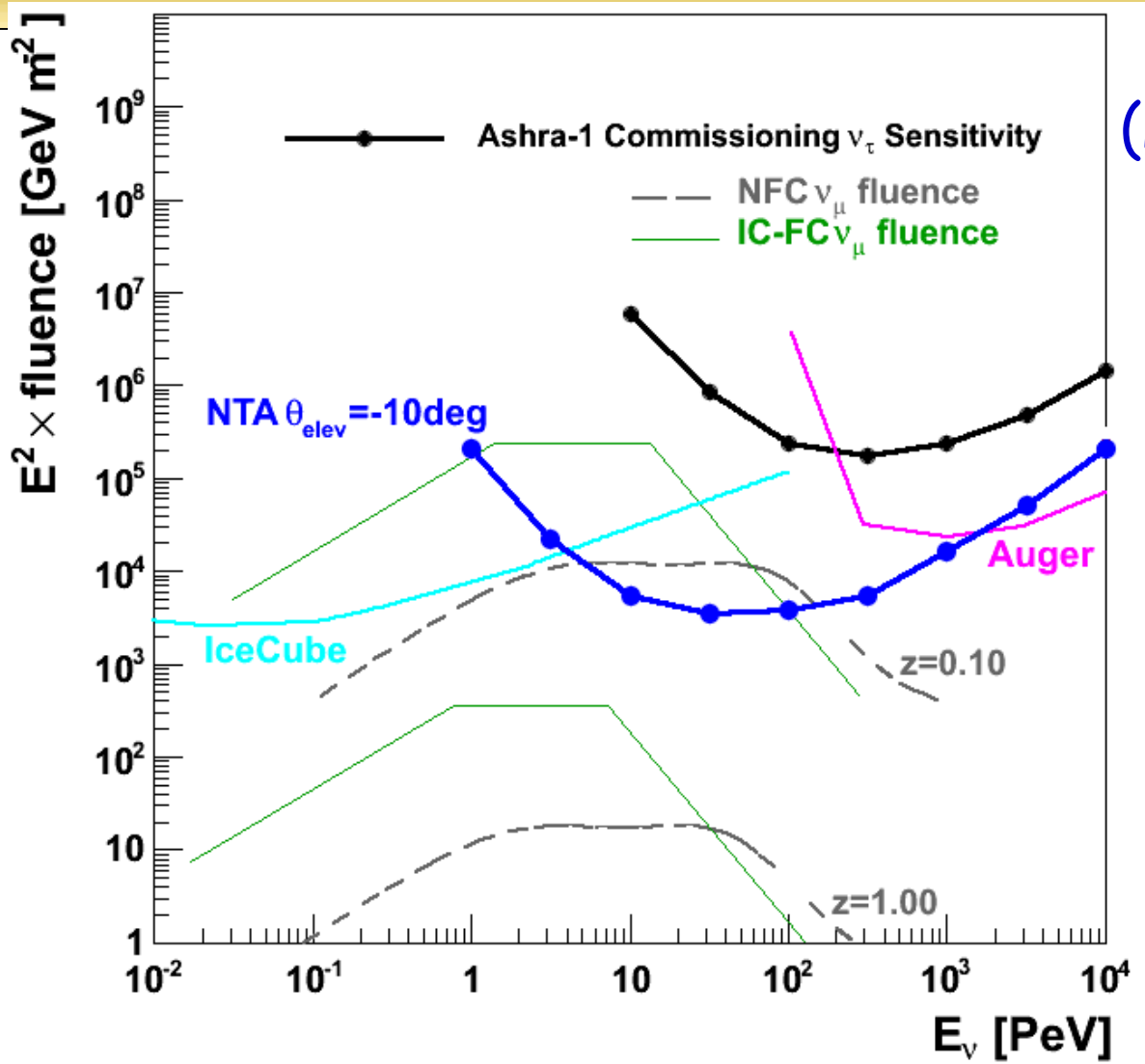
$E$ = 2.0 PeV, $\theta$ = 34º

What if one had better Sensitivity and accurate Pointing Info?

# IceCube PeV Events



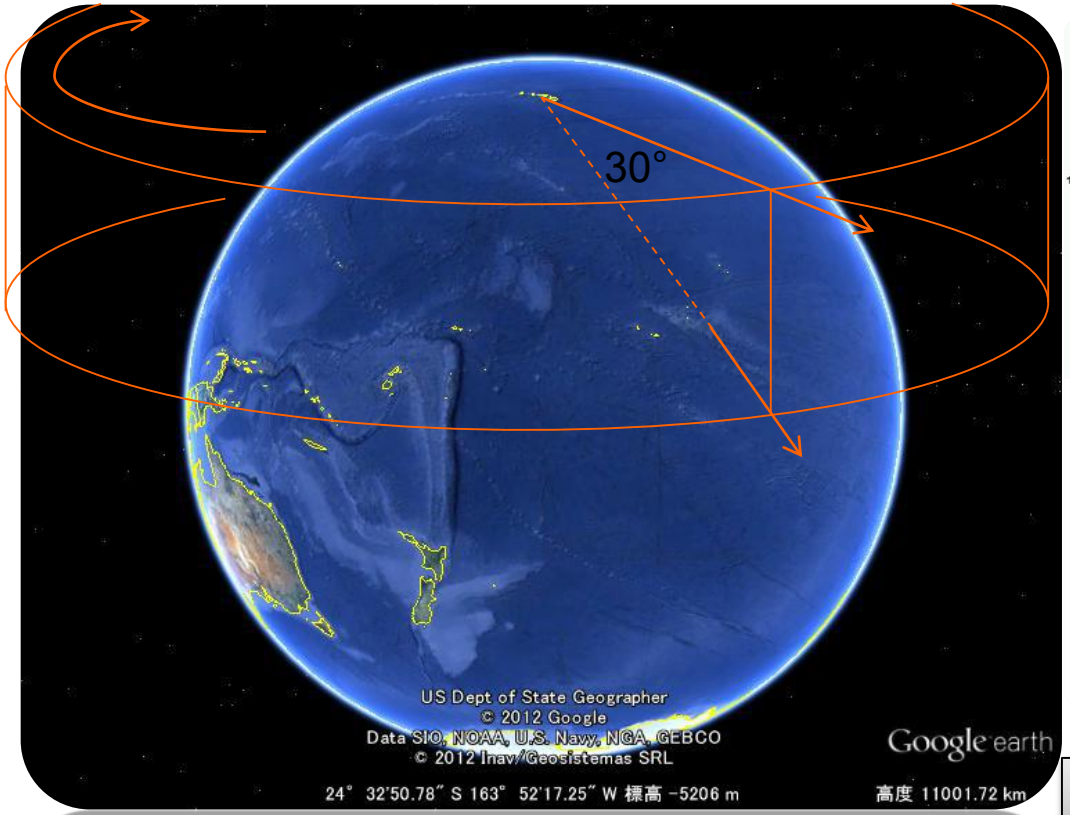
# NTA Differential Sensitivities

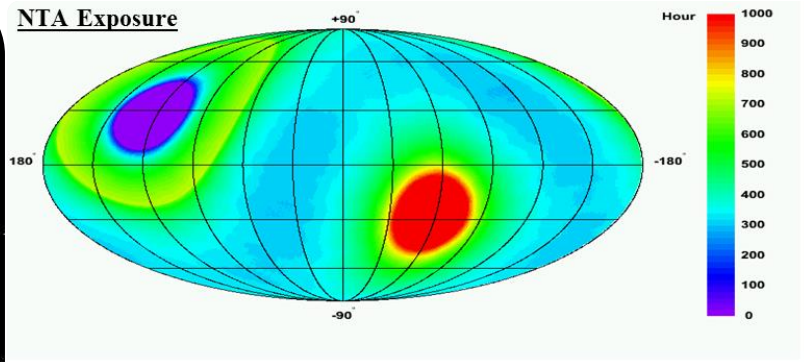


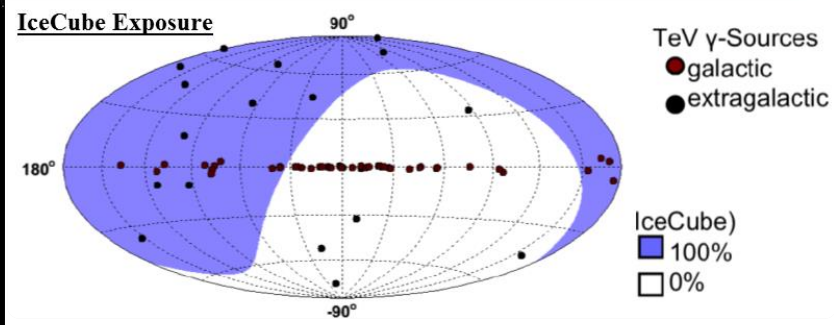

(LOI at hand)

**NTA Survey Depth: z ~ 0.15 (2 Glyr) for GRBν flux** (Hümmer et al., 2012)

# NTA $\nu_\tau$ Survey Performance




NTA can observe
Galactic Center

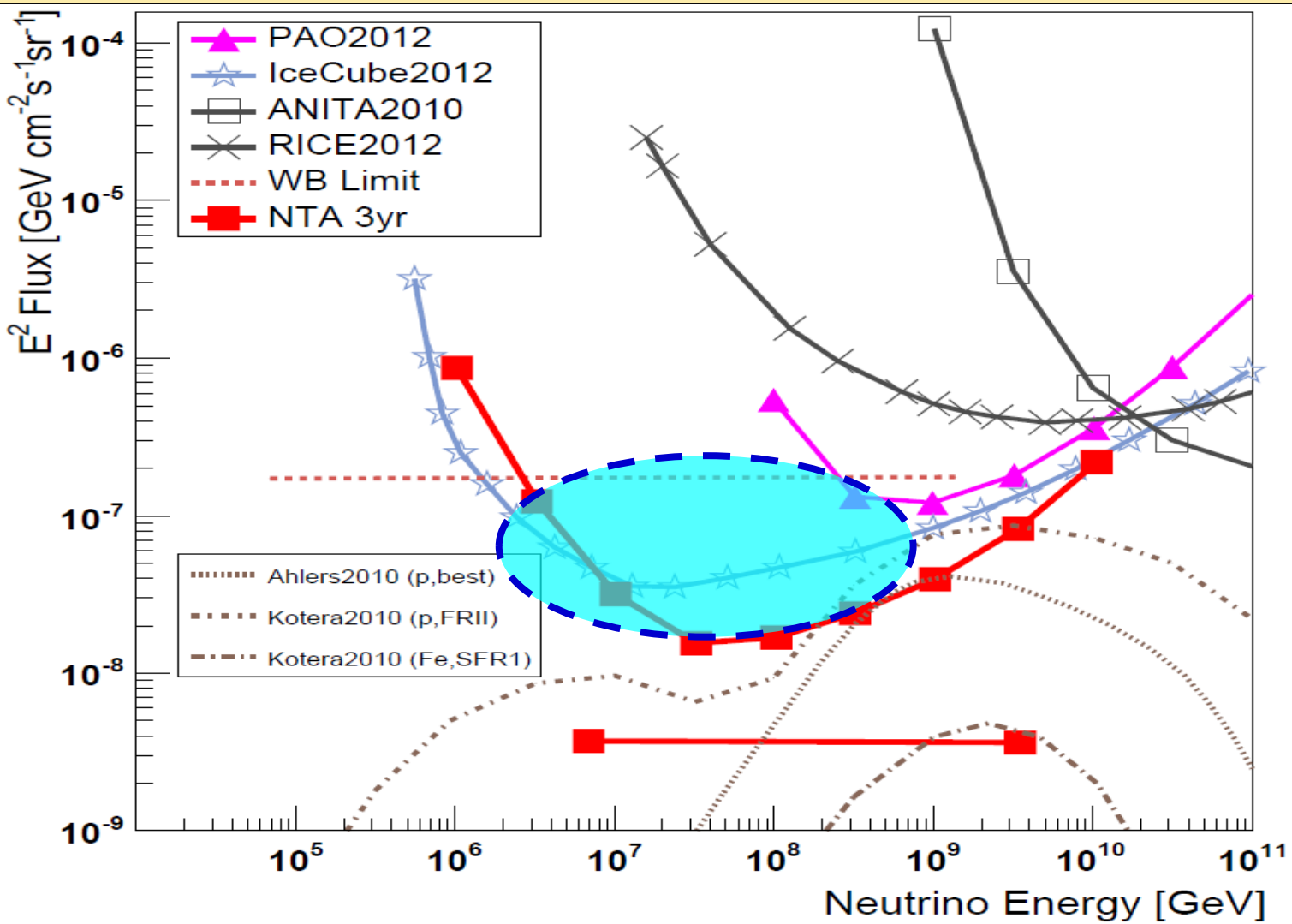
Duty 10-20% from Ashra-1

$\nu$ pointing accuracy < 0.2°

FOV Elevation 30° × Azimuth 360°

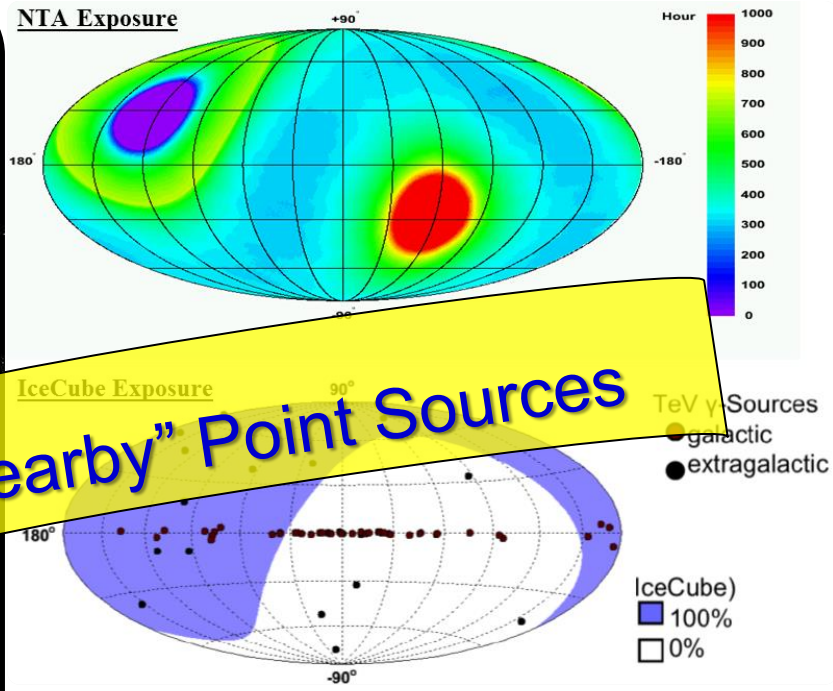
For GRB$\nu$
Survey Depth z < 0.15 (2 Glyr)

# NTA Diffuse Sensitivity (3 yr)




**NTA Survey Depth: z ~ 0.15 (2 Glyr) for GRBν flux** (Hümmer et al., 2012)

# NTA $\nu_\tau$ Survey Performance

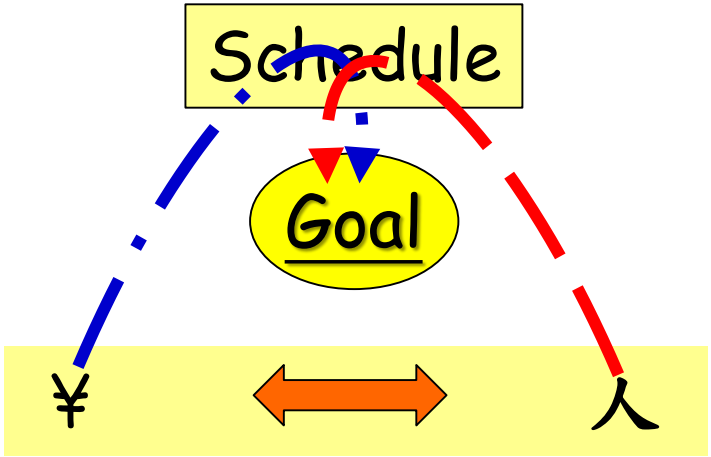



**Target is not Diffuse, but "nearby" Point Sources**

NTA can observe
Galactic Center

| |
|---|
| Duty 10-20% from Ashra-1 |
| $\nu$ pointing accuracy < 0.2° |
| FOV Elevation 30° × Azimuth 360° |
| For GRB$\nu$<br>Survey Depth z < 0.15 (2 Glyr) |

# V. Towards a New Collaboration




NTA Projected: ~ 7 countries

Call for Collaboration

| Site ID | Location | X [km] | Y [km] | Z [km] | FOV [sr] |
|---|---|---|---|---|---|
| Site0 | Center | 0.000 | 0.00 | 2.03 | $\pi$ |
| 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 | $\pi/2$ |

At least 30 DUs for Coverage, 100 Myen each

12 DU's per $\pi$ coverage

# Conclusion

## Neutrino Telescope Array (NTA)

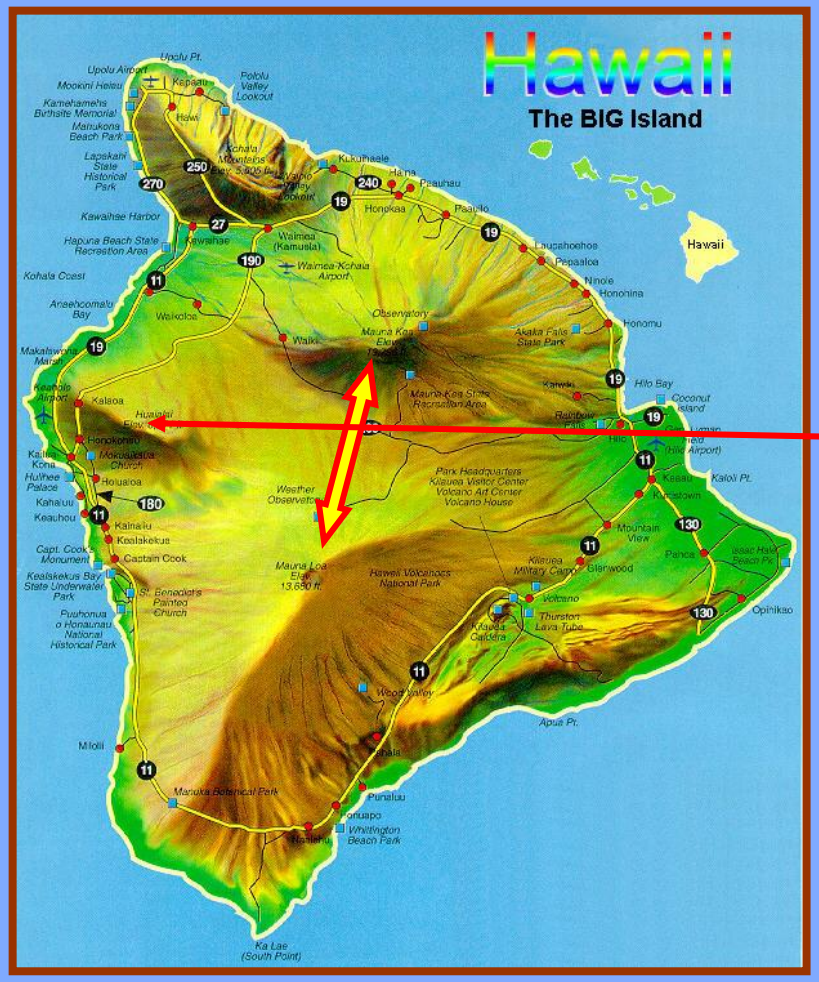
## Aim/Scientific Goal

Clear Discovery and Identification of Nonthermal Hadronic Processes in the Universe, be it Galactic, Extragalatic, or Cosmogenic.

Call for Collaboration

**Let's Go to Hawaii !!**

# Hawaii Big Island as Site: happened as *gotcha*




w/ Francois Vanucci

- Courtesy visit to CosPA-1 [Fred Lo]
  - Hawaii is known good Astro Site
  - Stood together in front of Hawaii map
  - *Snap*: Big Mountains w/ 40 km sep.
- Mt. Hualalai: M. Alfred Huang

Good view of Mauna Loa

Situated at dryer west side

Mauna Loa provide long base line

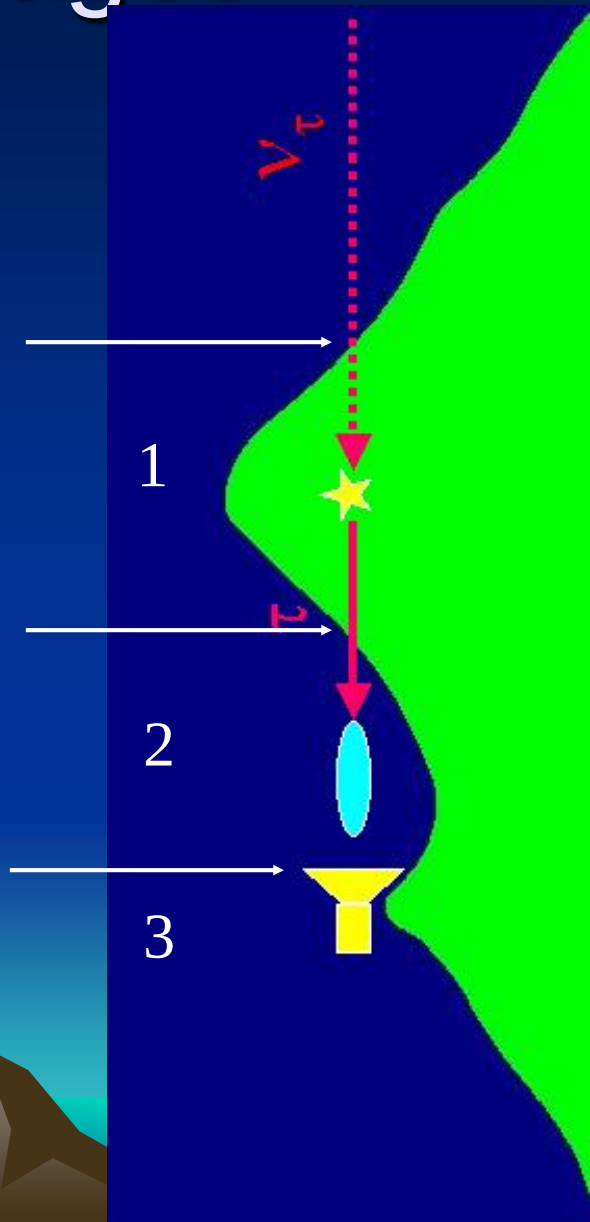
~ 90 km wide and 4 km high

GWS Hou & MA Huang, astro-ph/0204145

P Yeh et al., MPLA 19 (2004) 1117 [CosPA 2003 WS]

# Three simulation stages

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

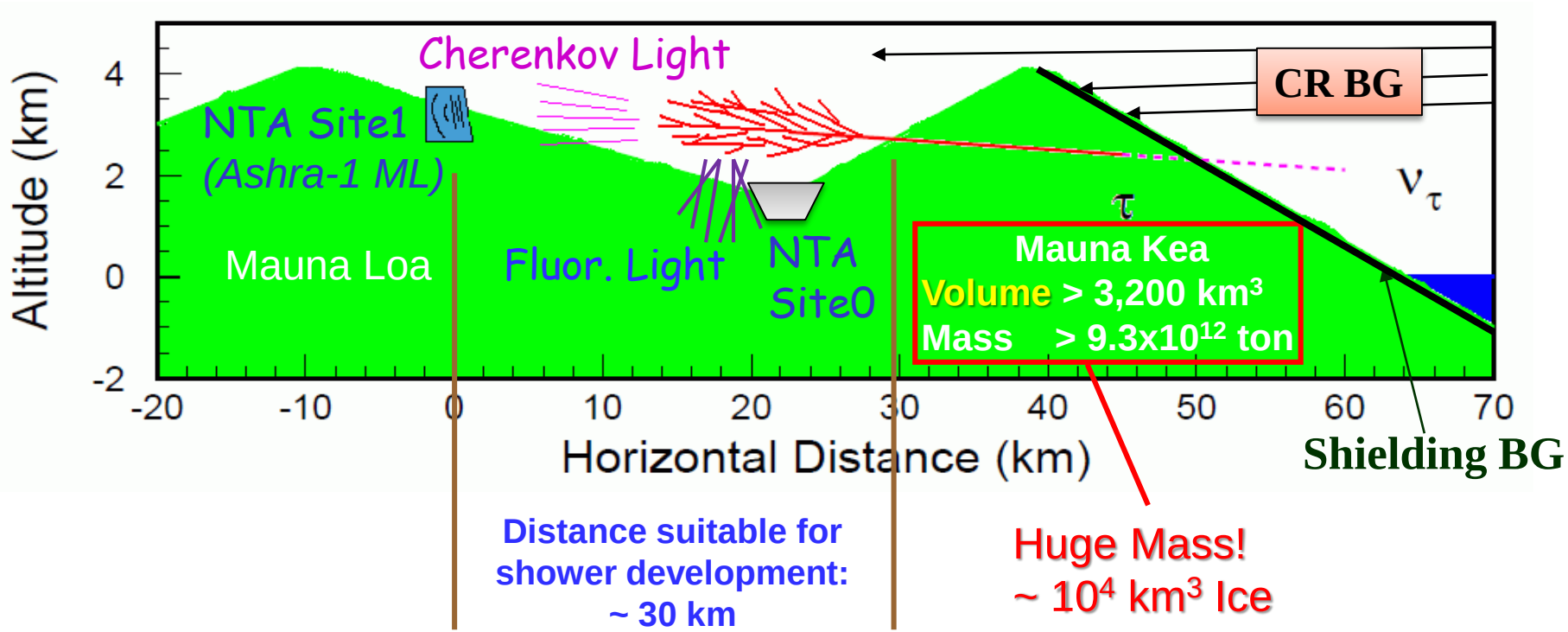


# NuTel

- NuTel is the first experiment *dedicated* to earth skimming for $\tau$ appearance, but was terminated ...
- PeV cosmic $\nu_\tau$ rate is ~ ~~0.5 event/year~~
- ~~First set of~~ two telescopes ready
- VHECR observation in Taiwan: prototype deployment in 2009 indicates high light background at Mei-Fong
- We learned challenge of mountain operation
  - ➔ Tried pair up with CRTNT (曹臻) ... they evolved ...
- Synergy w/ Ashra-1 (reconnect 9/2012) ➔ (Ashra) NTA

# Earth-skimming τ Shower Imaging Method

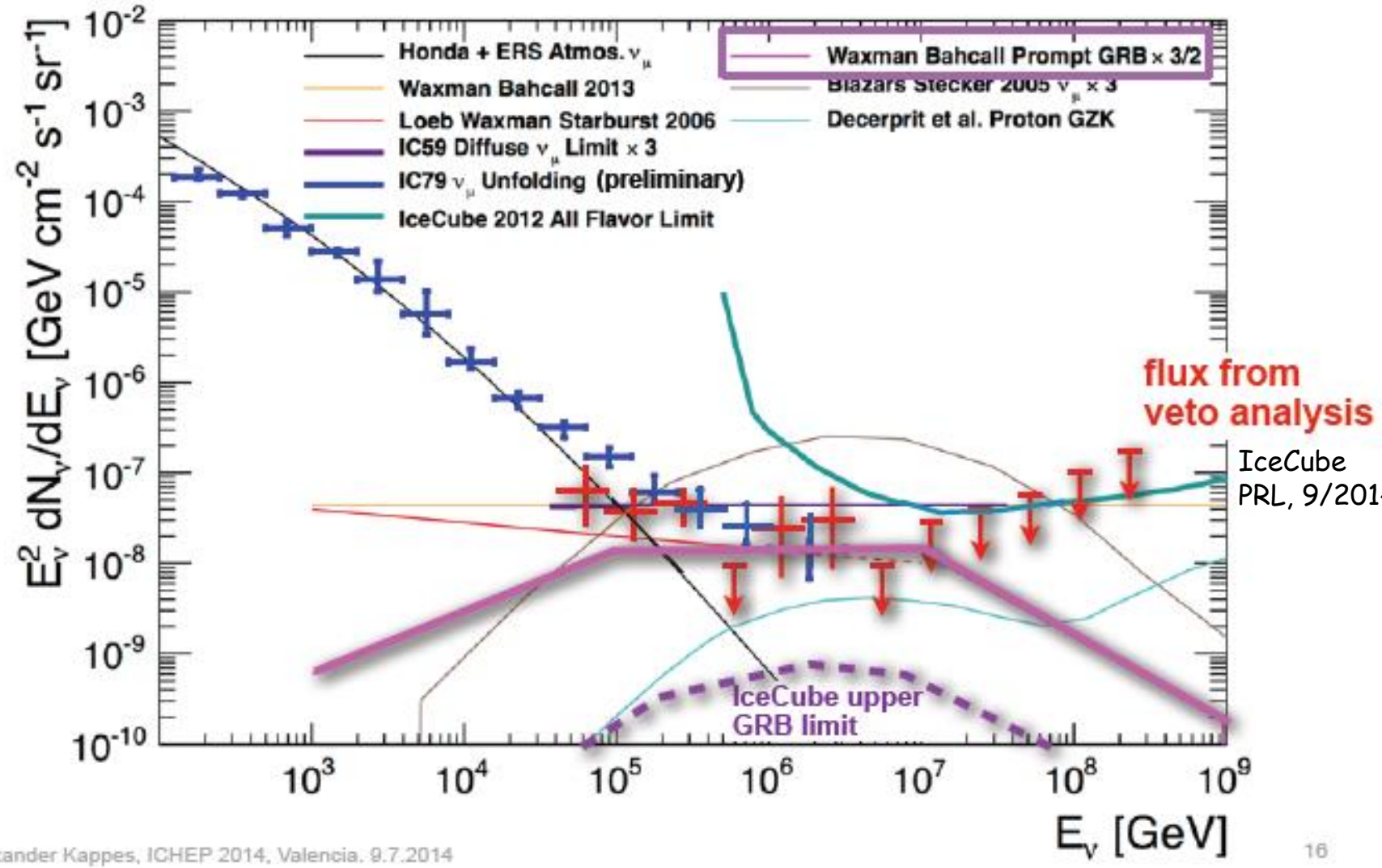
reminder



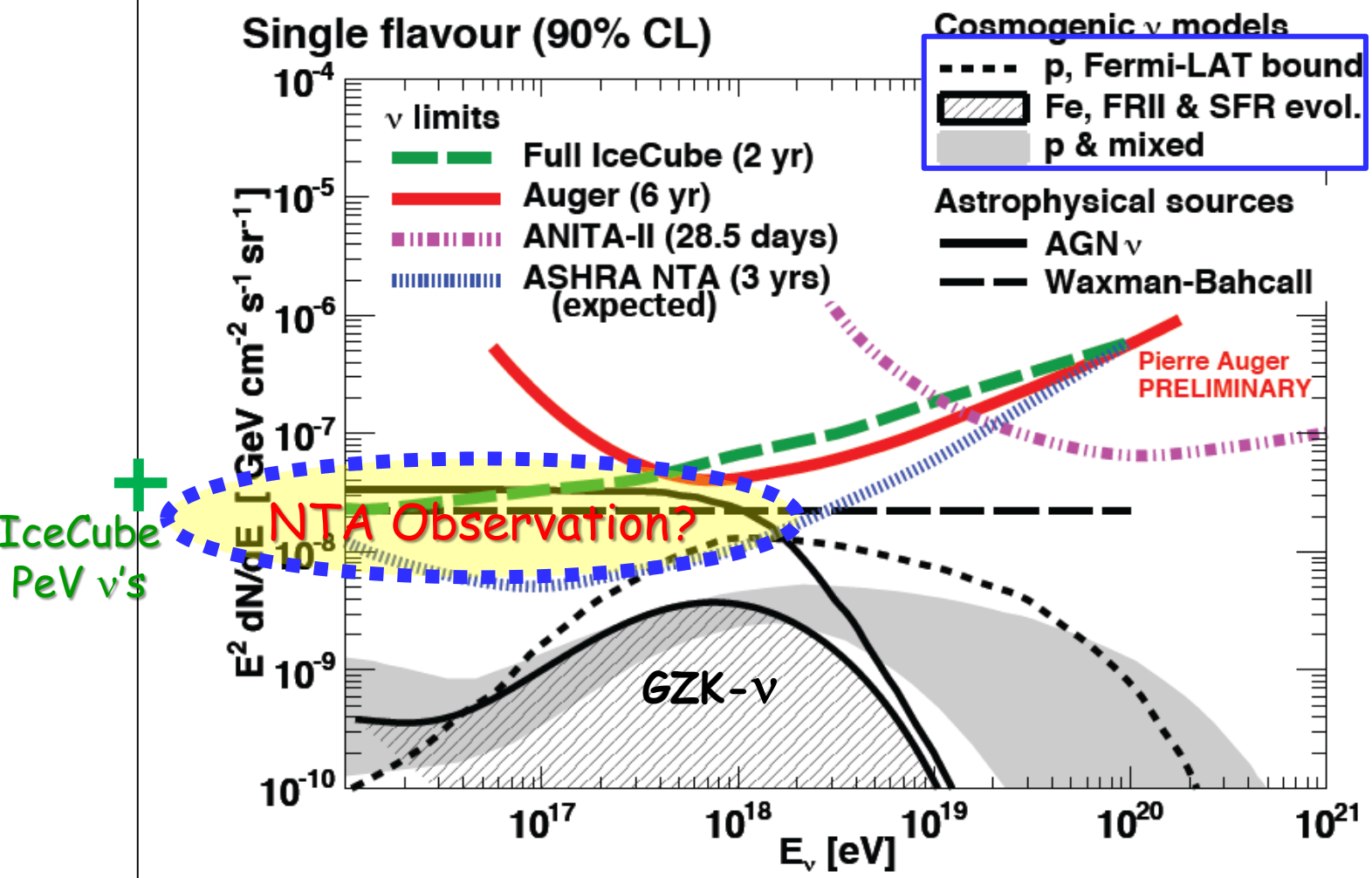

**Ashra-1 already demonstrated this method !**

ApJ, 736 (2011) L12

## Source candidates



# Differential limits to diffuse flux of UHEν



# NTA Organization

ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

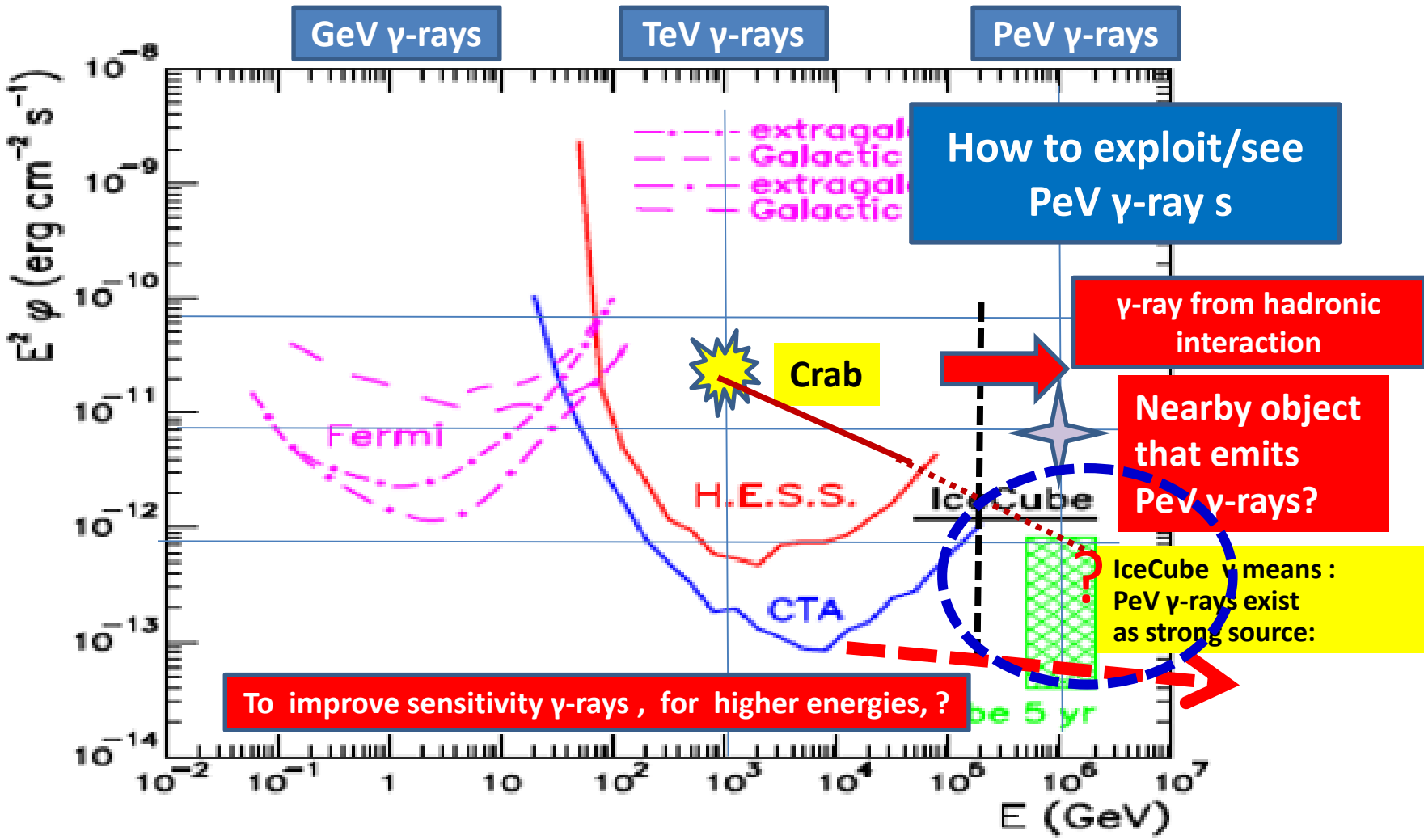
250 people, 39 institutions, 11 countries

Pierre Auger Observatory
the universe's highest energy particles

500 people, 18 countries

NTA Projected: $\lesssim$ 10 countries

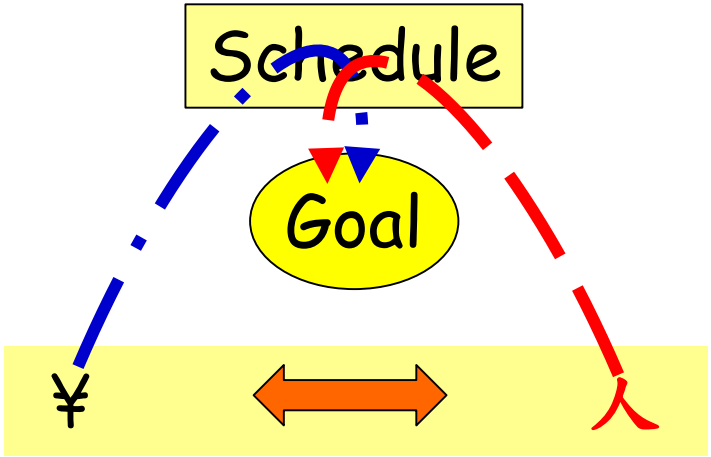
# Shed Light on PeV Gamma?




Courtesy T. Kifune.

LA. Anchordoqui et al./Journal of High Energy Astrophysics 1-2 (2014) 1-30.

# NTA Organization




NTA Projected: ~ 7 countries

Call for Collaboration

Currently: IEB [3: N, T, (US)A] ⇔ LIB (Local I.B.)

Initial Meeting 11/2012

Near-term Timeline } LOI at hand (submitted 2014) ⇒ VHEPA2015 (April) Call for Collaboration ⇒ Community Disc.? ICRC 2015

funding ~ 2 yrs; construction ~ 5 yrs

use Ashra-1 for test/sci