NTA

PeV-EeV Multi-messenger Explorer

VHEPA2019

Makoto Sasaki

ICRR UTokyo

Ashra-1/NTA

(proto-) collaboration

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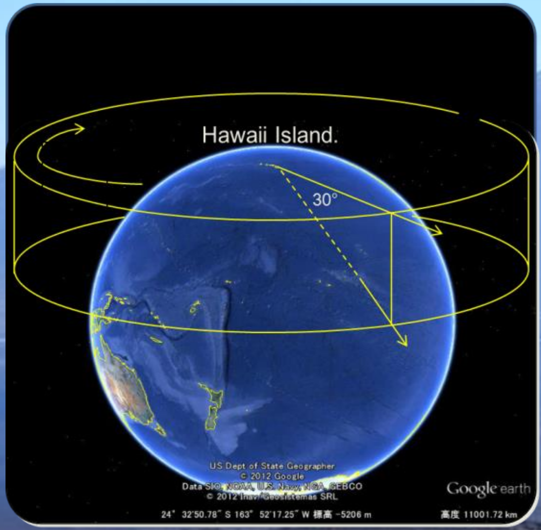
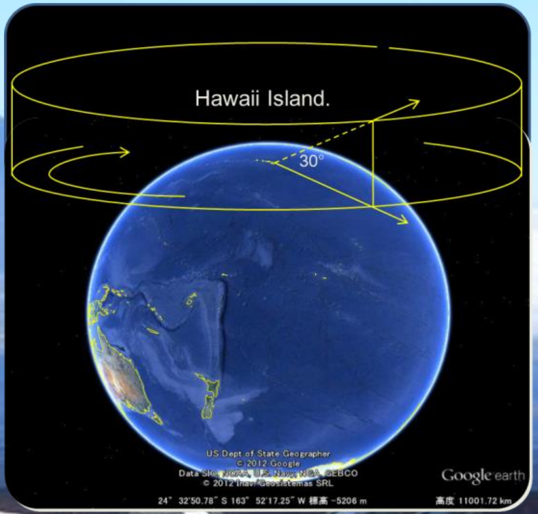
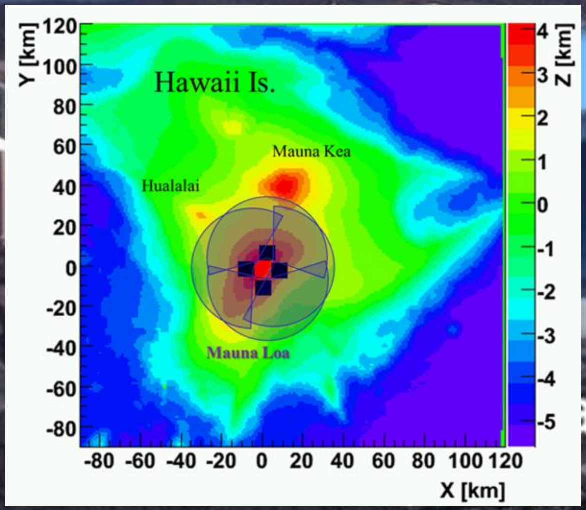
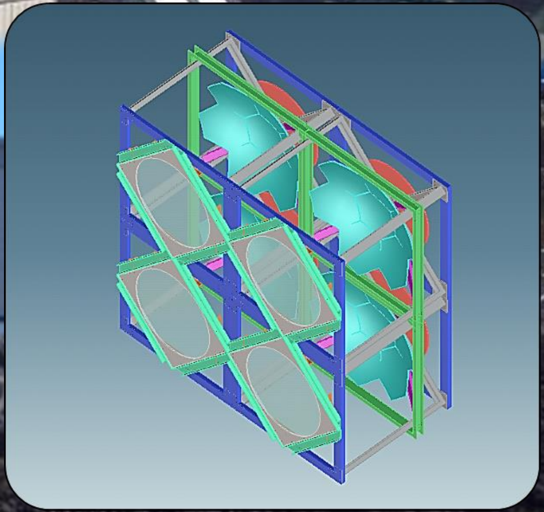
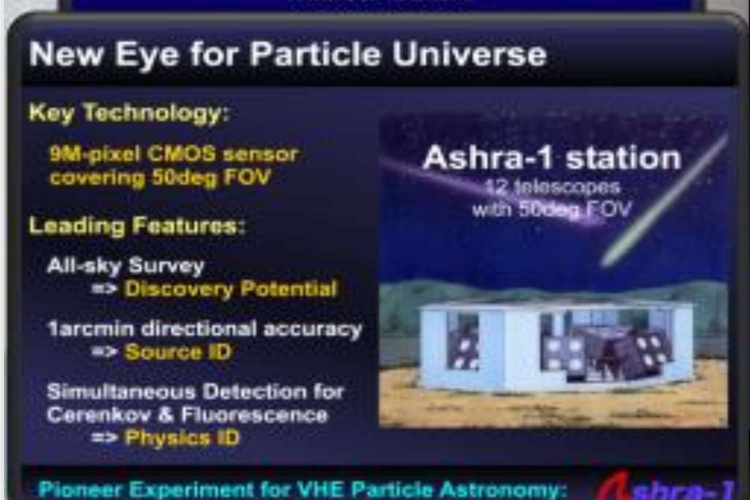


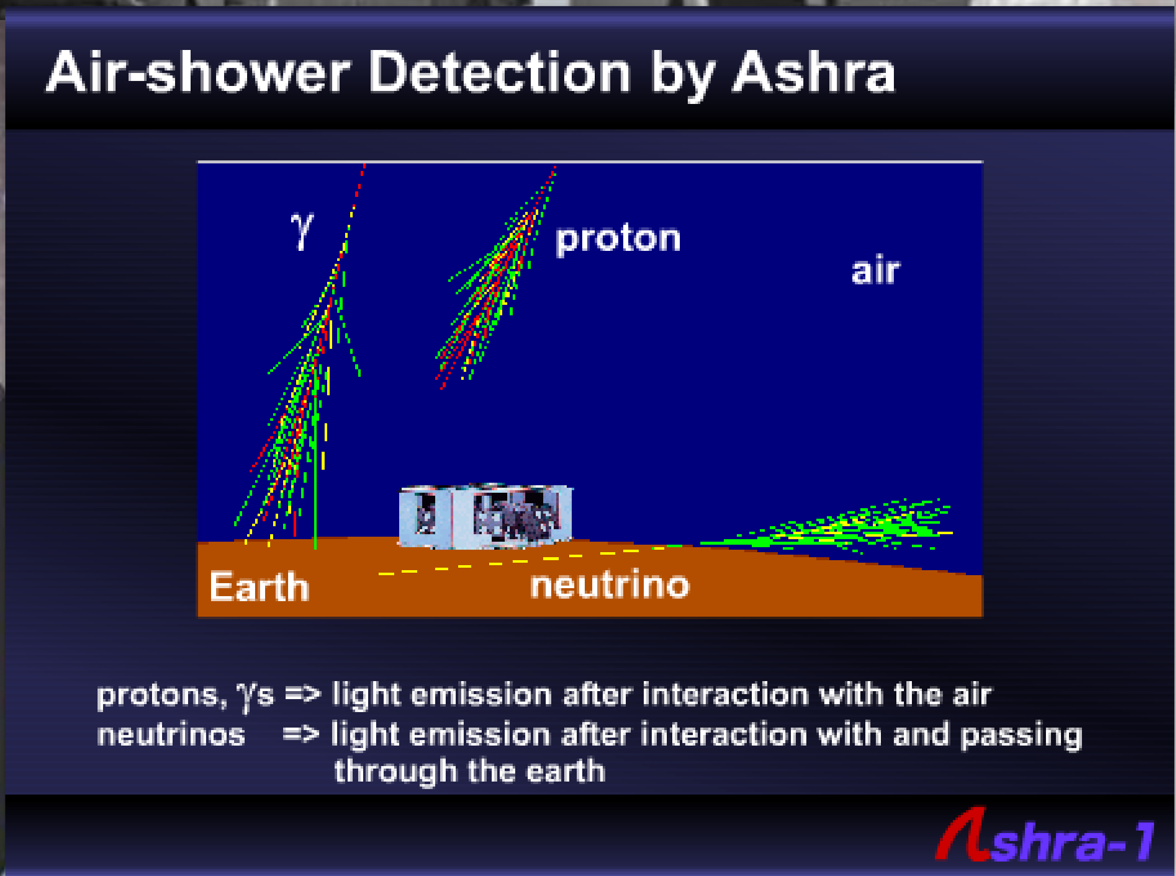






VHEPA-3 (March 20-22, 2003)





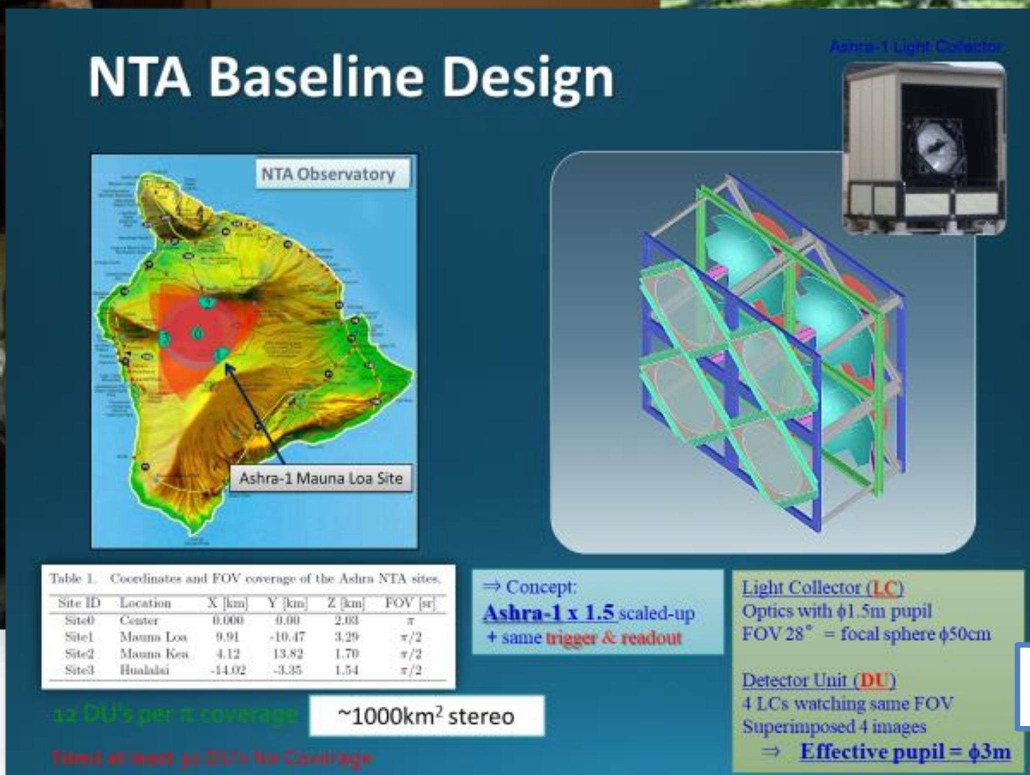
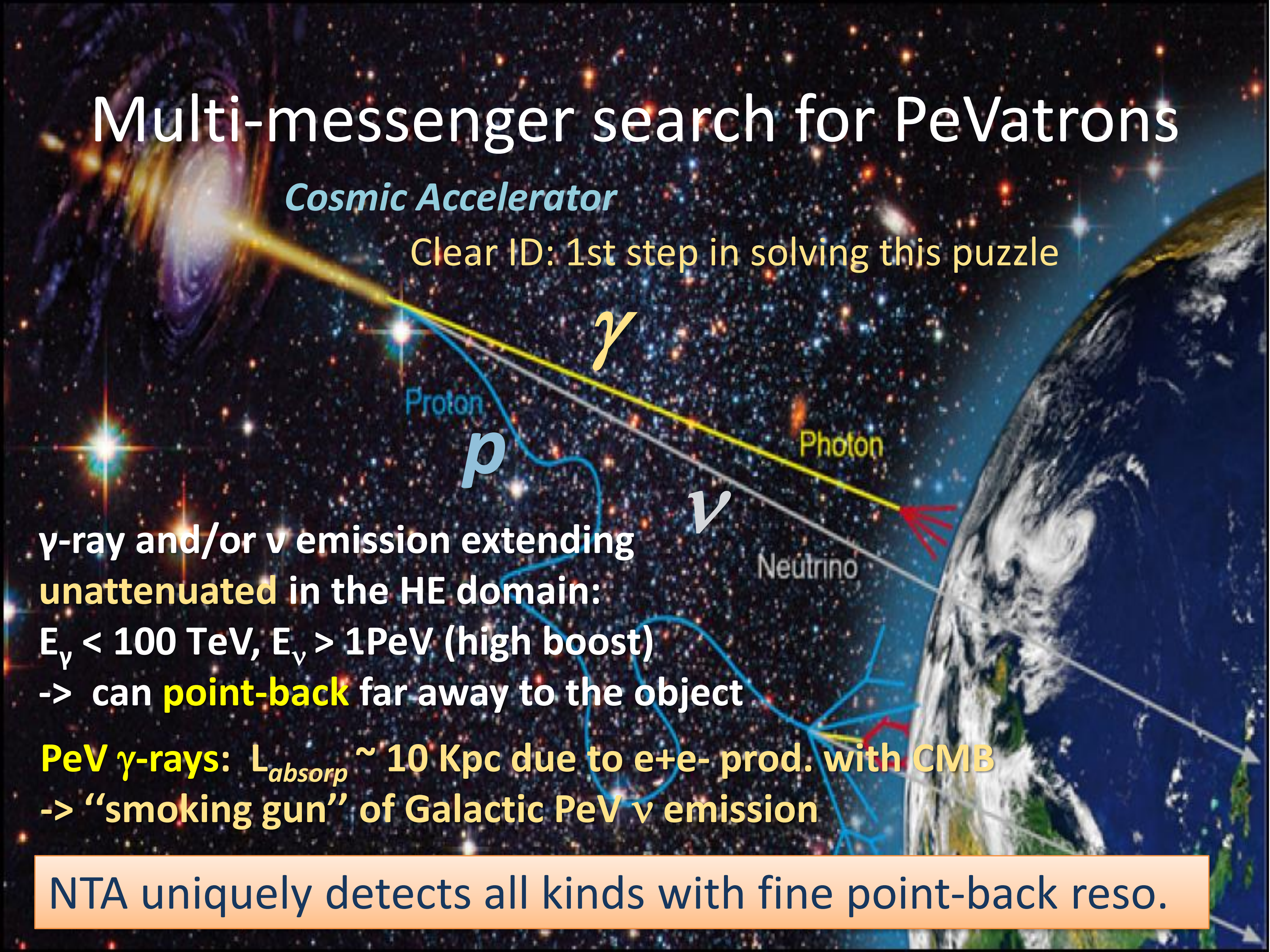


Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

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	$\pi/2$

NTA proto-collaboration & WG formed.

Multi-messenger search for PeVatrons



Clear ID: 1st step in solving this puzzle

γ-ray and/or ν emission extending
unattenuated in the HE domain:
E_γ < 100 TeV, E_ν > 1PeV (high boost)
-> can point-back far away to the object

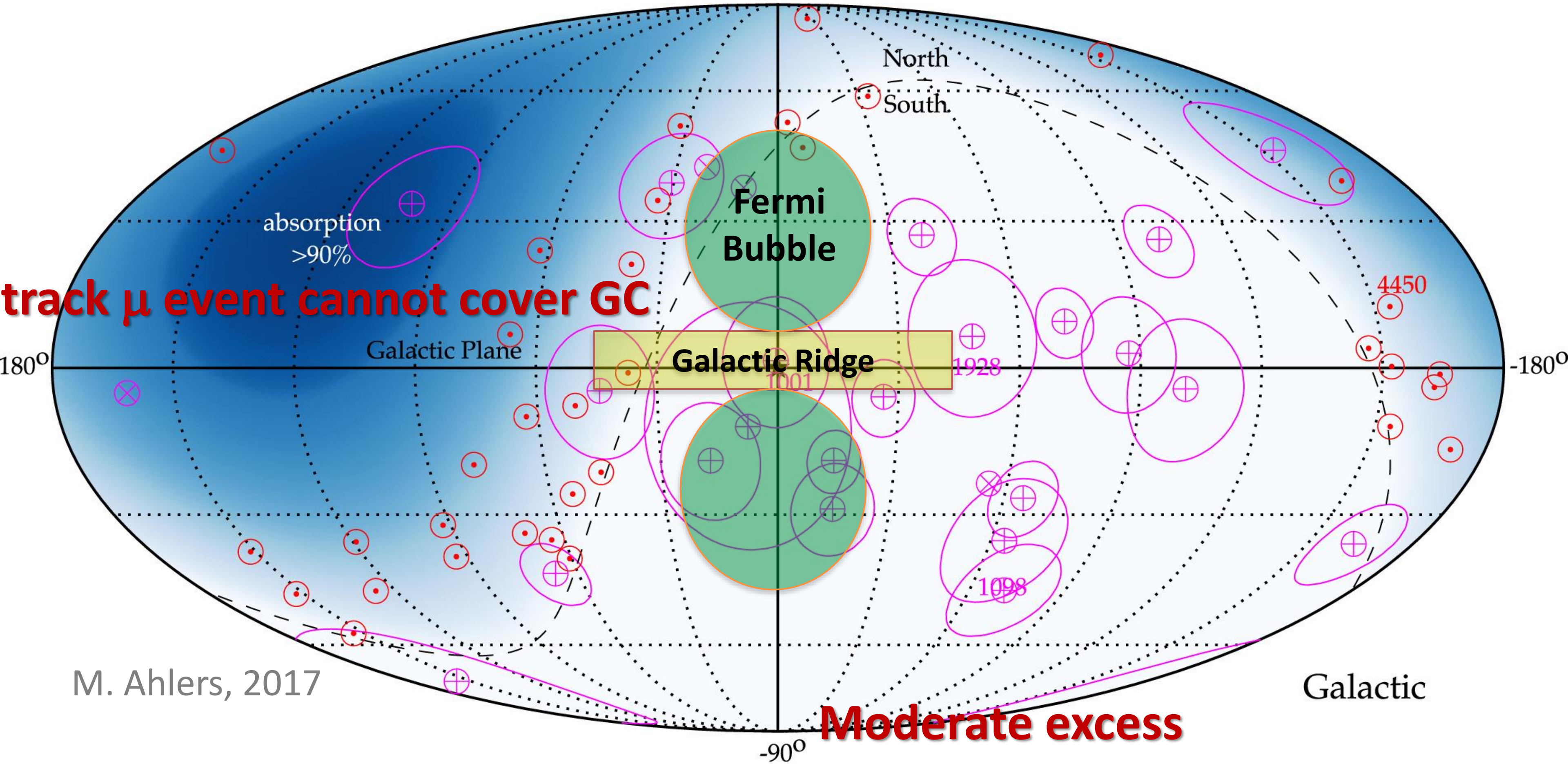
PeV γ-rays: L_{absorp} ~ 10 Kpc due to e+e- prod. with CMB
-> "smoking gun" of Galactic PeV ν emission

NTA uniquely detects all kinds with fine point-back reso.

The IceCube signal

Sources not yet identified clearly without TXS0506+056 case

Arrival directions of most energetic neutrino events (HESE 6yr (magenta) & $\nu_\mu + \overline{\nu}_\mu$ 8yr (red))



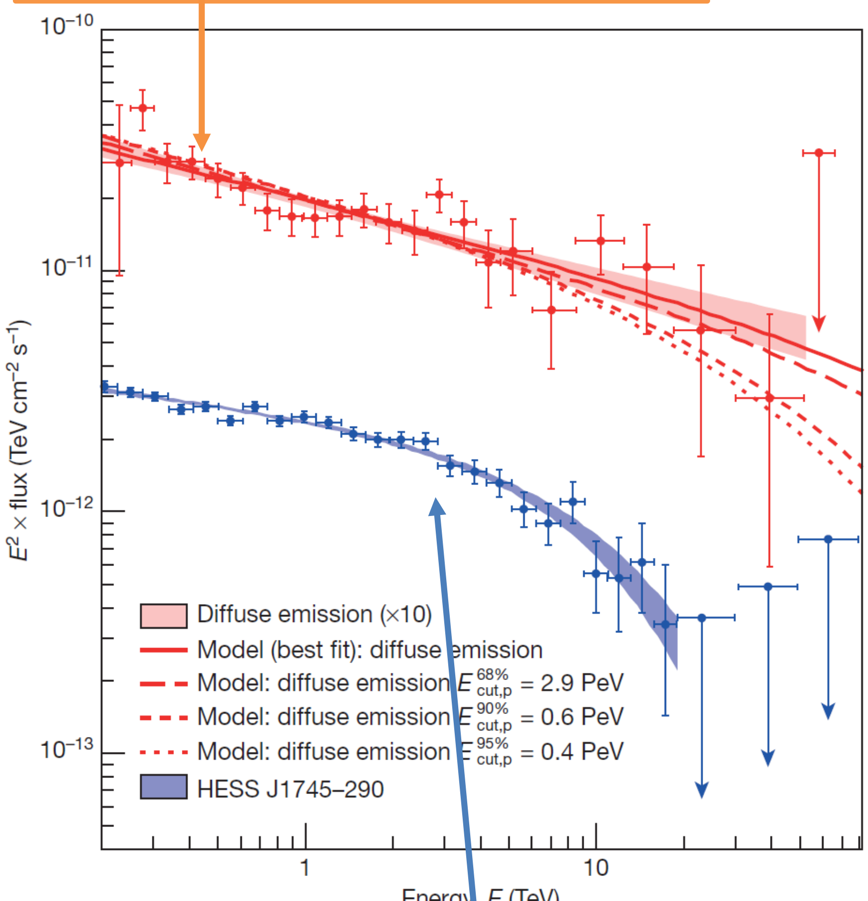
track μ event cannot cover GC

M. Ahlers, 2017

Moderate excess
Galactic Ridge? Fermi Bubbles?

PeVatron in the Galactic Center?

Diffuse emission from the GC without a perceivable cutoff



Point source emission with a 10 TeV cut-off

To clearly fix it, detector required:

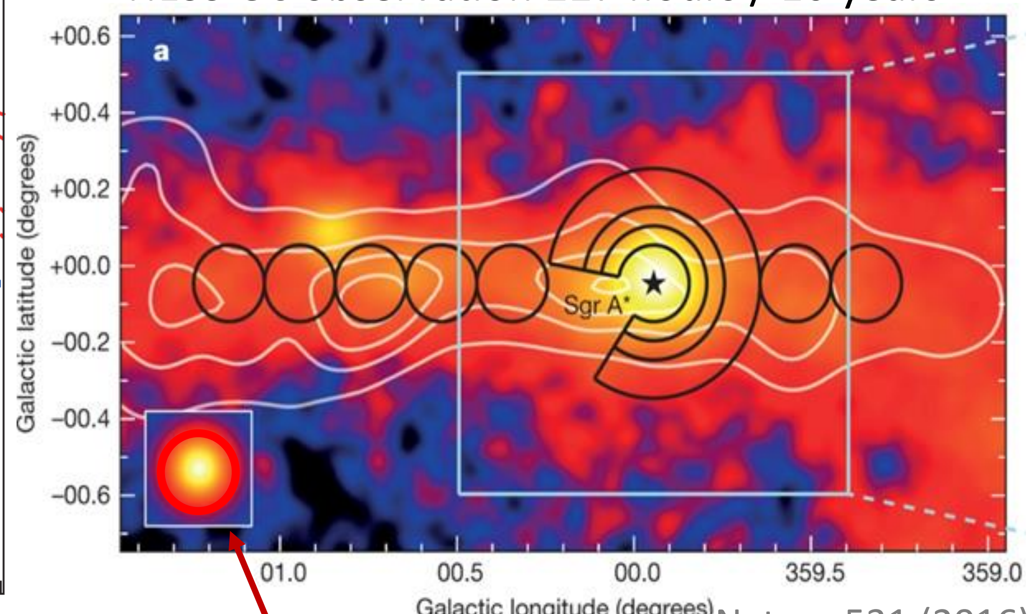
1) **γ-ray/ν multiple observation**

2) 0.1 deg. resolution like IACT

3) good sensitivity for E_γ > 50 TeV

-> NTA meets.

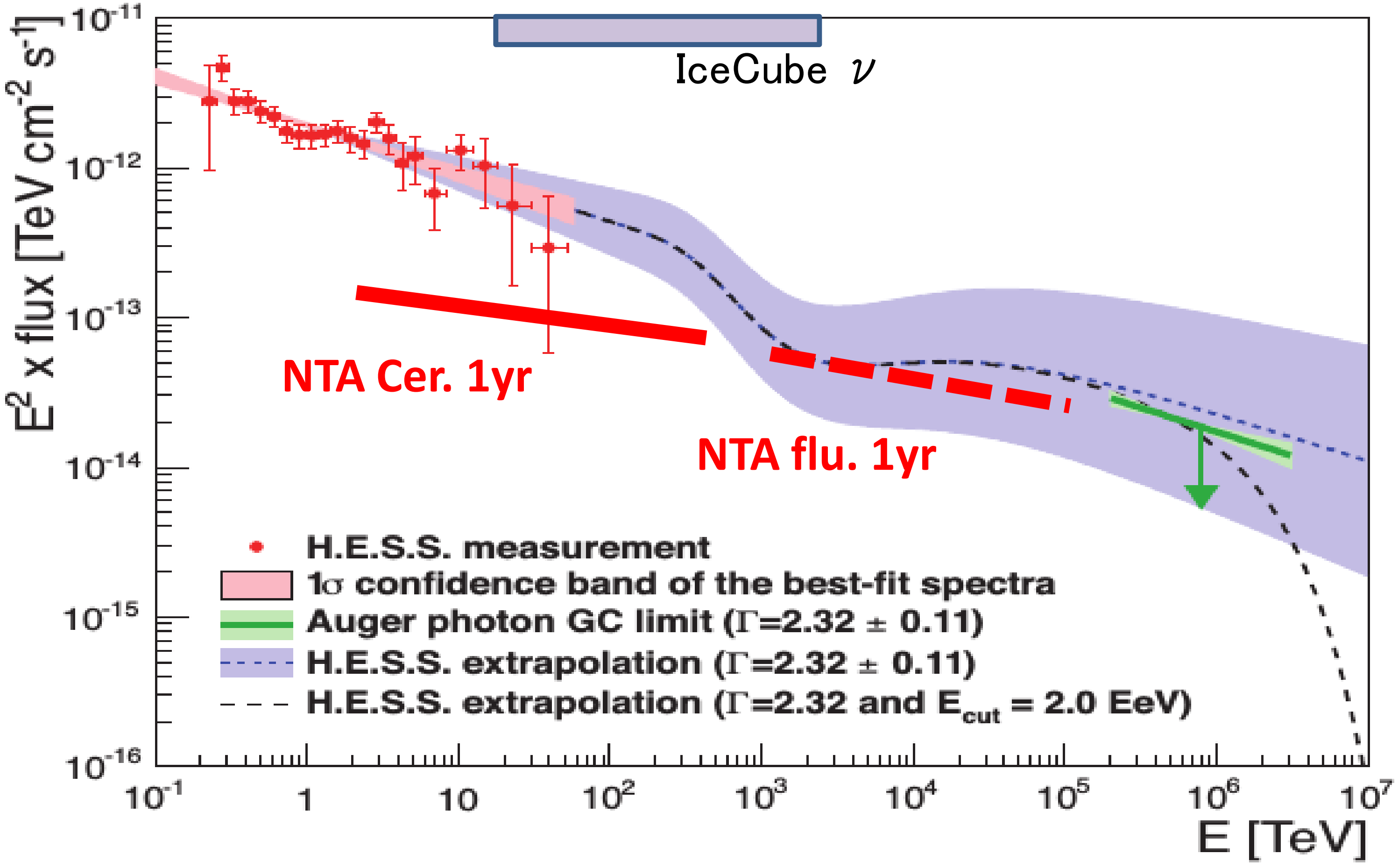
HESS GC observation 227 hours / 10 years



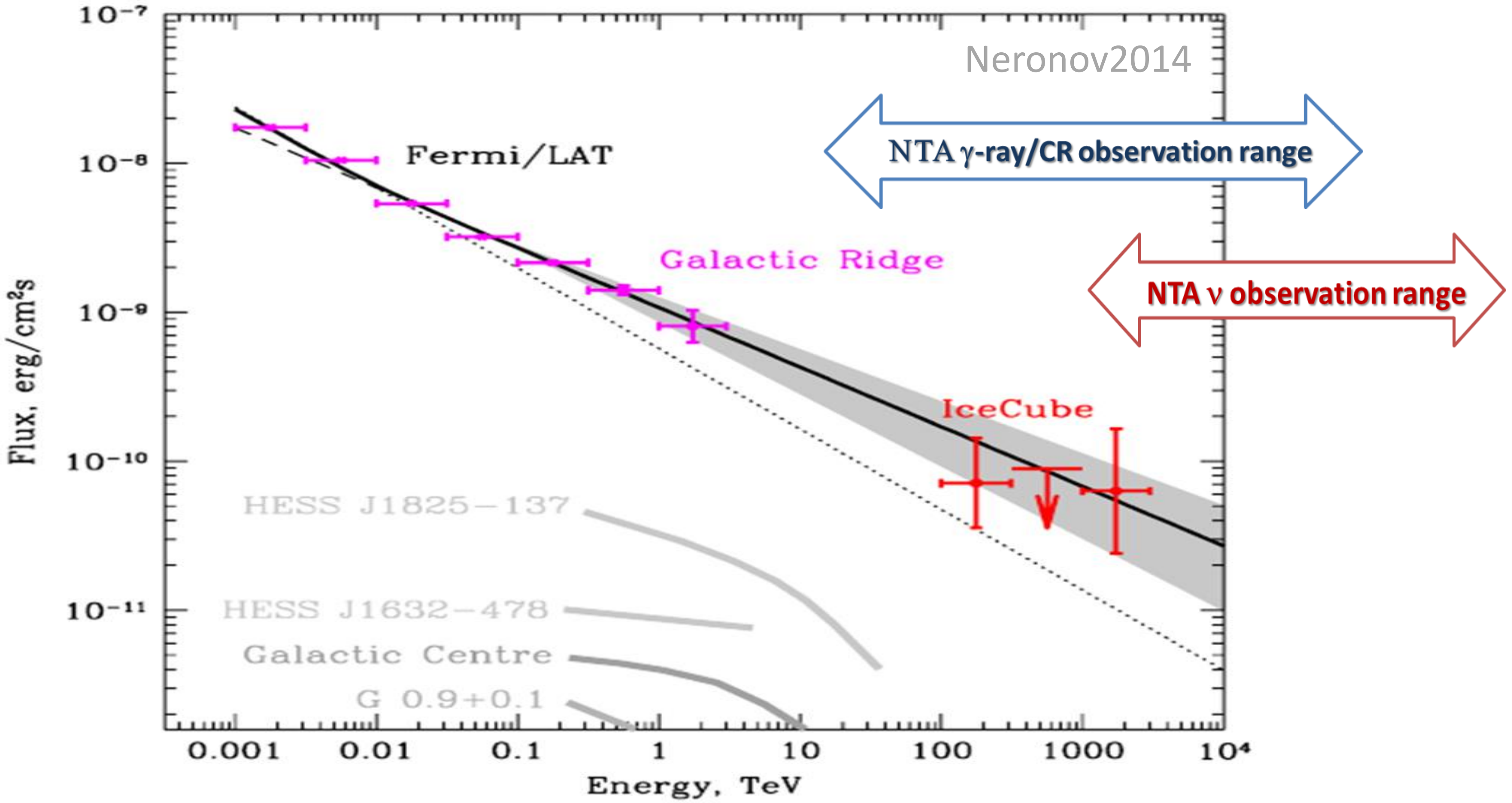
Nature 531 (2016)

HESS PSF

NTA GC Sensitivity



Galactic Ridge diffuse PeV emitter?



ν & γ Emission at Source:

Provides Source Physics

Provides VHE Universe "Labo."

photo-pion process:

$$p\gamma \to \Delta \to n\pi^+ \qquad \pi^0 : \pi^+ = 2:1$$

$$p\gamma \to \Delta \to p\pi^0 \qquad n + \pi^+ \to pe\bar{\nu}_e + e^+\nu_e\nu_\mu\bar{\nu}_\mu$$

$$1\nu_\mu : 1\bar{\nu}_\mu : 1\nu_e \qquad (\nu_\mu + \bar{\nu}_\mu) : (\nu_e + \bar{\nu}_e) = 2:1$$

hadro-nuclear process:

$$pp \to \pi X \qquad \pi^- : \pi^0 : \pi^+ = 1:1:1$$

$$2\nu_\mu : 2\bar{\nu}_\mu : 1\nu_e : 1\bar{\nu}_e \qquad (\nu_\mu + \bar{\nu}_\mu) : (\nu_e + \bar{\nu}_e) = 2:1$$

ν & γ fluxes :

$$\phi_\gamma = C \times E_\gamma^{-\alpha}$$

$$\phi_\nu = C \times (1 - r_\pi)^{\alpha-1} \times E_\nu^{-\alpha}, \text{ where } r_\pi = (m_\mu/m_\pi)^2$$

ν-oscillation:

$$\nu_e : \nu_\mu : \nu_\tau = 1:2:0 \to 1:1:1$$

ν & γ Emission in *CR* Propagation:

On-resonance: Cosmogenic or GZK process:

$$p\gamma_{\text{CMB}} \rightarrow \Delta \rightarrow n\pi^{+} \qquad \pi^{\pm} \rightarrow \mu\nu_{\mu} \rightarrow e\nu_{e}\nu_{\mu}\nu_{\mu} \qquad E_{\nu} \simeq \frac{1}{4}E_{\pi}$$

$$p\gamma_{\text{CMB}} \rightarrow \Delta \rightarrow p\pi^{0} \qquad \pi^{0} \rightarrow \gamma\gamma \qquad E_{\gamma} \simeq \frac{1}{2}E_{\pi}$$

Off-resonance: EBL process:

$$p + \gamma_b \rightarrow p + e^{+} + e^{-}$$

$$p + \gamma_b \rightarrow n + \pi^{+} \qquad \pi^{\pm} \rightarrow \mu\nu_{\mu} \rightarrow e\nu_{e}\nu_{\mu}\nu_{\mu} \qquad E_{\nu} \simeq \frac{1}{4}E_{\pi}$$

$$p + \gamma_b \rightarrow p + \pi^{0} \qquad \pi^{0} \rightarrow \gamma\gamma \qquad E_{\gamma} \simeq \frac{1}{2}E_{\pi}$$

Deflection angle of propagating *CR protons*:

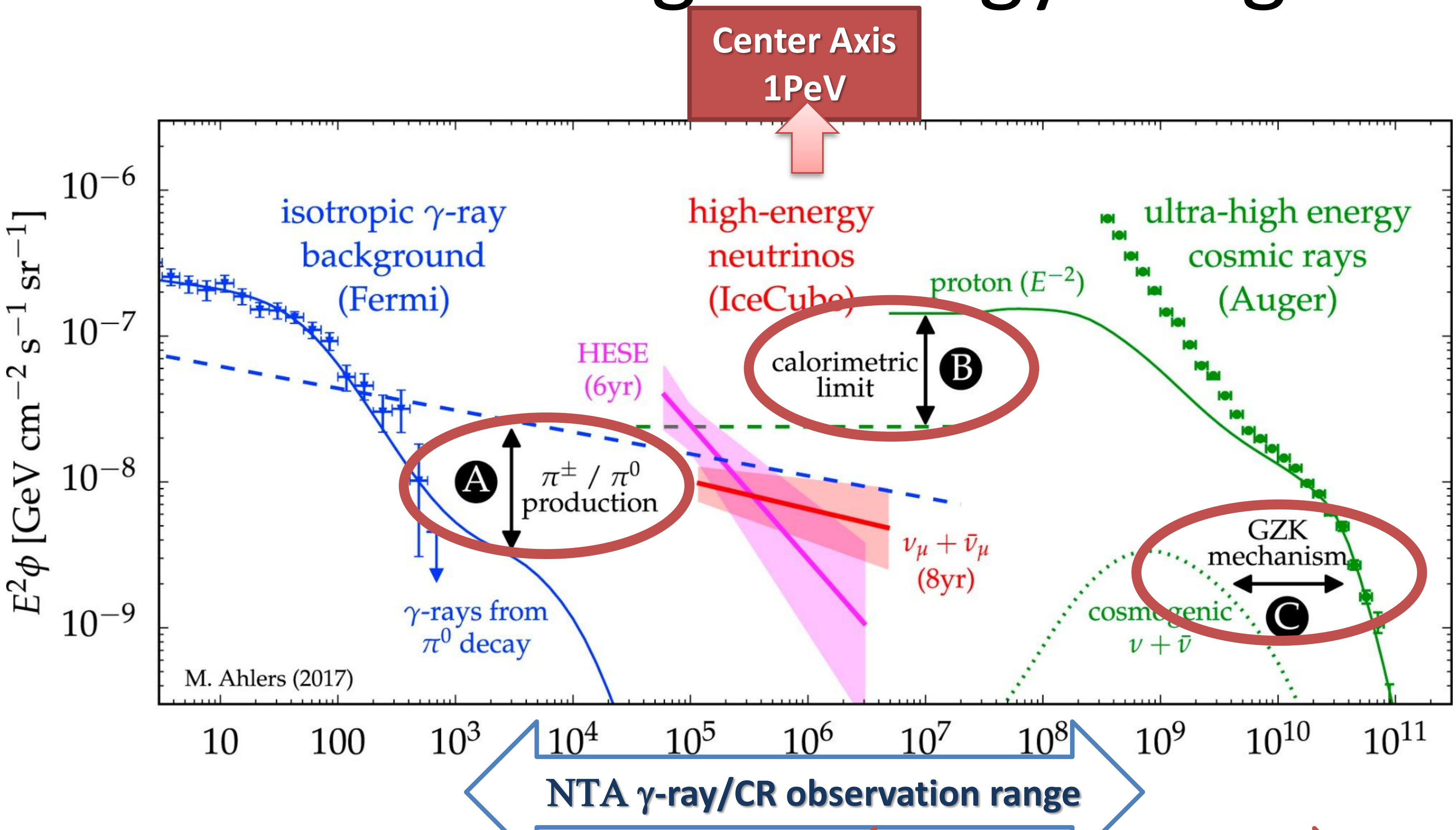
$$\Delta\theta \sim 0.1^{\circ} \left(\frac{B}{10^{-14}\text{G}}\right) \left(\frac{4 \times 10^{7}\text{GeV}}{E}\right) \left(\frac{D}{1\,\text{Gpc}}\right)^{1/2} \left(\frac{l_c}{1\,\text{Mpc}}\right)^{1/2}$$

D is the distance to the source D and l_c is the average correlation length.

Still point-like

PeV-EeV ν & γ Astronomy!

Multi-messenger energy budget



NTA checks γ/CR/ν fluxes.
Unique E range coverage.

Mauna Loa: one of the best sites for imaging astroparticle

The largest subaerial volcano in both mass and volume, Mauna Loa has historically been considered **the largest volcano on Earth**. It is an active shield volcano with relatively gentle slopes, with a volume estimated at approximately 18,000 cubic miles (**75,000 km^3**). [en.wikipedia.org/wiki/Mauna_Loa]

→ **2×10^{14} ton ~ 200,000 km^3 Ice**

Ashra/NTA designed as ES-ν_τ Imager

Chronology:

2002: ES ν_τ AS method published

2002: ES-ν_τ Imager NTA proposed

2002: renamed into Ashra

2003: Ashra-1 funded

2004: 1st search for OpF on GRB

2008: 1st search for ES ν_τ on GRB

2013: NTA LoI

2014: VHEPA2014 @ Kashiwa

2016: VHEPA2016 @ Honolulu

N·H
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Astroparticle Physics 19 (2003) 37–46
Astroparticle Physics
www.elsevier.com/locate/astropart

Detecting very high energy neutrinos by the telescope array

Makoto Sasaki *, Yoichi Asaoka, Masashi Jobashi

4. Earth-skimming tau neutrinos

Very high energy neutrinos penetrate the Earth and convert to charged leptons which then travel through the Earth. This sequence is illustrated for an event with a nadir angle θ in Fig. 7. We define

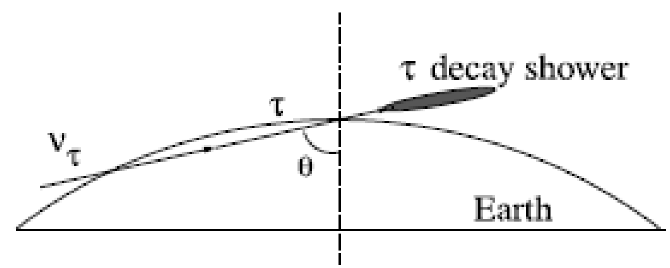
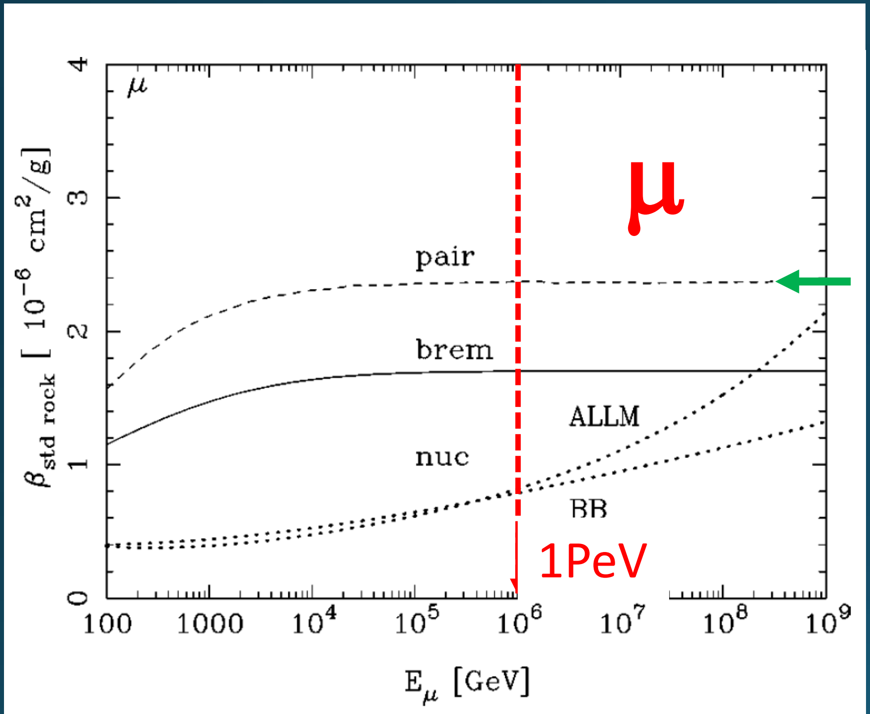
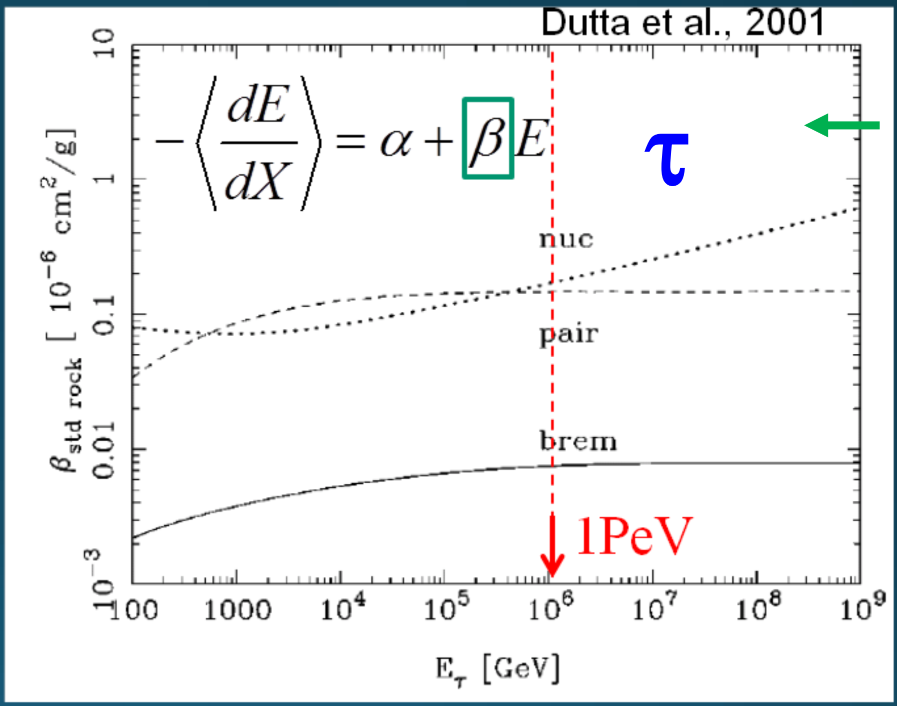


Fig. 7. A schematic picture of Earth-skimming tau neutrino events.

Tau / Mu Propagation in Rock



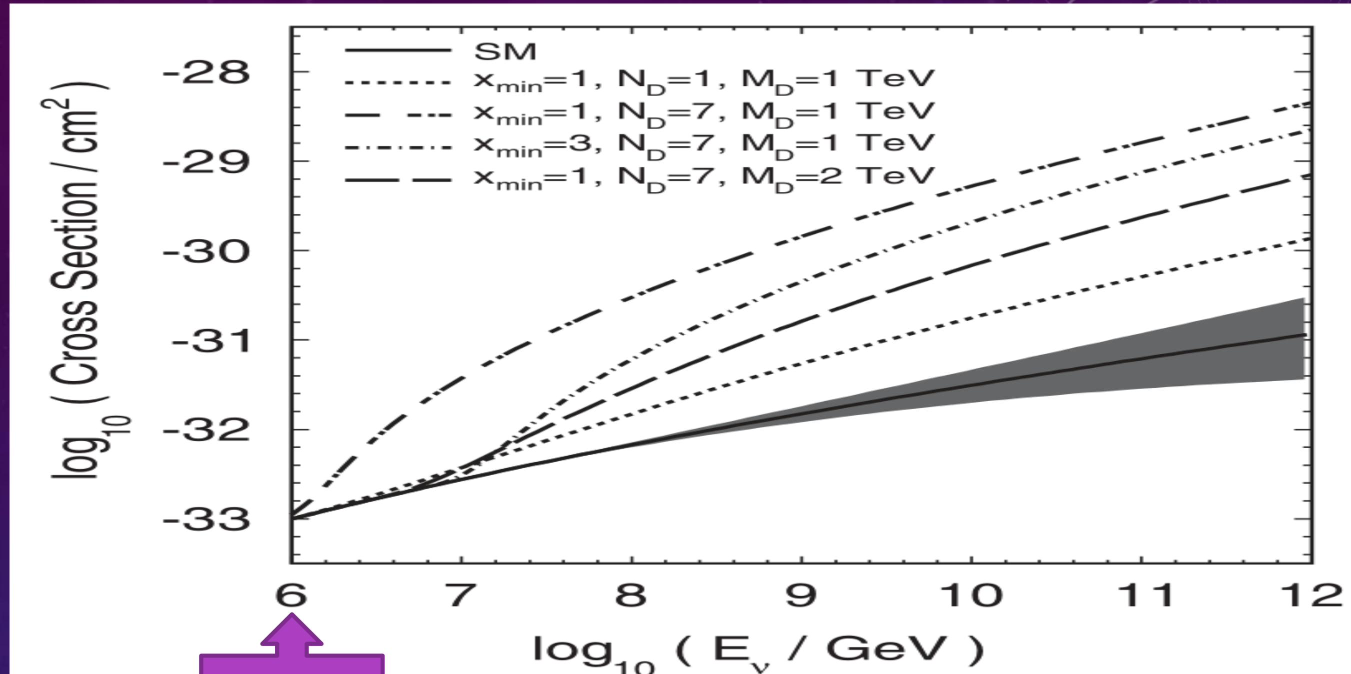


Radiation term is suppressed due to mass Mτ / Mμ~17.

Photonuclear effect dominates above 1PeV.

NTA

EXTRA DIMENSION SEARCH

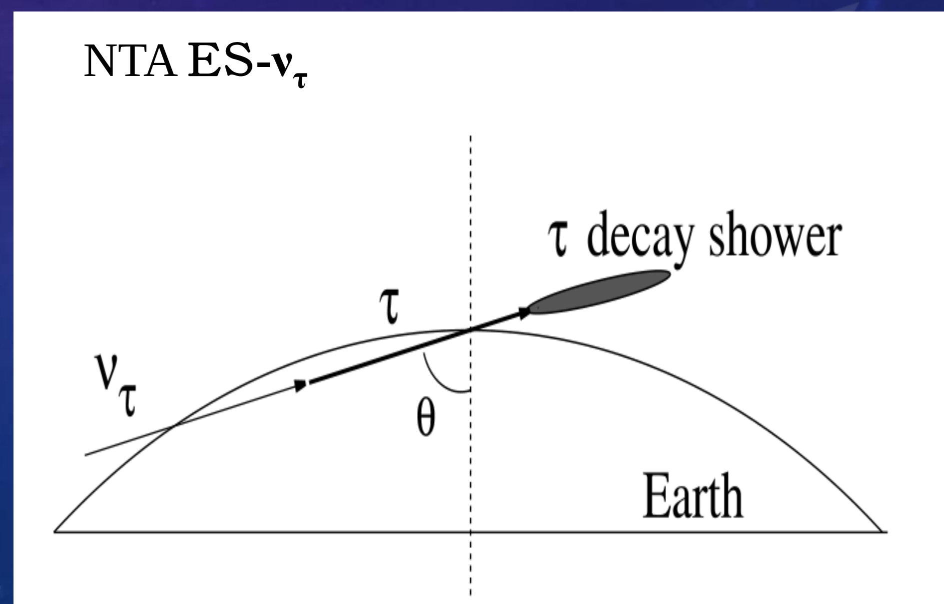


1 PeV

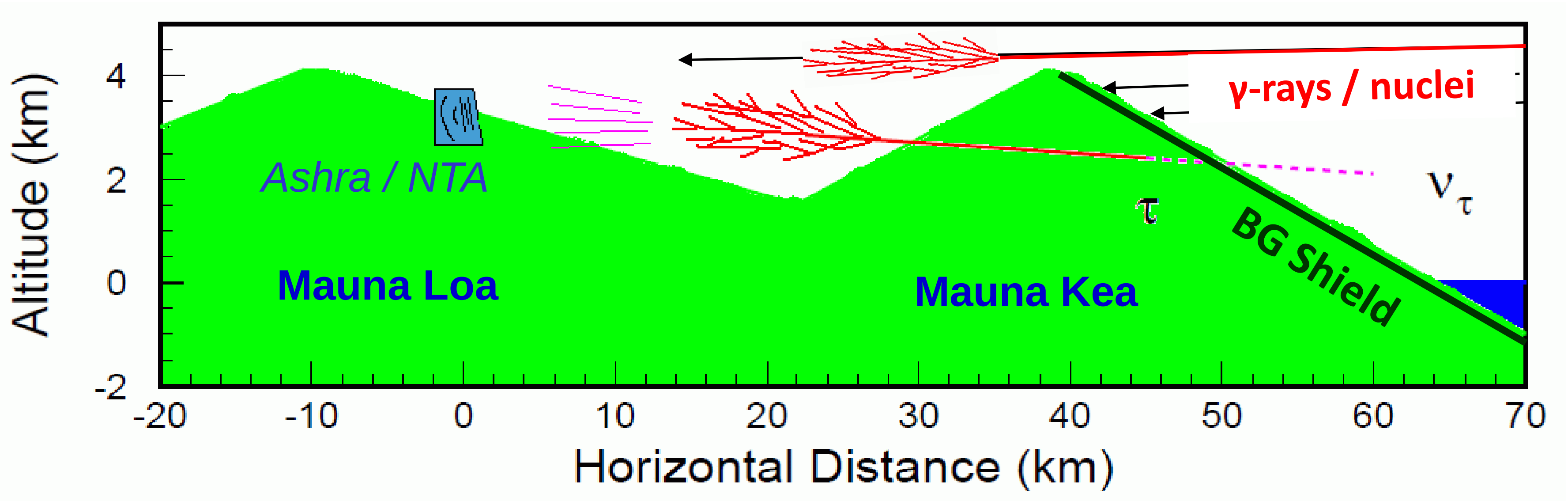
A.Connolly et al., PRD 83, 113009 (2011)

E_ν (PeV)	L_{CC}^{ν} ($10^7 g/cm^2$)	$-\theta_{elev}$ (deg)
1	270	32
10	94	16
100	35	5.9
1000	14	2.3

[M.Sasaki et al., Astropart. Phys. 19 (2003) 37]



Ashra/NTA: Quasi-Horizontal AS Detector



- huge ν target mass
- τ emerges since it is heavy
- separated volumes for ν target and light yield
- AS light transparent in air
- BG shielded
  -> phys. BG free environment

Primary ID with arrival direction

⇒① AS from Earth or Mtn.

⇒ ν_τ ($\pi^\pm$) sources

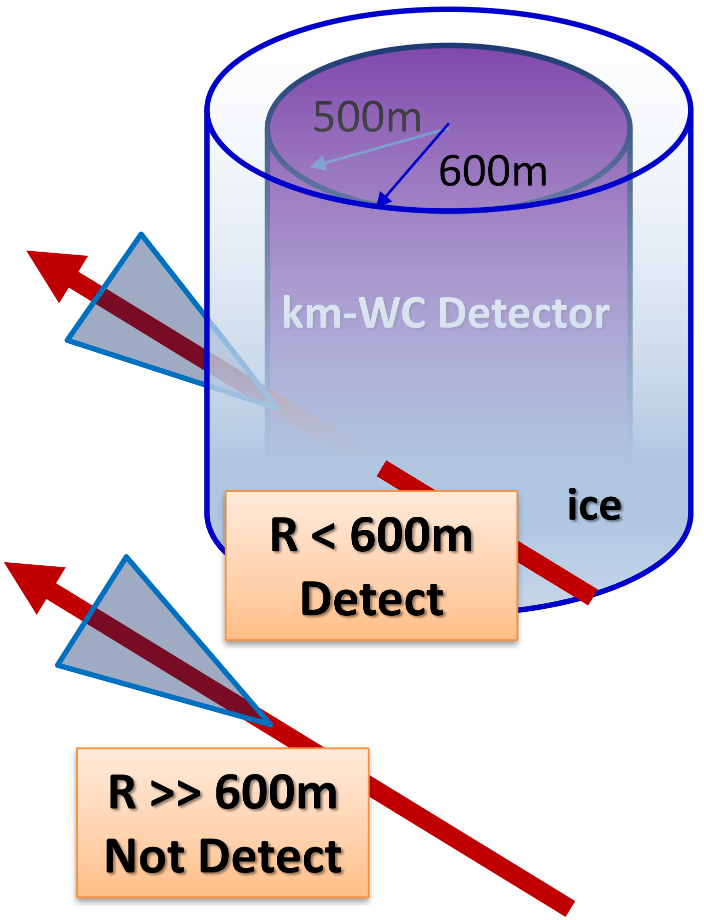
⇒② AS from Sky: γ-rays or CR

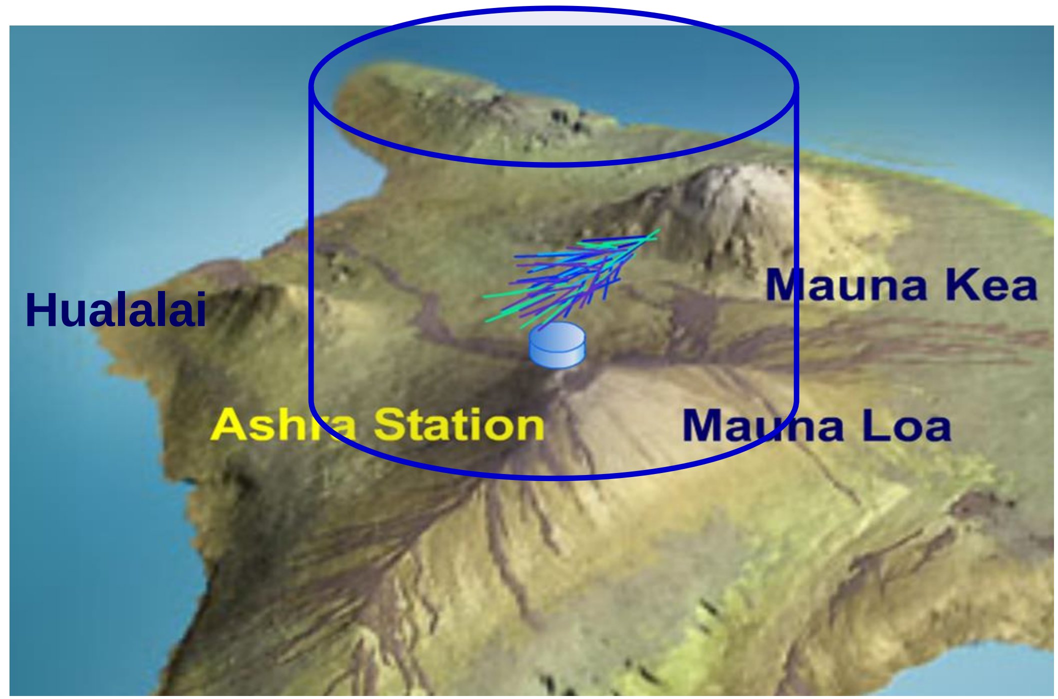
⇒ PS: association

⇒ diffuse: shower-shape

⇒ γ-ray (π^0) sources

Advantage of using air-shower light for VHE neutrino search

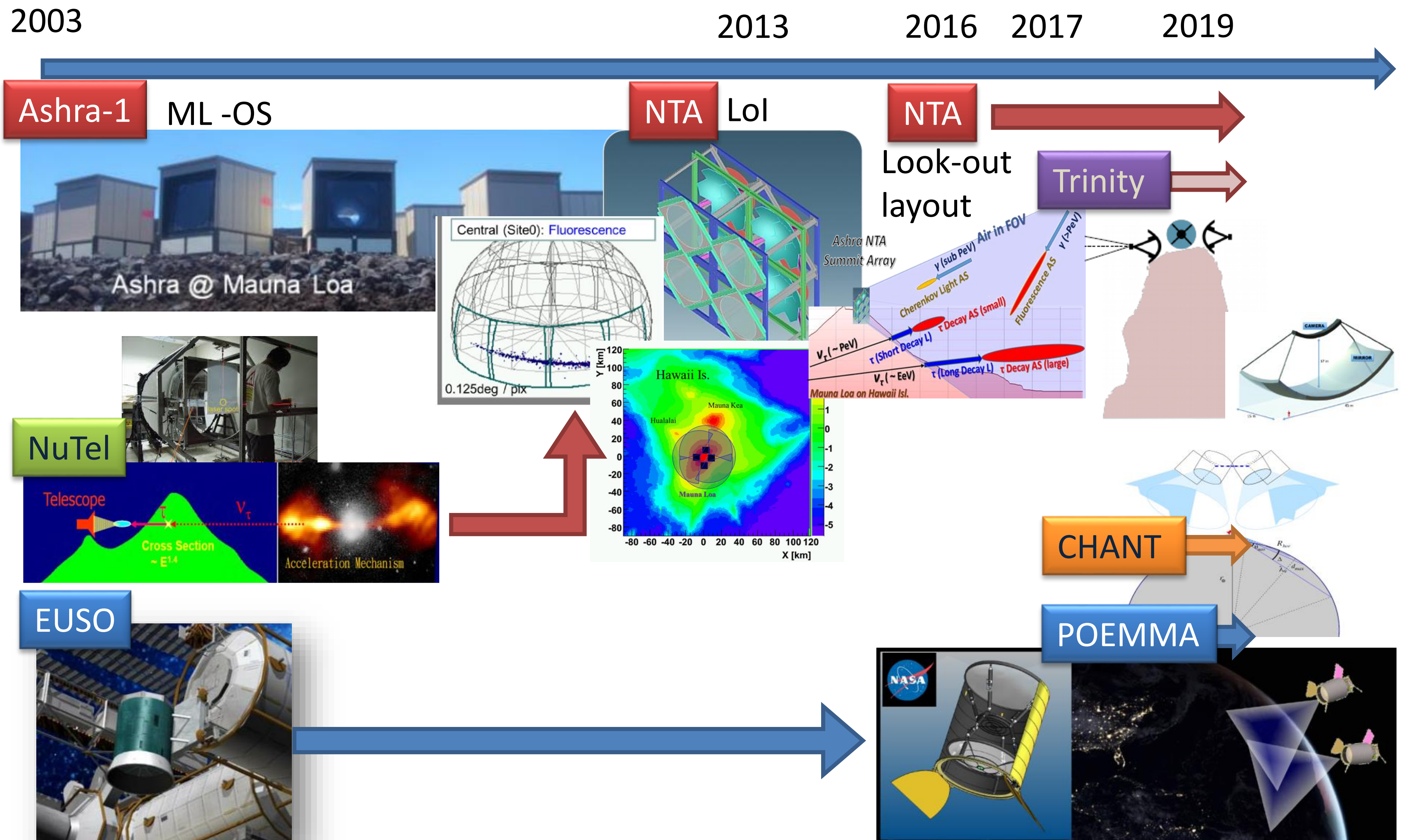




Attenuation: 100m in ice

Attenuation: 20km @ UV in air
>50km @ λ=500nm

ES-ν_τ imagers

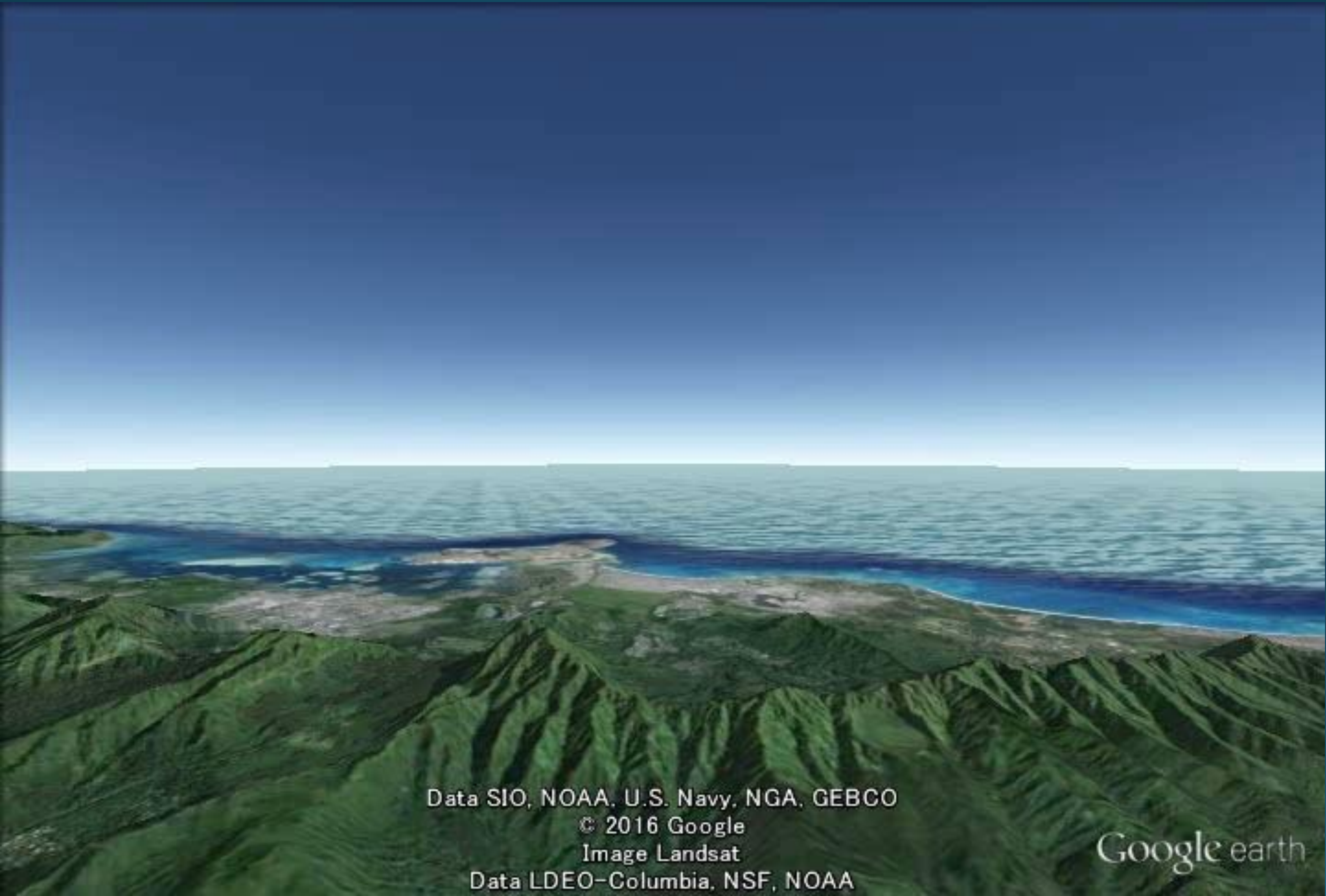


John Krizmanic, UHECR2018

Ashra-1 Mauna Loa Obs. Site (ML-OS)

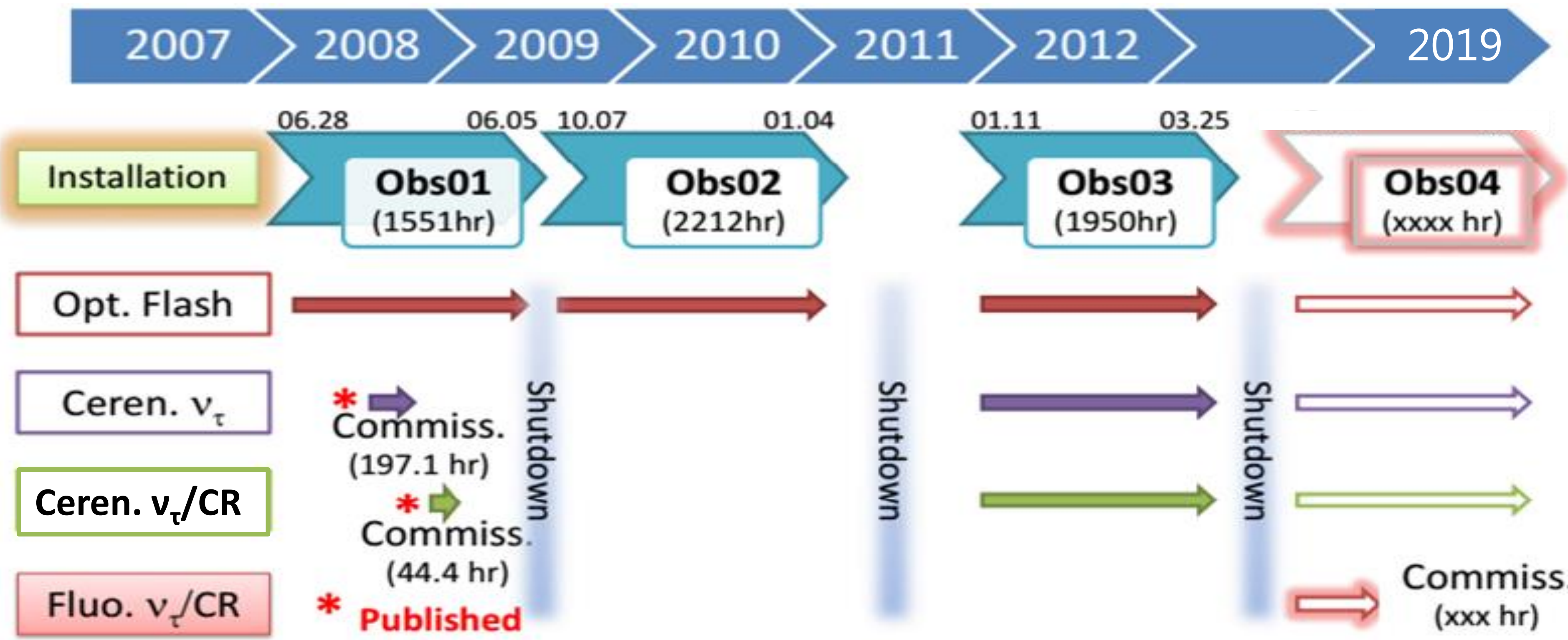
Ashra-1 Construction of ML-OS
(2005-2007)

Let's tour the Ashra-1 ML-OS!



Ashra-1 Observation Periods

2013以降、
観測資金の問題



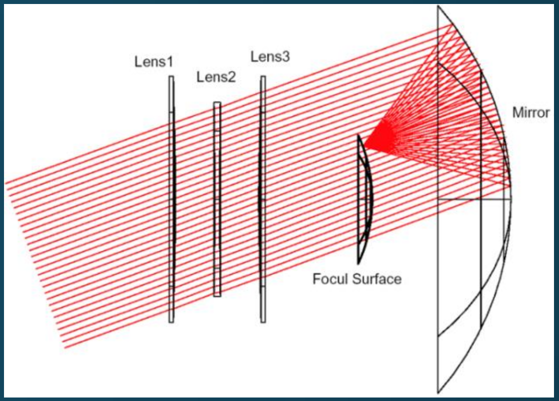
- Total Obs. Time: 5713hr
- Ave. Duty: 19 %

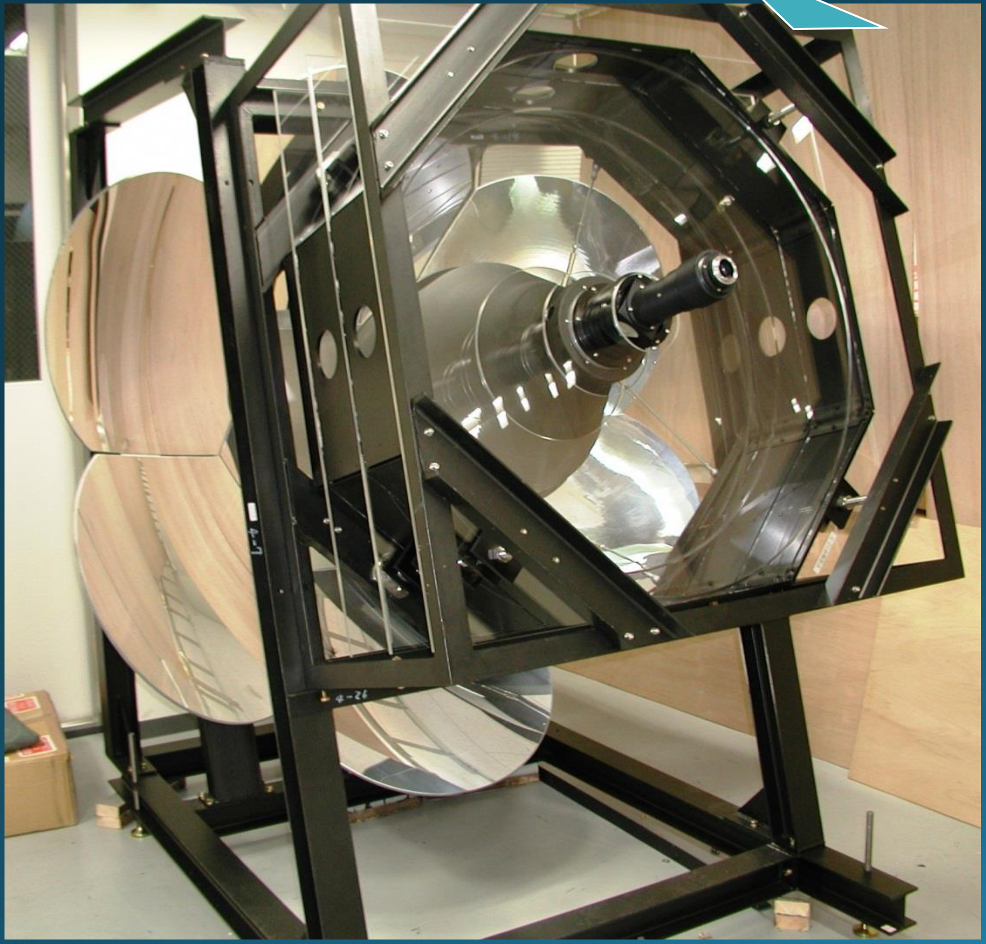
Satellite	GRB Name	$t_{inFOV} - t_0$ [sec]
Swift	GRB081203A	$-1.2\times10^4 - 5.6\times10^3$
Fermi	GRB090428	$-8.1\times10^3 - 5.9\times10^3$
Fermi	GRB090429C	$-4.1\times10^3 - 1.7\times10^3$
Swift	GRB091024	$-1.6\times10^3 - 3.3\times10^2$
Fermi	GRB100216A	$-4.0\times10^3 - 1.1\times10^4$
Swift	GRB100906A	$-1.0\times10^4 - 4.0\times10^3$
Fermi	GRB120120	$-1.4\times10^3 - 8.9\times10^3$
Fermi	GRB120129	$-1.6\times10^3 - 6.7\times10^3$
Fermi	GRB120327	$-9.9\times10^3 - 8.2\times10^1$
Swift	GRB120911	$-2.4\times10^4 - 6.8\times10^1$
Fermi	GRB121019	$-1.7\times10^3 - 7.3\times10^3$
Swift	GRB121212A	$-5.8\times10^3 - 2.6\times10^4$
Fermi	GRB130206	$-3.3\times10^3 - 7.5\times10^4$
Fermi	GRB130215	$-2.7\times10^3 - 4.3\times10^2$

- 5 Swift, 9 Fermi Triggers in FOV
- A lot of events pass FOV within 24 hrs

5-faceted
Rain & Fog Monitor

Ashra-1 Light Collector



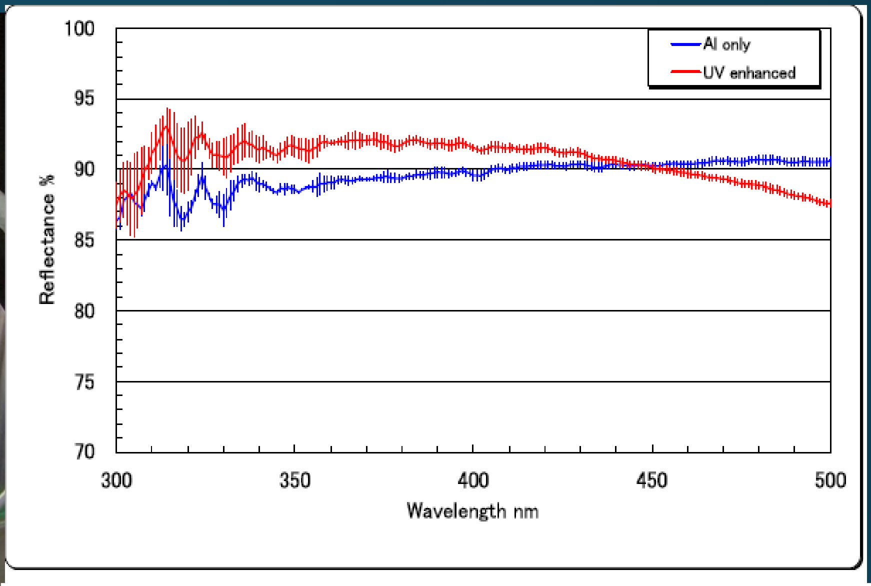


- Optics:
  - **Modified Baker-Nunn**
- Components:
  - **Correcting lens** (1.0~1.2mϕ) with 3 acrylic cut plates
  - **Spherical mirror** (2.2mϕ) with 7 curved glass plates on adjustable tables.
  - **Photoelectric lens IT** (0.5mϕ) on focal sphere suspended with Stewart platform mechanism
  - **Mount structure** with steel channels for easy assembly

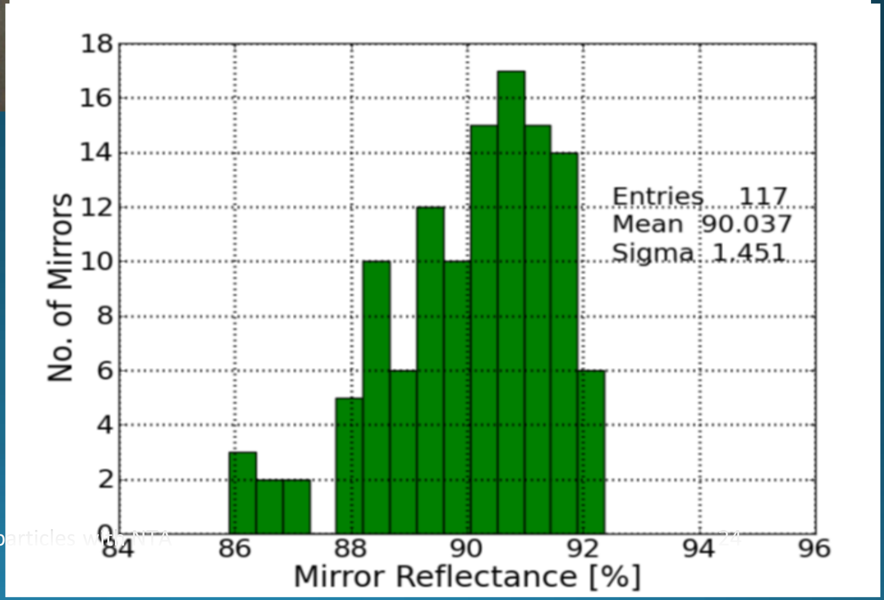
=> arcmin. resolution over 42deg FOV

=> Very cost-effective

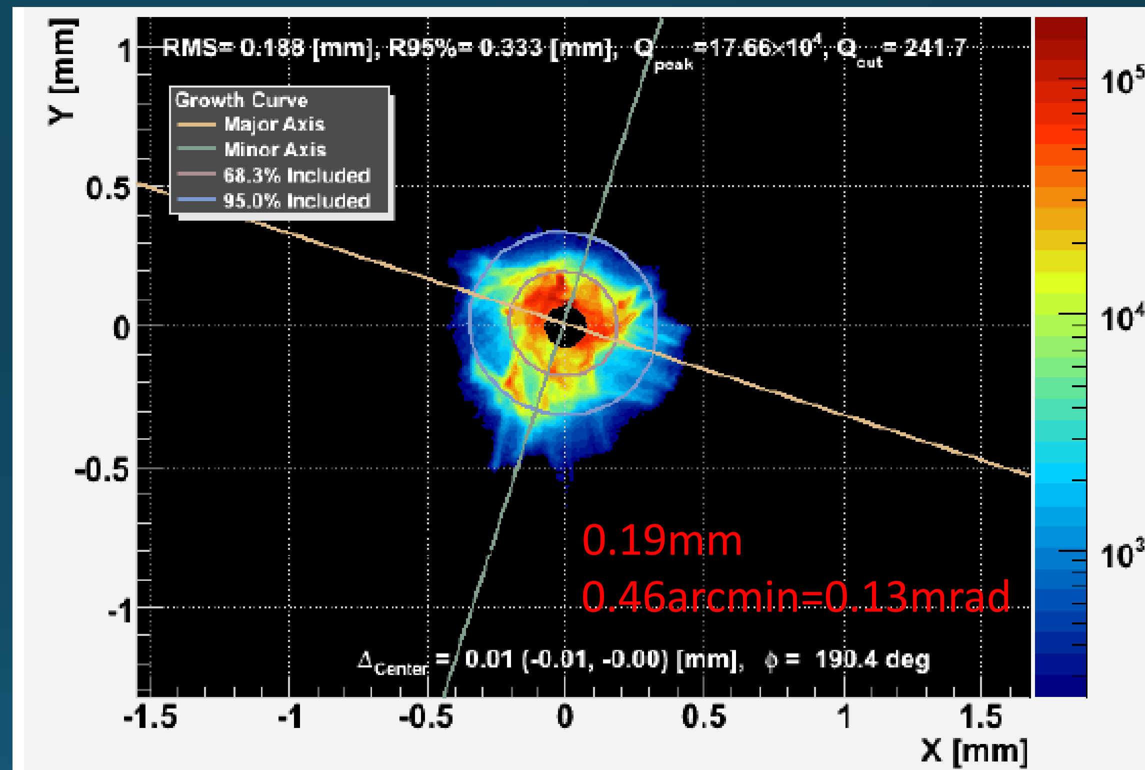
Segment Mirror



1. Float glass curved mirror:
   ϕ850 x t8 Cut => 10 kg / seg . piece
   Total 7seg / LC => ϕ2.2m & ~70kg.
2. Evaporation of Al + Al_2O_3 coating
   => UV enhanced
3. On-site test just before installation:
   all segments (~200 pieces) OK:
   >85% @ 470nm => >88% @ <400nm



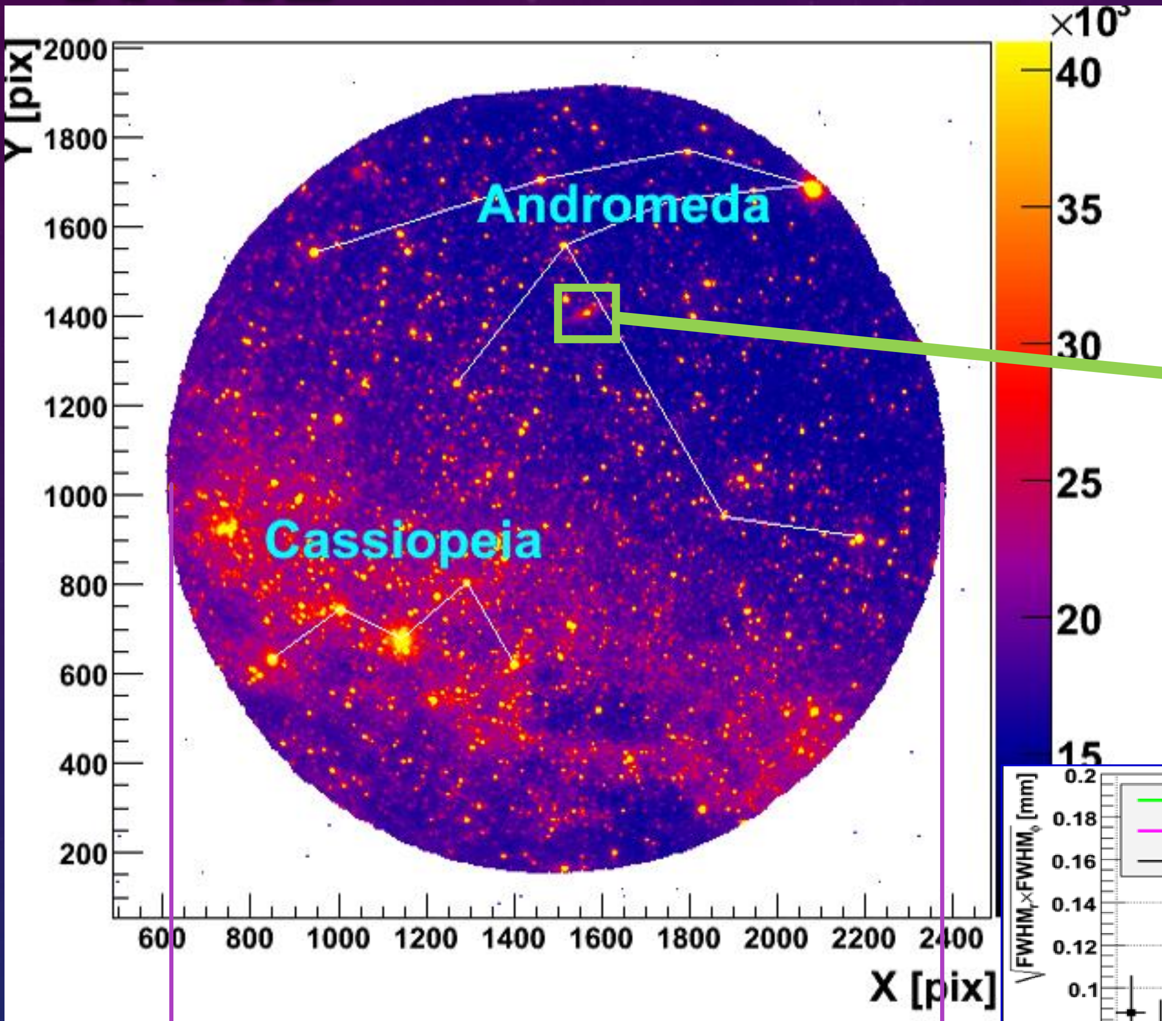
Mirror Adjustment



Installation of Segment Mirror on Mount @ Ashra Mauna Loa Site

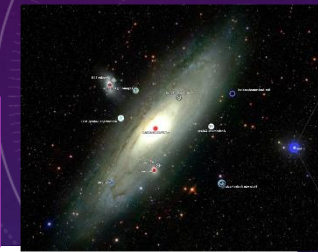
- Total spot size measured after adjusting 6 segment mirrors on mount:
  => Combined spot σ = 0.19mm
  => corresponding to 0.46arcmin = 0.13mrad

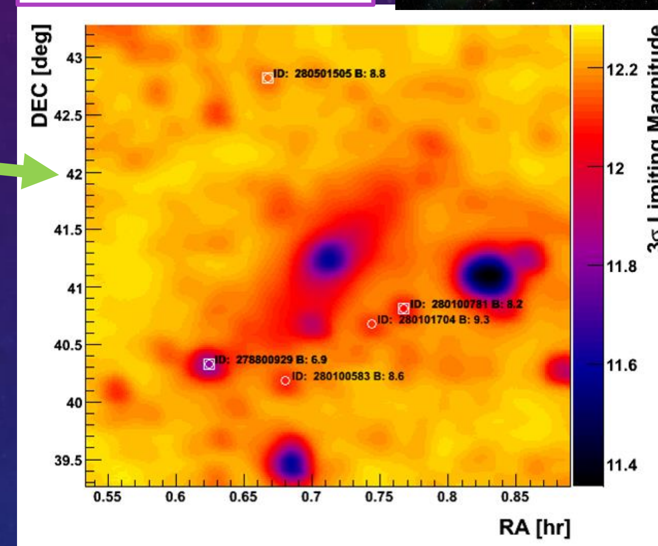
2-3 arcmin. Resol. Over 42deg FOV with Ashra-1 LC

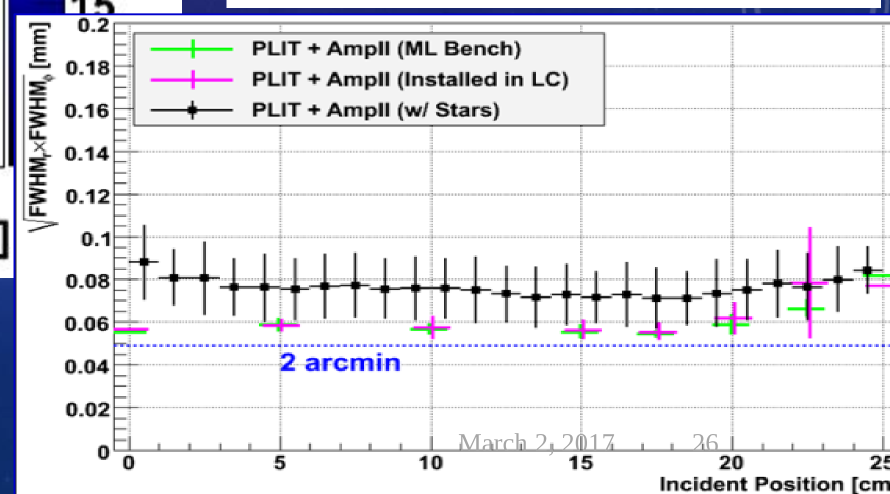


42deg.

12Mag./1s exposure







Ashra-1 Pipeline Trigger & Readout

demonstrated

Same Fine Image to Multiple Triggers

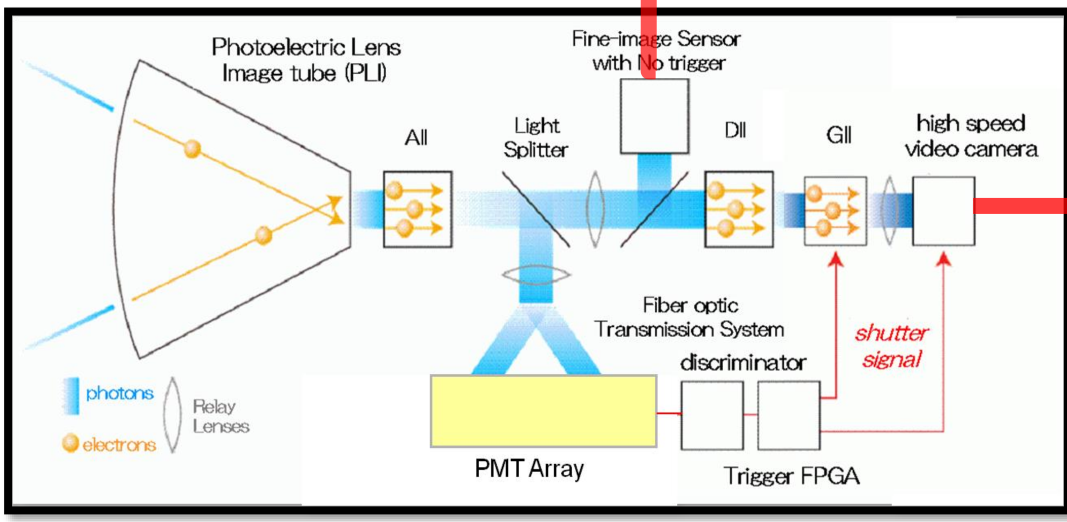
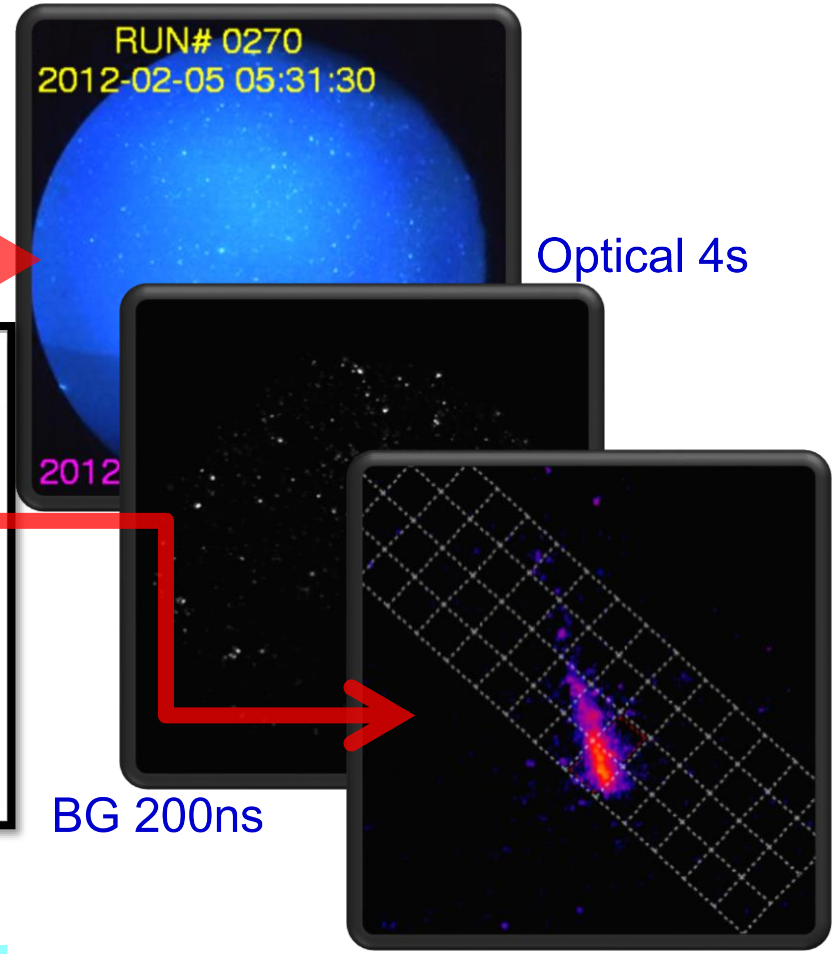


Photo-electric Image Pipeline (**PIP**)



Optical 4s

BG 200ns

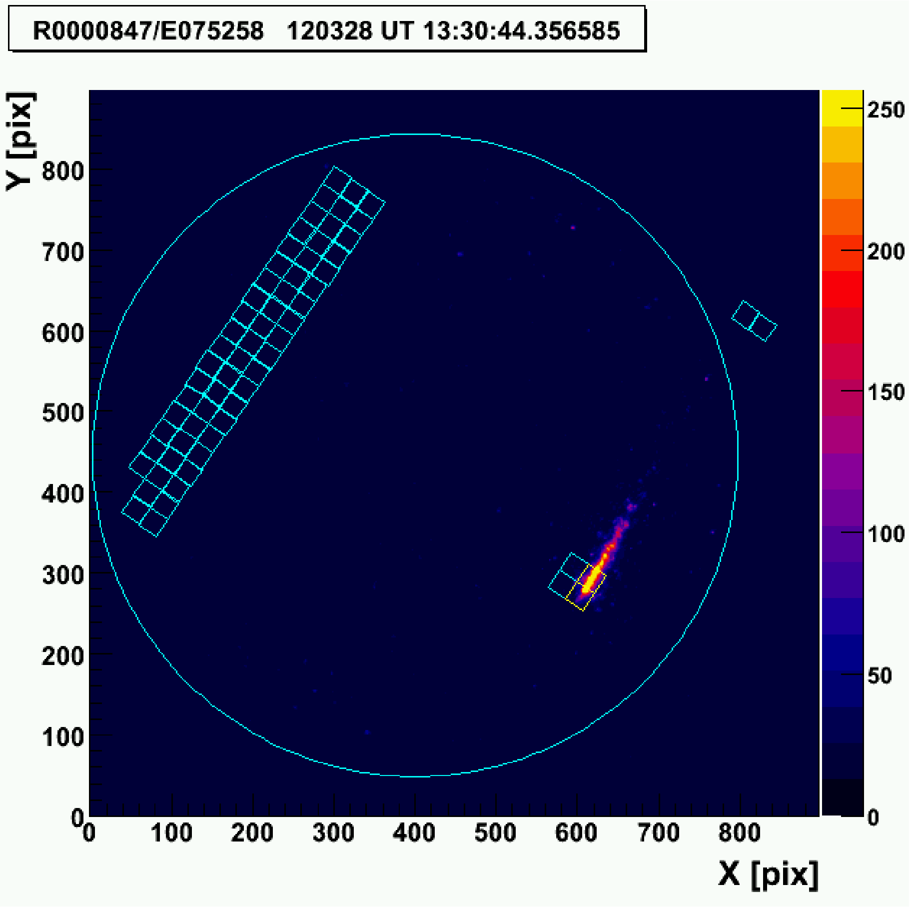
CR 200ns

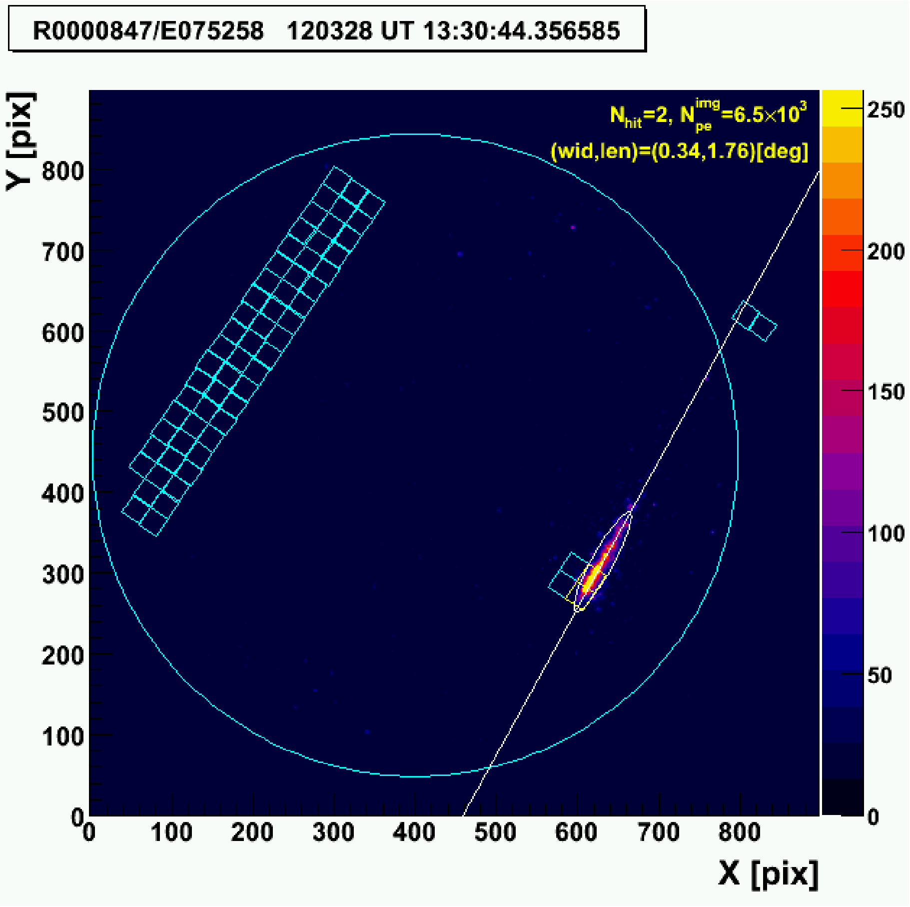
Multi-Messenger Approach with
One Detector System

High Pixelation w/ CMOS → Fine Resolution

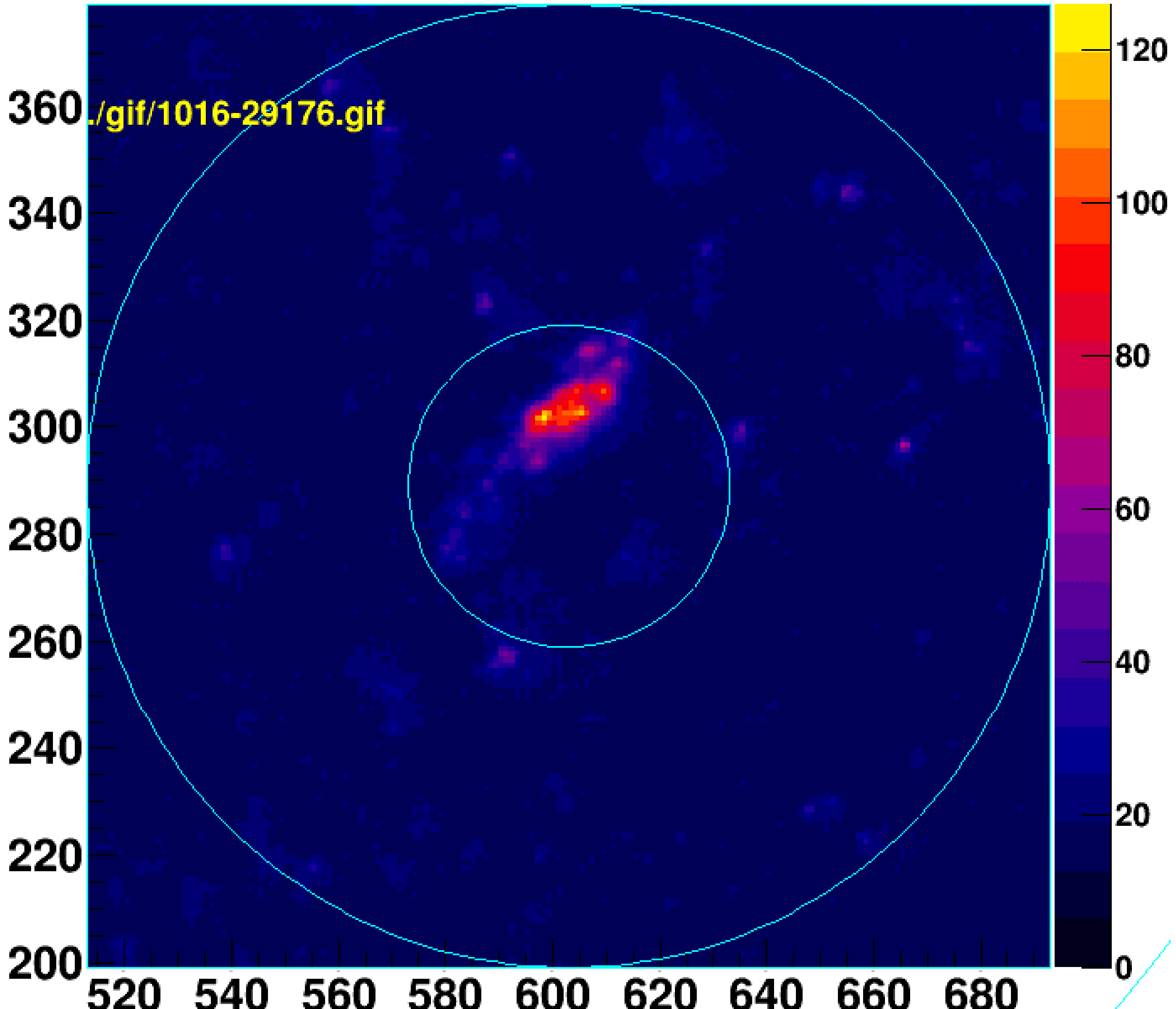
1st imaging air-shower with self-trigger

Real Shower Images



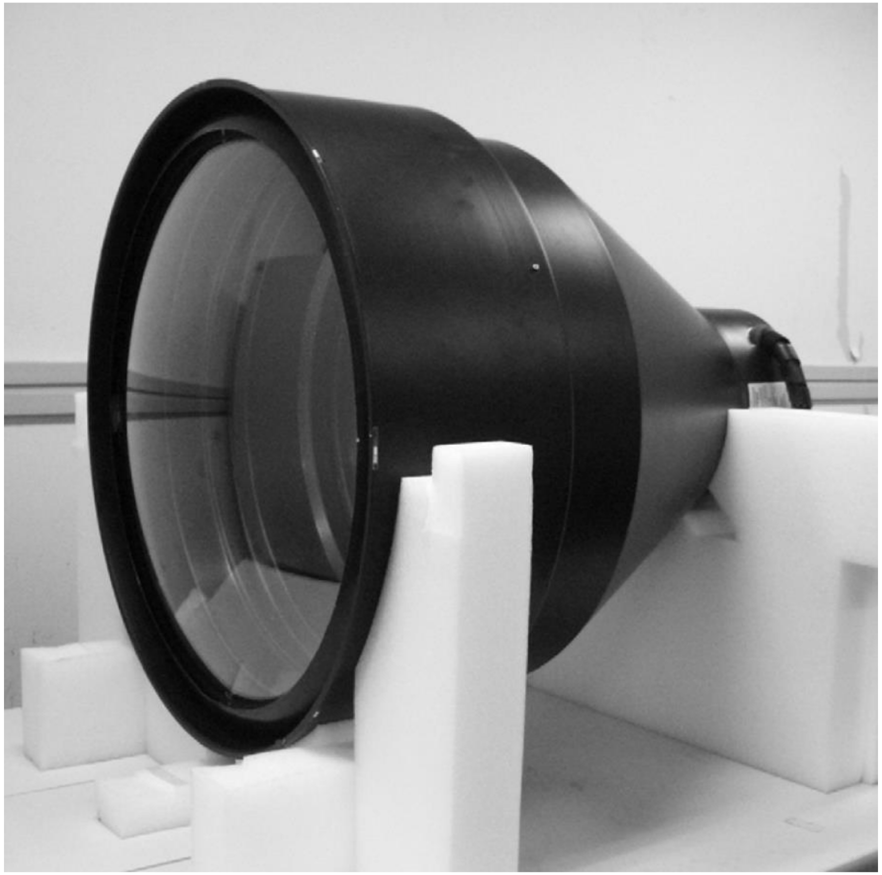


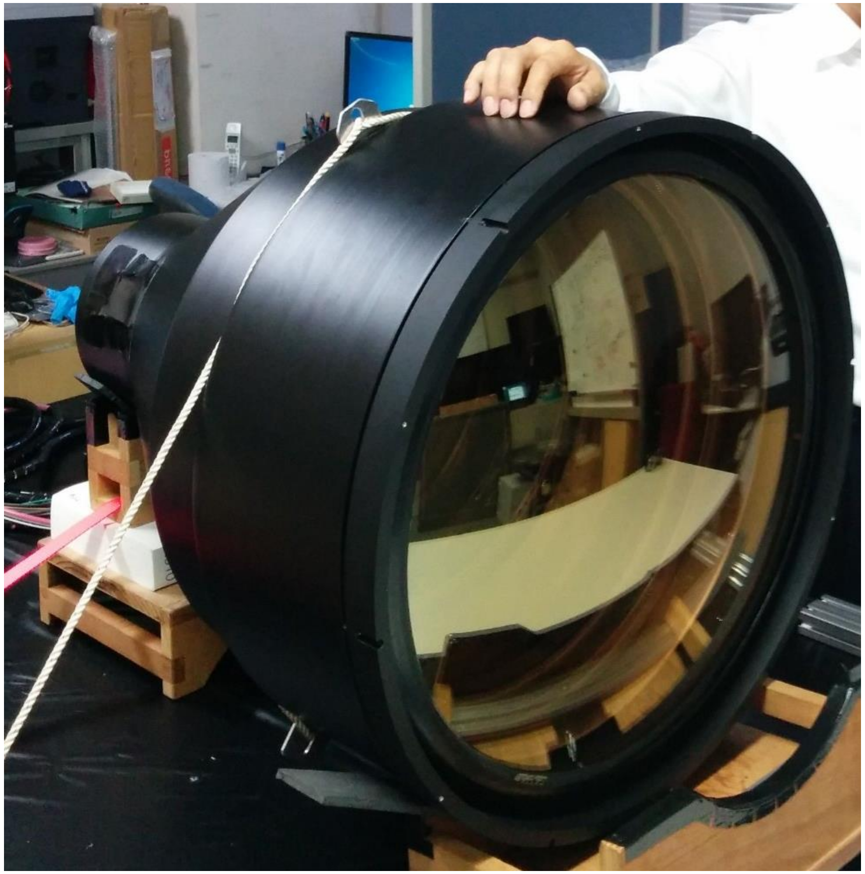
- All AS images -> Hillas image parameters, i.e. Width, Length, …
- Same threshold and cluster cuts are applied as ν_τ search.


./gif/1016-29176.gif
360
340
320
300
280
260
240
220
200
520
540
560
580
600
620
640
660
680
120
100
80
60
40
20
0

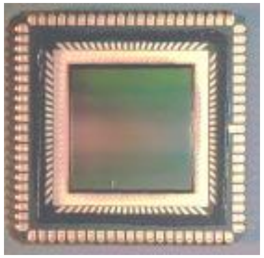
Photoelectric lens Imaging Tube

PLI-2011 vs PLI-2016





Ashra-1 fine sensor with trigger (FST) under test



Ashra
fine sensor

2048x2048pix
makes fine image

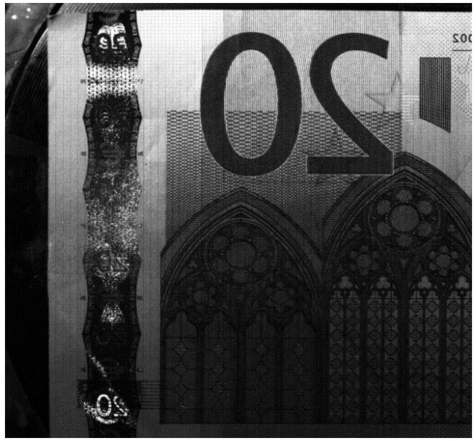
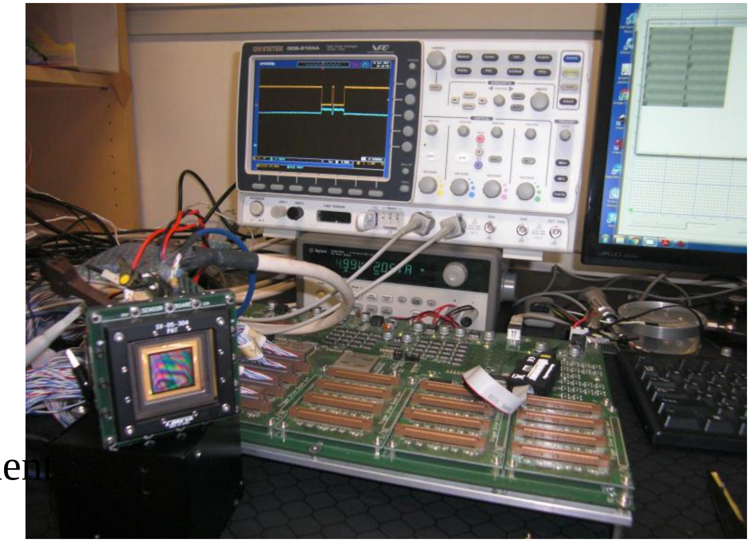
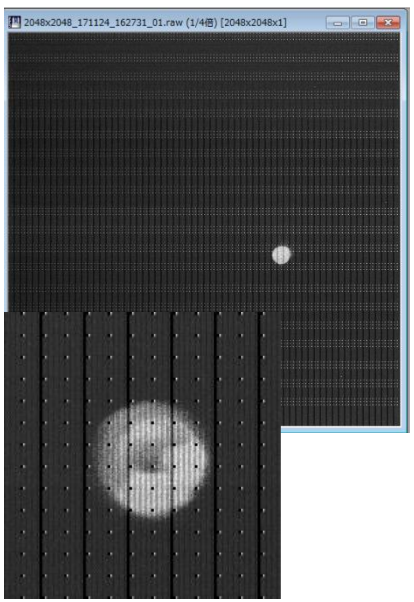
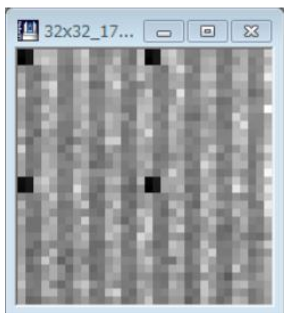


image taken with 64x64 independent
macro cell exposed and readout

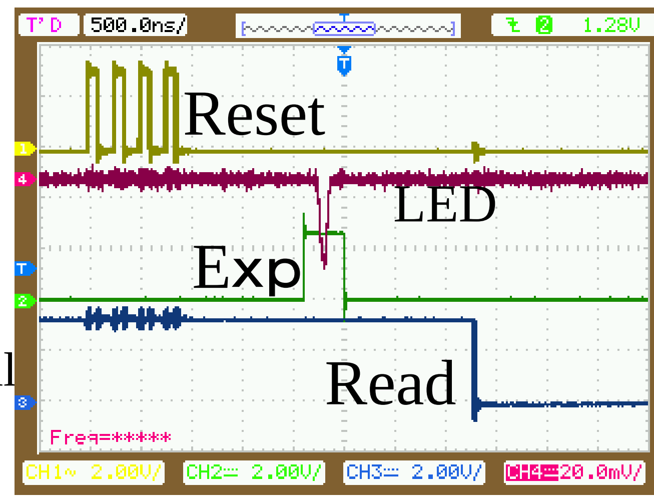




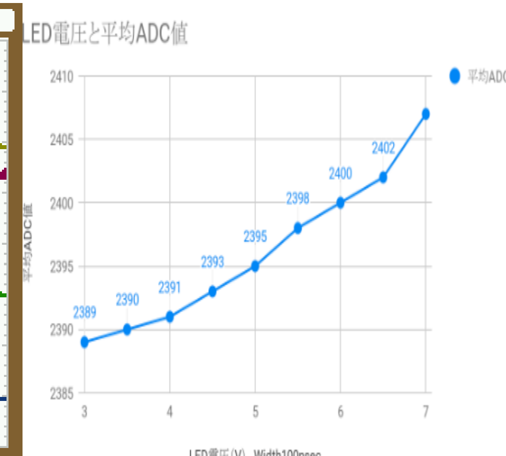
LED image with
FST



Unit macro cell
of 32x32pix



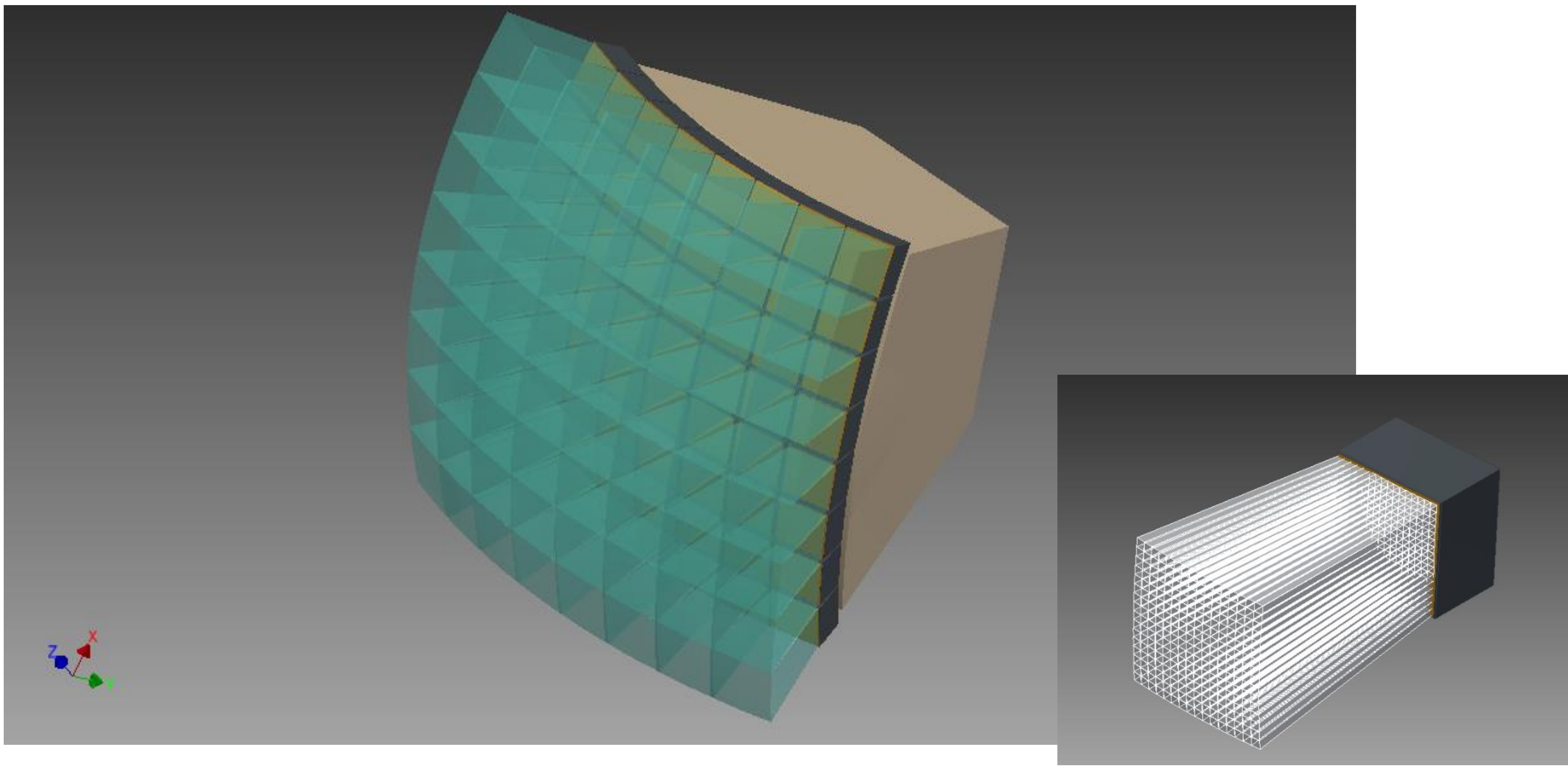
Waves of macro cell operation



LED luminosity-ADC

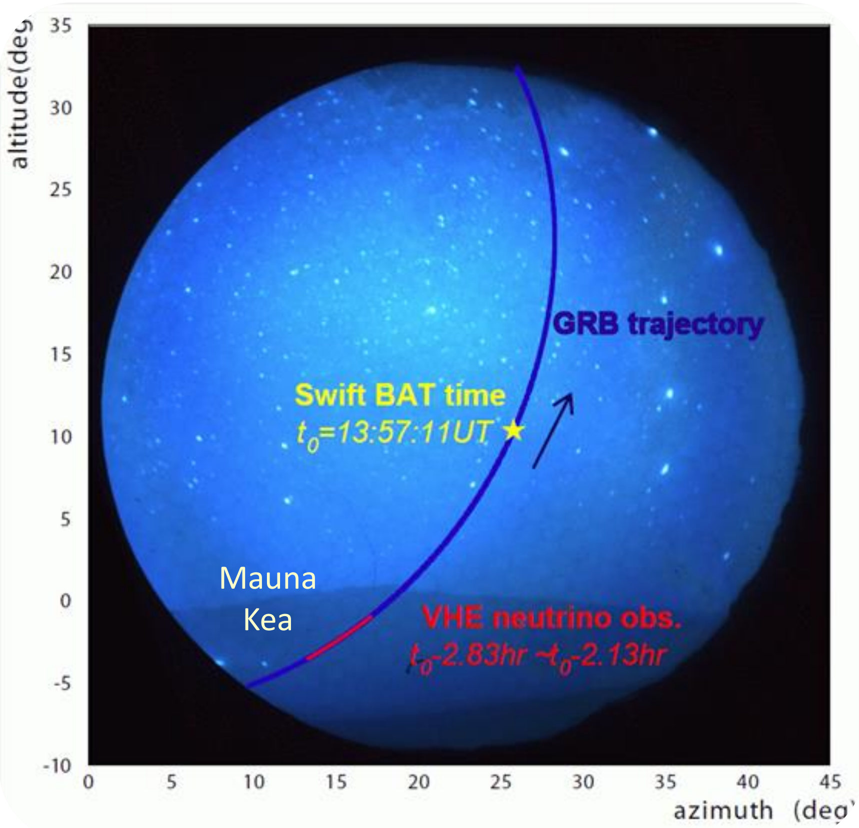
Ashra/NTA fine sensor work well
=> can image long duration far AS light.

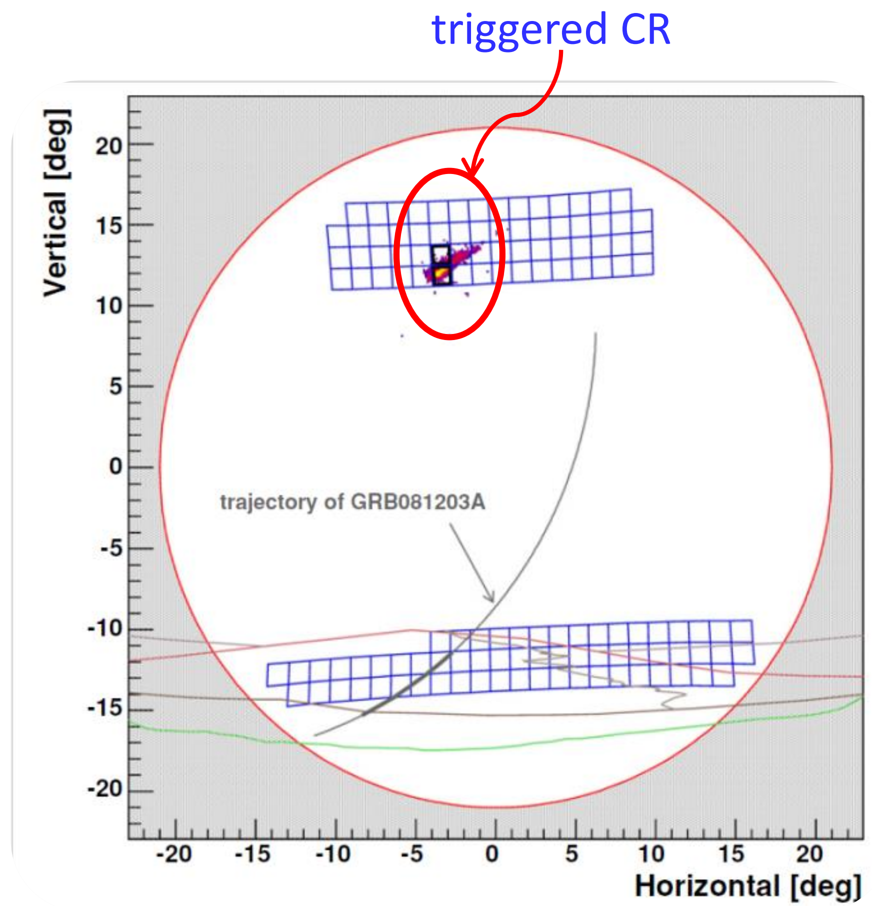
Focal plane camera backup-option
128×128pix SiPM array



III. Ashra-1 & 1st Search for GRB ν_τ

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 ν_τ

THE ASTROPHYSICAL JOURNAL LETTERS, 736:L12 (5pp), 2011 July 20 doi:10.1088/2041-8205/736/1/L12

OBSERVATIONAL SEARCH FOR PeV–EeV TAU NEUTRINO FROM GRB081203A

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[4] Department of Physics and Astronomy, University of Hawaii at Hilo, Hilo, HI 96720-4091, USA
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I'm not an author.

Received 2011 April 29; accepted 2011 June 10; published 2011 June 28

ABSTRACT

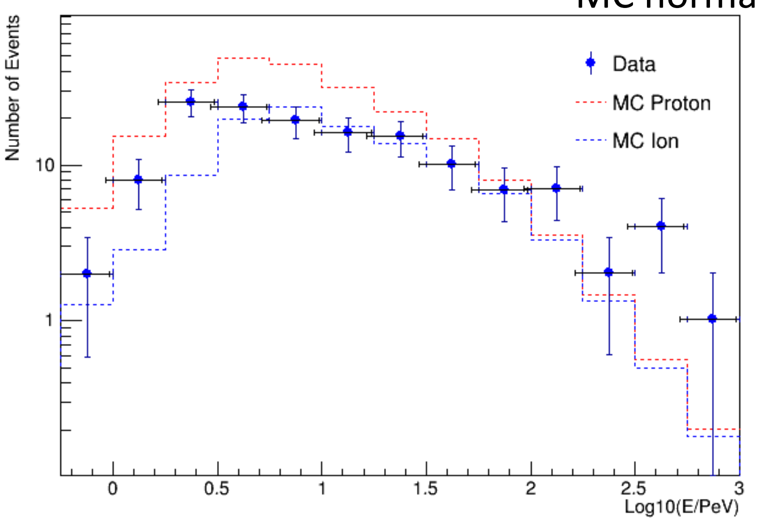
We report the first observational search for tau neutrinos (ν_τ) from gamma-ray bursts (GRBs) using one of the Ashra light collectors. The Earth-skimming ν_τ technique of imaging Cherenkov τ showers was applied as a detection method. We set stringent upper limits on the ν_τ fluence in PeV–EeV region 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 ν_τ complements other experiments in energy range and methodology, and suggests the prologue of "multi-particle astronomy" with a precise determination of time and location.

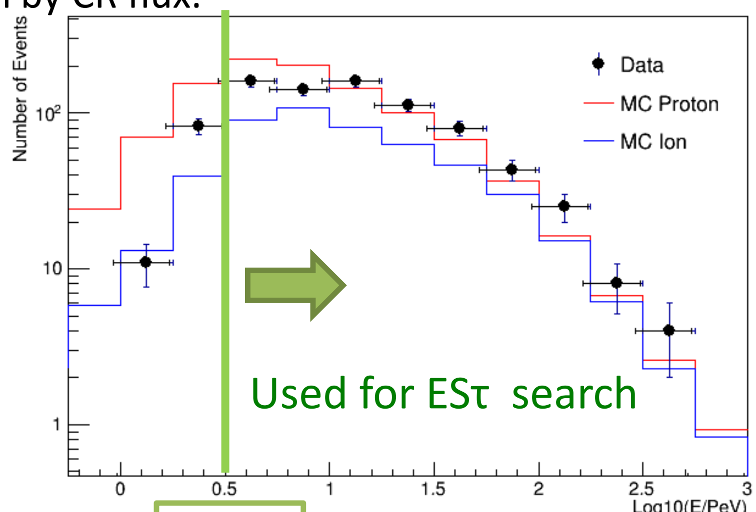
Checks with CR E_{obs} Spectrum

Obs01 events

Obs03 events

MC normalization by CR flux.





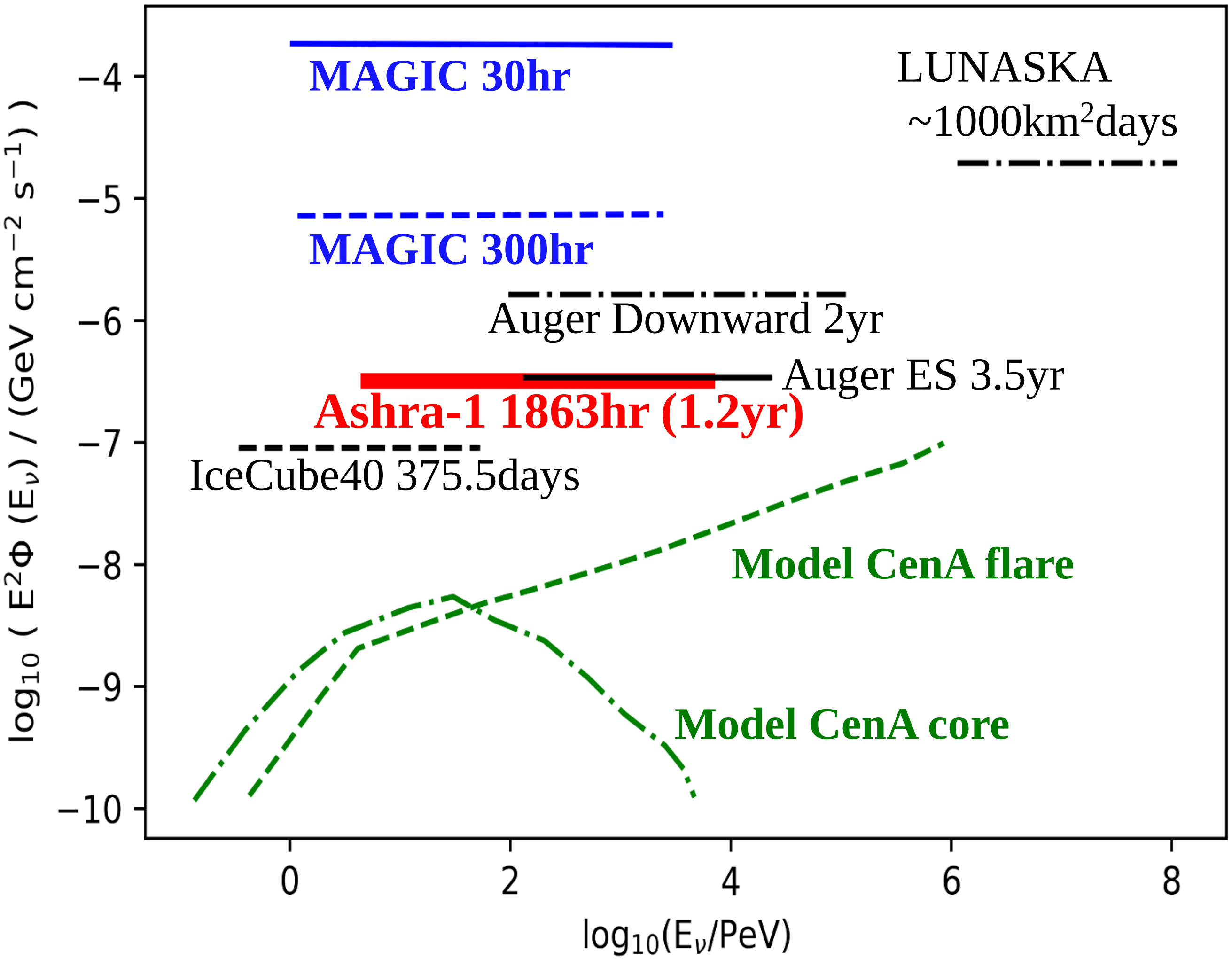
3PeV

Source of Systematics	Error [%]
Trigger Threshold	19
Atomsphere & Optics	21
DAQ Efficinecy	6.3
Weather Condition	6.4
Sensitivity Total	30
Fine Image Gain	30

→ Will be negligible by using a LED flasher calibrator.

Comparison of PS Tau Neutrino Flux Limits

Ashra-1 Obs03　最高のESτ即時感度達成



Auger (2012).
GI-Astro-Ph.HE, 1–21.

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

LUNASKA (2011).
MNRAS 410(2), 885–889.

IceCube (2011).
ApJ 732(1).

Cuoco (2008).
PRD 78(2), 1–5.

Kachelrieß (2009).
New Journal of Physics, 11.

NTA Summit Array Baseline Design

4 Stations (■) at 3000-3500m asl. on Mauna Loa

9 detector units / 1 station

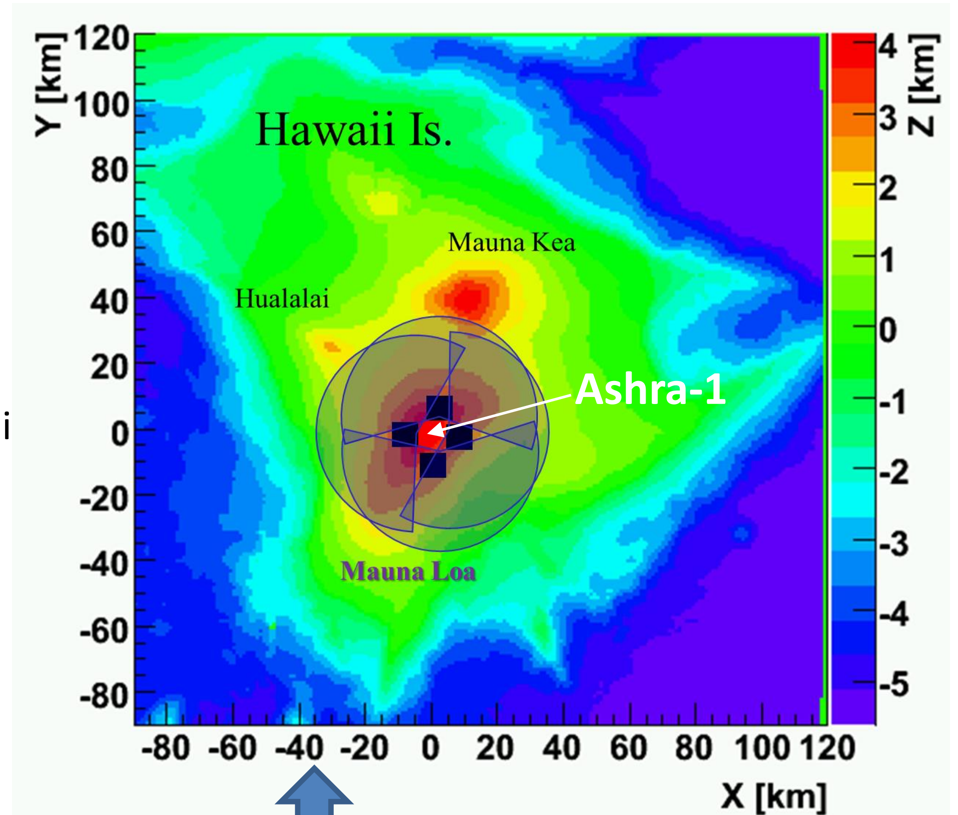
Zenith angle = 30° (65° -95°),

Azimuth angle = 240° with 9 detector uni

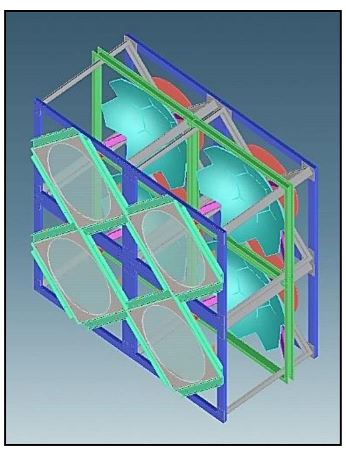
→ Stereo obs. at almost all azimuth angles

Northern most station = Ashra-1 Mauna Loa Site

Topographic map implemented in NTA simulation



NTA DU



NTA Detector Unit = Multi-Tel. with 4 LCs

Ashra-1 x 1.5 scaled-up

+ same trigger & readout

Light Collector (LC)

Optics with **ϕ1.5m** pupil

FOV 30° = focal sphere ϕ50cm

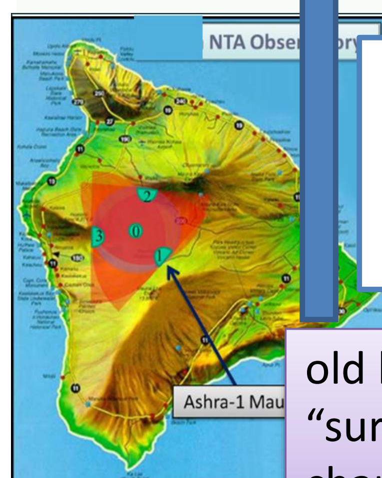
Detector Unit (DU)

4 LCs watch same FOV

Coadded 4 images

⇒ **Effective pupil = ϕ3m**

⇒ **Easy to reject CR-μ**



Enhance sensitivity ~PeV

More air-mass can be used

Better multi-static ratio

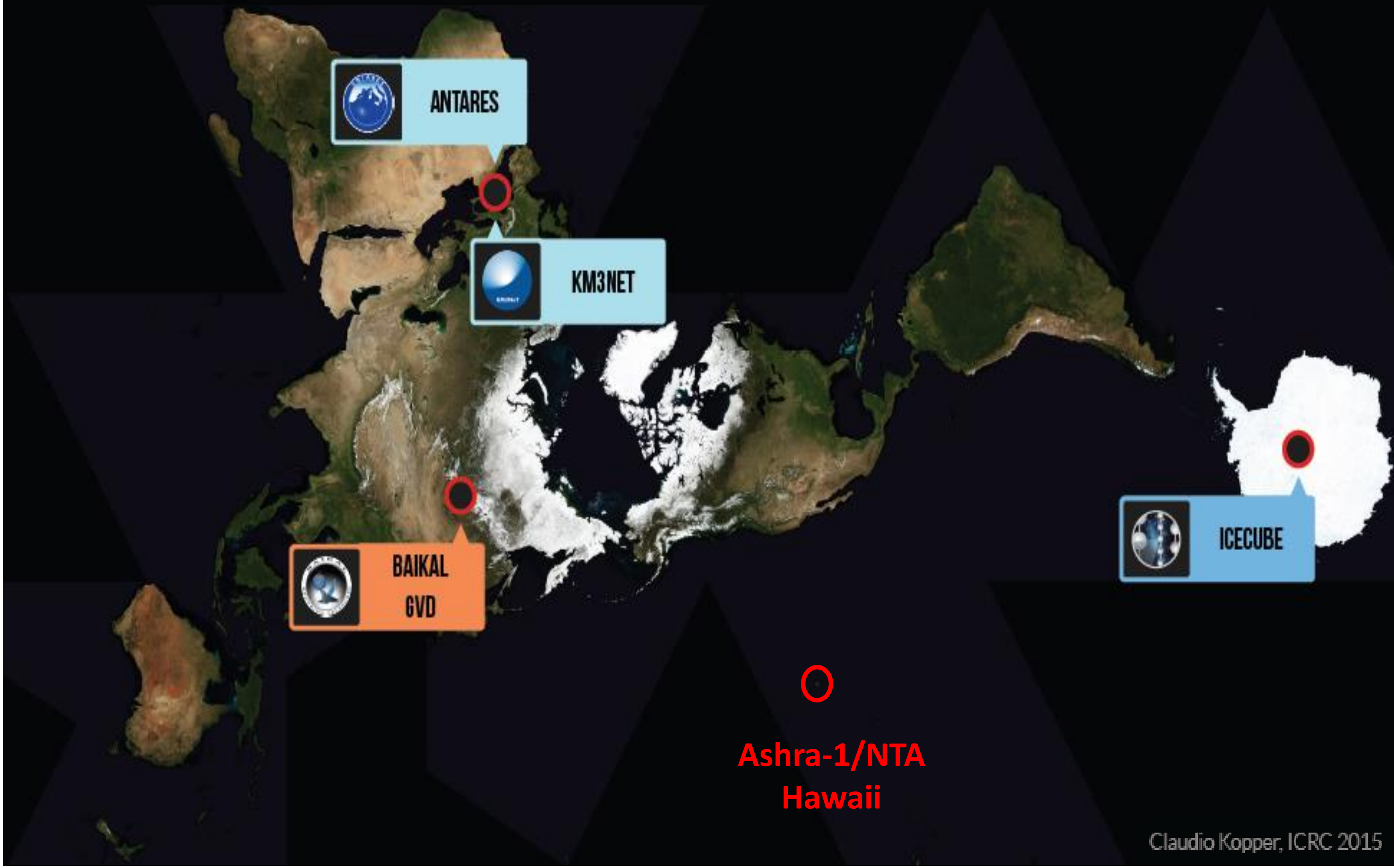
Better environ. Condition

old layout design "surrounded-by-mtn's" changed in 2016.

NEUTRINO TELESCOPE SITES

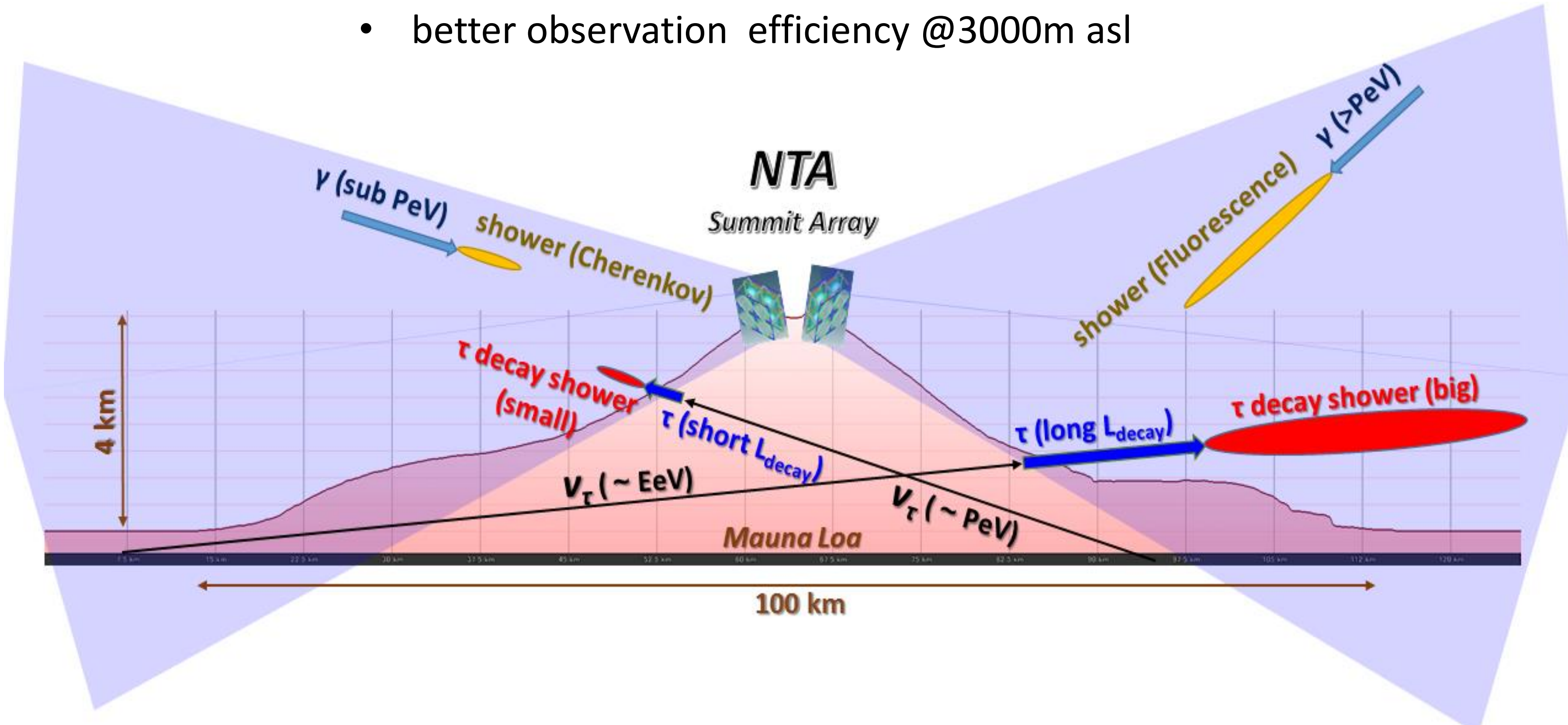
deep natural sites with water/ice (deep sea, lakes, glaciers)

Mountain & Air

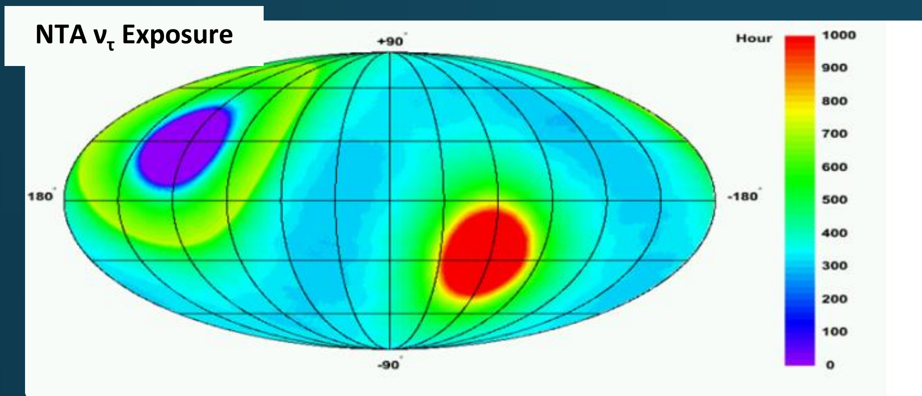


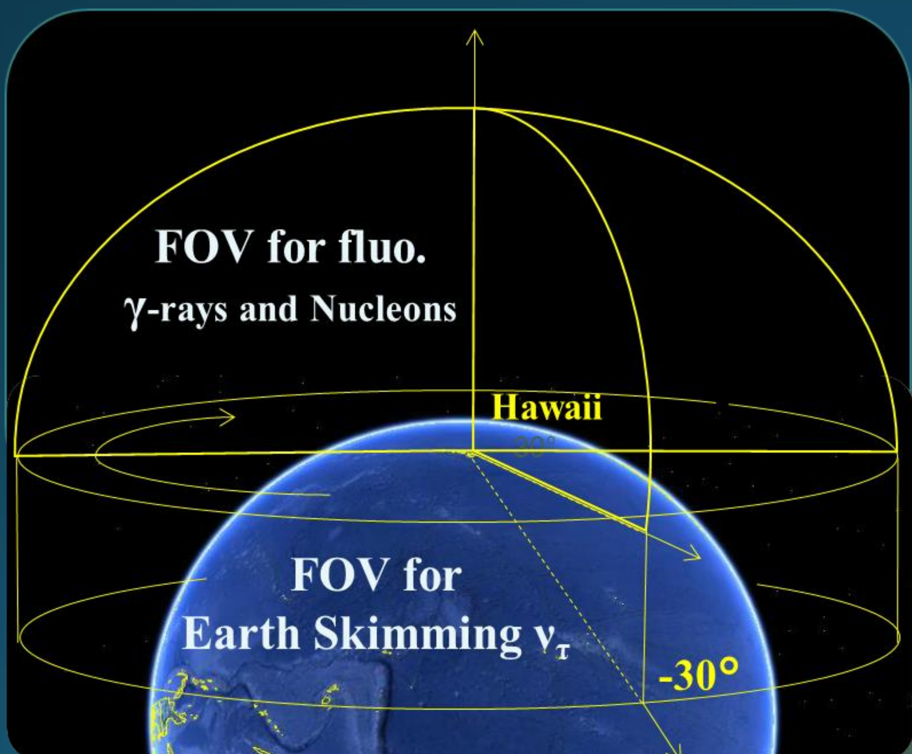
NTA summit array detection of ν / γ-ray / CR

- τ decay length： $L_\tau \sim 50\text{m} (E_\tau/\text{PeV})$
  ⇒ can watch nearler 1～10PeV AS max
- lower detection E thereshold
- better observation efficiency @3000m asl



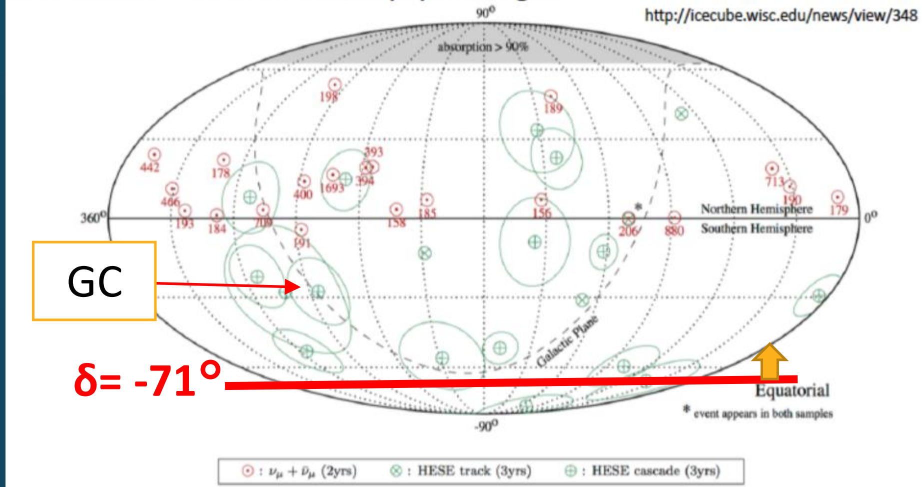
FOV and Exposure





Only highest energy events are shown.

Most of these events are of astrophysical origin.



Cascade resolution 10-15° - mainly Southern hemisphere

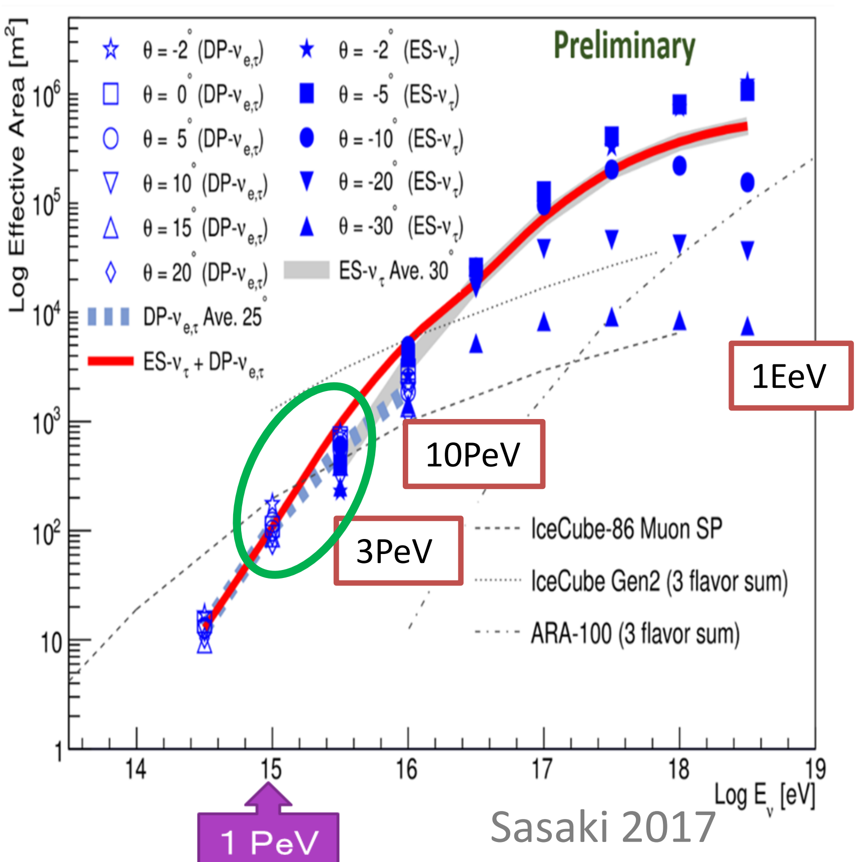
Muon resolution 0.5° - only Northern hemisphere

https://icecube.wisc.edu/science/highlights

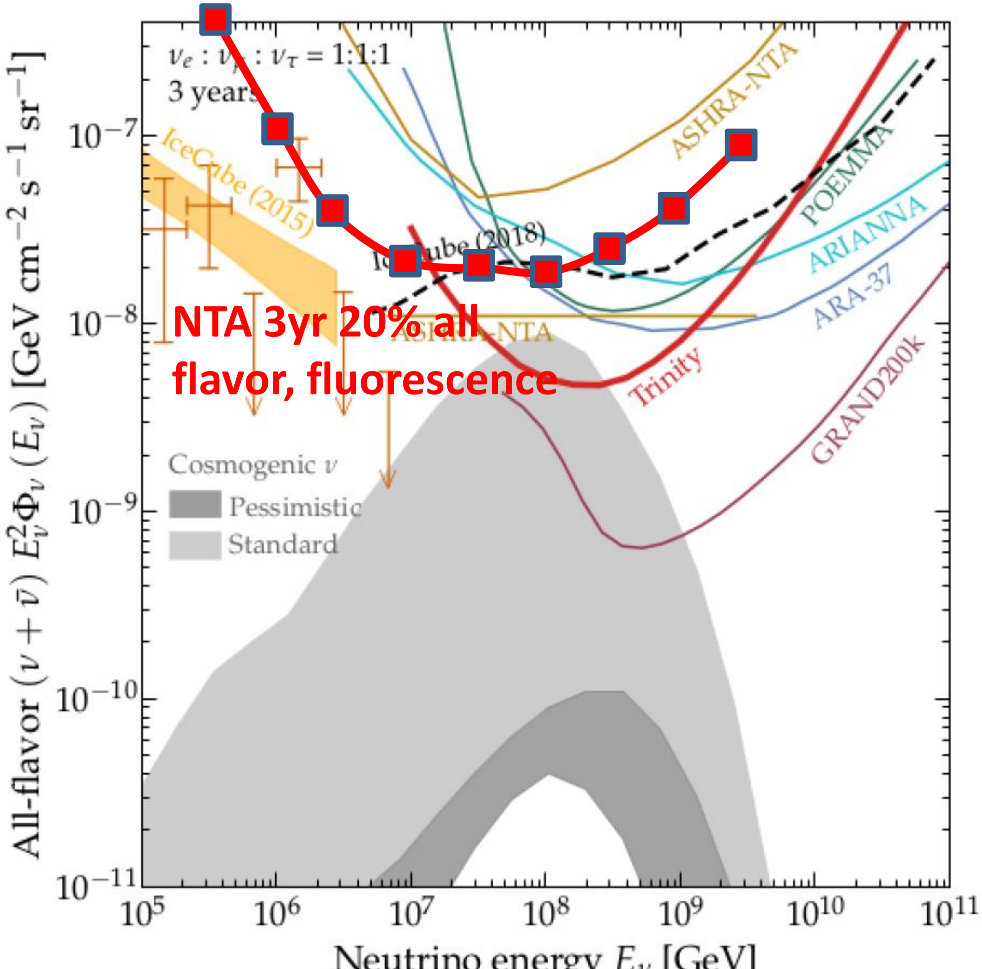
Detector	Latitude	Zenith	Dec. min, max
KASCADE	49.0°N	< 35°	14°, 84°
EAS-TOP	42.5°N	< 35°	7°, 78°
GAMMA	40.5°N	< 30°	10°, 71°
UMC	40.2°N	< 40°	0°, 80°
CASA-MIA	40.2°N	< 60°	-20°, 90°
Tibet	30.1°N	< 50°	-20°, 80°
NTAγ	19.5°N	< 95°	-71°, 90°
HAWC	19.0°N	< 45°	-26°, 64°
GRAPES-3	11.4°N	< 25°	-14°, 36°
IceTop	90.0°S	< 30°	-90°, -60°

NTA diffuse ν sensitivity: only with fluorescence light

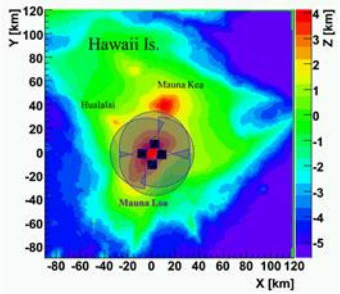
ν Effe. Area

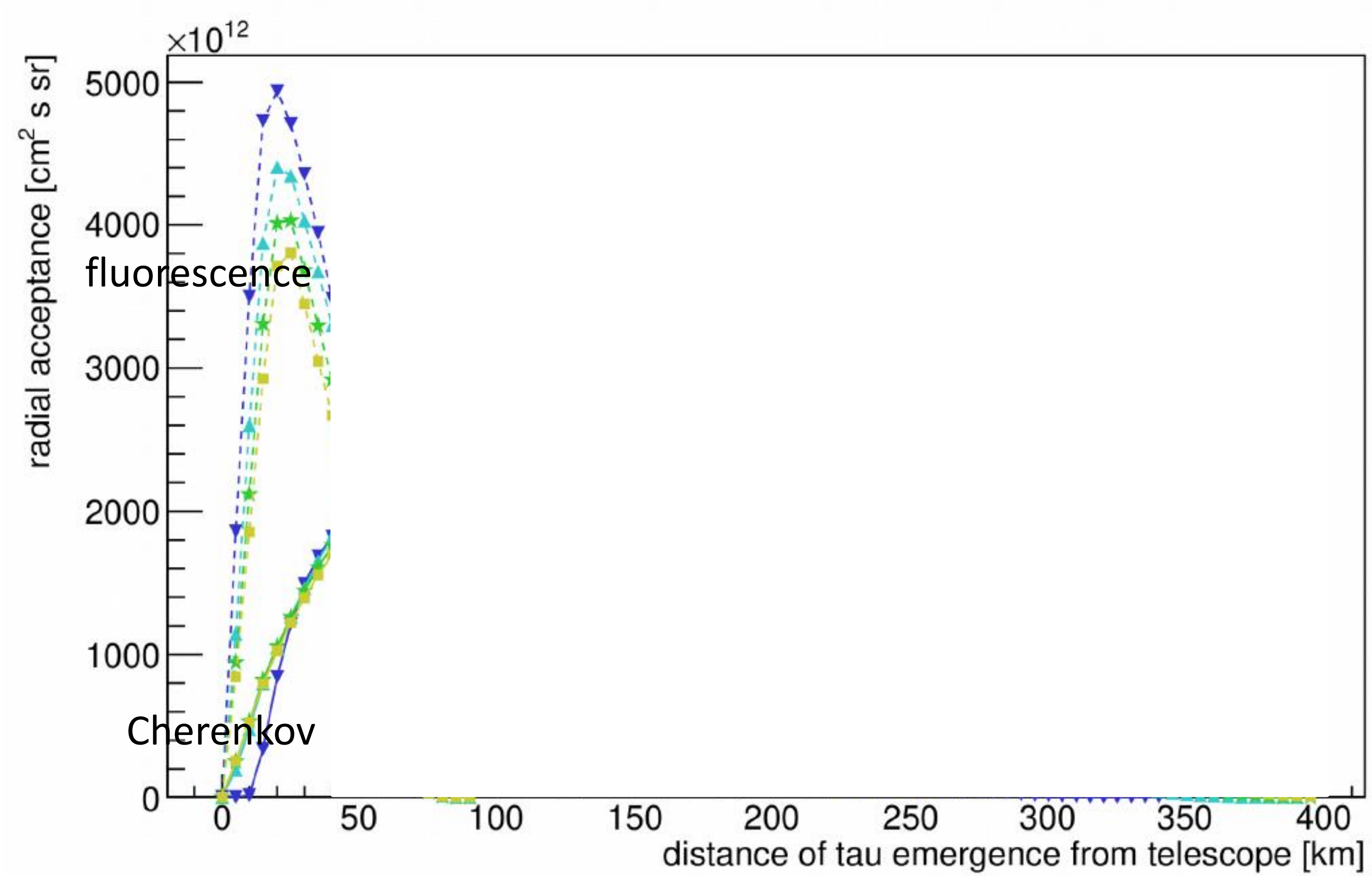


Sasaki 2017



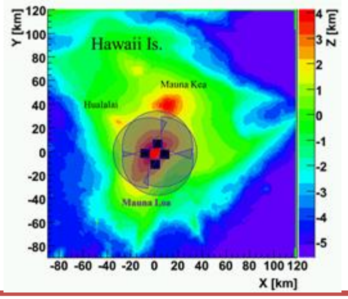
ES ν_τ Acceptance with fluorescence & Cherenkov



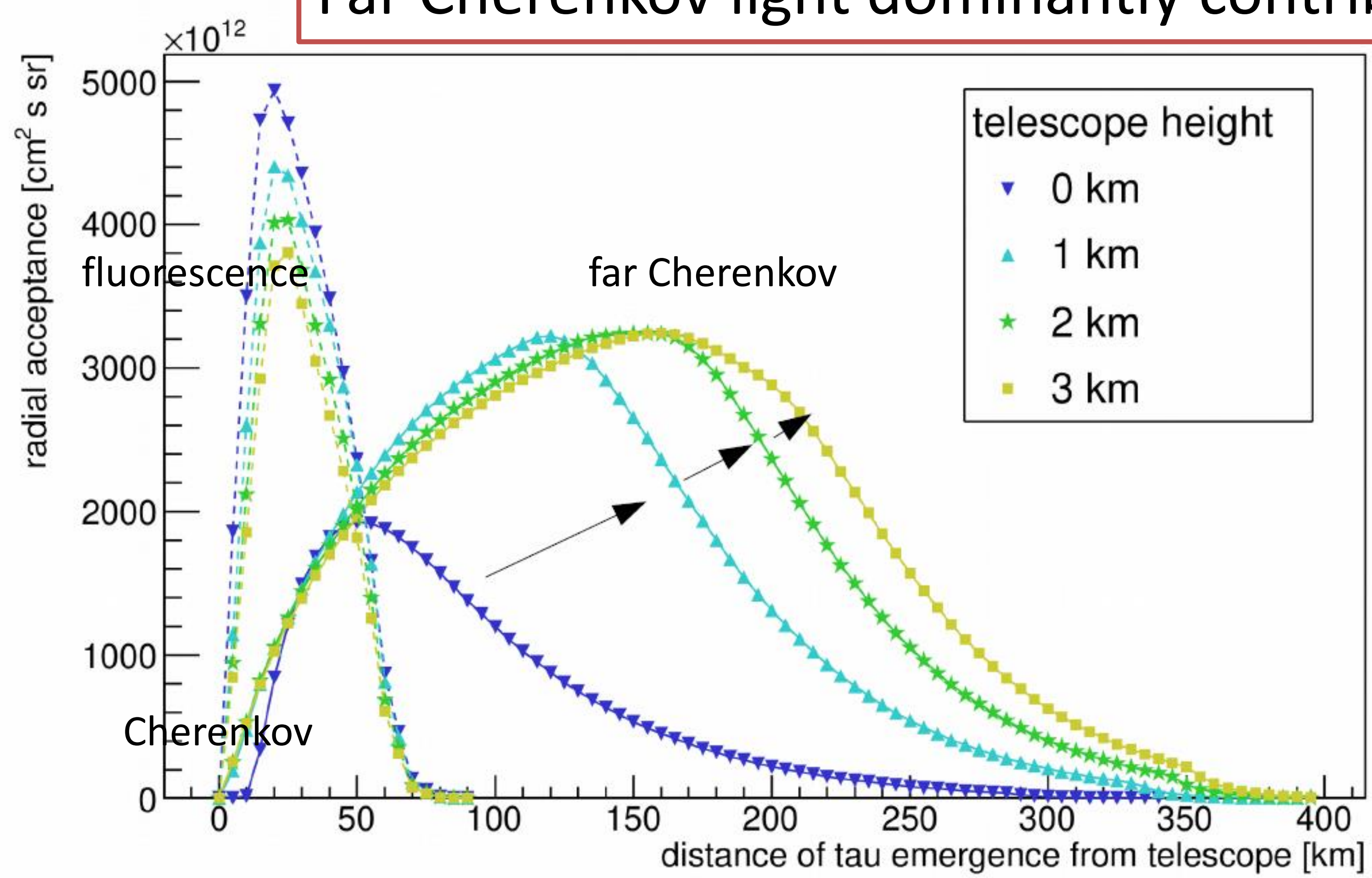


Otte arXiv:1811.09287

ES ν_τ Acceptance with fluorescence & Cherenkov

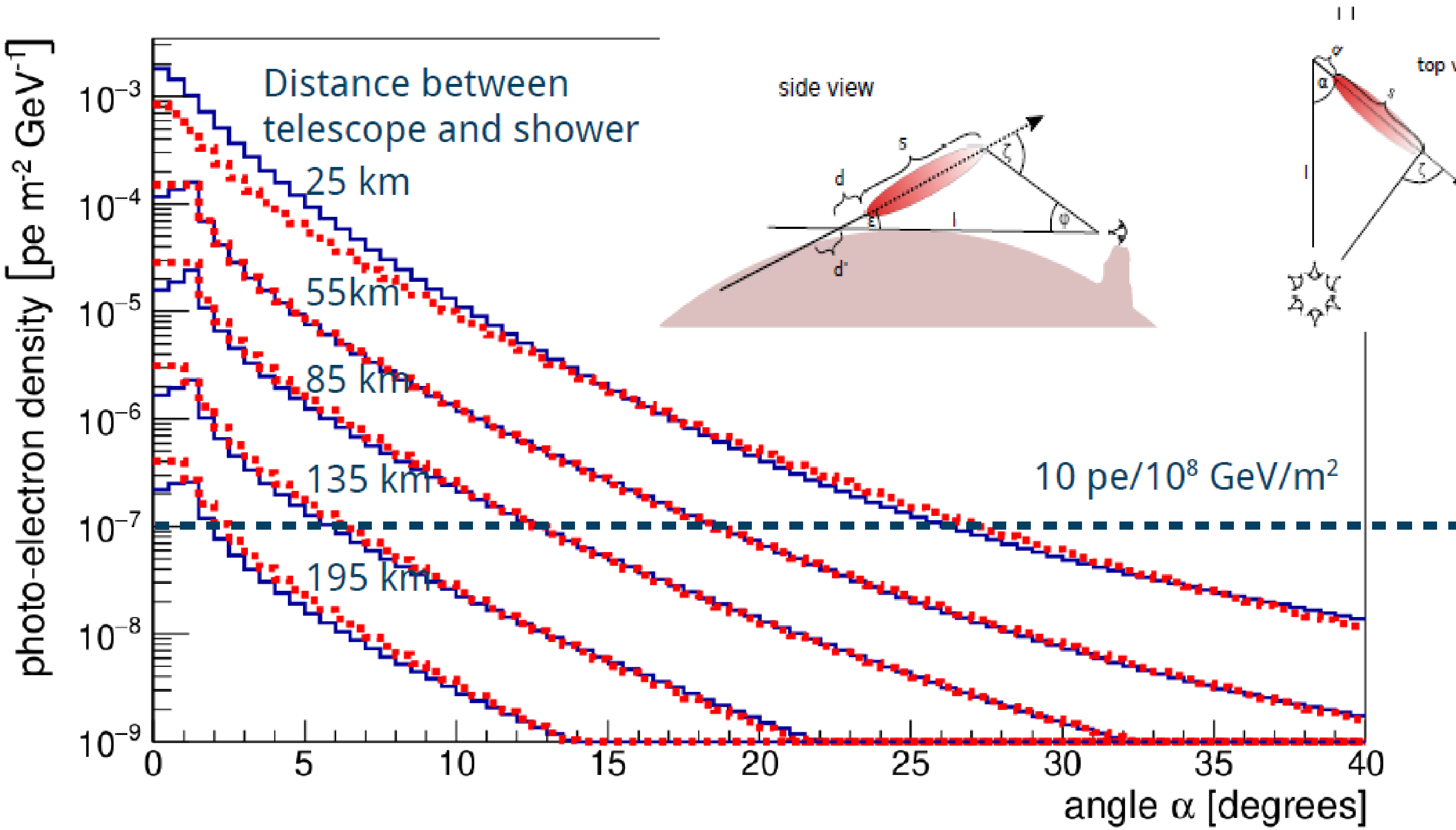


Far Cherenkov light dominantly contributes.



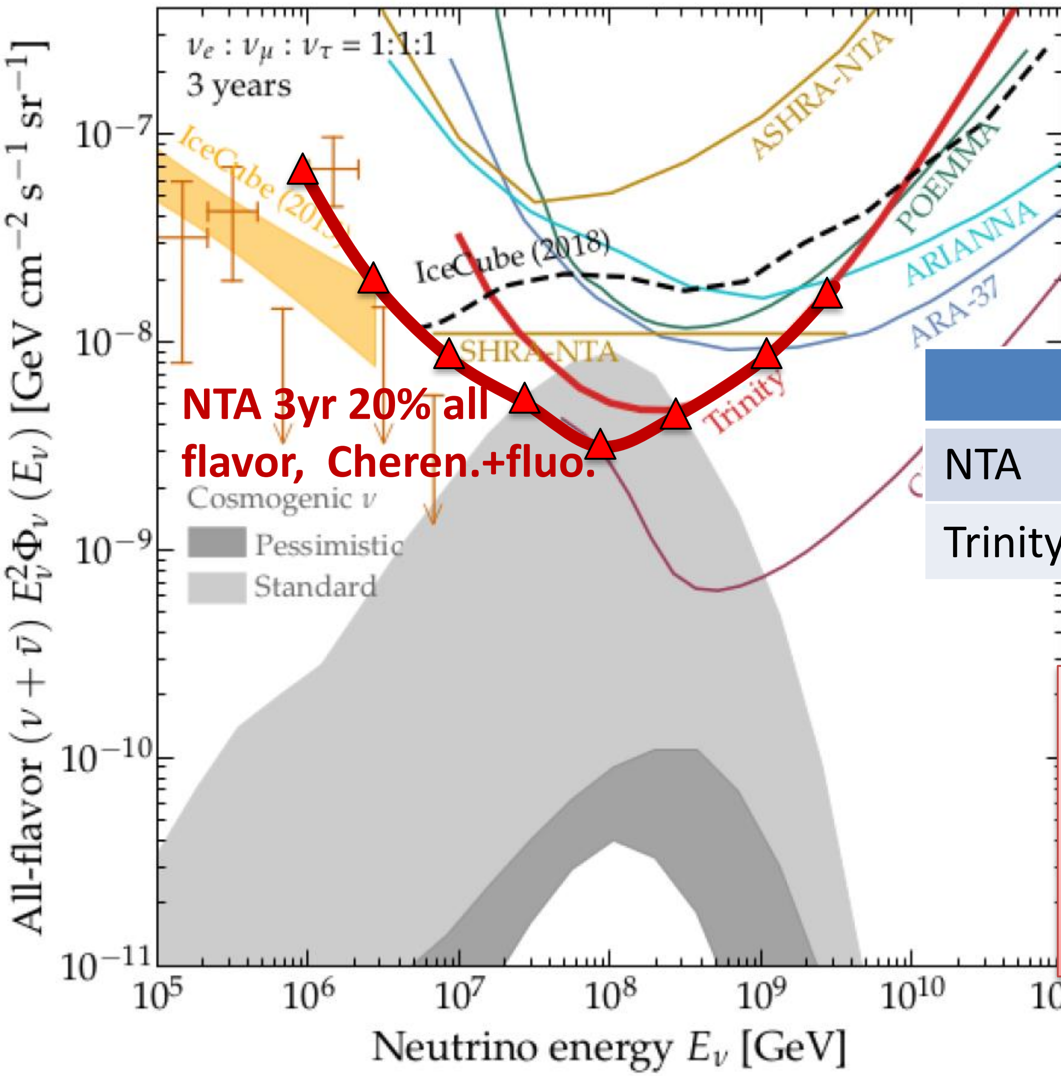
Otte arXiv:1811.09287

ES τ shower light pool



Otte arXiv:1811.09287

NTA diffuse ν sensitivity: with Cherenkov & fluorescence light



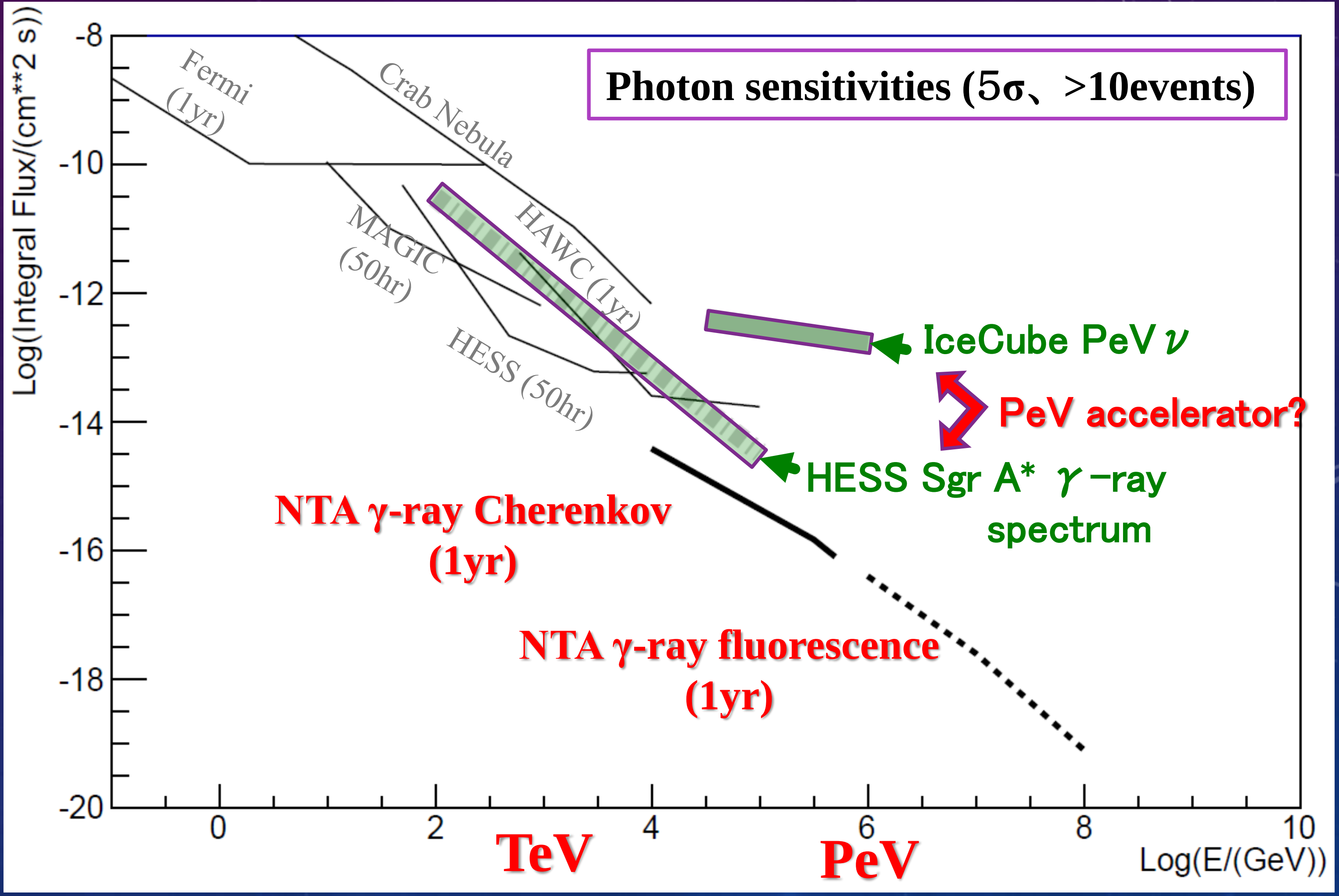
NTA can not lose to Trinity with sensitivity!

	aper.	height	Fov	Resol.
NTA	10 m^2	**3** km	360° x**30**°	**0.125**°
Trinity	10 m^2	**2** km	360° x **5**°	**0.3**°

NTA most sensitive for 1PeV-100PeV ν

Clear test:
IceCube PeV ν extension
Cosmogenic ν

Integrated γ-ray Flux Sensitivities



NTA

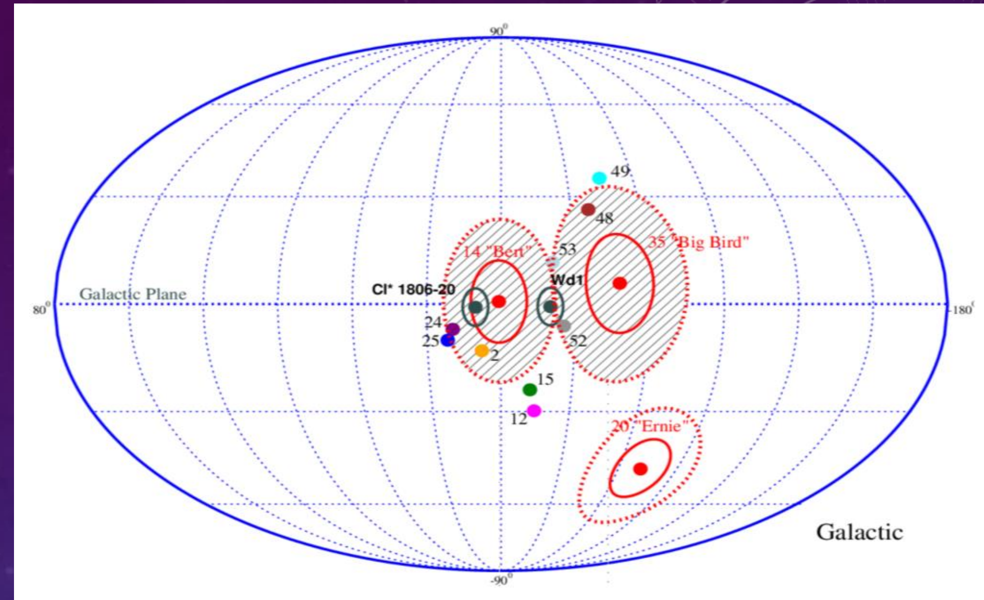
Compact Star Clusters in GP SNR γ-ray &ν Emissions

1σ, 2σ error circles from the center position of the IceCube PeVν

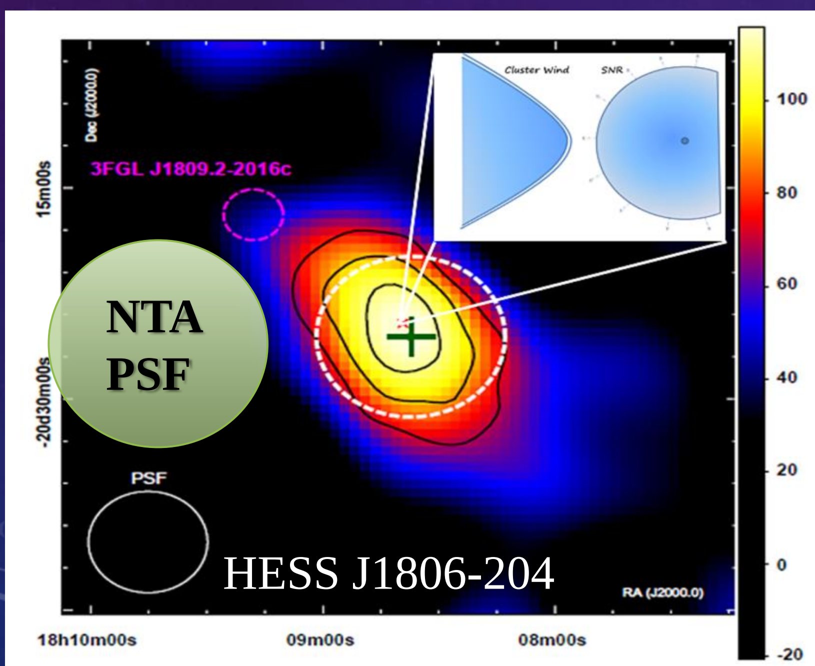
Evoluting young SNR:

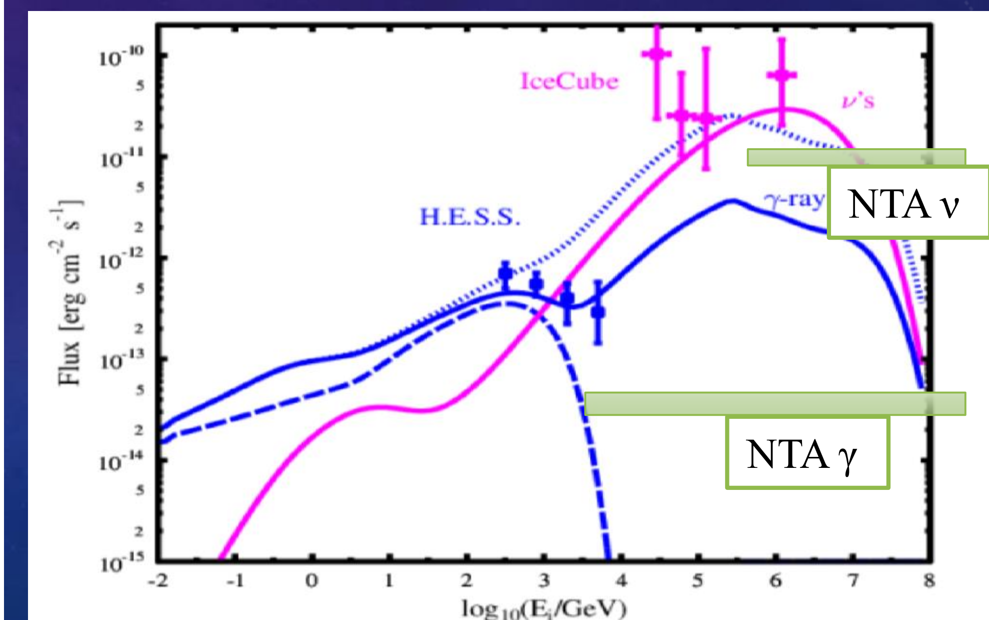
Westerlund 1 and HESS J1806-204

Colliding steller flow (CSF) model



Bykov et al., AIP Conference Proceedings 1792, 020003 (2017)

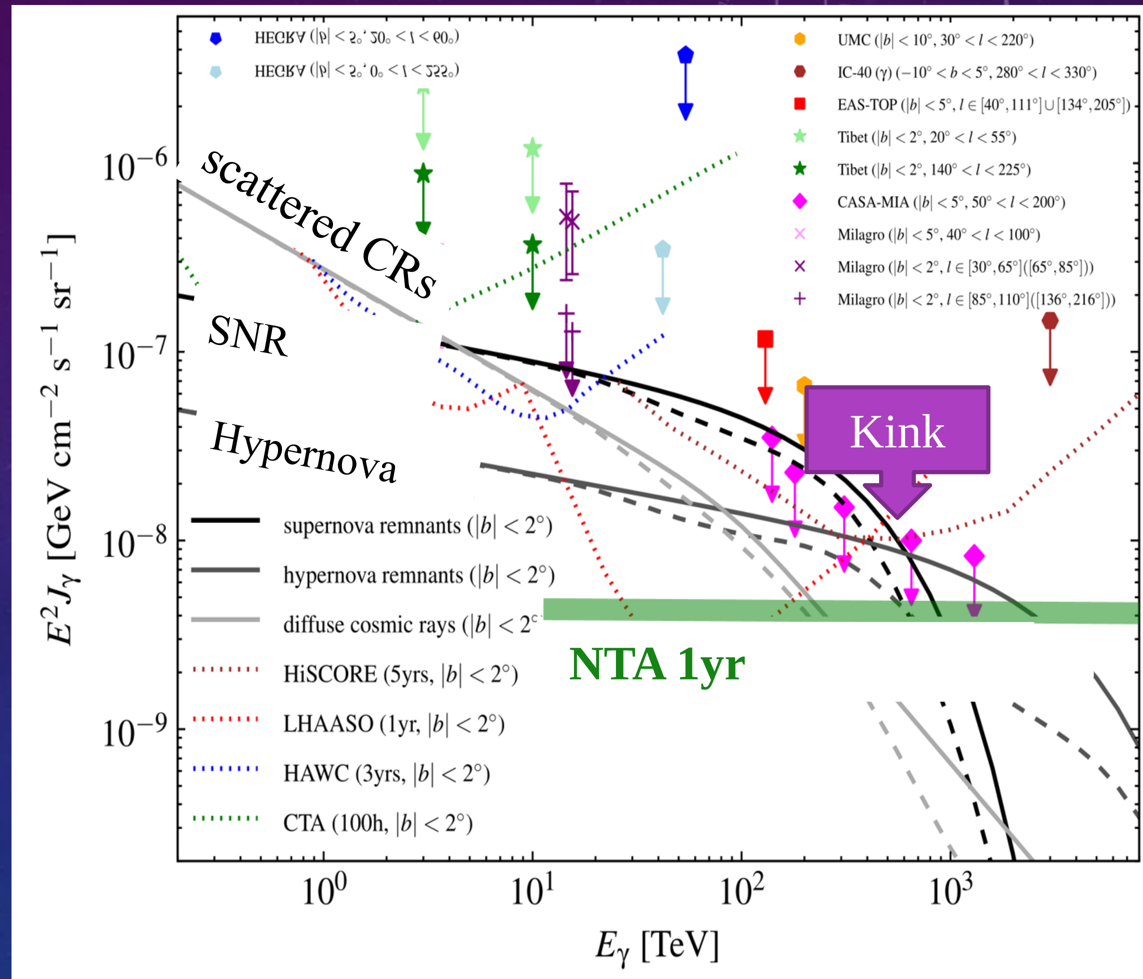




NTA

PRD 90 (2014):023010

Galactic Plane
TeV-PeV Diffuse γ-rays
Hypernova



Galactic Plane:

- ~1200 SNRs
- ~20 Hypernova
- reserved accelerated protons
- *pp interaction with* ⇒
- diffuse γ-ray and ν emission

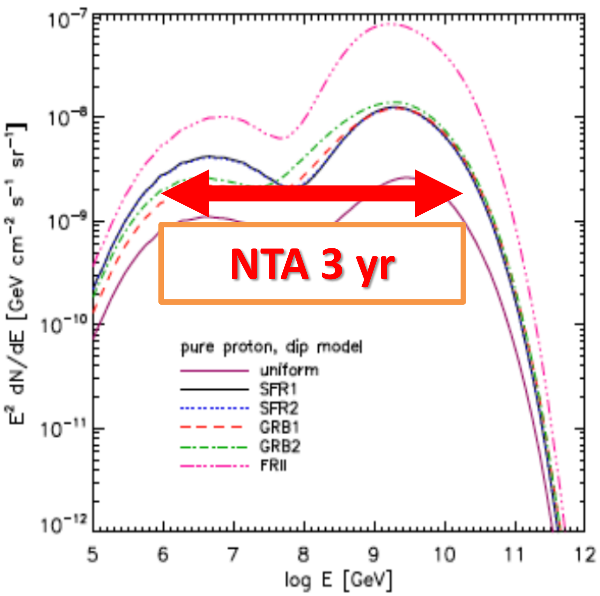
TeV-PeV γ-ray Observation:

- GC (α= 266.4° , δ= -28.9°)
- GP (|b|<2°)
- are not included in FOV efficiently

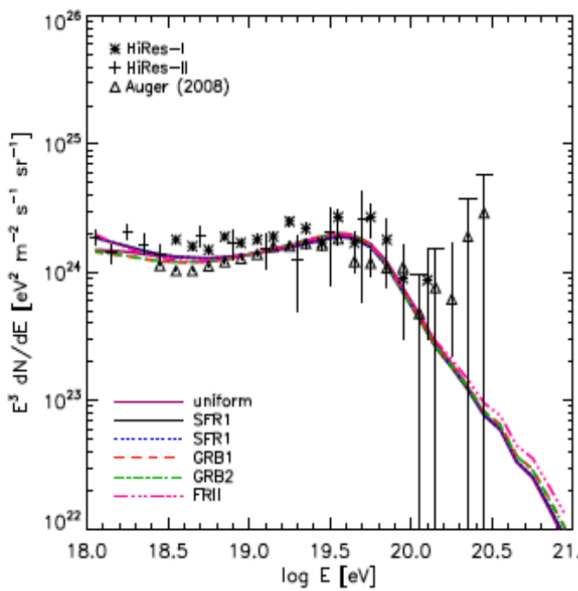
Powerful NTA γ-ray imaging observation with wide FOV

UHECR Pure-P Hypothesis

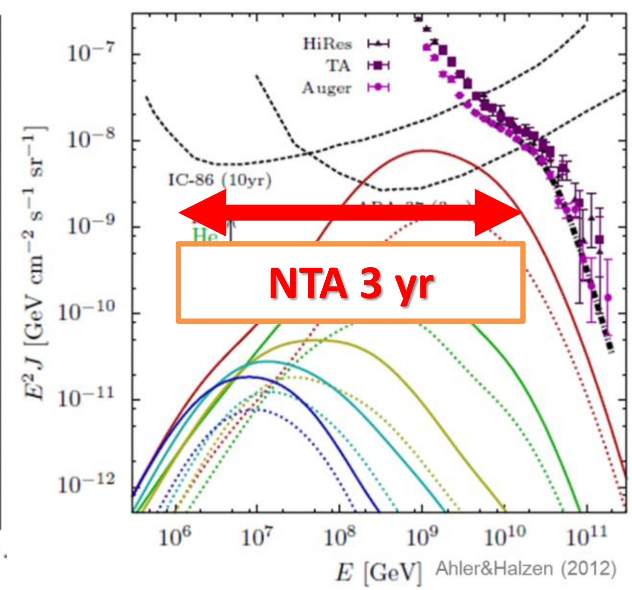
neutrinos



cosmic rays



neutrinos



Kotera, Allard & Olinto, JCAP 1010 (2010) 013.

Pure proton evolution, dip model

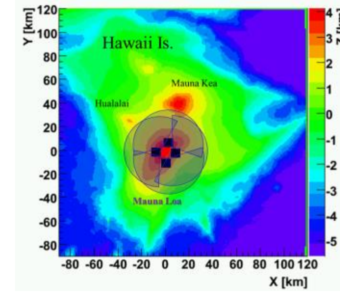
Ahler & Halzen (2012)

Composision dependence

***NTA* can resolve UHECR pure-p models**

Roads to NTA

Ashra-1 → NTA



2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023

NTA

国際共同観測拠点

request

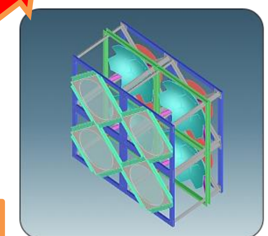
R&D, prototype, partially construction

observation

6+4 units GC $\gamma + \nu$ monitor

6units GC γ monitor

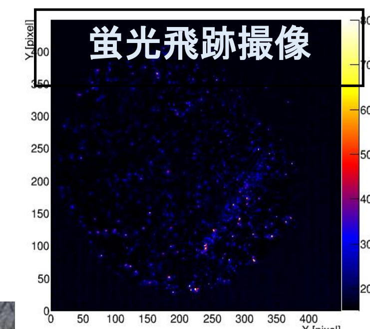
Obs.04



Ashra-1

Int. demonstration site

Test obs./ Physics obs. / establish auto-operation・data flow・analysis



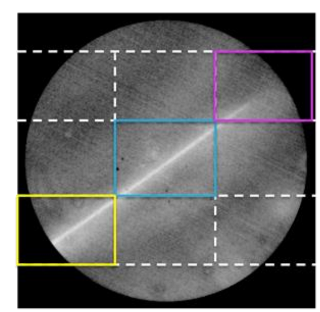
Akeno

国内開発拠点

assembly/laser obs./ aging. long-term test

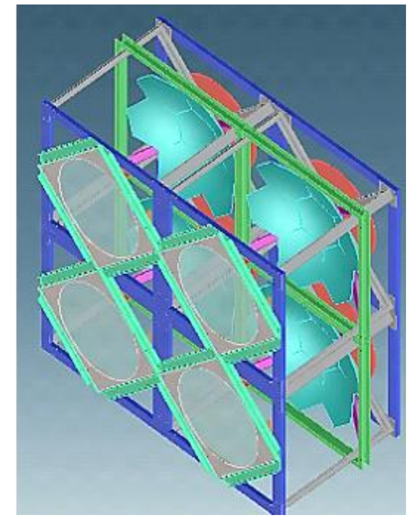
Laboratories

element development, test



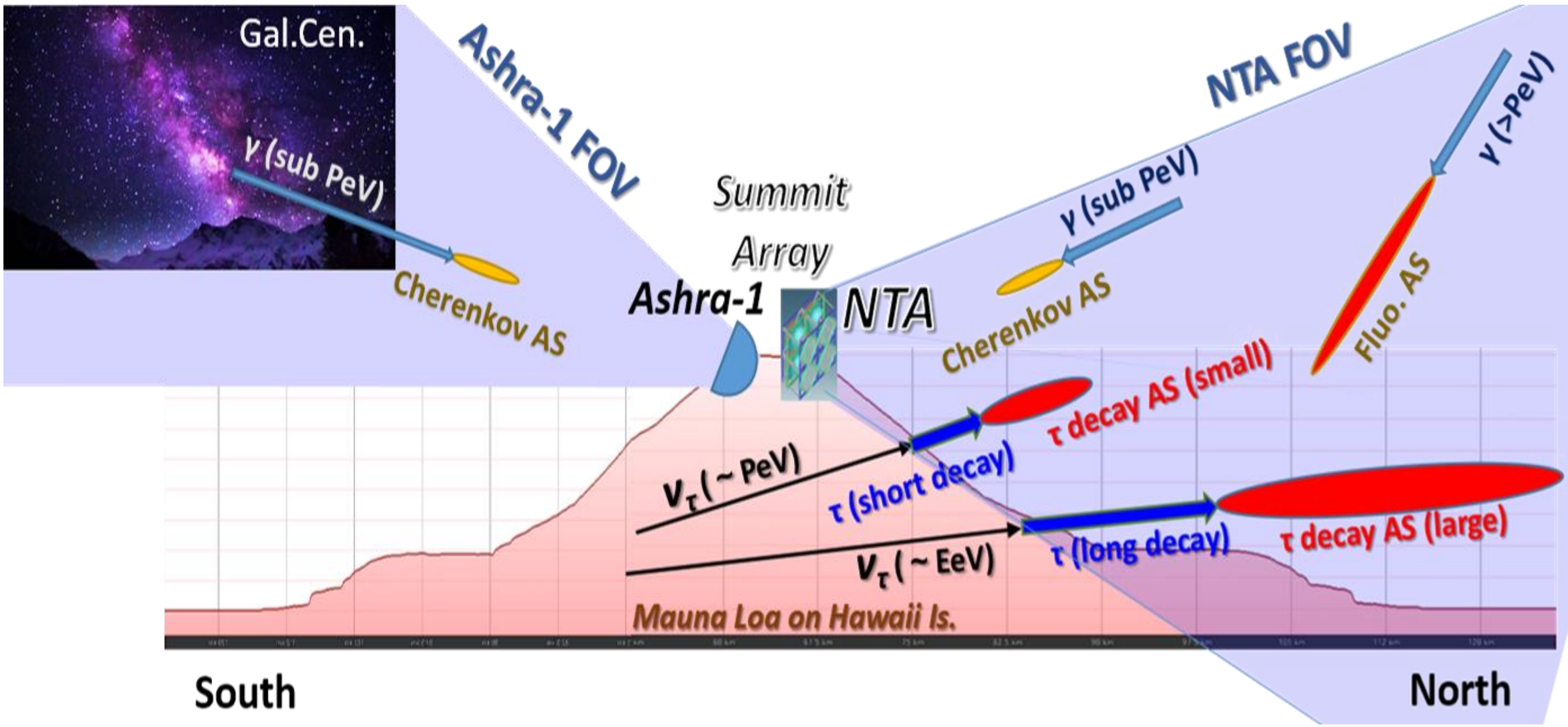
トリガー撮像を行った画像

NTA detector unit proto under testing



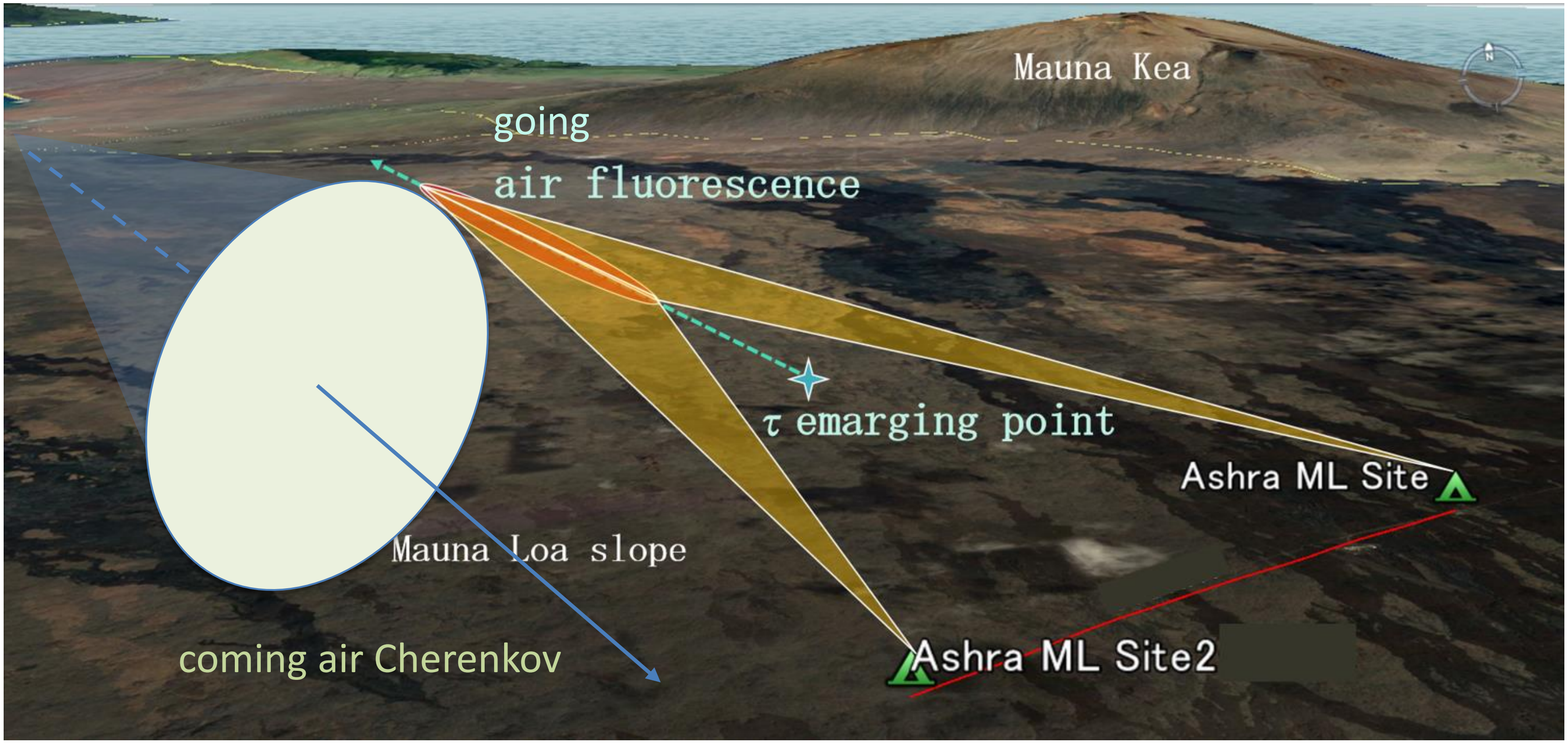
Trigger/readout test with YAG laser pulses

Galactic buldge survey with Ashra-1/NTA

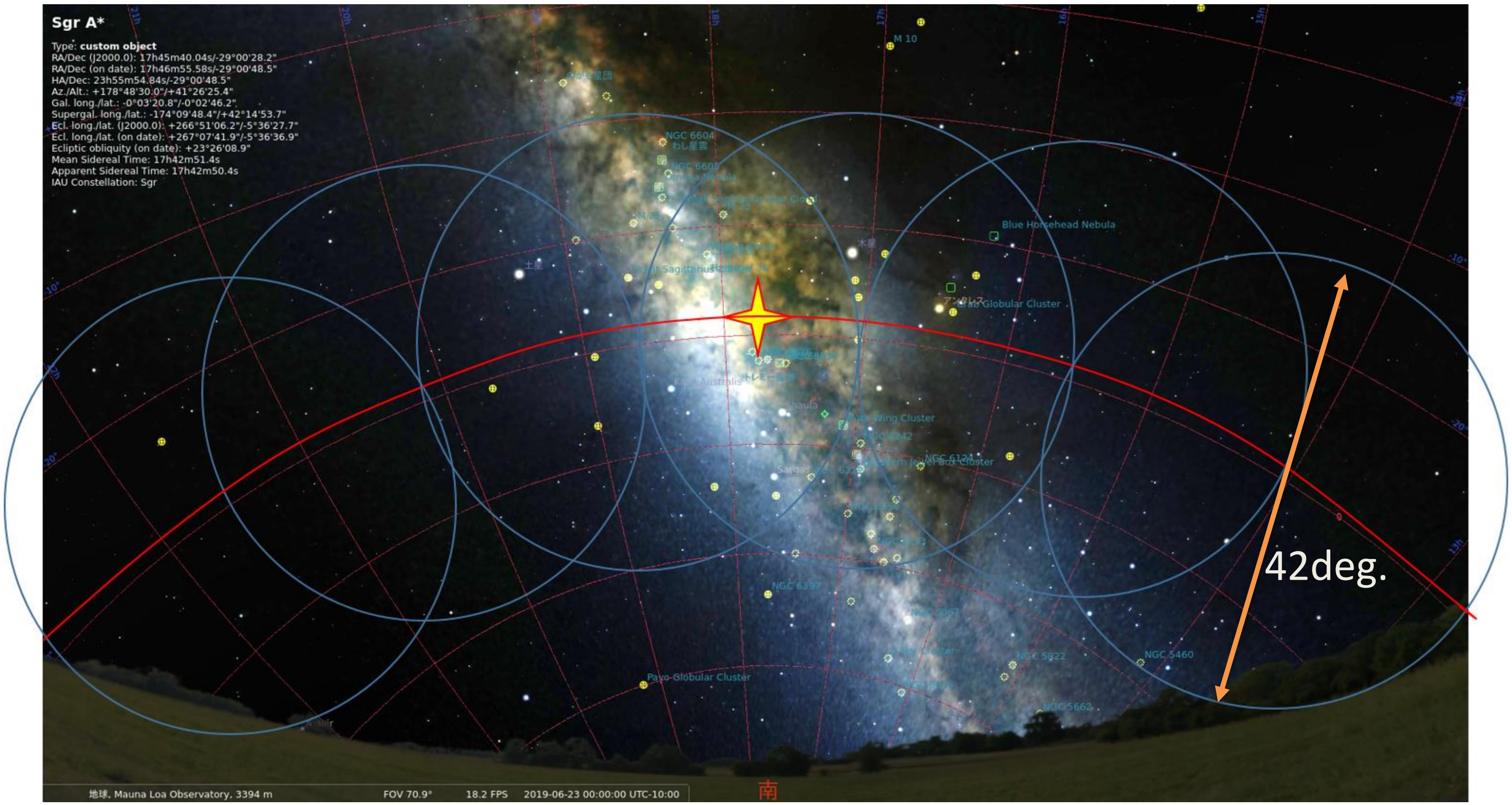


Concept of imaging observation of PeV ν's, γ-rays, and nuclei with NTA summit array.
Simultaneously 6 Ashra-1 light correctors watch γ-rays from the galactic bulge.
NTA can effectively check the coincidence between ν_τ and γ-ray events.

Horizontal air light can earn the detector acceptance

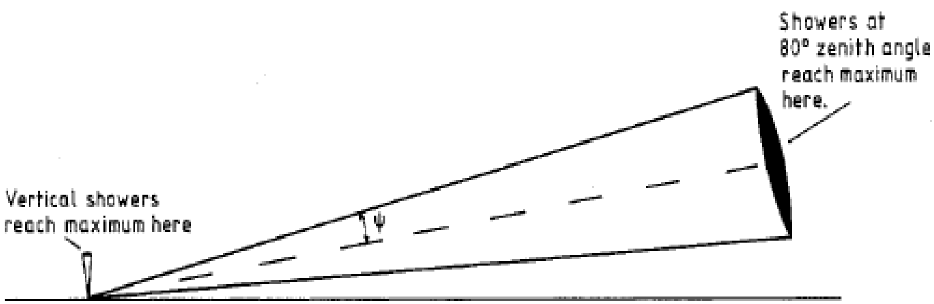


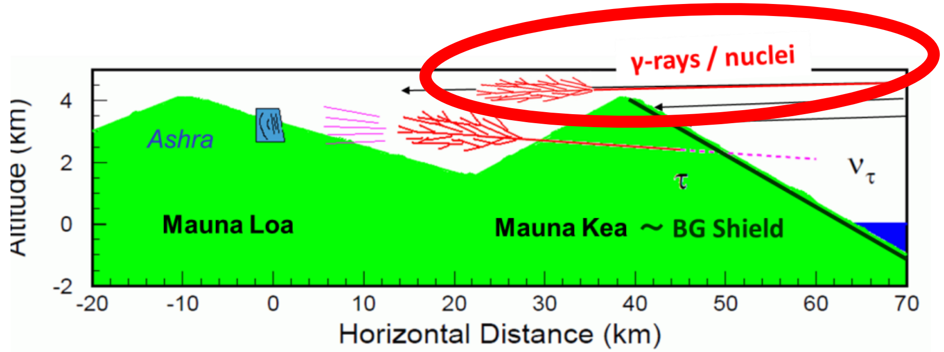
Layout of Ashra-1 FOVs



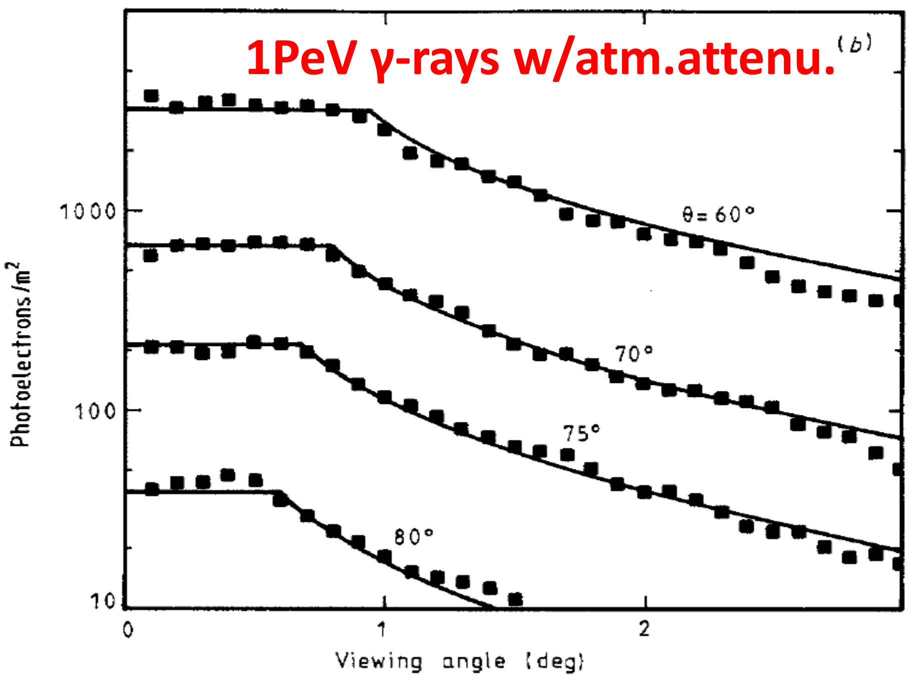
Simulated southern sky at the Ashra-1 Mauna Loa site at 0:00 on June 23, 2019.
The star mark indicates the location of the galactic center (GC).
The track of GC (arc) and the FOV of the rearranged Ashra-1 light collectors (circles) are also shown.

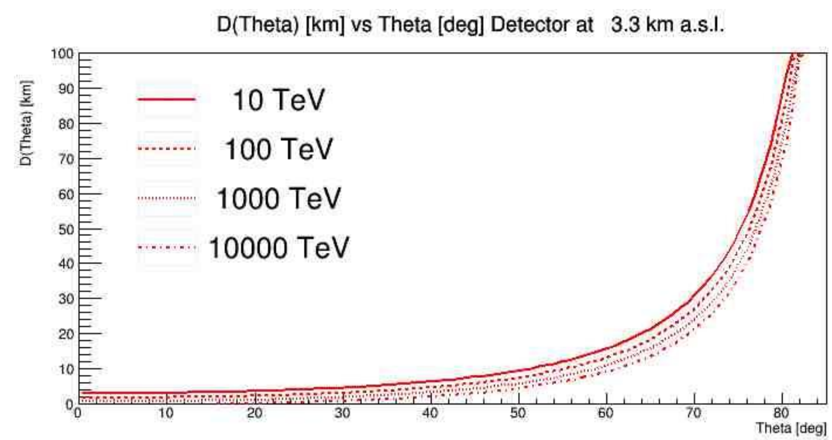
Large Zenith Angle γ-ray Detection
(60 deg. < Zenith θ < 90 deg.)





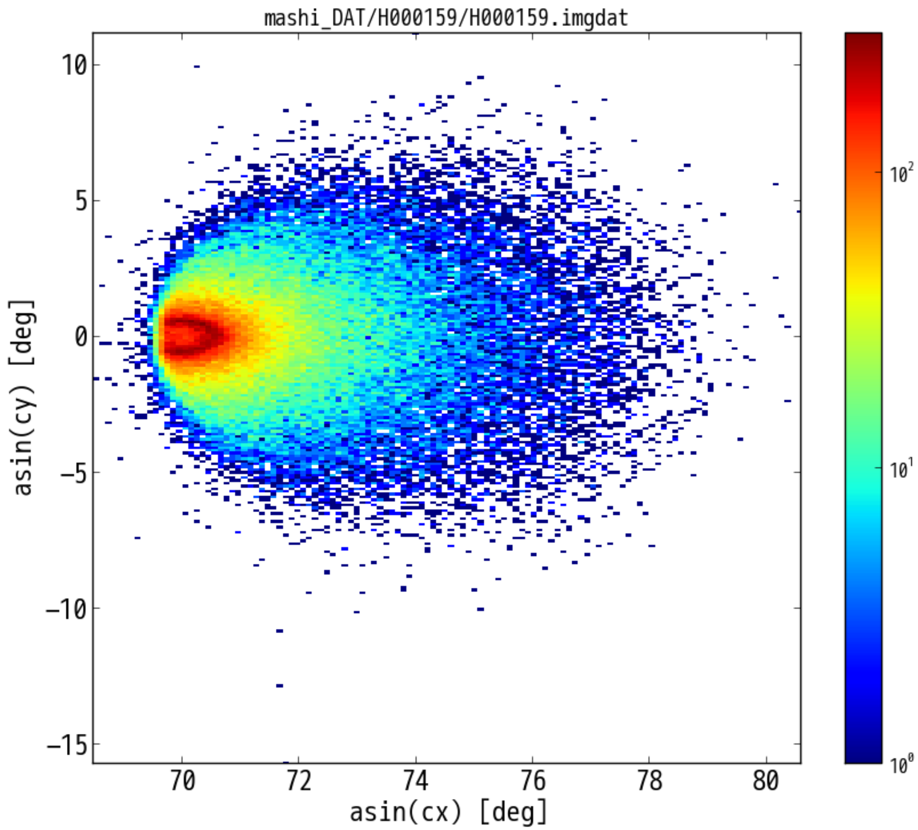
P.Sommers & J.W.Elbert, J.Phys.G: Nucl.Phys. 13 (1987) 553

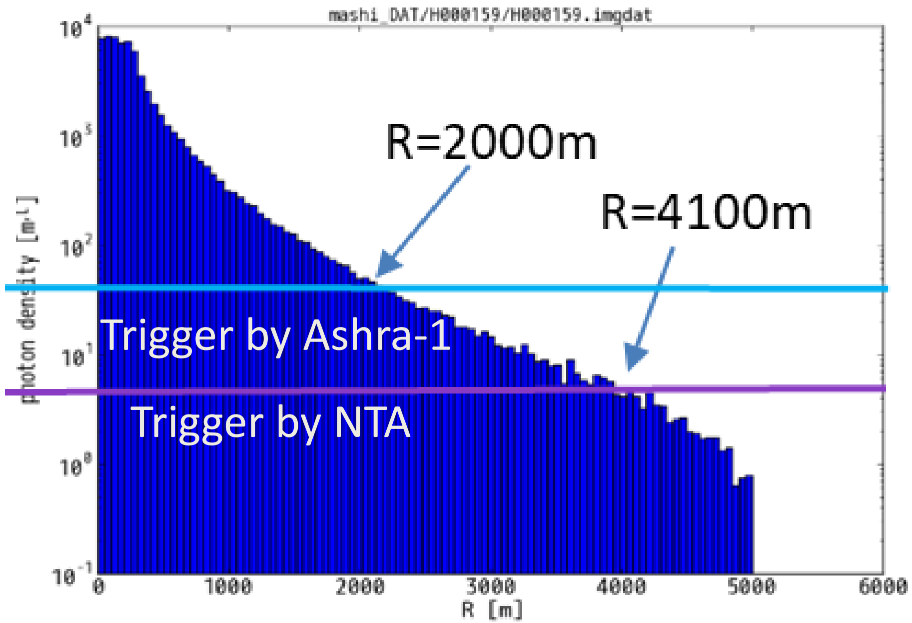




Can keep sensitivity for PeV Cerenkov γ-rays

70 deg. γ-ray shower features





NTA eff. detection area
50 km^2

Ashra-1 eff. detection area
13 km^2

Advantage of Ashra-1/NTA GC γ survey

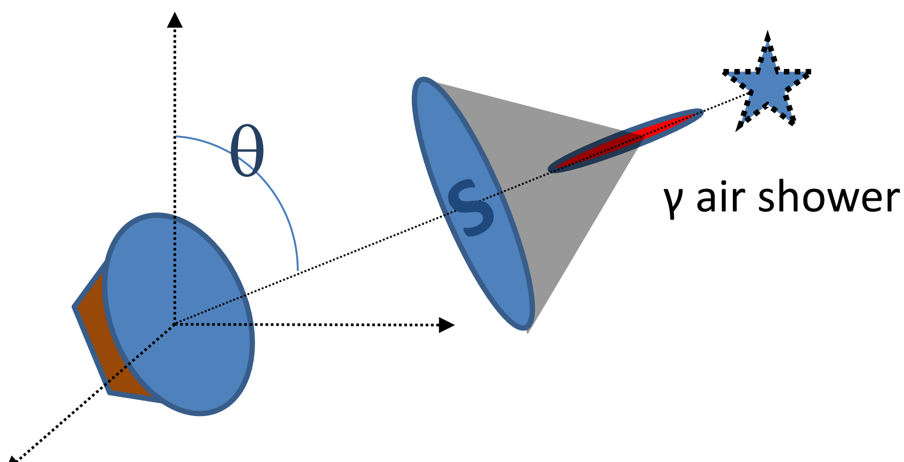
Ashra-1/NTA

Effective detection area S :

S increase as θ due to far Cherenkov

Cherenkov light : small attenuation

⇒ more advantage for higher Energy



GC survey （HESS : 227hr/10yr）

T = 1150～1900 hr/yr (θ = 48~90°)

S = 0.3 km^2/1unit @10 TeV (θ = 70°)

12 km^2/1unit @1 PeV (θ = 70°)

Ground 2D particle array

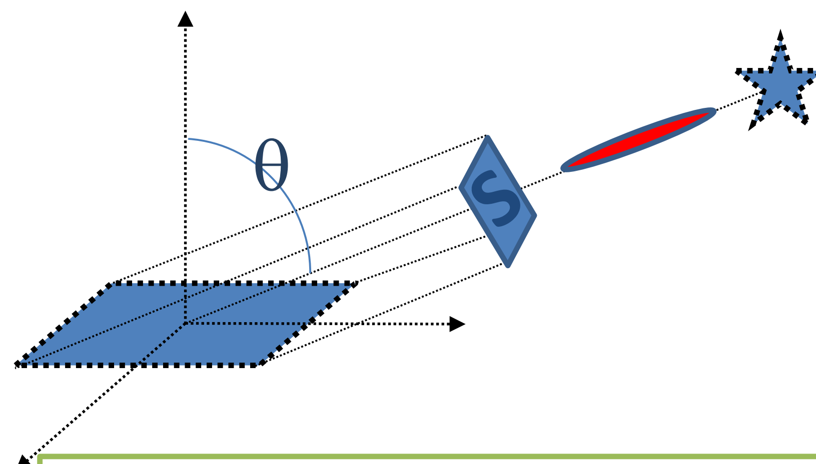
$S = S_0 \cos\theta$

Shower particle electron :

severe attenuation

=> Only effective θ < 45°

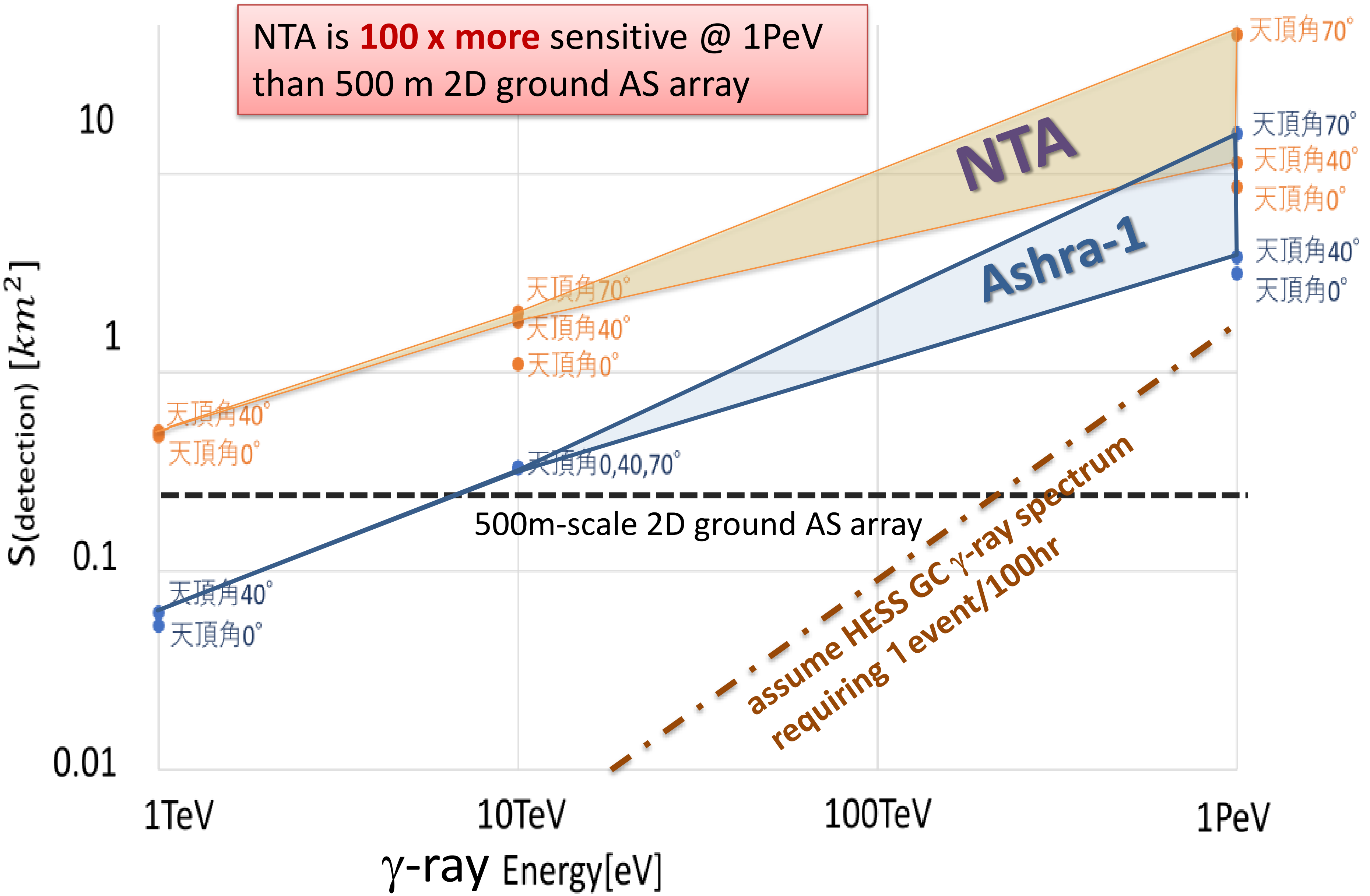
=> Duty cycle 50%



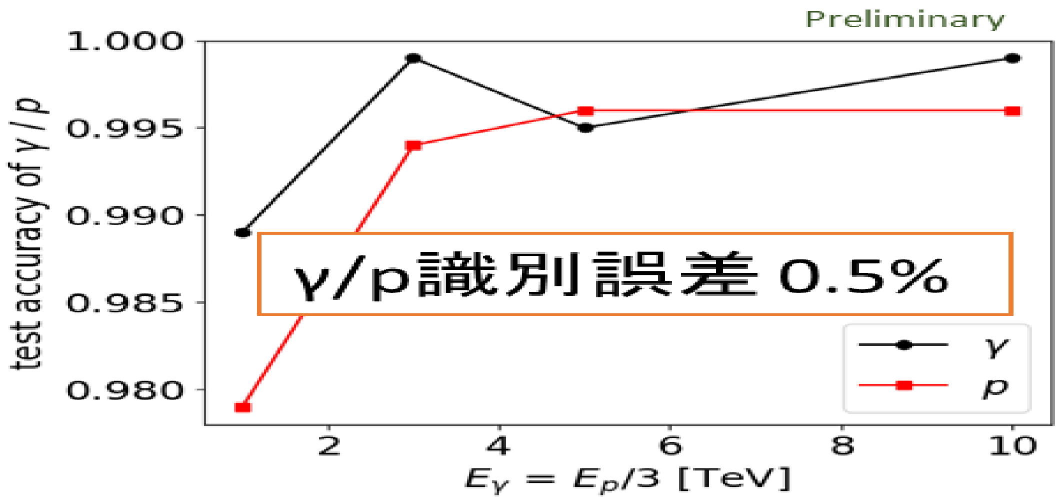
T = 2300 hr/yr (θ < 45°) @南緯16度

S < 0.2 km^2 (500m 2D array)

GC γ-ray Effective Detection Area vs Energy

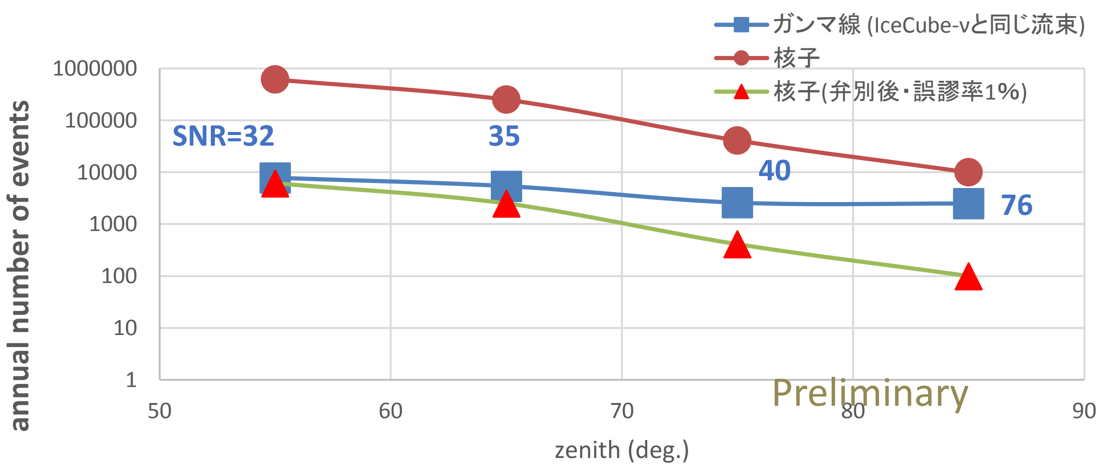


Deep Learning Separation of γ/CR



(M.Sasaki JPS2017A)

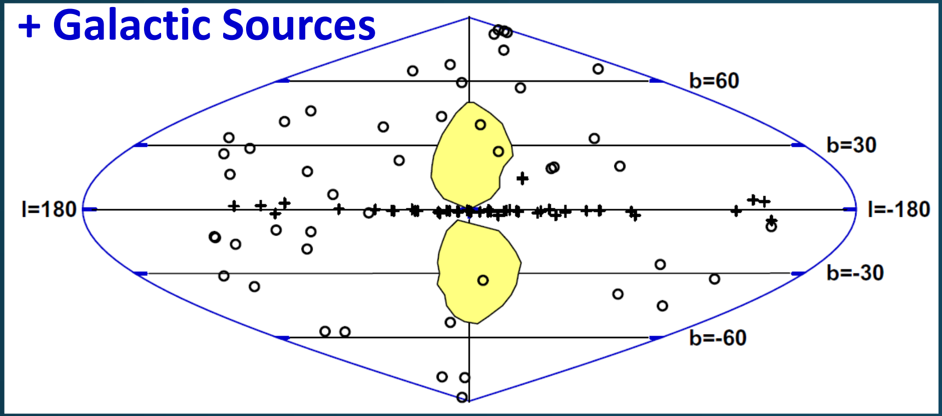
Ashra-1 Galactic ridge survey 4deg.x40 deg.region)



DT error rate of 0.7%
(J. R. Gonzáles, 2017,tesis.pucp.edu.pe)

Ashra/NTA can identify γ/CR from Galactic ridge 4deg.x 40deg. assuming 1% error with the DL method.

Galactic ν Source Candidates from TeVCat



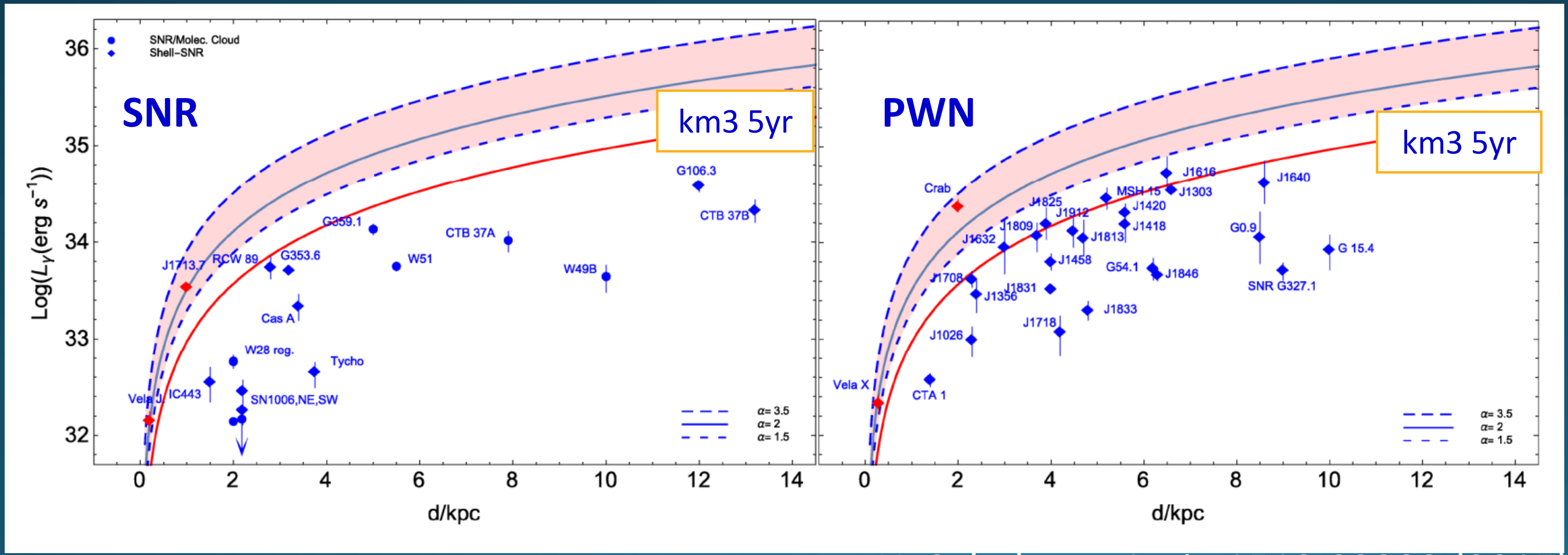
T. Gaisser & T. Stanev, Astroparticle Physics, 39-40 (2012).

SNRs:
- RX J1713.7-3946
- RX J0852.0-4622

PWNe:
- Vela-X

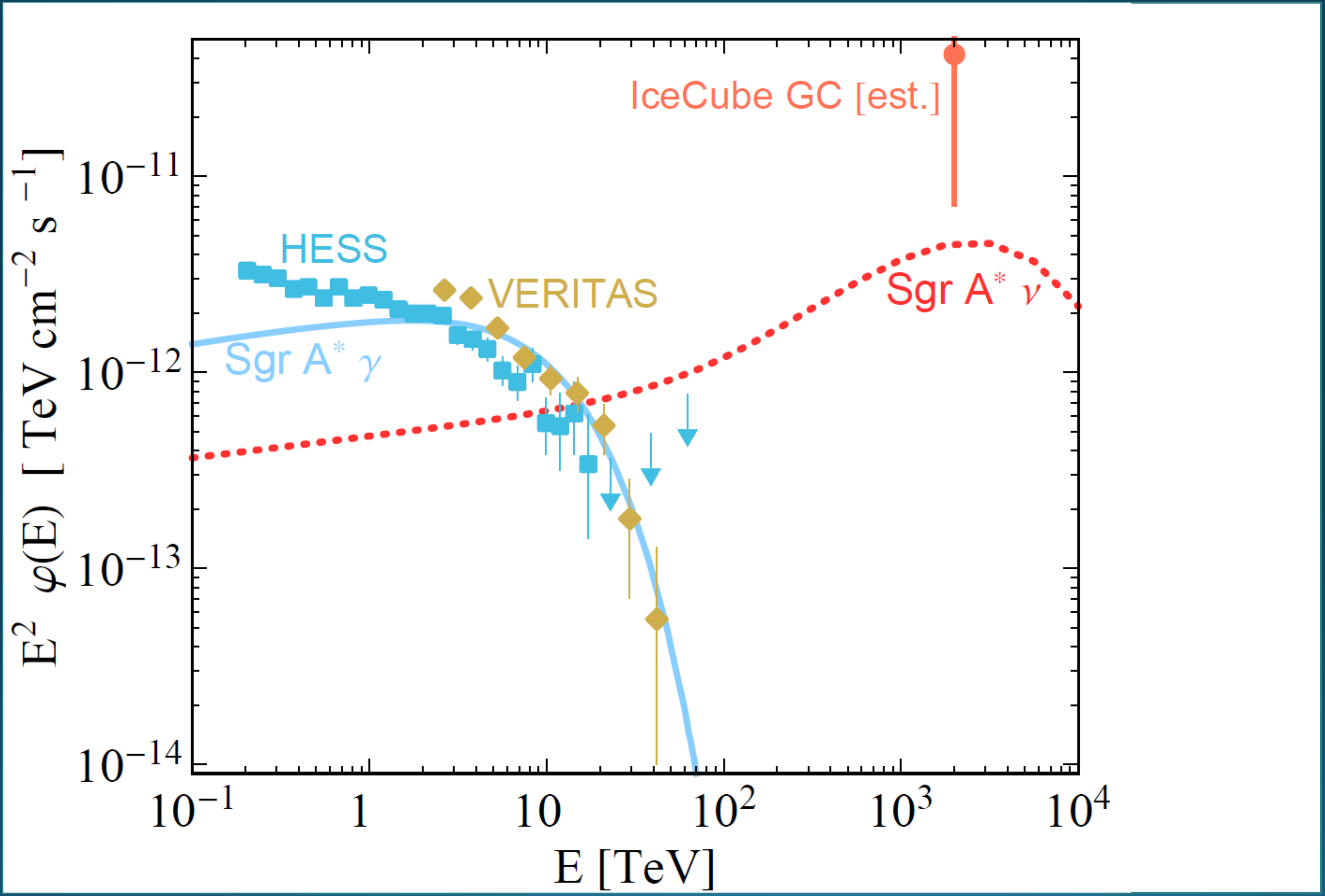
Binaries:
- Cygnus-X3, LS 5039

… More candidates assume hadron produced γ e.g. IC 443, W44.



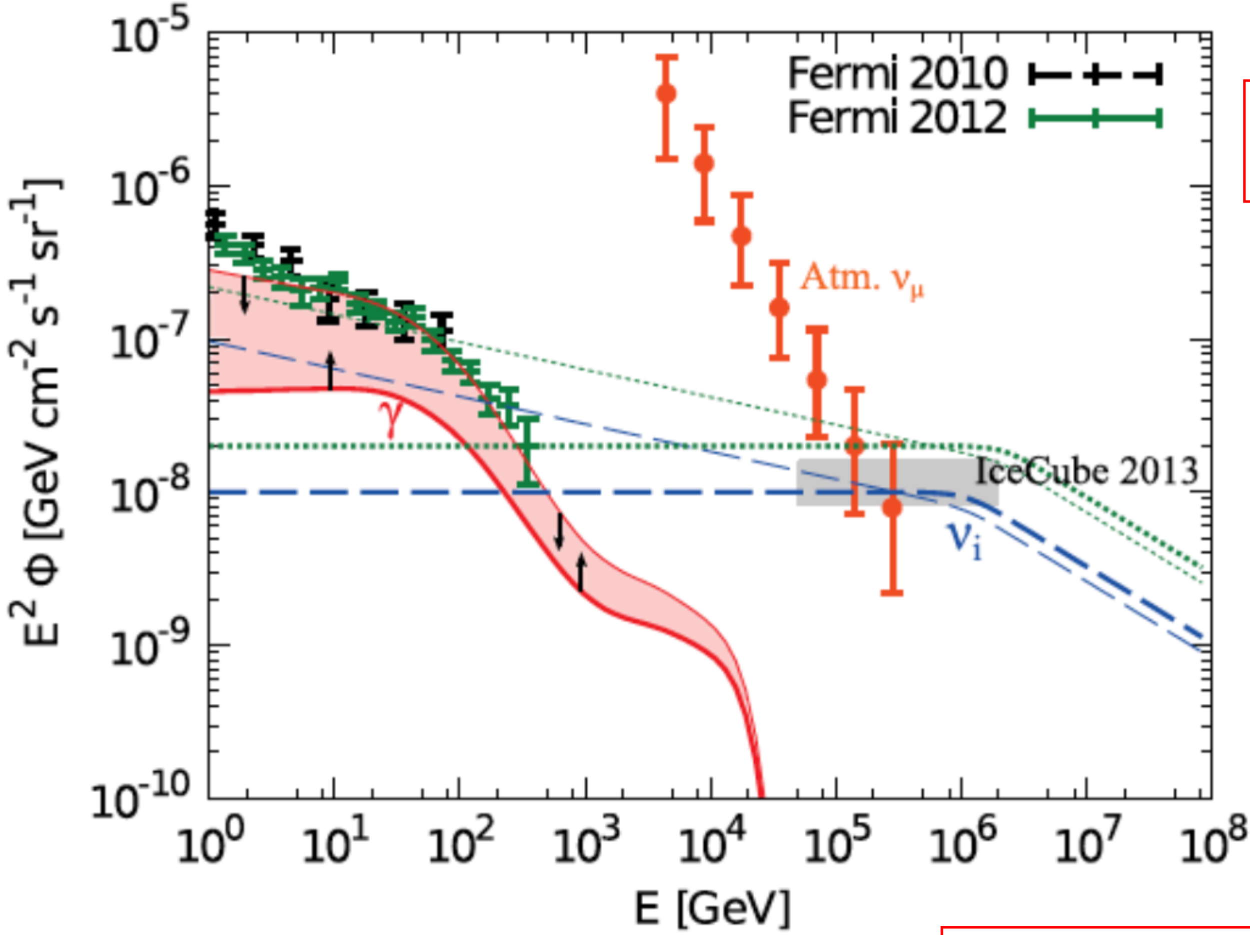
N. Sahakyan, Arxiv:1512.02333 (2015).

GC TeV γ source



Matthew D. Kistler, Arxiv:1511.05199.

Hadronuclear origin of νs from AGN/SBG



Murase, Ahlers, Lacki, PRD 88 (2013) 121301

$$\Gamma = 2.0, 2.18$$

Range shows spectral index range. Not much effect due to redshift evolution model.

Green dotted, before electromagnetic cascades:

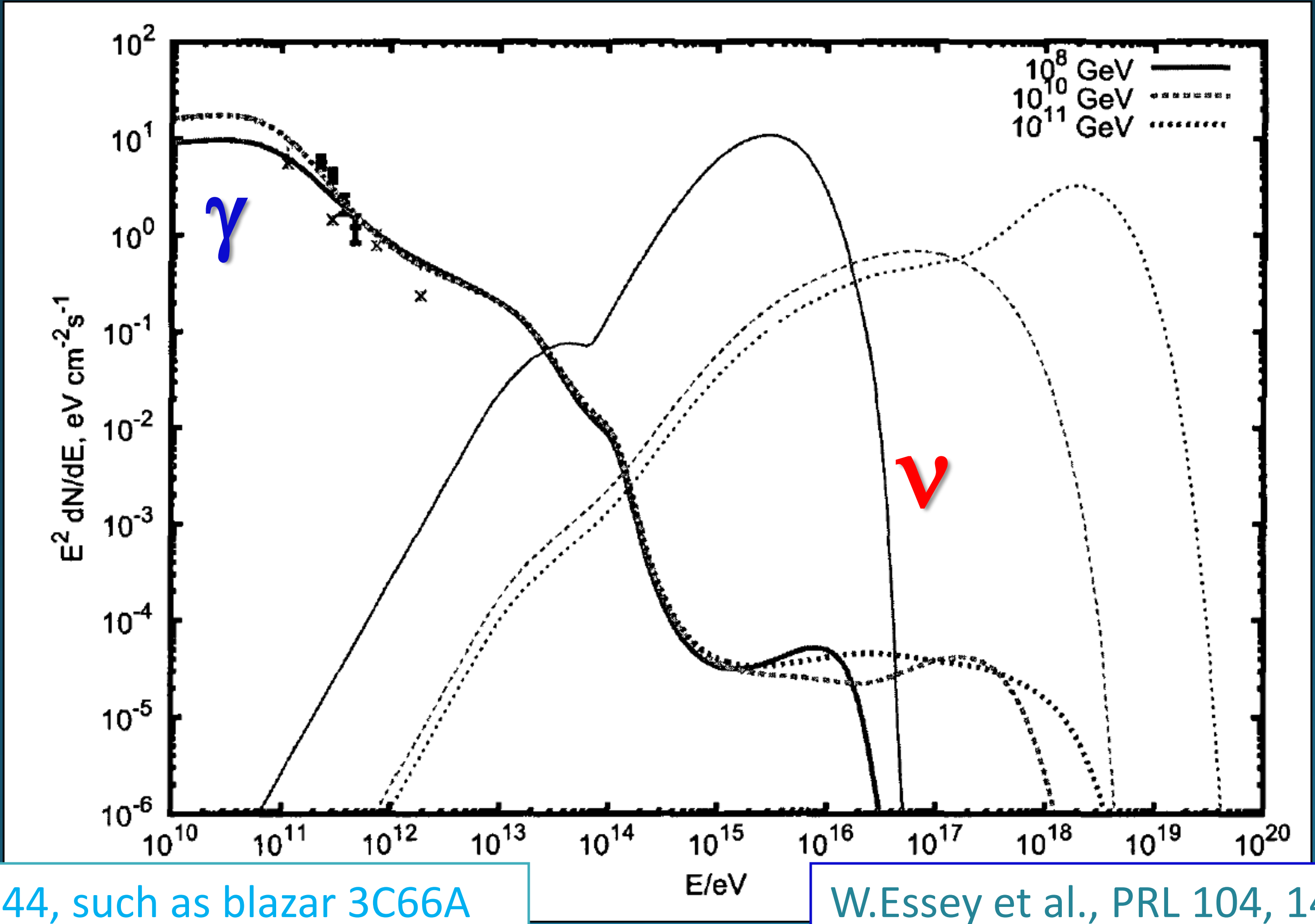
$$E_\gamma^2 \Phi_\gamma \simeq 2(E_\nu \Phi_{\nu_i})|_{E_\nu = 0.5 E_\gamma}$$

Possibility for separation of PP/Pγ mechanism

ν & γ from CRs Produced by Distant Blazars

$$p + \gamma_b \rightarrow p + e^+ + e^-$$
$$p + \gamma_b \rightarrow n + \pi^+$$
$$p + \gamma_b \rightarrow p + \pi^0$$

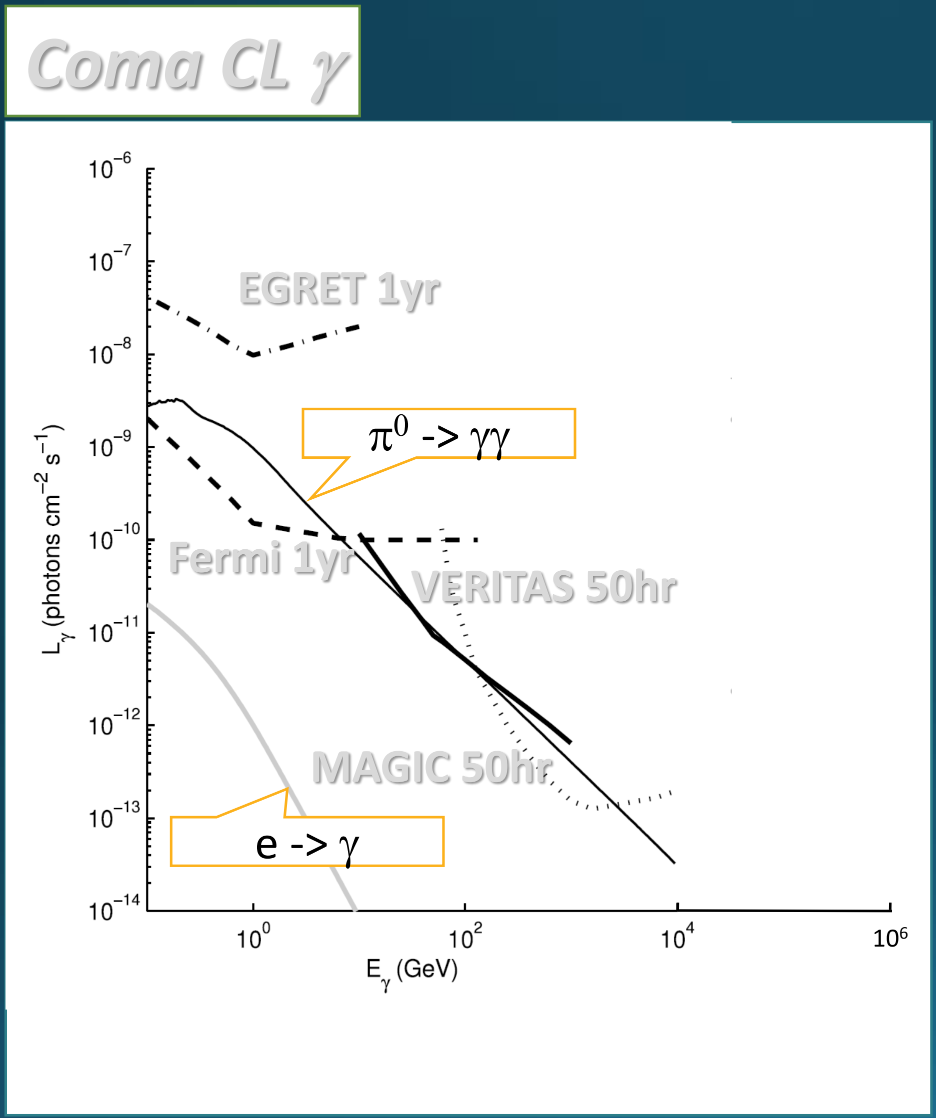
$$\Delta\theta \sim 0.1^\circ \left(\frac{B}{10^{-14}\mathrm{G}}\right)\left(\frac{4\times10^7\mathrm{GeV}}{E}\right)\left(\frac{D}{1\,\mathrm{Gpc}}\right)^{1/2}\left(\frac{l_c}{1\,\mathrm{Mpc}}\right)^{1/2}$$

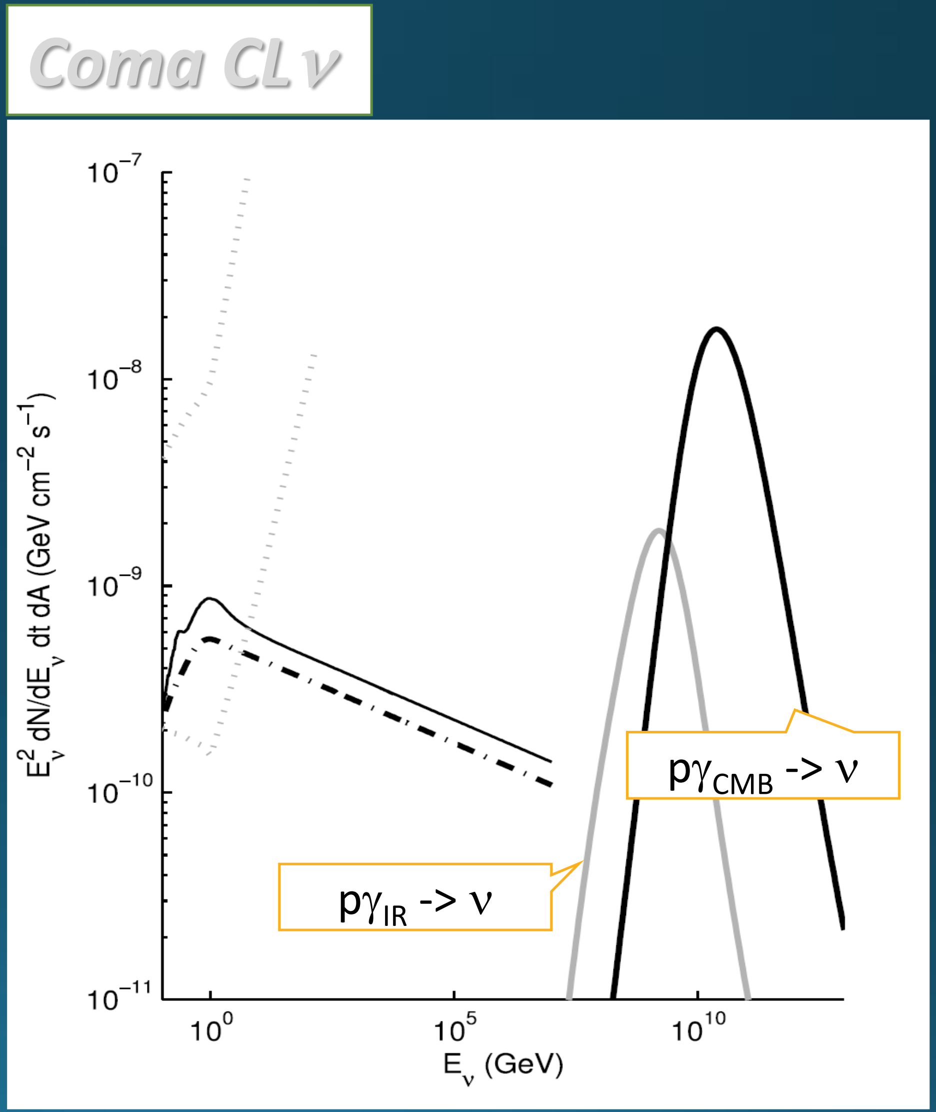


z = 0.44, such as blazar 3C66A

W.Essey et al., PRL 104, 141102 (2010)

ν & γ from Galaxy CLusters





B. Wolfe et al., ApJ 687:193-201, 2008

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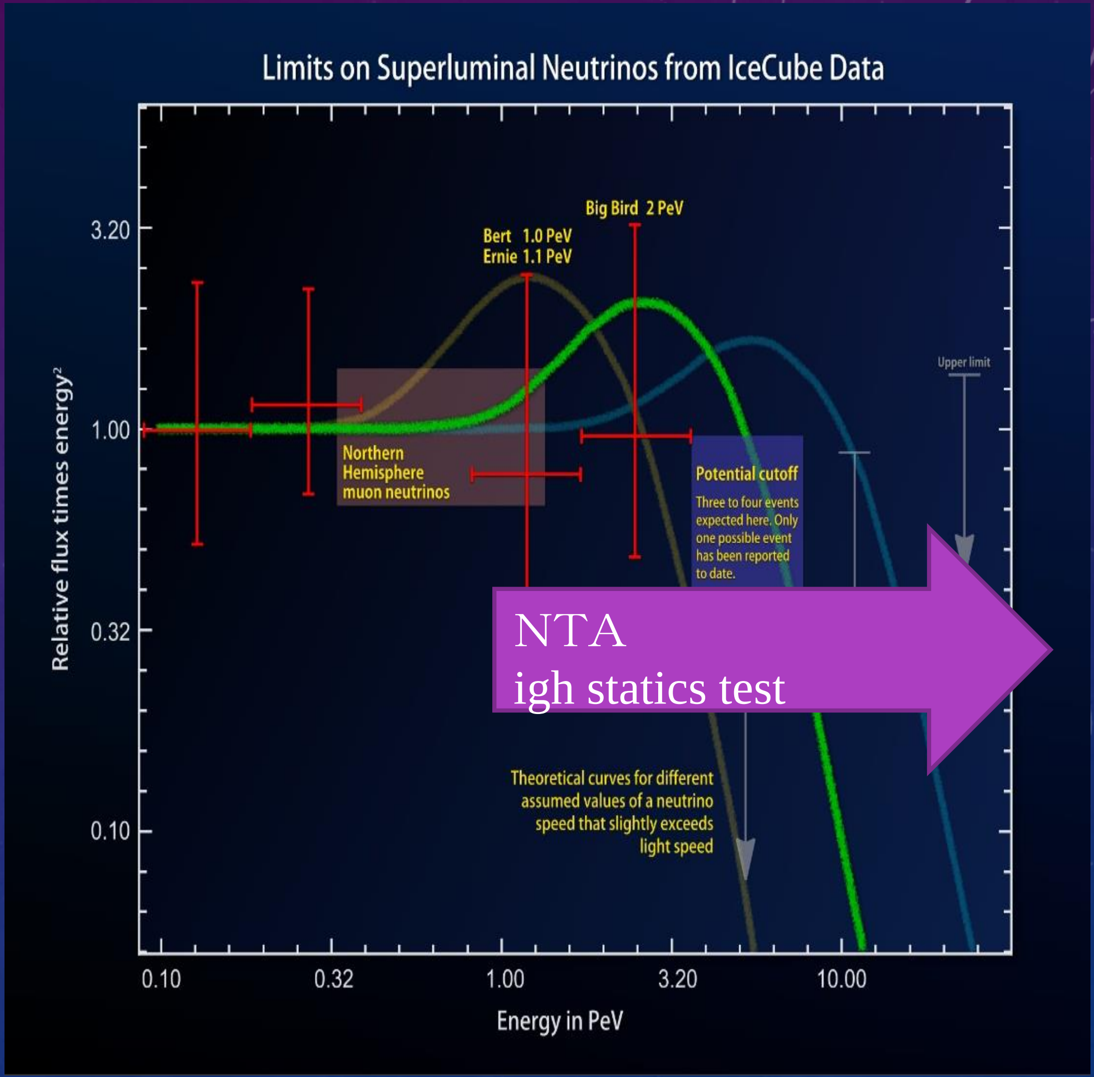
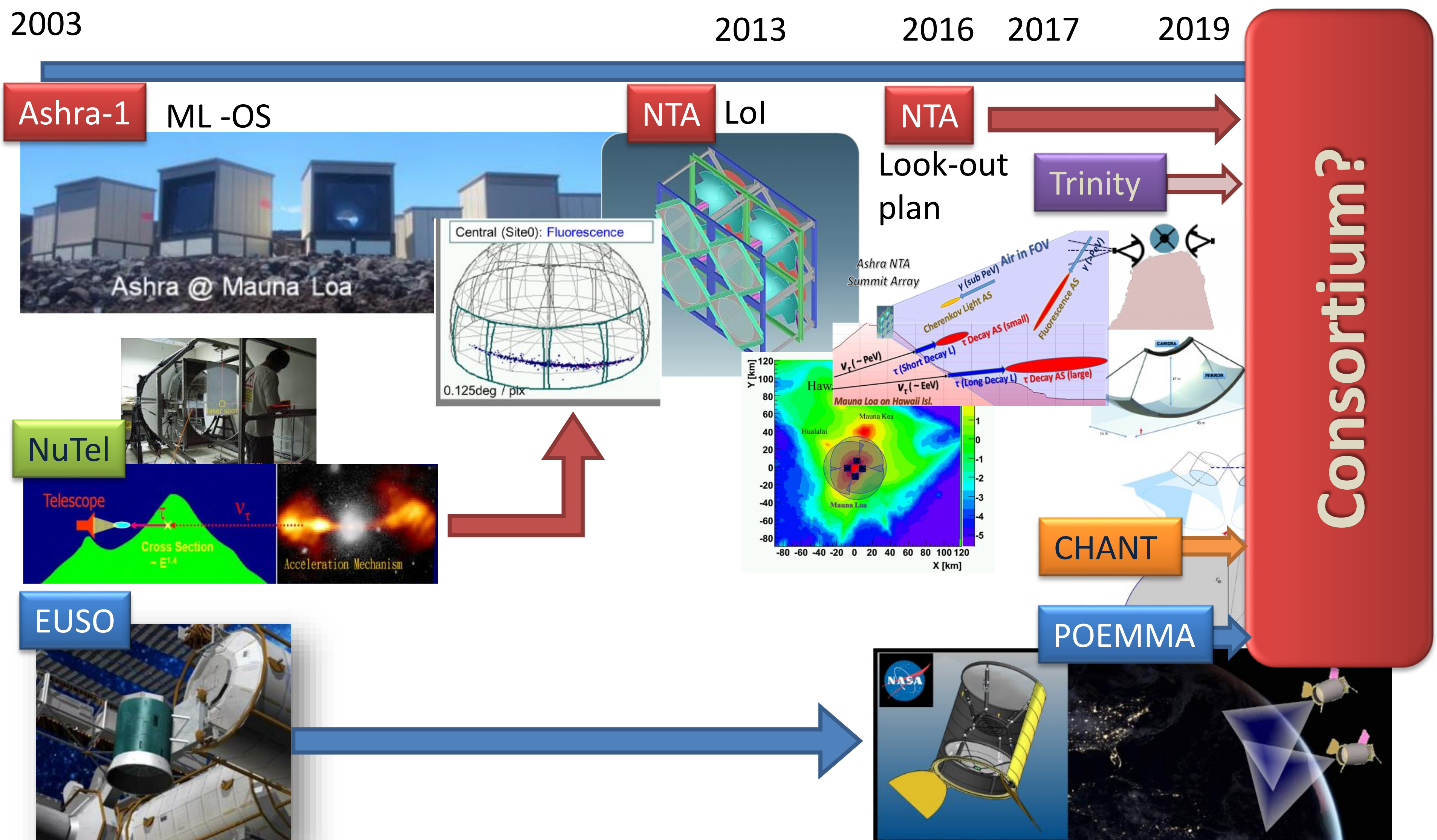
NASA： https://www.nasa.gov/feature/goddard/nasa-goddard-scientist-gives-outlaw-particles-less-room-to-hide

Lorentz Invariance Violation



ES-ν_τ imager Consortium?



Summary

Neutrino Telescope Array is a fairly evolved grandchild of DUMAND and Whipple.

Advantageous sensitivity, accuracy, integrity, and real experience.

Multi-messenger explorer with wide FOV fine imager probing PeV-EeV energy domain with clear determination.

Let’s step forward to global γ-ray & ν telescope array consortium .

NTA