Ashra

ICRR Ex. Rev. 2019

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Toward VHE Particle Astronomy (VHEPA)

Chronology:
1997: TA grand design
2000: Signal Finder / Track Finder FE circuits
2000: PAO started construction
2002: ES-ν_τ FD method published
2002: ES-ν_τ Imager NTA proposed
2002: renamed into Ashra
2003: VHEPA3 WS @ Kashiwa
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 WS @ Kashiwa
2015: VHEPA2015 WS @ Taipei
2016: VHEPA2016 WS @ Honolulu
2016: redesigned NTA (summit layout)
2019: VHEPA2019 WS @ Kashiwa

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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

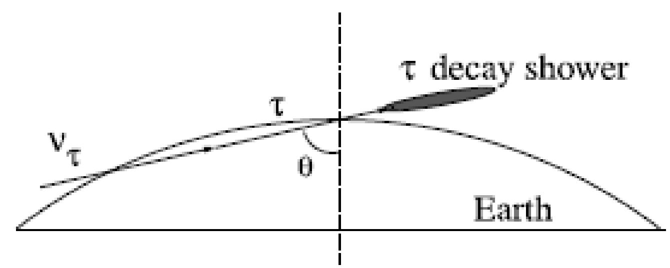
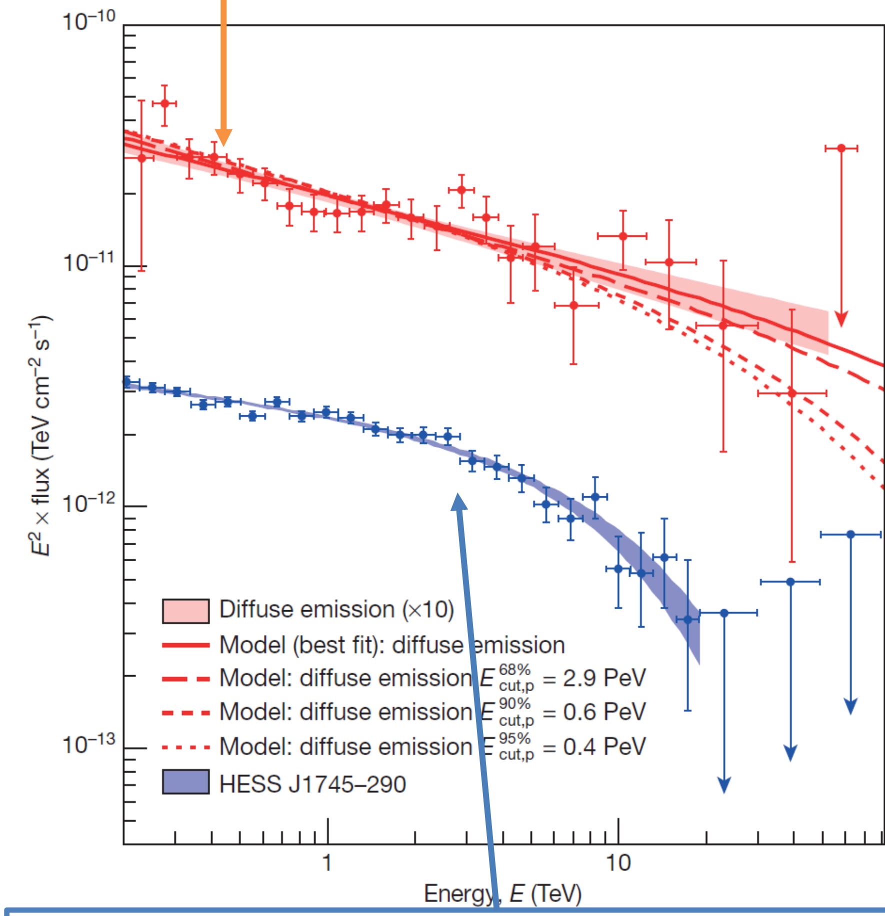


Fig. 7. A schematic picture of Earth-skimming tau neutrino events.

Target Example of VHEPA: Galactic Center

Diffuse emission from the GC without a perceivable cutoff



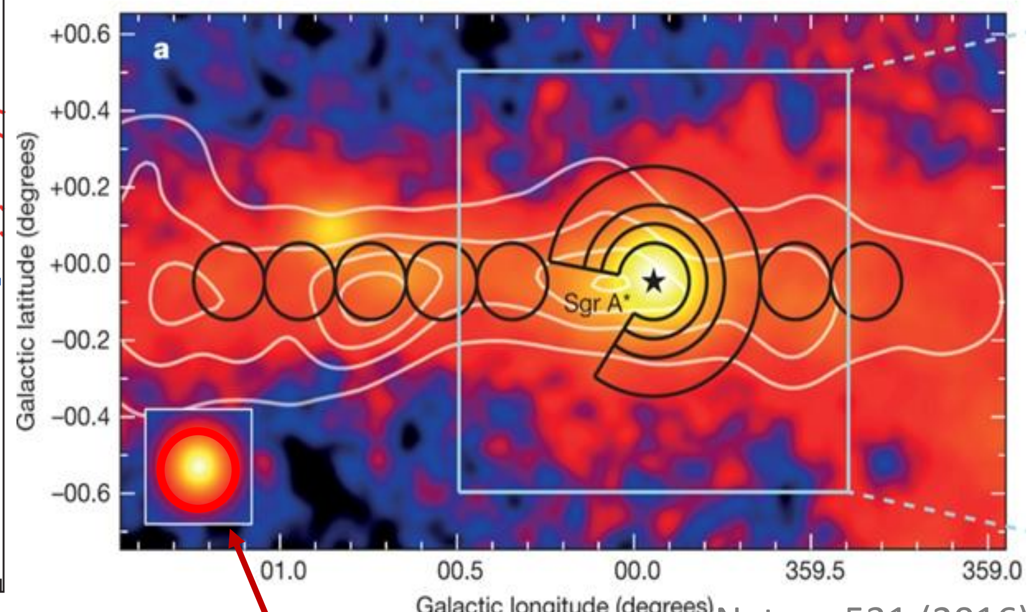
Point source emission with a 10 TeV cut-off

To clearly fix it, the detector is required to:

1) **γ-ray/ν multiple observation**
2) 0.1 deg. resolution like IACT
3) good sensitivity for E_γ > 50 TeV

-> Ashra/NTA meets.

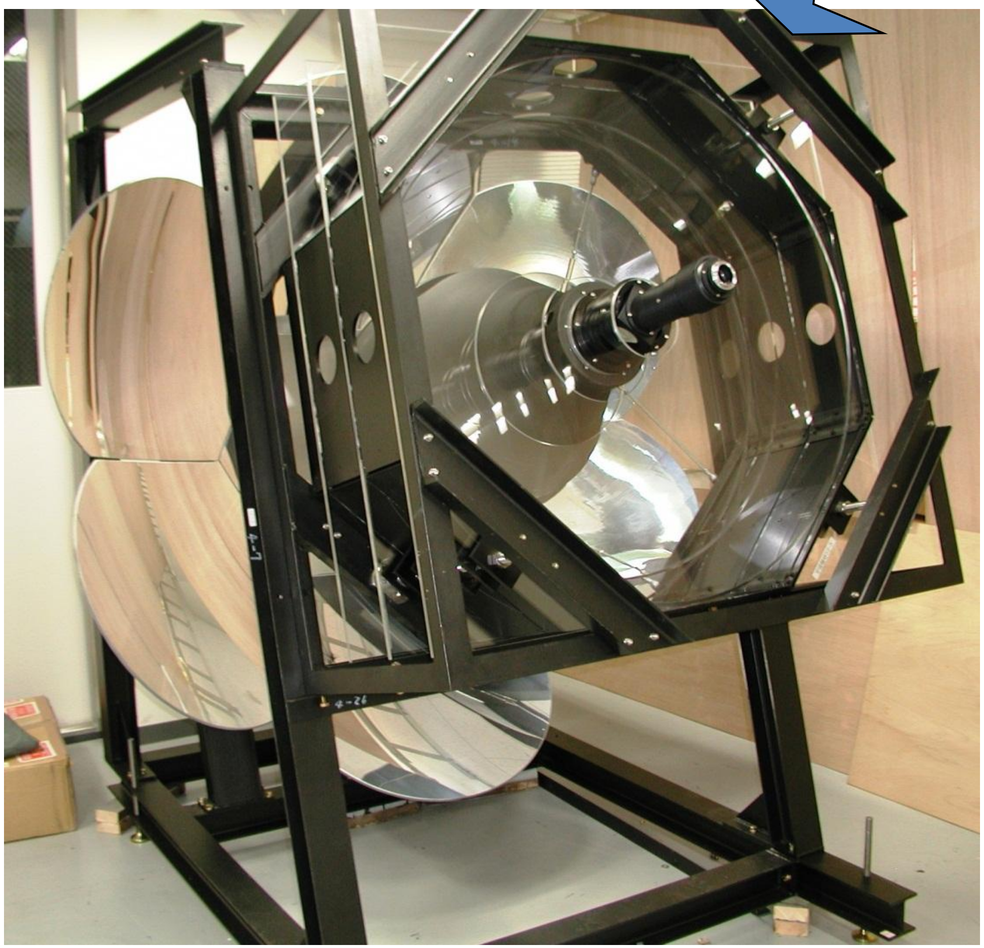
HESS GC observation 227 hours / 10 years
=> Need monitor obs. with wider FOV IACT.

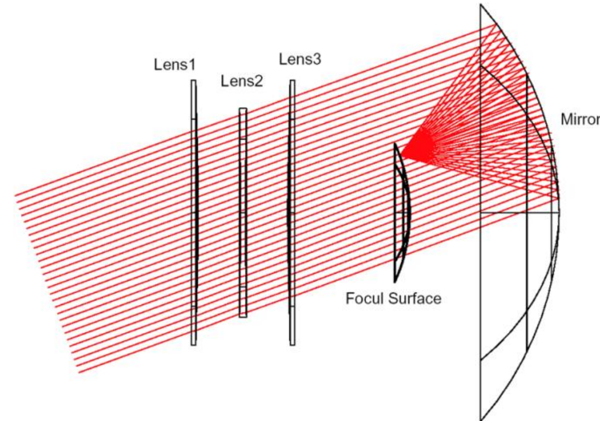


Nature 531 (2016)

HESS PSF

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

=> affordably cost-effective

Ashra-1 Pipeline Trigger & Readout

demonstrated

Same Fine Image to Multiple Triggers

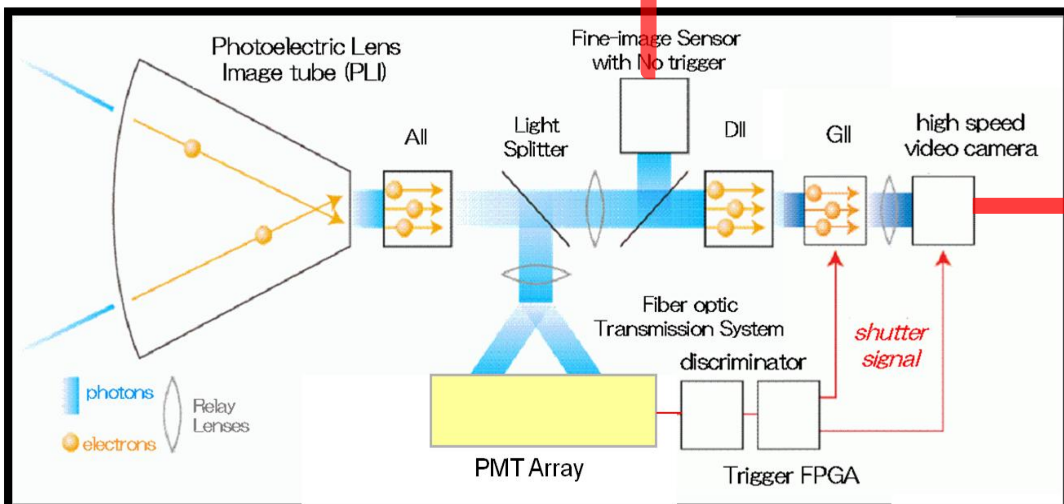
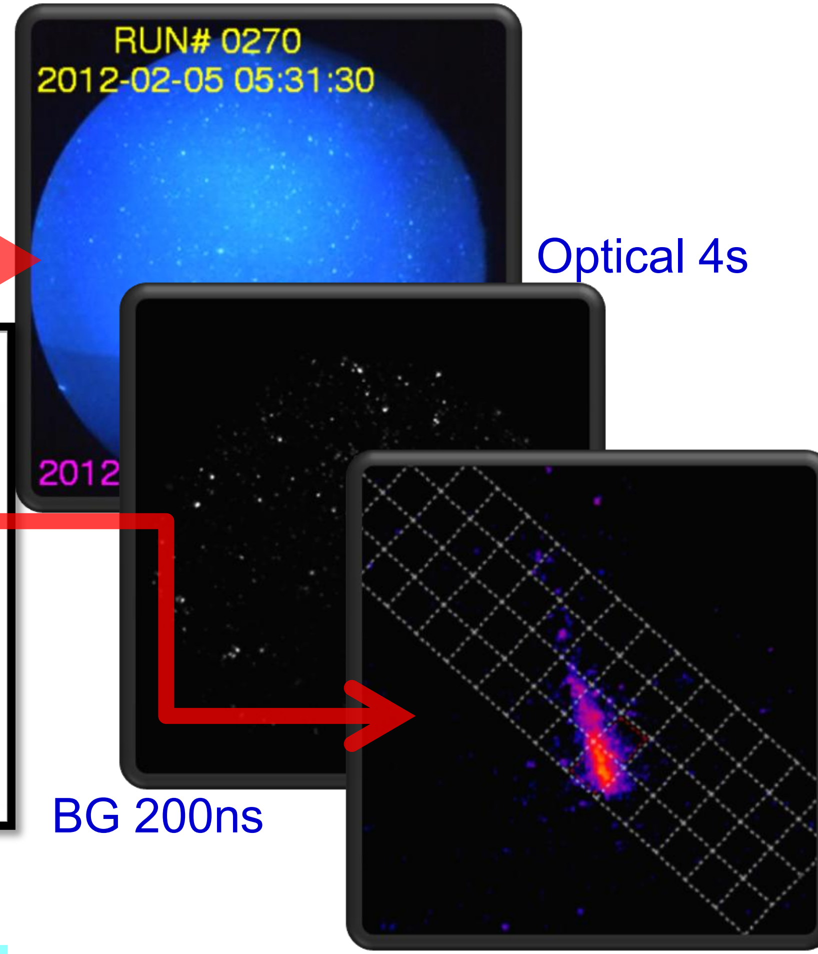


Photo-electric **I**mage **P**ipeline (**PIP**)



Optical 4s

BG 200ns

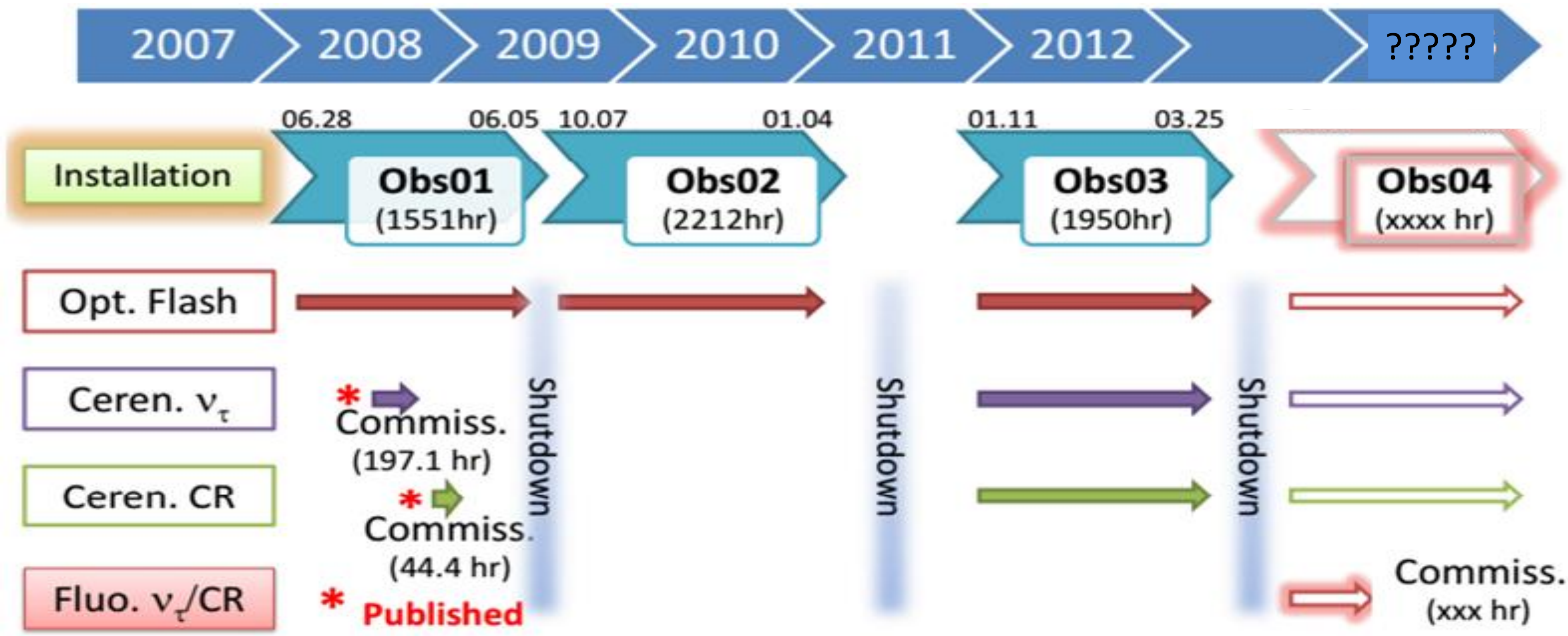
CR 200ns

1st imaging air-shower with self-trigger

Multi-Messenger Approach with
One Detector System

High Pixelation w/ CMOS → Fine Resolution

Ashra-1 Observation Periods

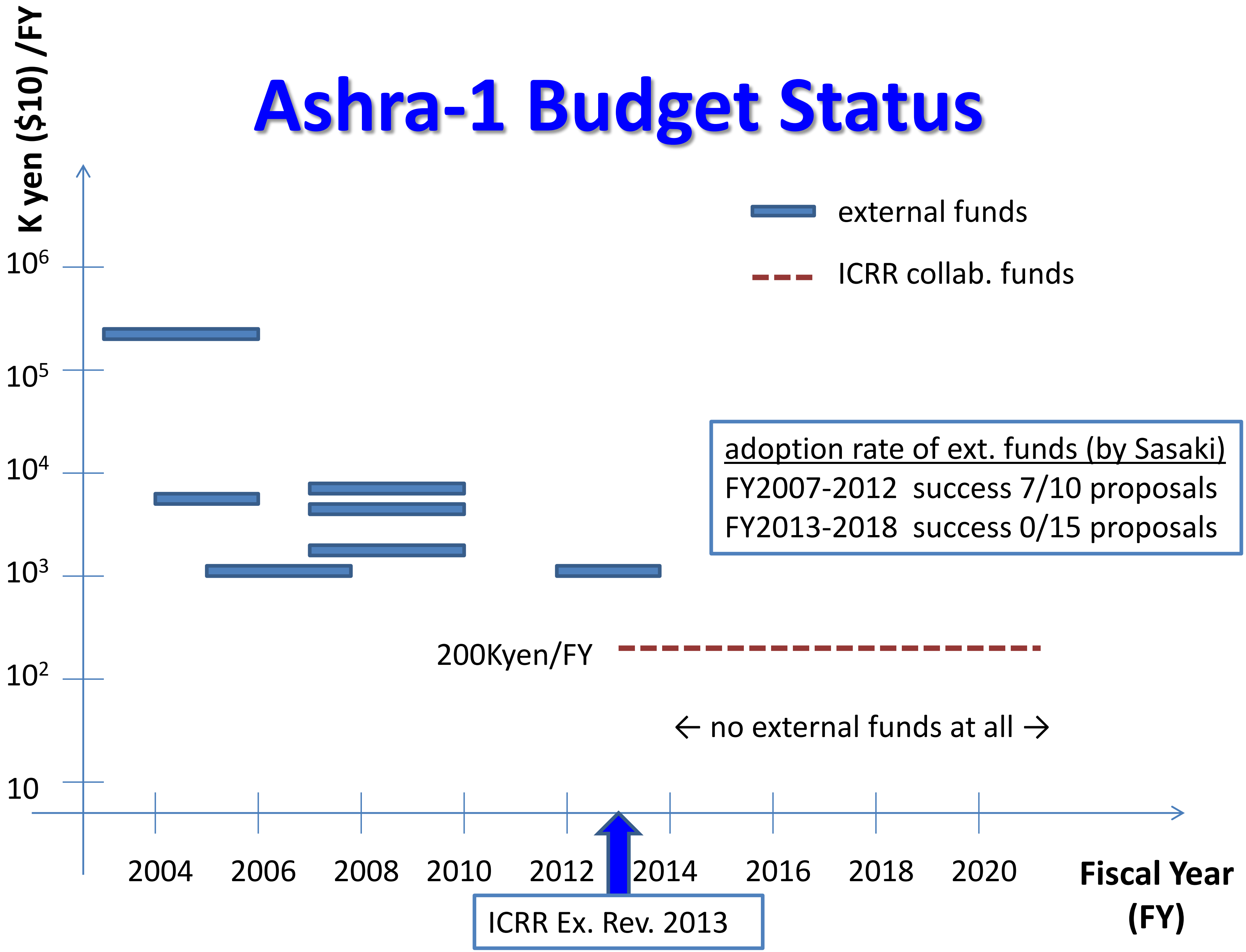


- Total Obs. Time: 5713hr
- Ave. Duty: 19 %

5-faceted
Rain & Fog Monitor

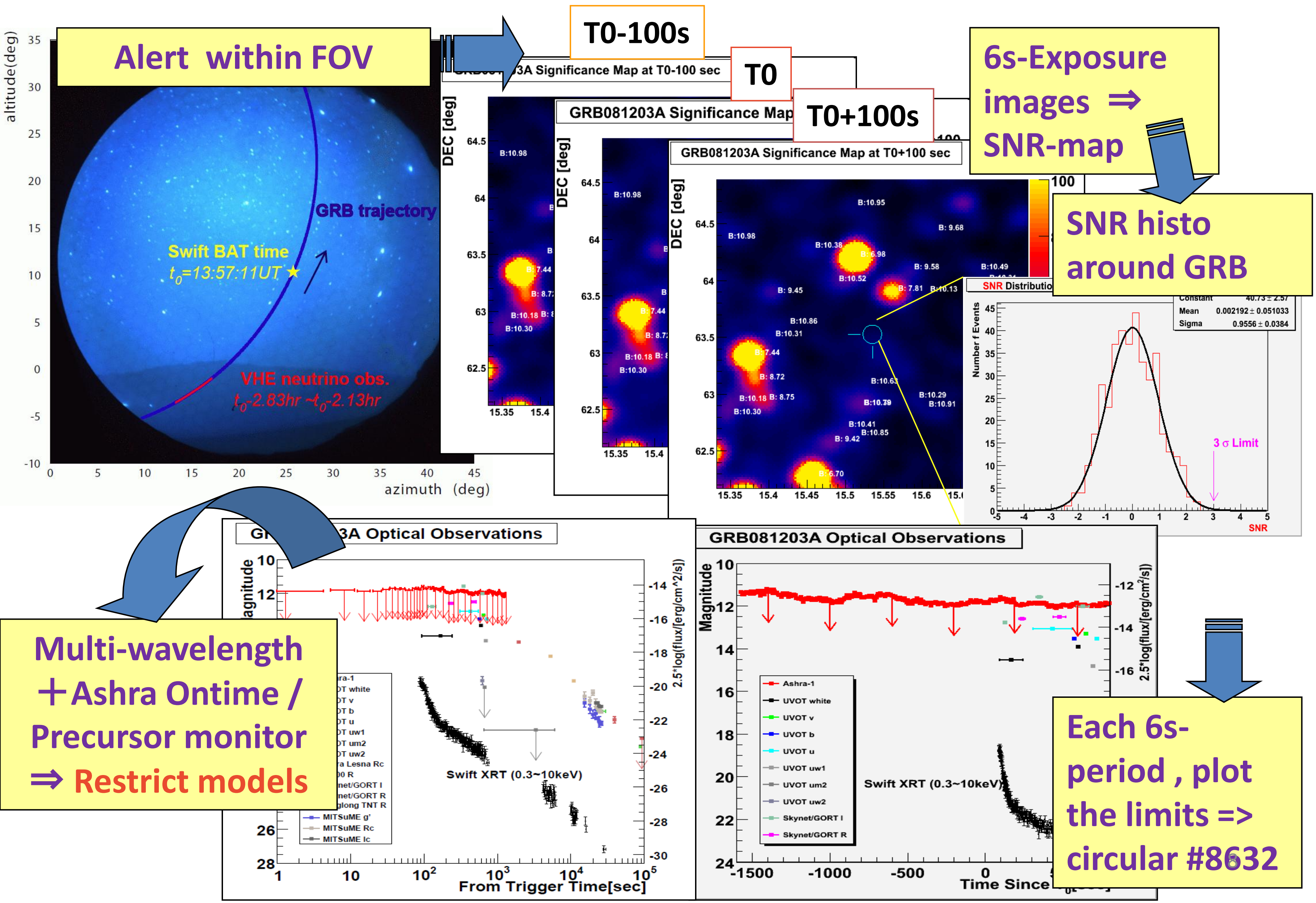
Satellite	GRB Name	$t_{inFOV} - t_0$ [sec]
Swift	GRB081203A	$-1.2\times10^4 - 5.6\times10^3$
Fermi	GRB090428	$-8.1\times10^3 - 5.9\times10^3$
Fermi	GRB090429C	$-4.1\times10^3 - 1.7\times10^3$
Swift	GRB091024	$-1.6\times10^3 - 3.3\times10^2$
Fermi	GRB100216A	$-4.0\times10^3 - 1.1\times10^4$
Swift	GRB100906A	$-1.0\times10^4 - 4.0\times10^3$
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



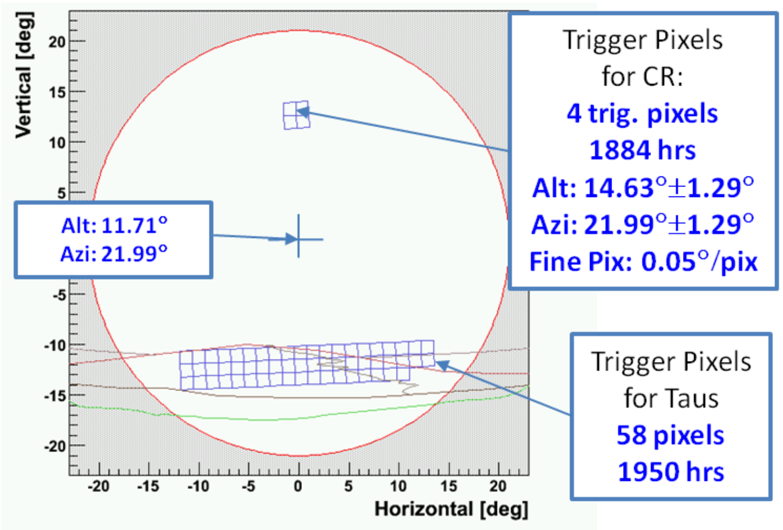
Ashra-1 Budget Status
K yen ($10) /FY
external funds
ICRR collab. funds
10^6
10^5
10^4
10^3
10^2
10
adoption rate of ext. funds (by Sasaki)
FY2007-2012 success 7/10 proposals
FY2013-2018 success 0/15 proposals
200Kyen/FY
← no external funds at all →
2004
2006
2008
2010
2012
2014
2016
2018
2020
Fiscal Year (FY)
ICRR Ex. Rev. 2013

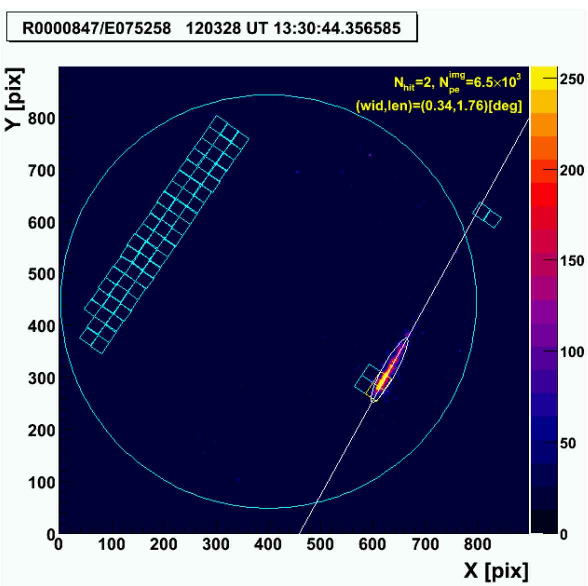
GRB Optical Flash Search (GRB081203A)

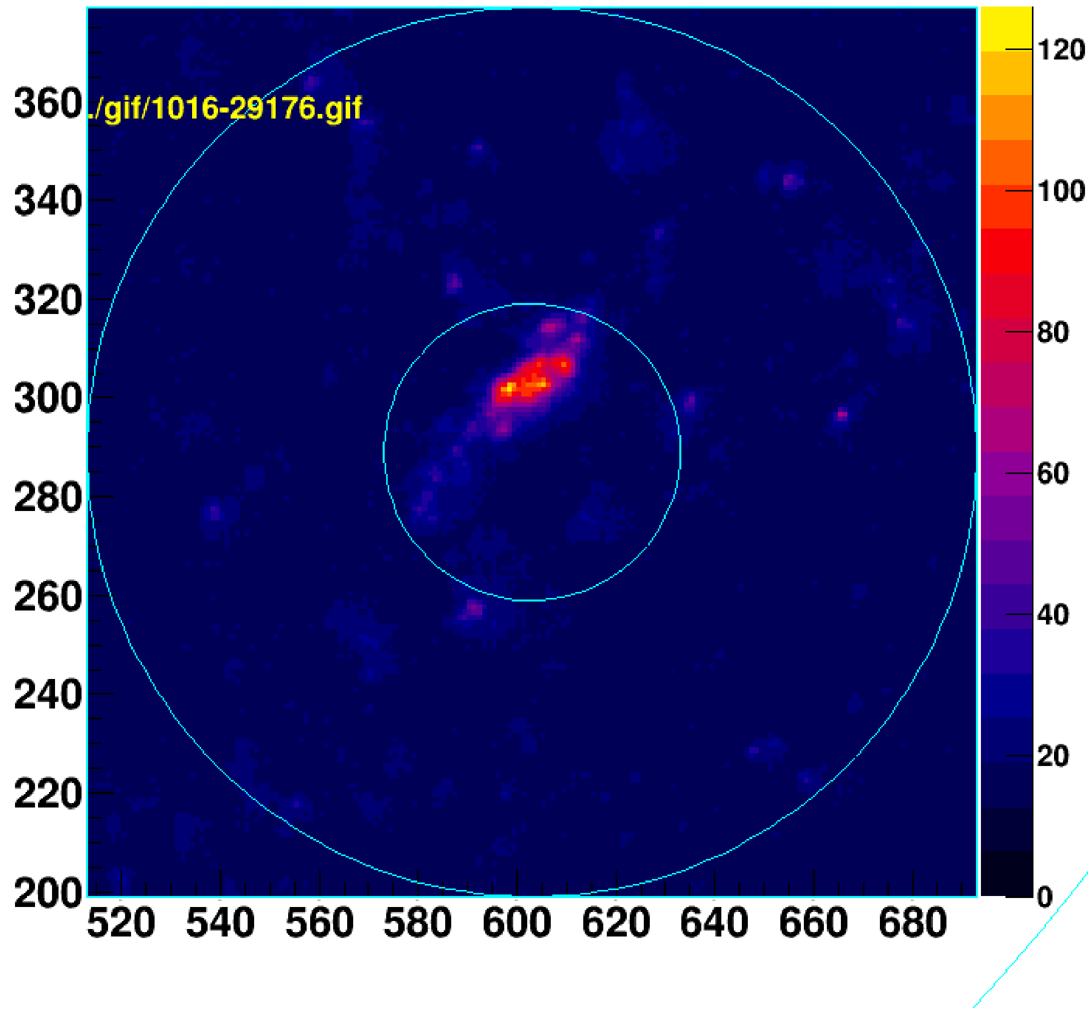


AS Cerenkov Images taken by Ashra-1

Obs03 (2012-2013):





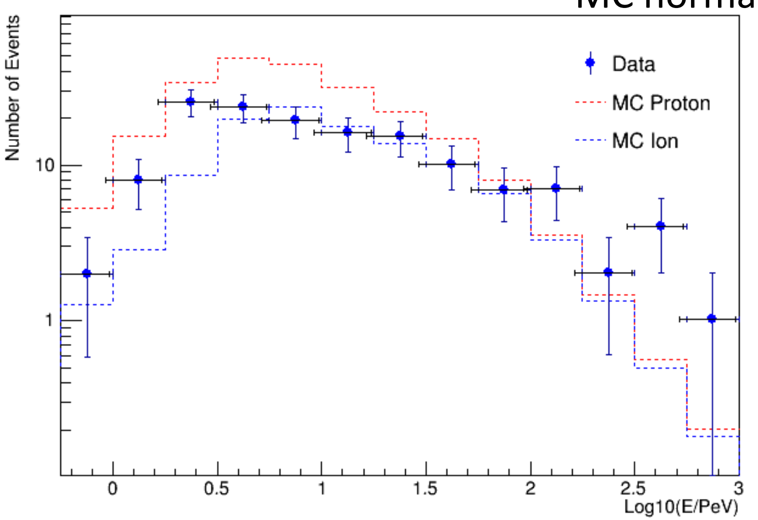


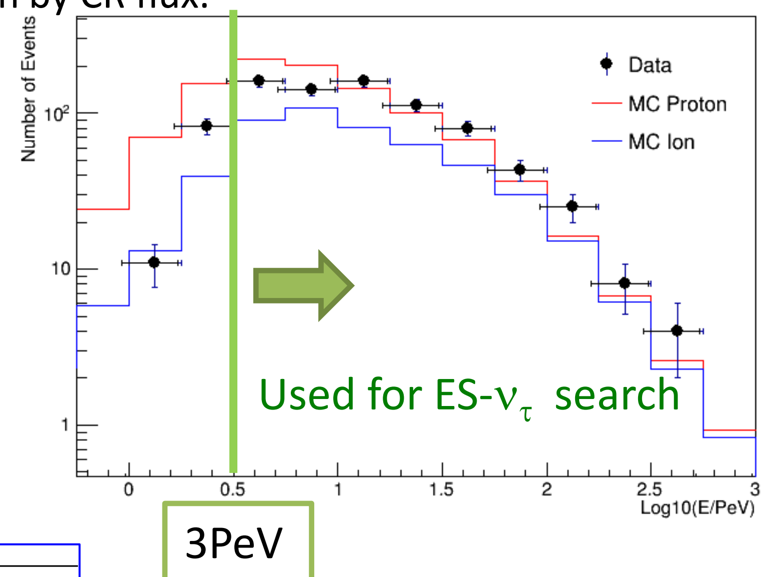
CR Observed Energy Spectrum

Obs01 events

Obs03 events

MC normalization by CR flux.

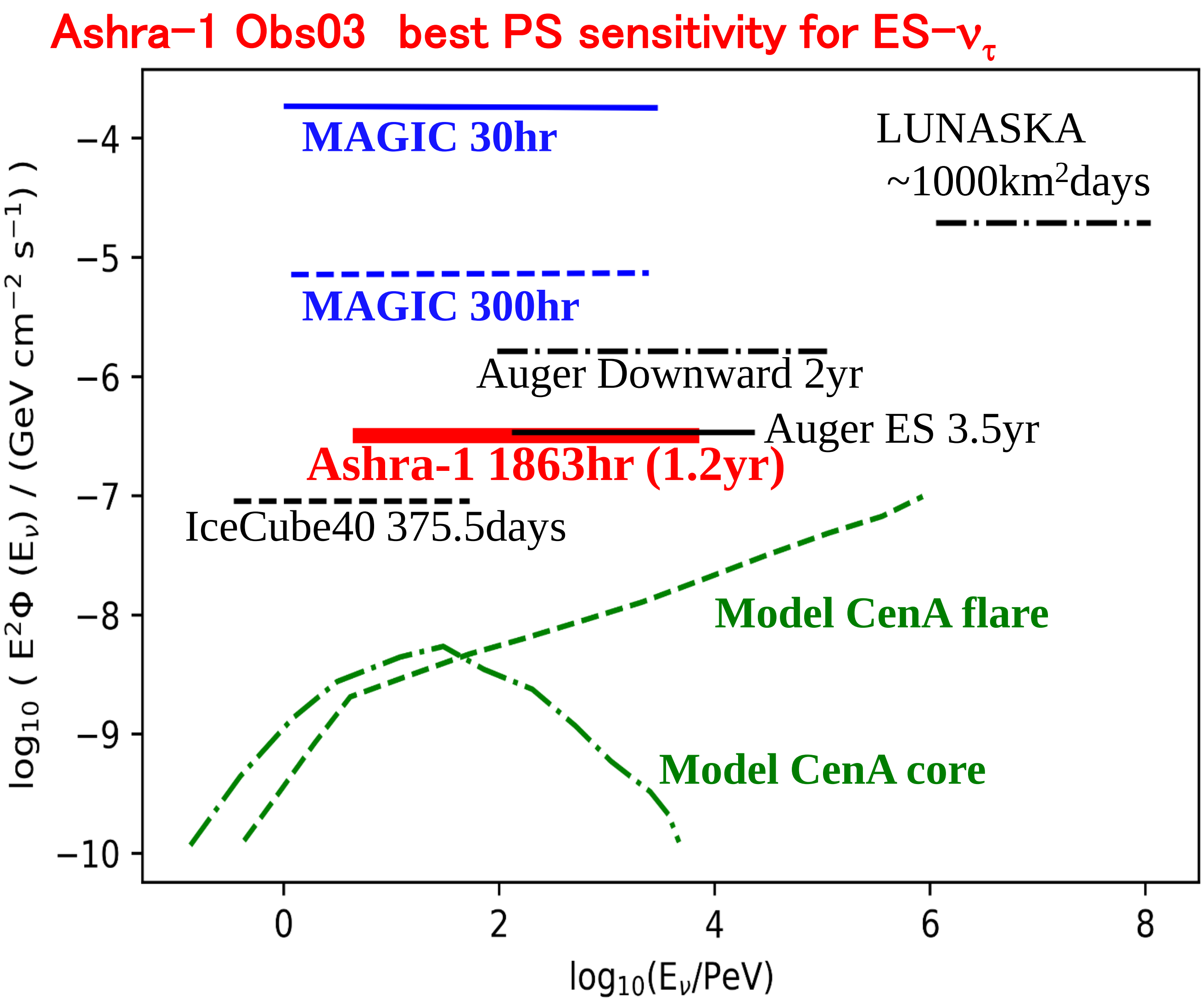




Source of Systematics	Error [%]
Trigger Threshold	19
Atomsphere & Optics	21
DAQ Efficinecy	6.3
Weather Condition	6.4
Sensitivity Total	30
Fine Image Gain	30

→ Will be negligible by using a LED flasher calibrator.

Comparison of ES Tau Neutrino Flux Limits



Auger (2012).
GI-Astro-Ph.HE, 1–21.

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

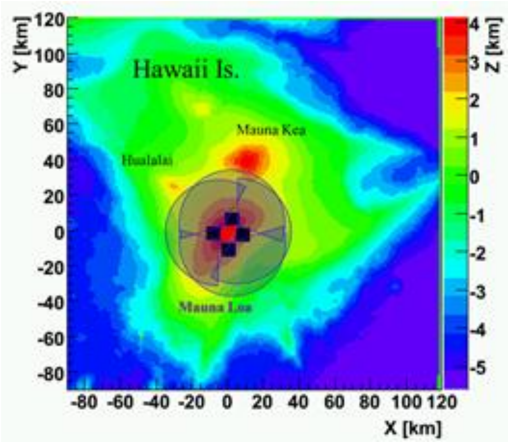
LUNASKA (2011).
MNRAS 410(2), 885–889.

IceCube (2011).
ApJ 732(1).

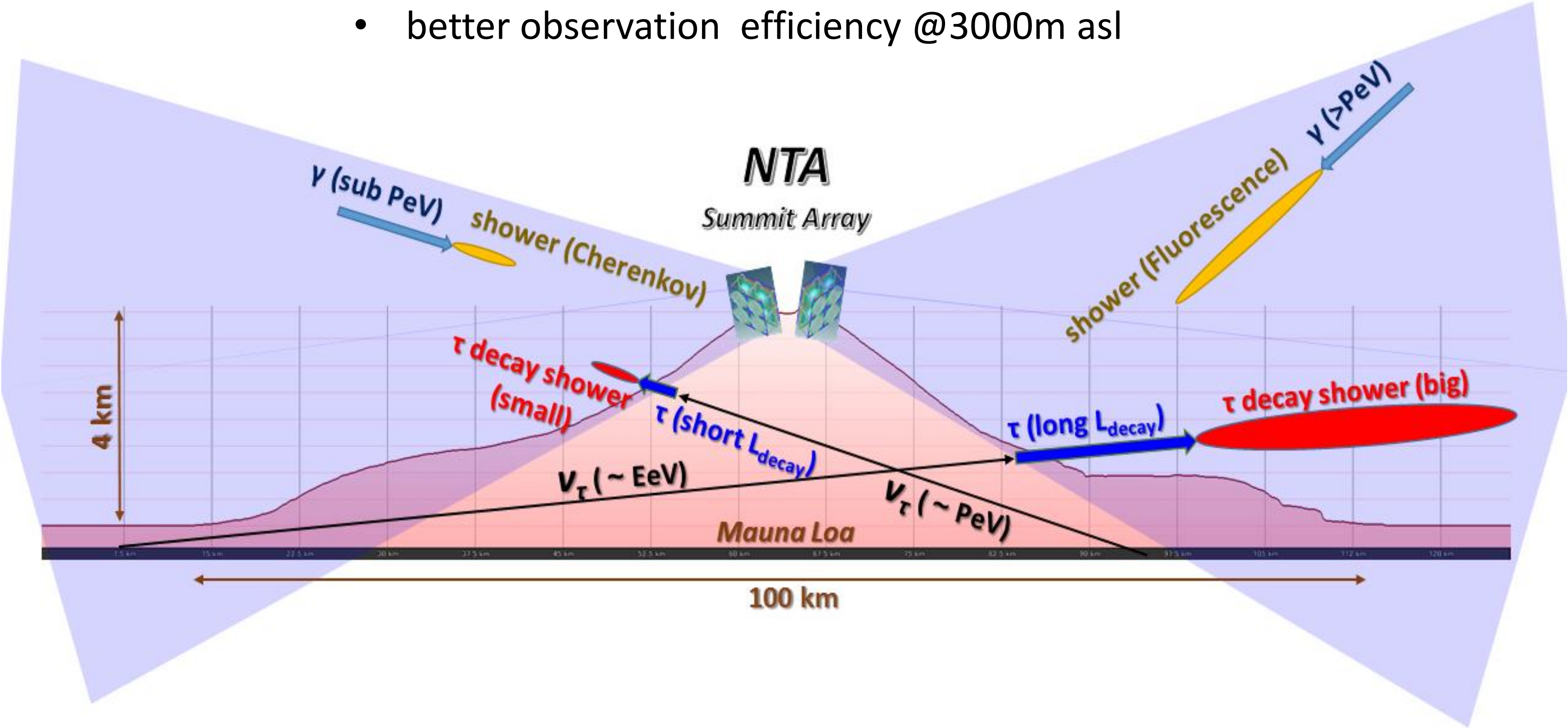
Cuoco (2008).
PRD 78(2), 1–5.

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

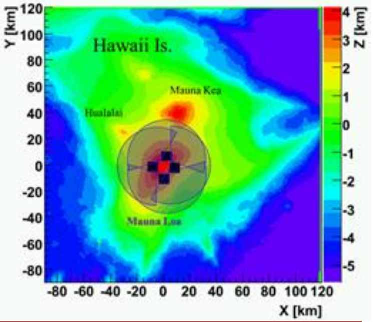
NTA summit array detection of ν / γ-ray / CR



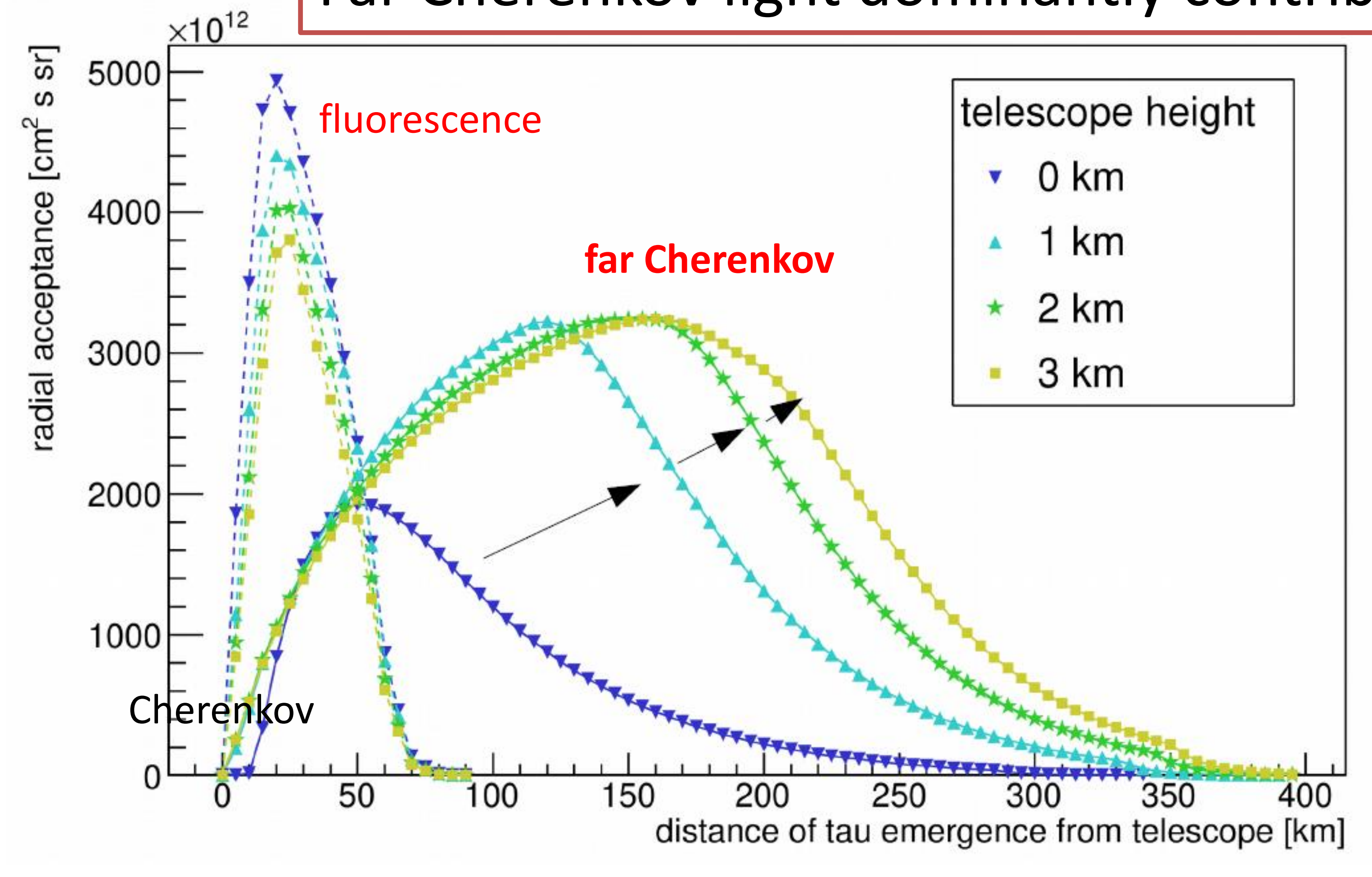
- τ decay length: $L_\tau \sim 50\text{m}\,(E_\tau/\text{PeV})$
  ⇒ can watch nearler 1～10PeV AS max
- lower detection E thereshold
- better observation efficiency @3000m asl



ES ν_τ Acceptance with fluorescence & Cherenkov

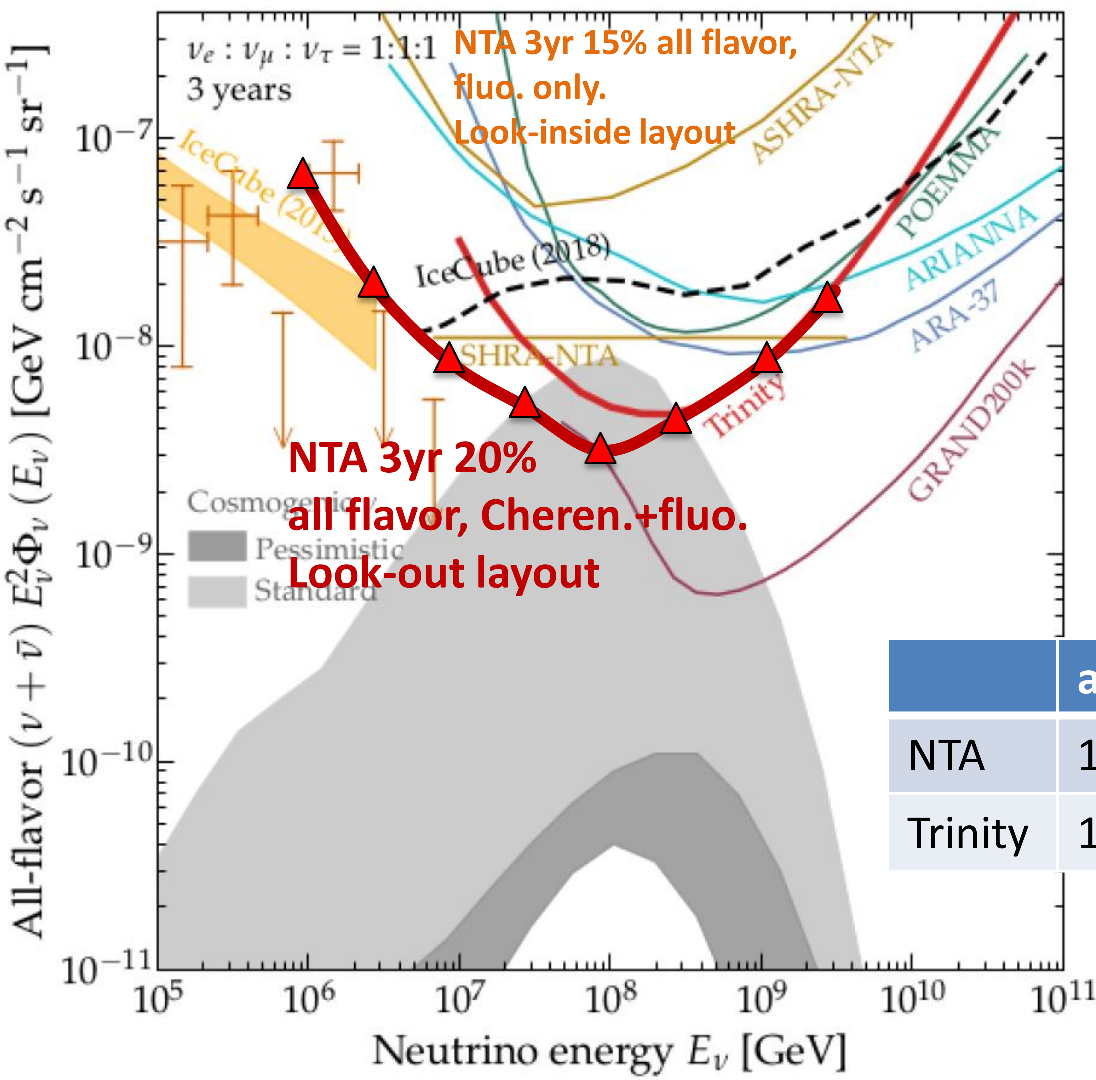


Far Cherenkov light dominantly contributes.



Otte arXiv:1811.09287

NTA diffuse ν sensitivity: with Cherenkov & fluorescence light



NTA most sensitive for 1PeV-100PeV ν

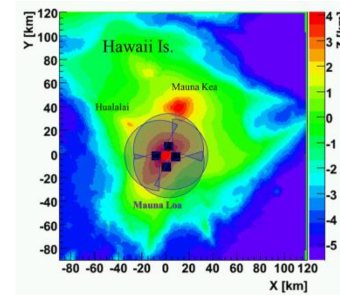
Clear test:
IceCube PeV ν extension
Cosmogenic ν

NTA can not lose to Trinity with sensitivity

	aper.	height	Fov	Resol.
NTA	10 m^2	3 km	360° x30°	0.125°
Trinity	10 m^2	2 km	360° x 5°	0.3°

Roads to NTA

Ashra-1 → NTA



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

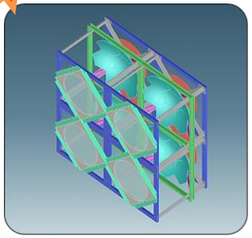
NTA — request | R&D, prototype, partially construction | observation

Int. observation center

6+4 units GCγ +ν monitor

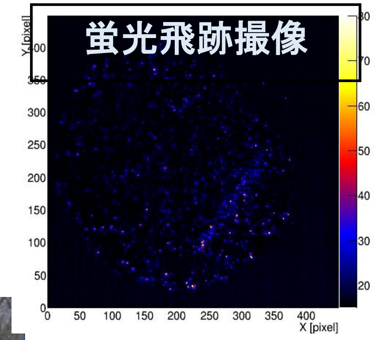
6units GCγ monitor

Obs.04



Ashra-1 — Test obs./ Physics obs. / establish auto-operation・data flow・analysis

Int. demonstration site

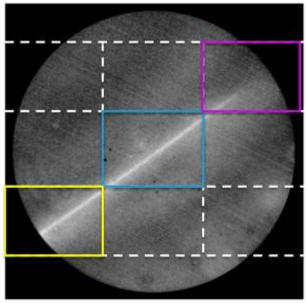


Akeno — assembly/laser obs./ aging. long-term test

Domestic development center

Laboratories

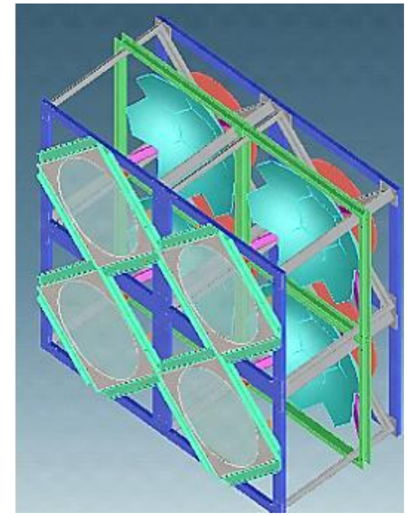
element development, test



トリガー撮像を行った画像

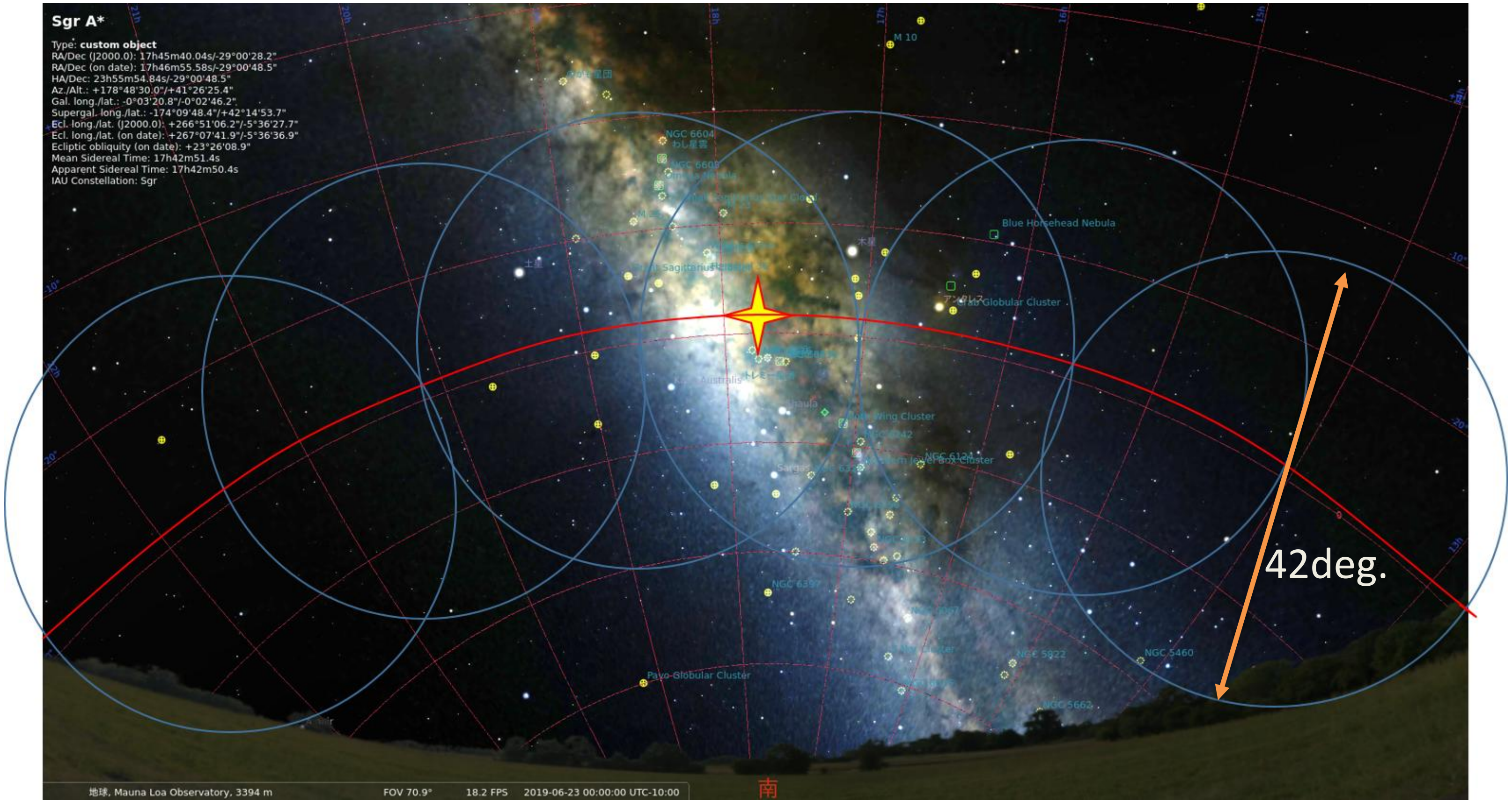
NTA detector unit proto testing triggers

NTA detector unit proto



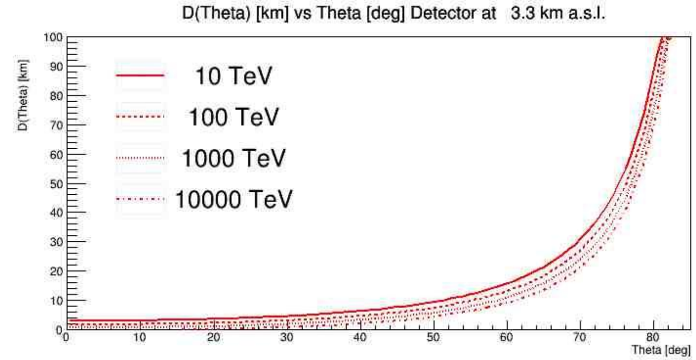
Trigger/readout test with YAG laser pulses

Layout of Ashra-1 FOVs in Obs.4



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.

Advantage of Ashra-1/NTA imaging GC γ



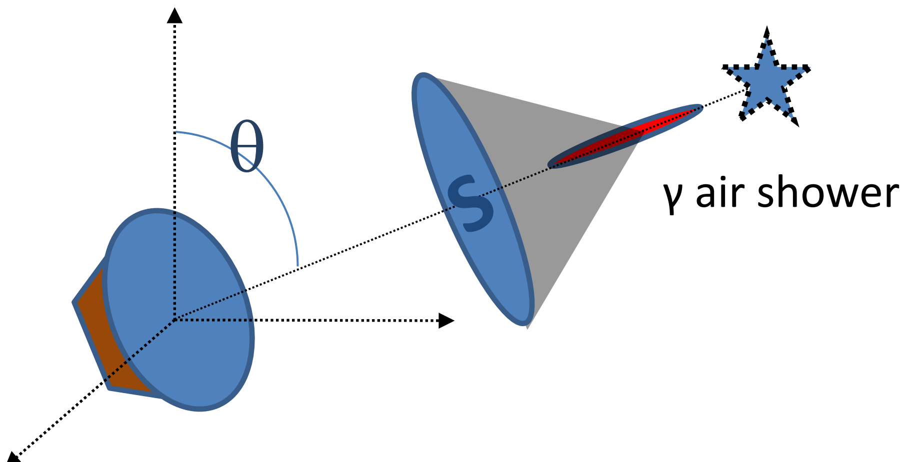
Ashra-1/NTA

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

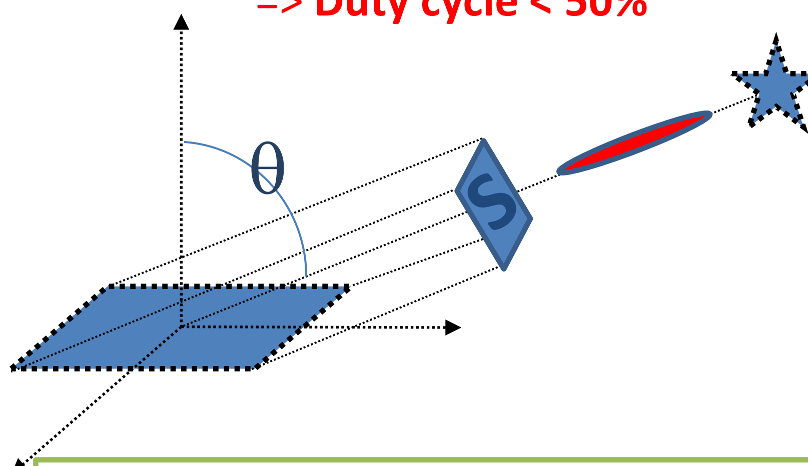
$S = S_0 \cos\theta$

Shower particle electron：

severe attenuation

=> Only effective θ < 45°

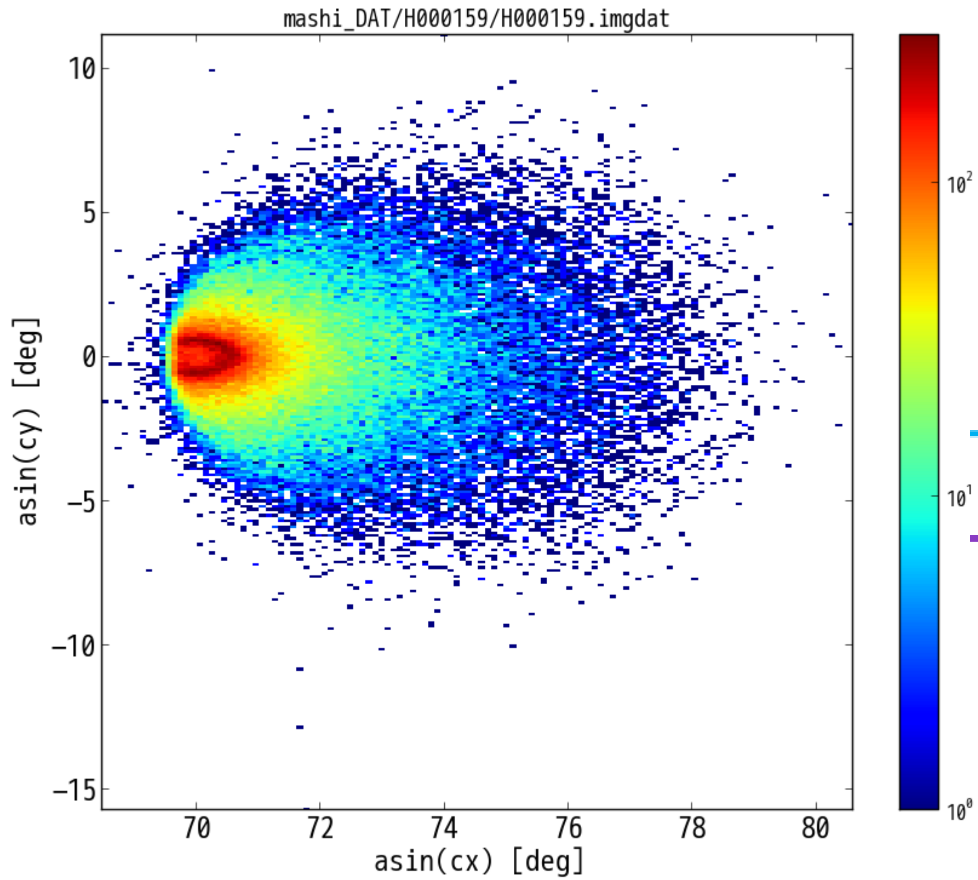
=> Duty cycle < 50%

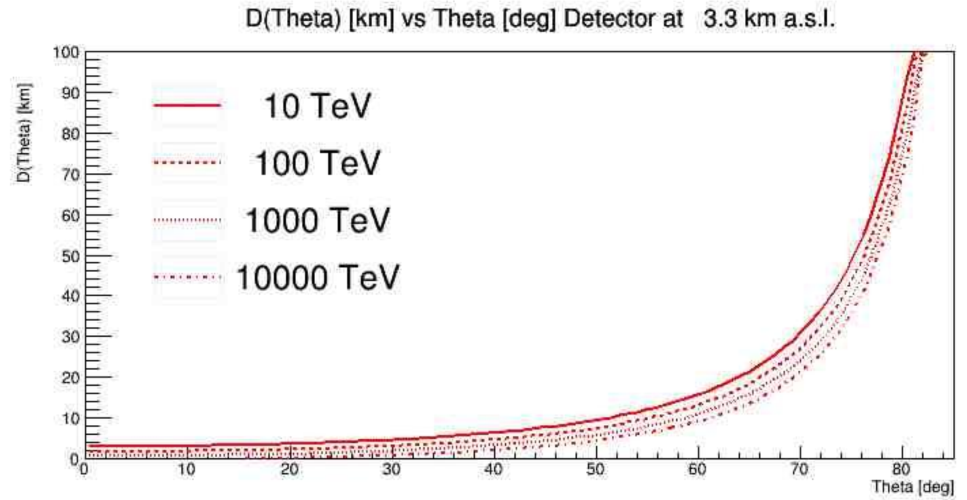


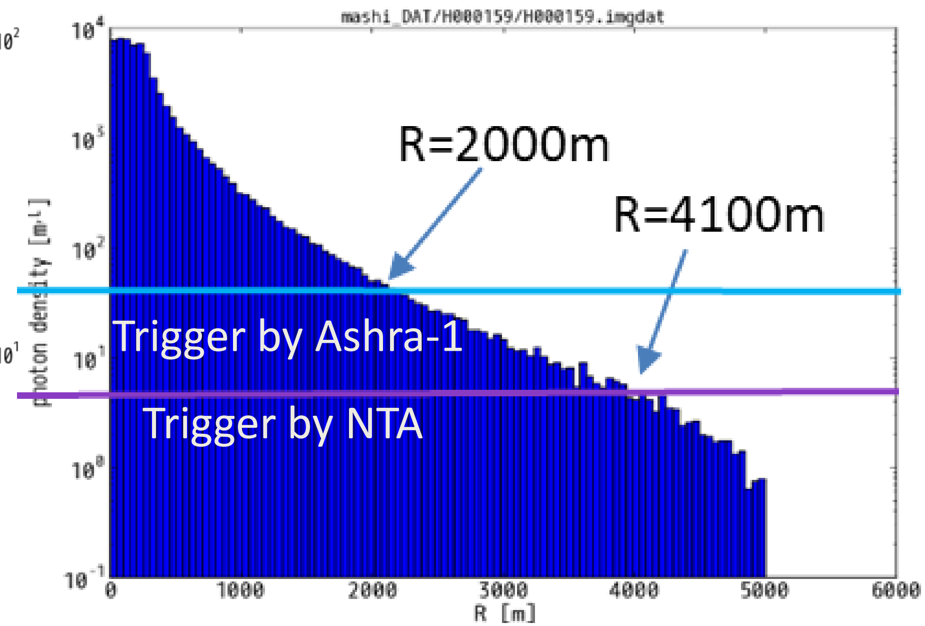
T = 2300 hr/yr (θ < 45°) @S. lat.16 deg

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

70 deg. γ-ray AS features



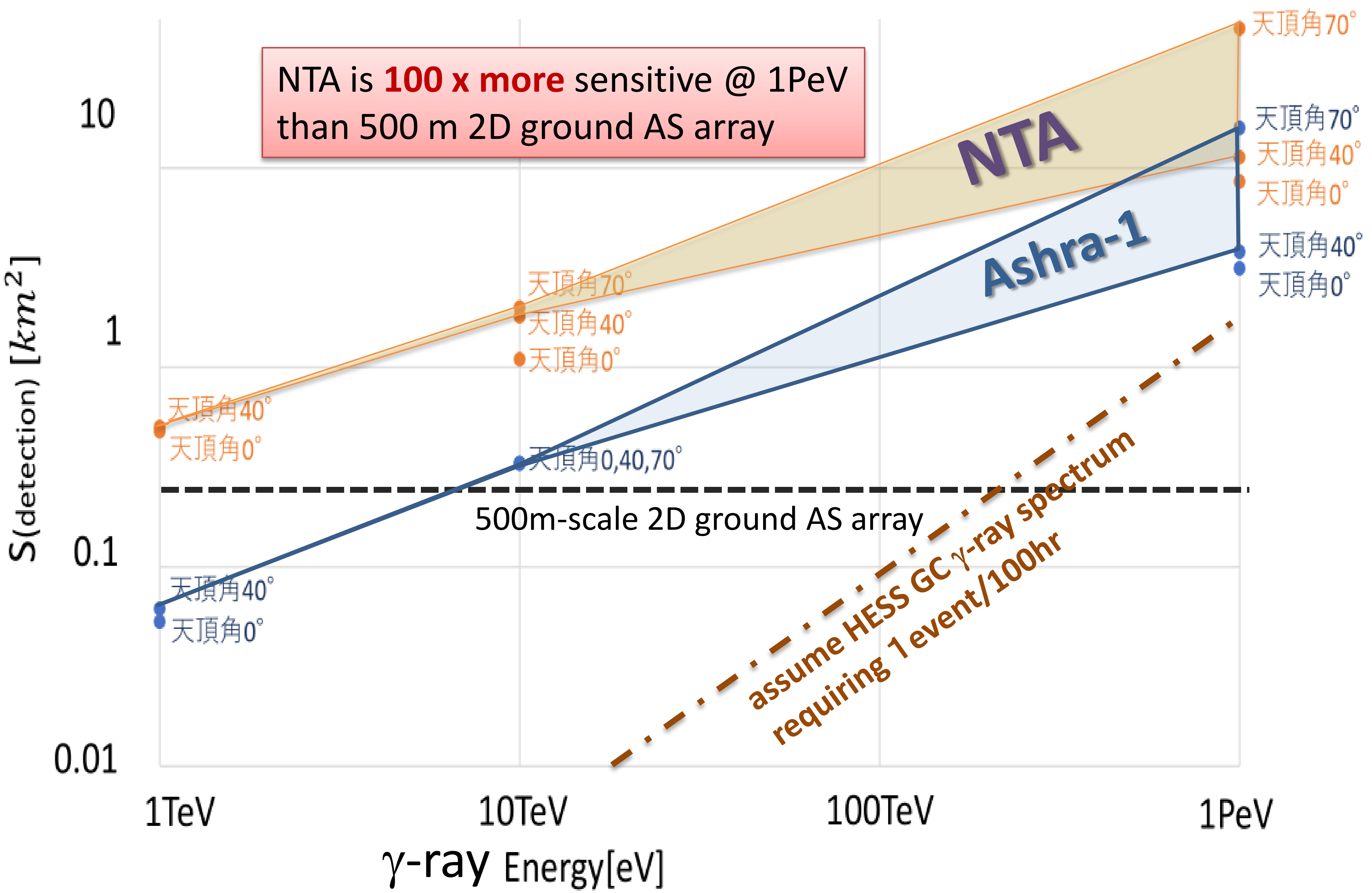




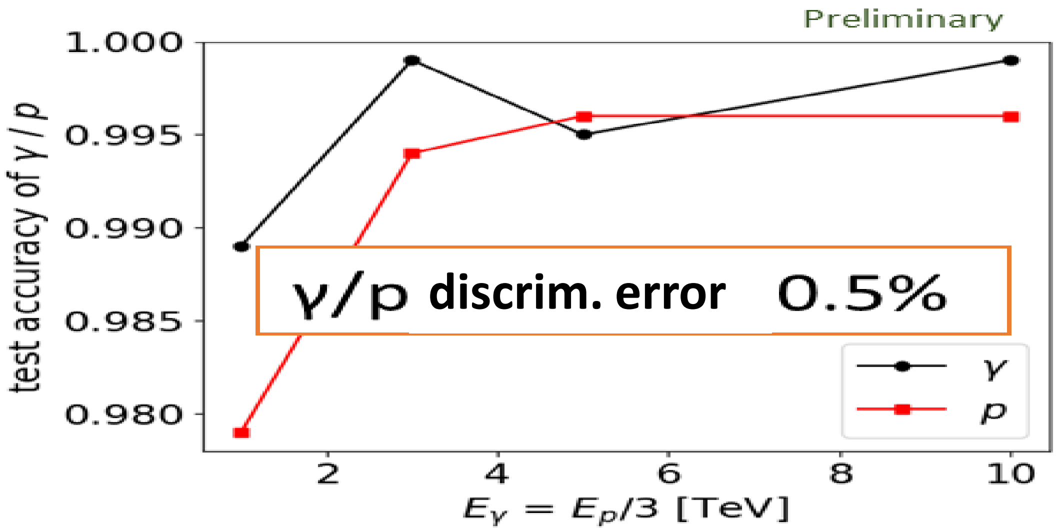
NTA eff. detection area 50 km^2

Ashra-1 eff. detection area 13 km^2

GC γ-ray Effective Detection Area vs Energy



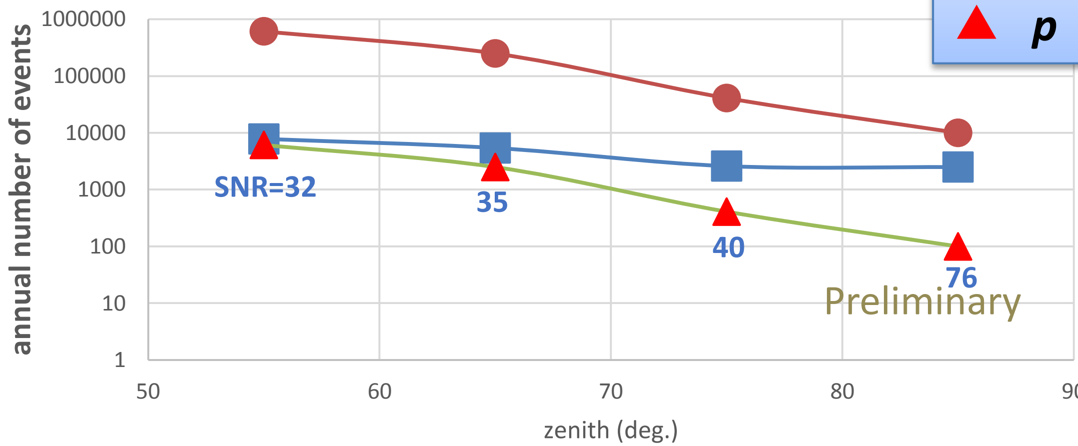
Deep Learning γ/CR Separation in GC monitor



(M.Sasaki JPS2017A)

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

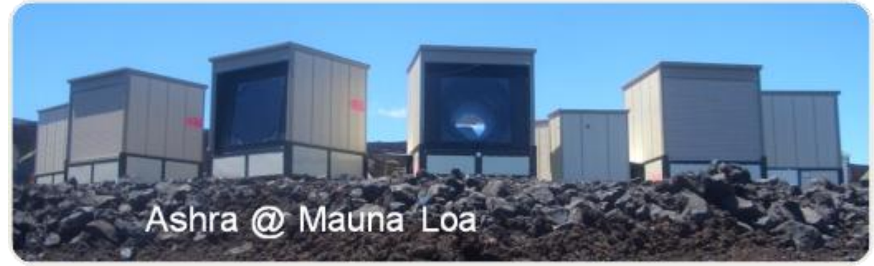
Ashra-1 Galactic ridge monitor
4deg. X 40deg. region



- ***γ*** assum same γ flux as IceCube ν flux
- ***p*** without DL discrim.
- ***p*** after DL discrim.

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

Conclusions



- Ashra/NTA: the 1st to realize VHEPA with γ and ν_τ
- Successfully demonstrated the unique features:
  - IACT resolution (0.1deg) covering GC buldge (40deg)
  - Simultaneous DAQ for Ceren., fluo. AS, and opt. transient images
  - CR spectrum, 1st ES-ν_τ search, 1st search for optical precursor …
- Obs.4: monitoring GC bulge Ceren. γ-rays
  - Large zenith method => larger light pool diameter at higher energies
  - Clearly settle the HESS extended spectrum
    => Discovery of "UHE" γ-rays from Pevatron.
  - Diffuse γ-ray region (even 4deg x 40deg) can be identified using DL.
- Must eliminate budget exhaustion since 2013 asaps.
- NTA to look out at the summit: enjoys huge acceptance for far Ceren. ES-ν_τ events. => the best ν sensitivity in PeV-EeV region with IACT reso.
  - Testing NTA proto at Akeno mainly for demonstration the fluo. trigger.