NTA

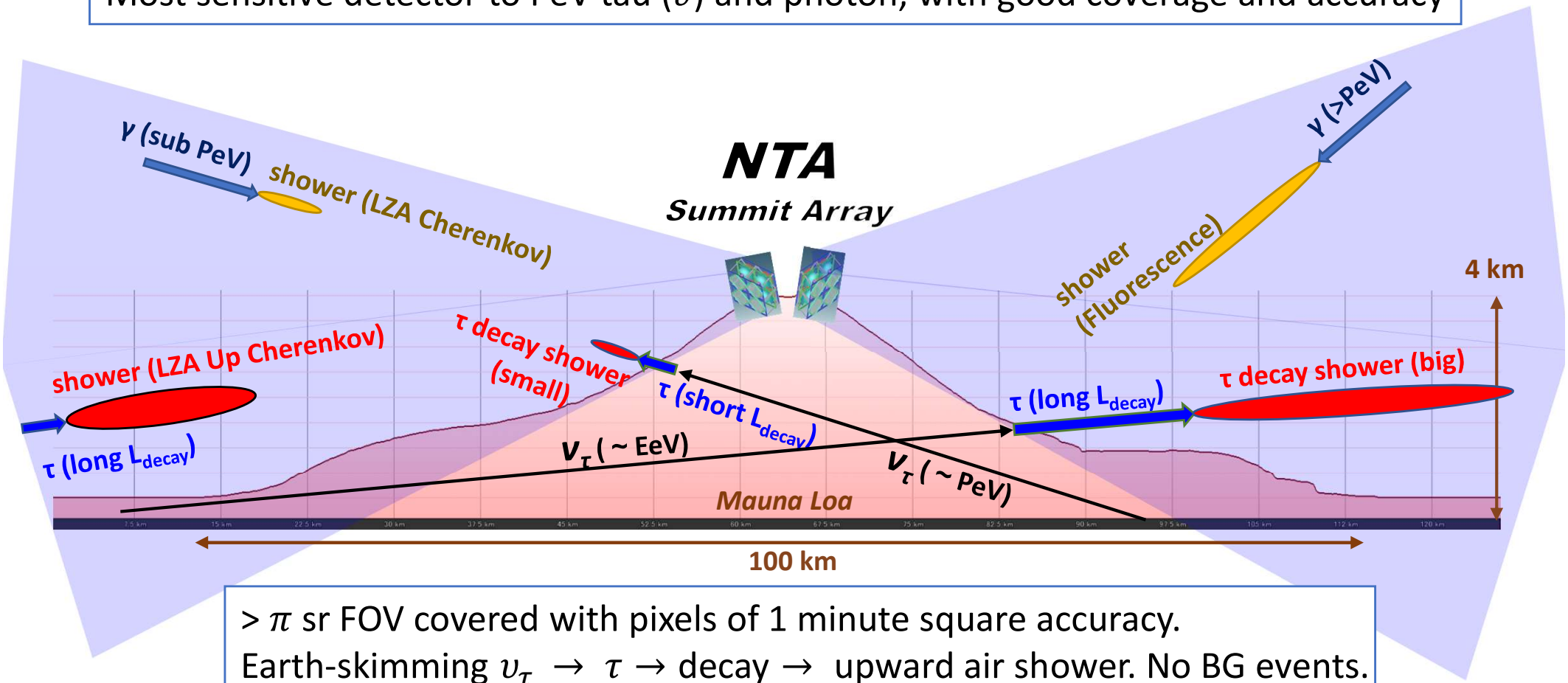
Very High Energy Physics and Astronomy with Tau and Photon Probes

Makoto Sasaki

UTokyo

Detection of VHE Tau and Photon

Most sensitive detector to PeV tau (υ) and photon, with good coverage and accuracy



> π sr FOV covered with pixels of 1 minute square accuracy.
Earth-skimming $\upsilon_\tau \rightarrow \tau \rightarrow$ decay $\rightarrow$ upward air shower. No BG events.
VHE photon air shower induced LZA Cherenkov → large effective area.
Look-out layout allows for lower E thres. Fluo. And LZA Cherenkov

NTA LOI (look-in layout array), M. Sasaki and G. W.-S. Hou, ArXiv:1408.6244 (2014).
NTA look-out layout summit array, M. Sasaki— PoS (ICRC2017) 941.

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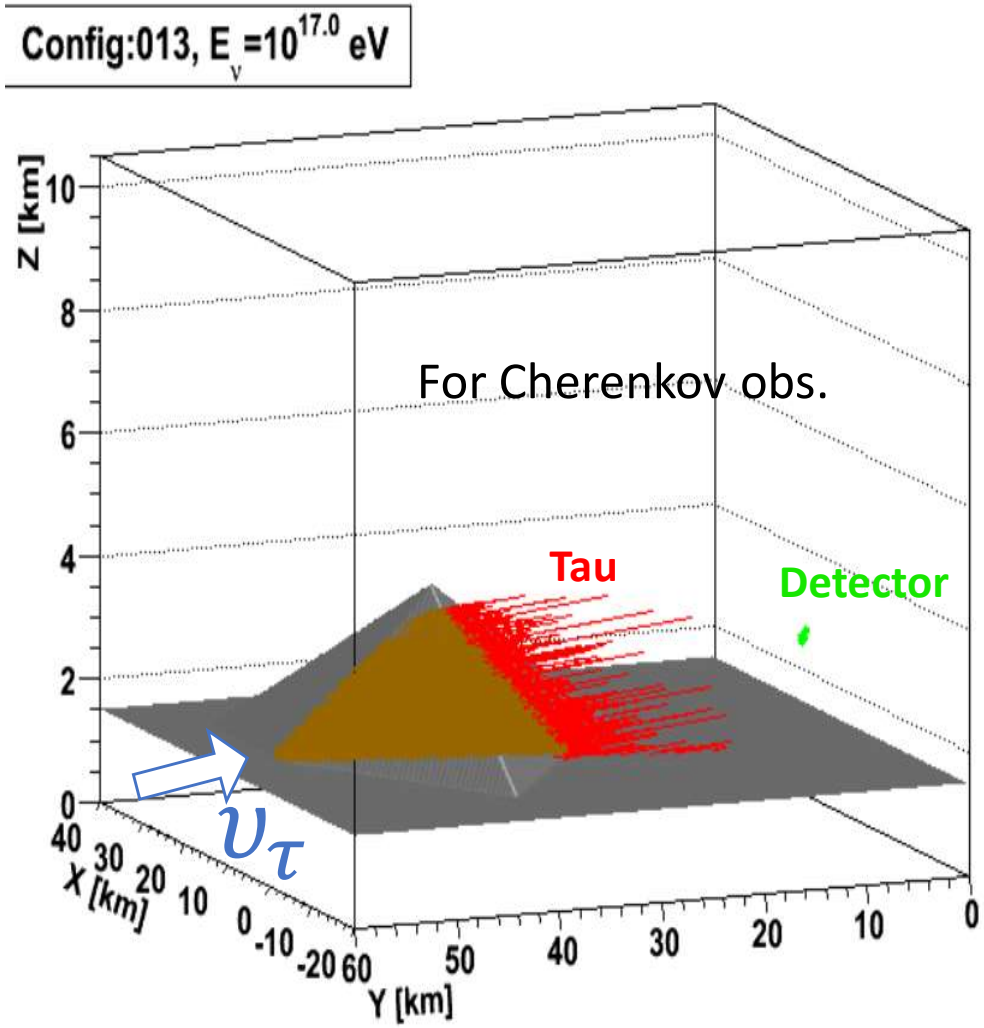
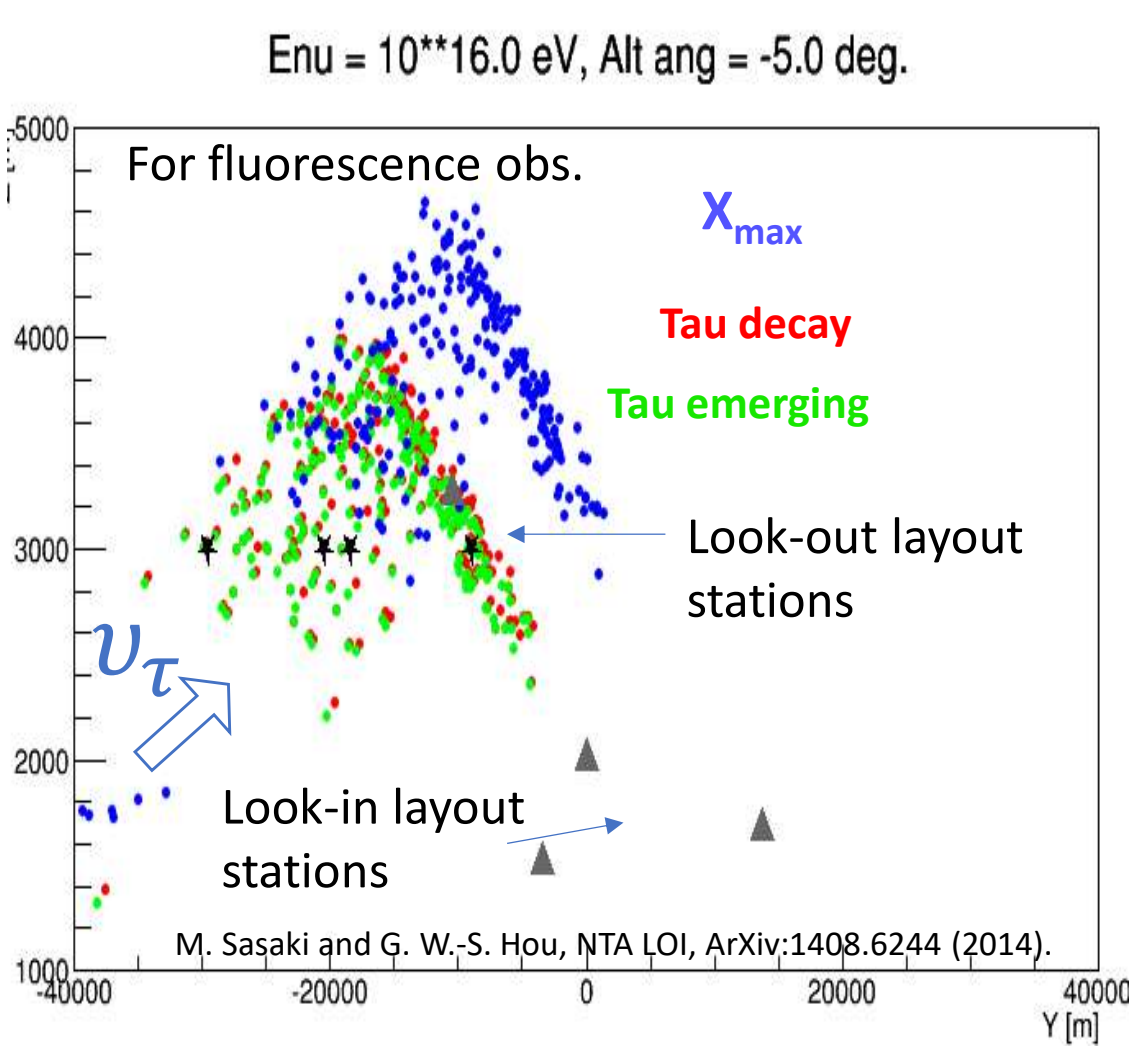
Tau emerging from mountain

Cherenkov for far showers in front.

Fluorescence for near showers coming from behind.





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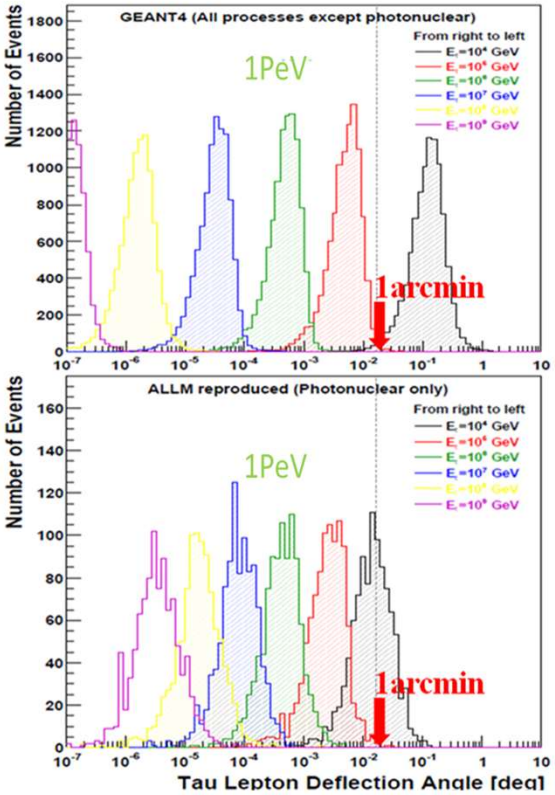
υ_τ direction and energy resolution

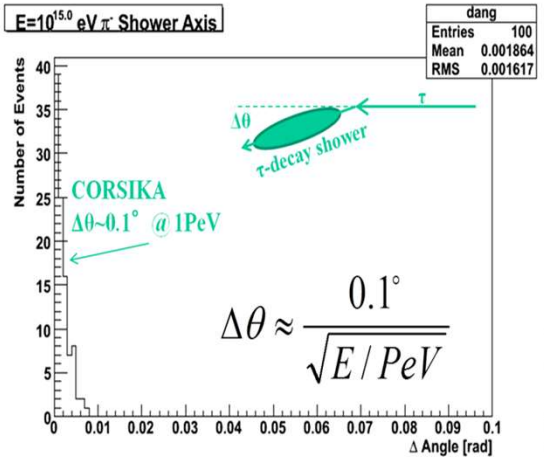
$\Delta\theta_{\upsilon\tau} = 0.1°/\sqrt{E/PeV}$

$\Delta E_{\upsilon\tau} = 20\sim40$ % at $E_{\upsilon\tau}\sim$ 1PeV

Tau Propagation Deflection in Rock



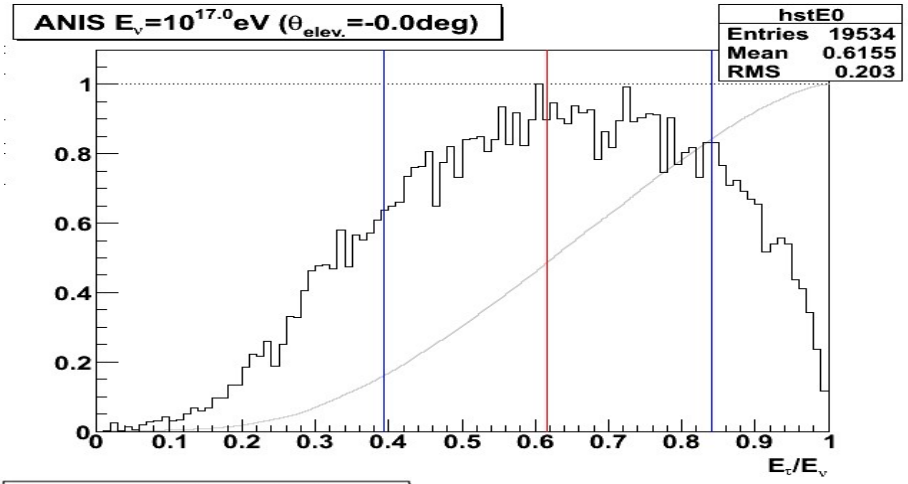
Possible Deflection << 1 arcmin



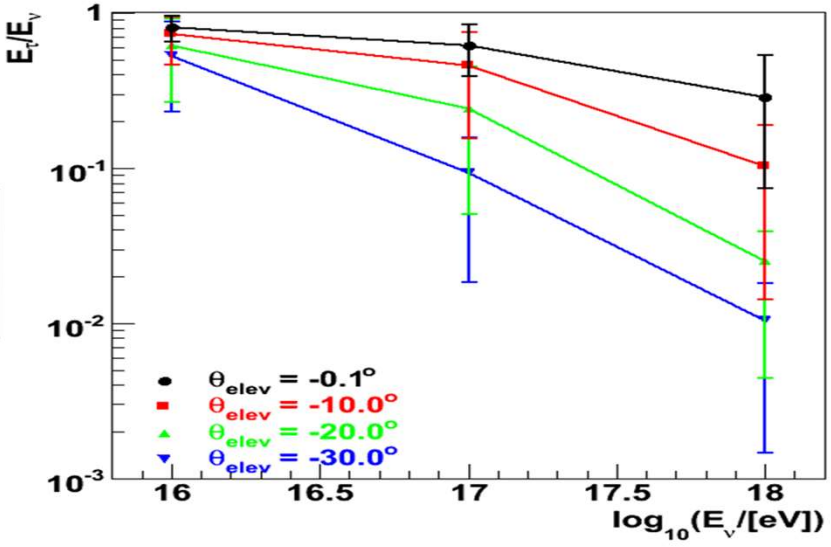
$$\Delta\theta \approx \frac{0.1^\circ}{\sqrt{E/PeV}}$$

Pointing ν with τ Shower < 0.1 deg

Higher Energy Better Accuracy Due to
1. Highly Boosting
2. Shower Size Statistics



Energy Resolution



τ Shower Can Remember the Original ν Direction Very Well

Y. Asaoka, M. Sasaki,, Astropart. Phys. 41, 7 (2013).

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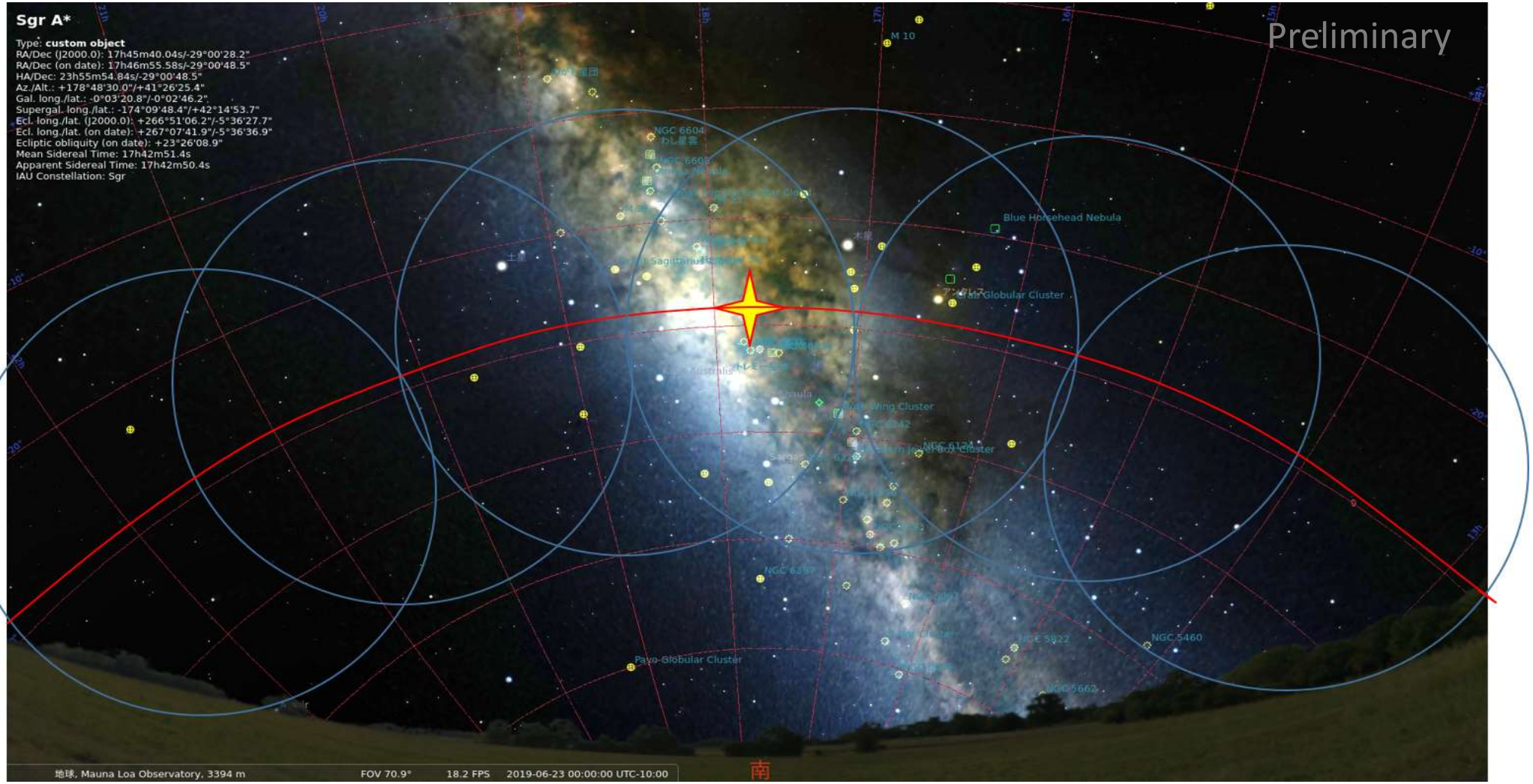
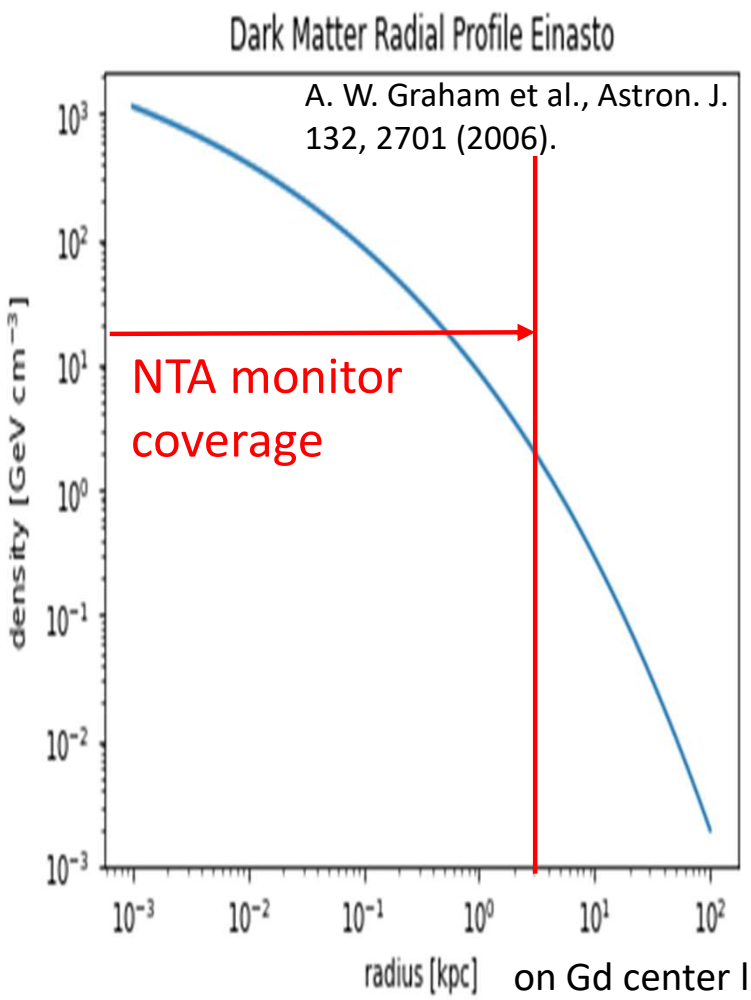
Southern sky field of view

NTA always cover the Galactic bulge (<20° from GC) in the night sky.



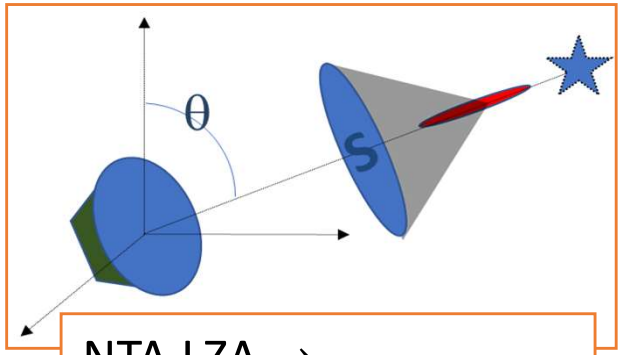
Galactic bulge monitor advantage

$< 20° \rightarrow r < 3$kpc on Gd center line
12% of total mass of DM halo

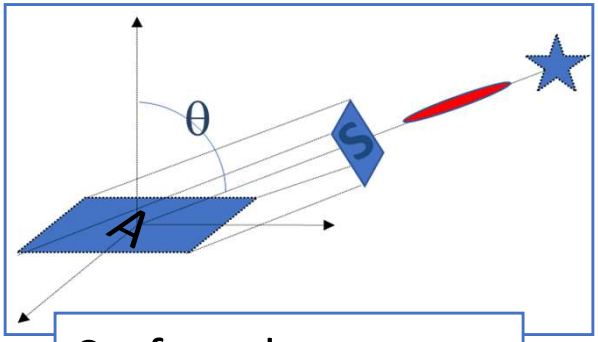


on Gd center line

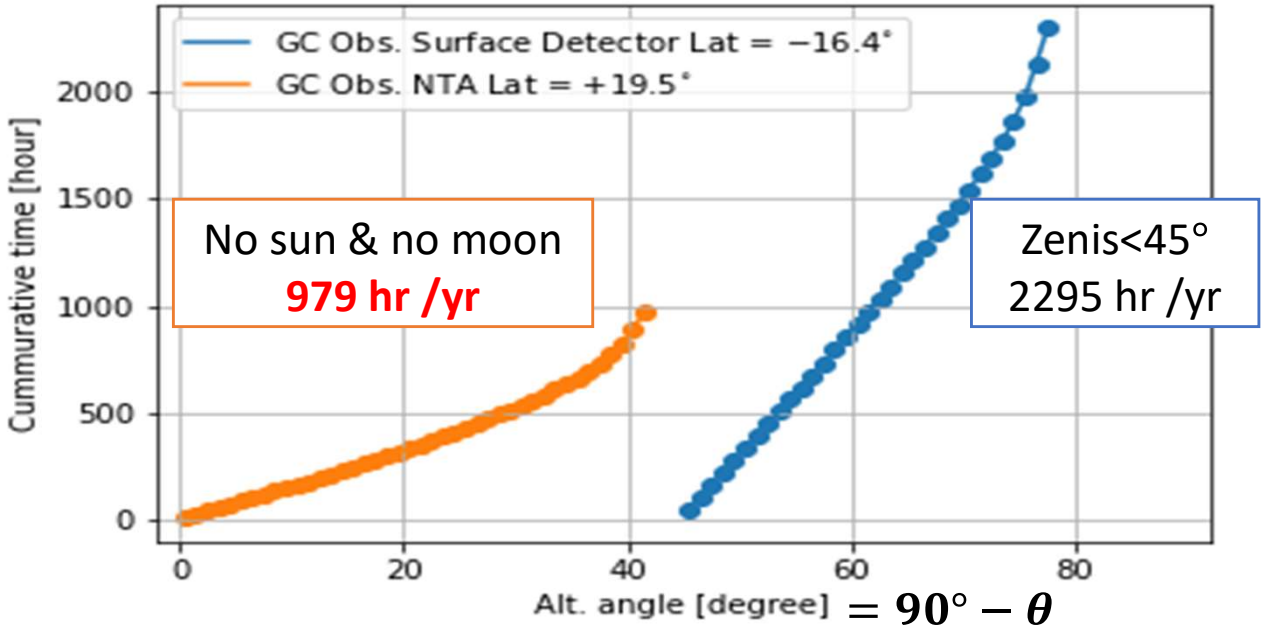
Moonless night condition is not so disadvantage



NTA LZA →
large effective area S



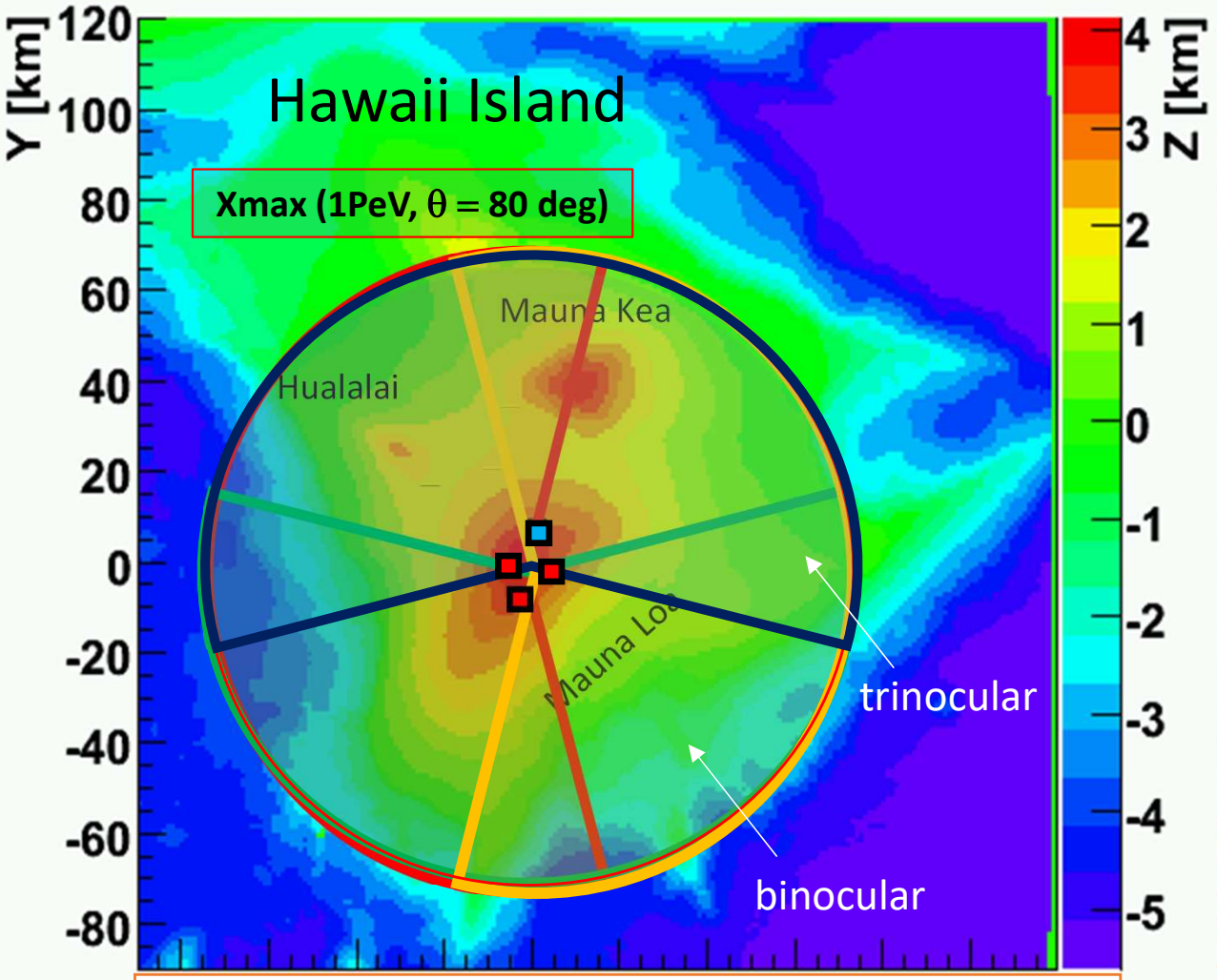
Surface detector
$S \propto A \cos\theta$



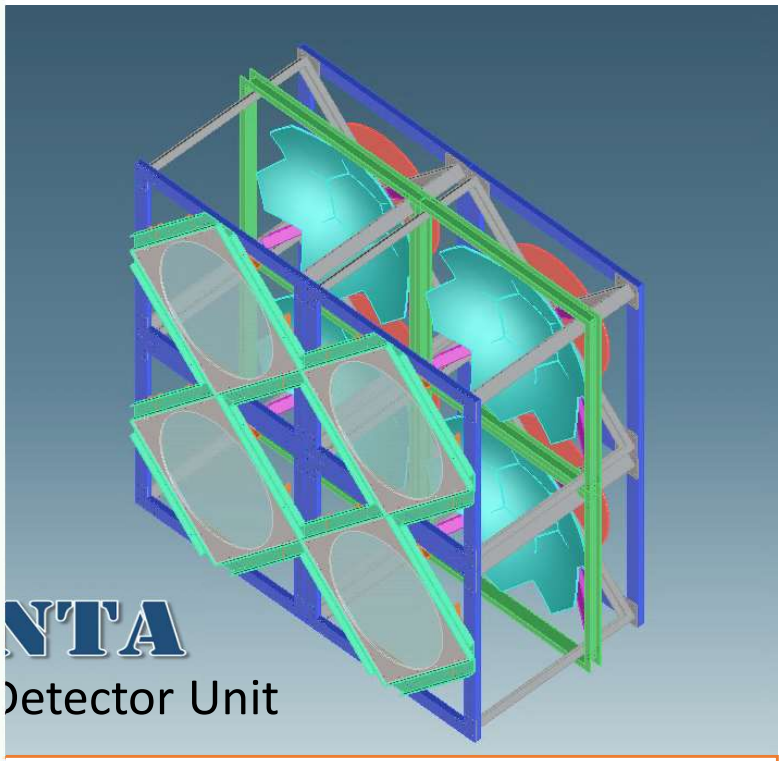
No sun & no moon
979 hr /yr

Zenis<45°
2295 hr /yr

Station layout and detector unit

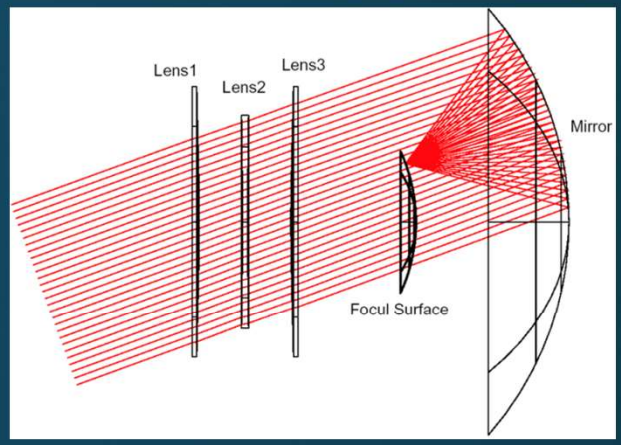


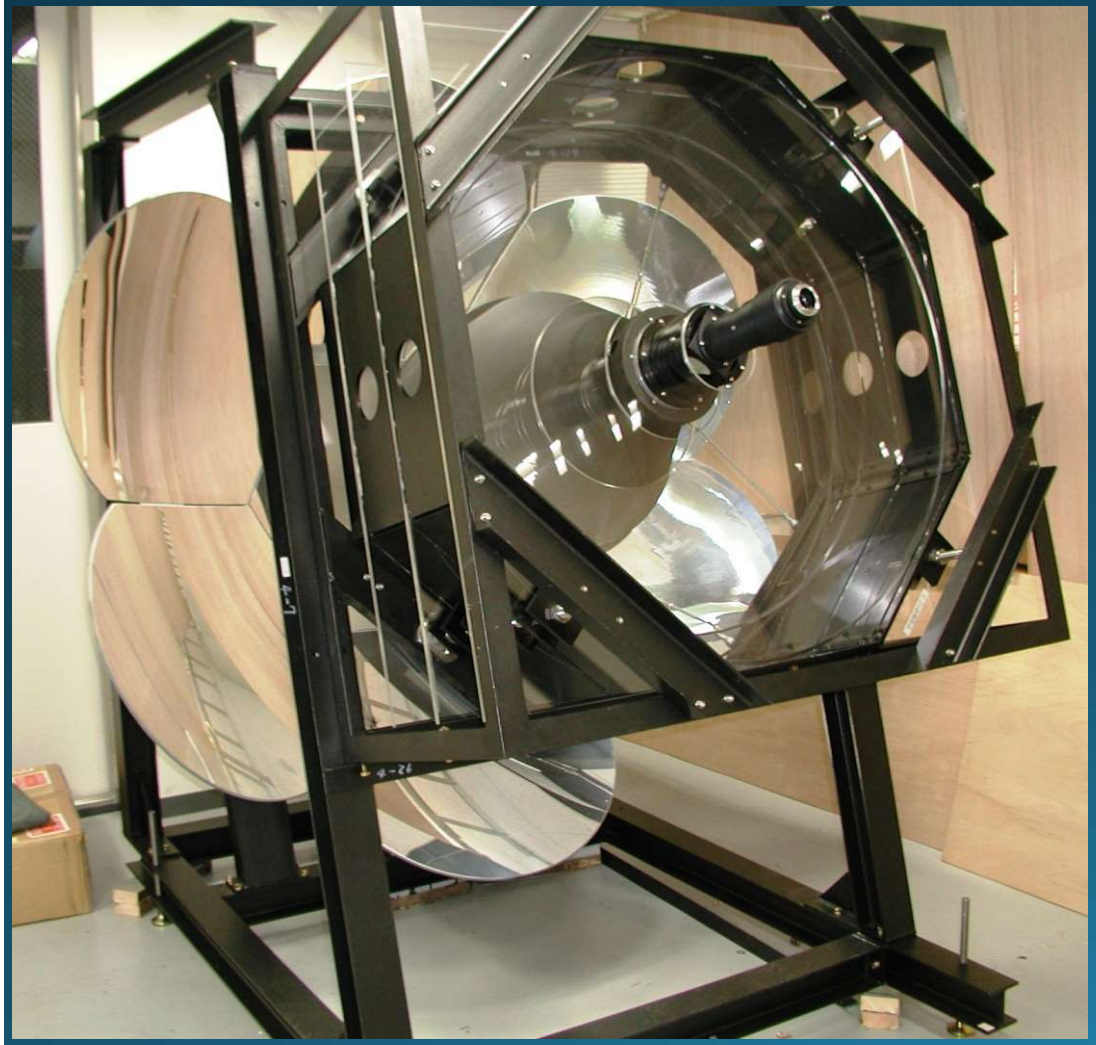
4 Stations x (210deg x 60deg)
High multi-eye detection rate



Ashra-1 LC 1.5 scaled-up x 4
Effective pupil size: 3m

Ashra-1 Light Collector





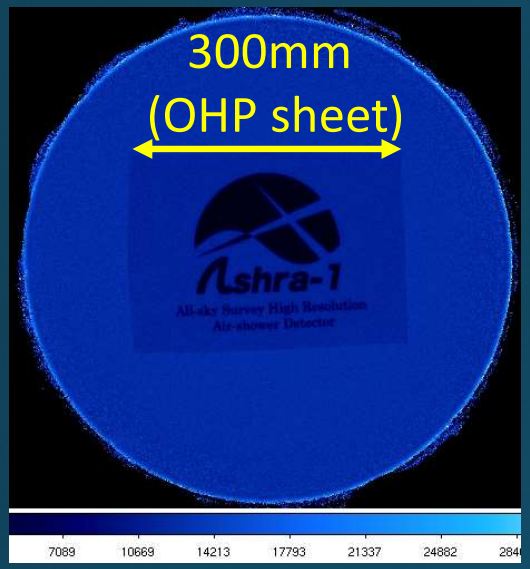
- Optics:
  - **Modified Baker-Nunn**
- Components:
  - **Correcting lens** (1.0~1.2mϕ) with 3 acrylic cut plates
  - **Spherical mirror** (2.2mϕ) with 7 curved glass plates on adjustable tables.
  - **Photoelectric lens IT** (0.5mϕ) on focal sphere suspended with Stewart platform mechanism
  - **Mount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

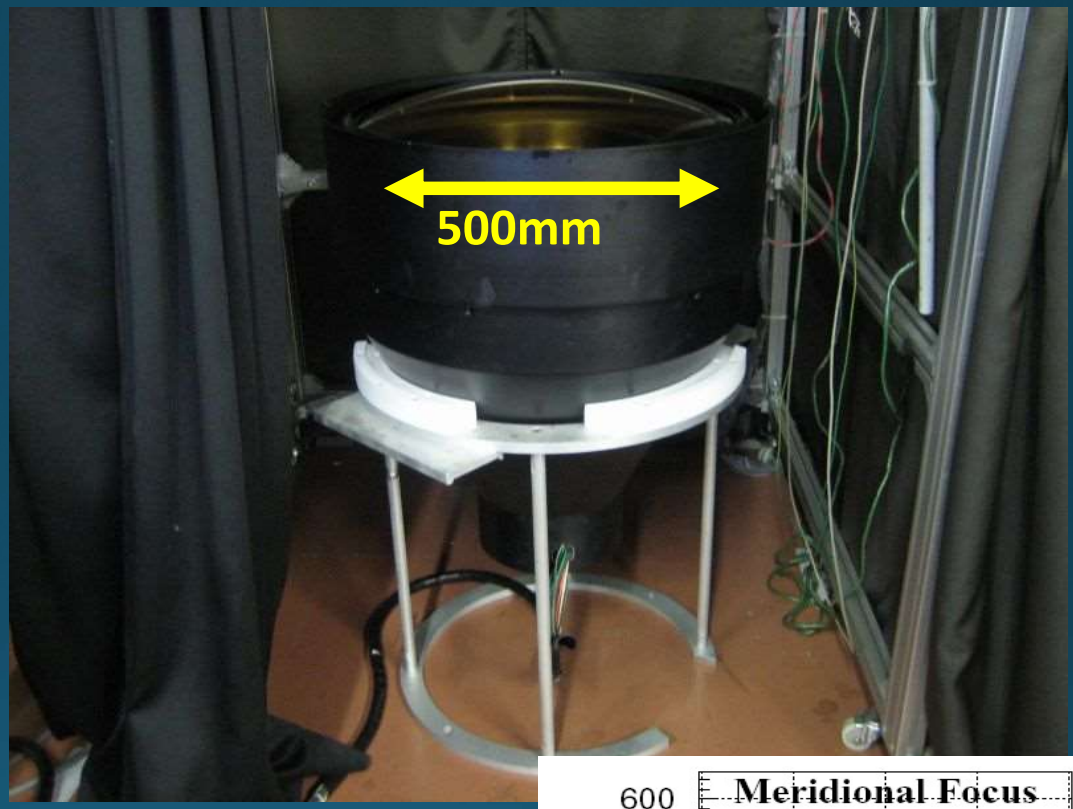
=> arcmin. resolution over 42deg FOV

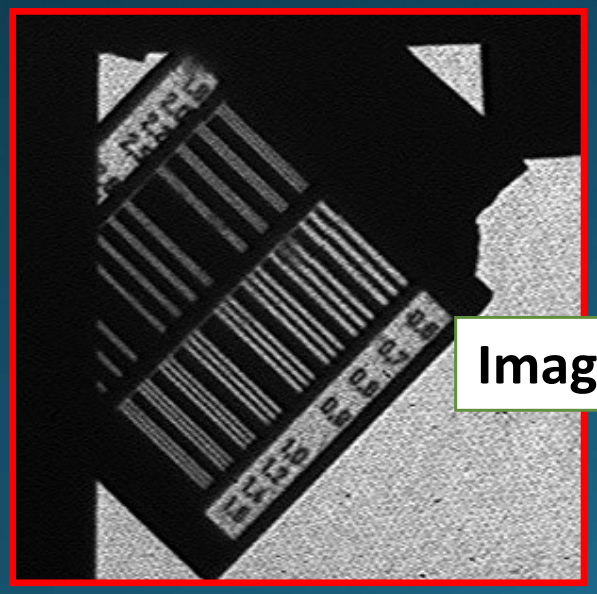
=> Very cost-effective

Imaging Test of 20” PLI

Output Image Example



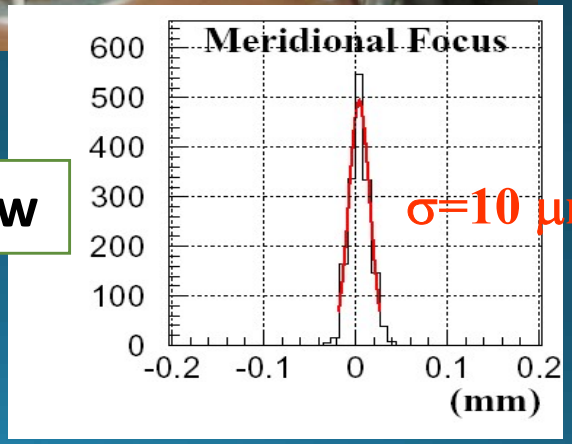




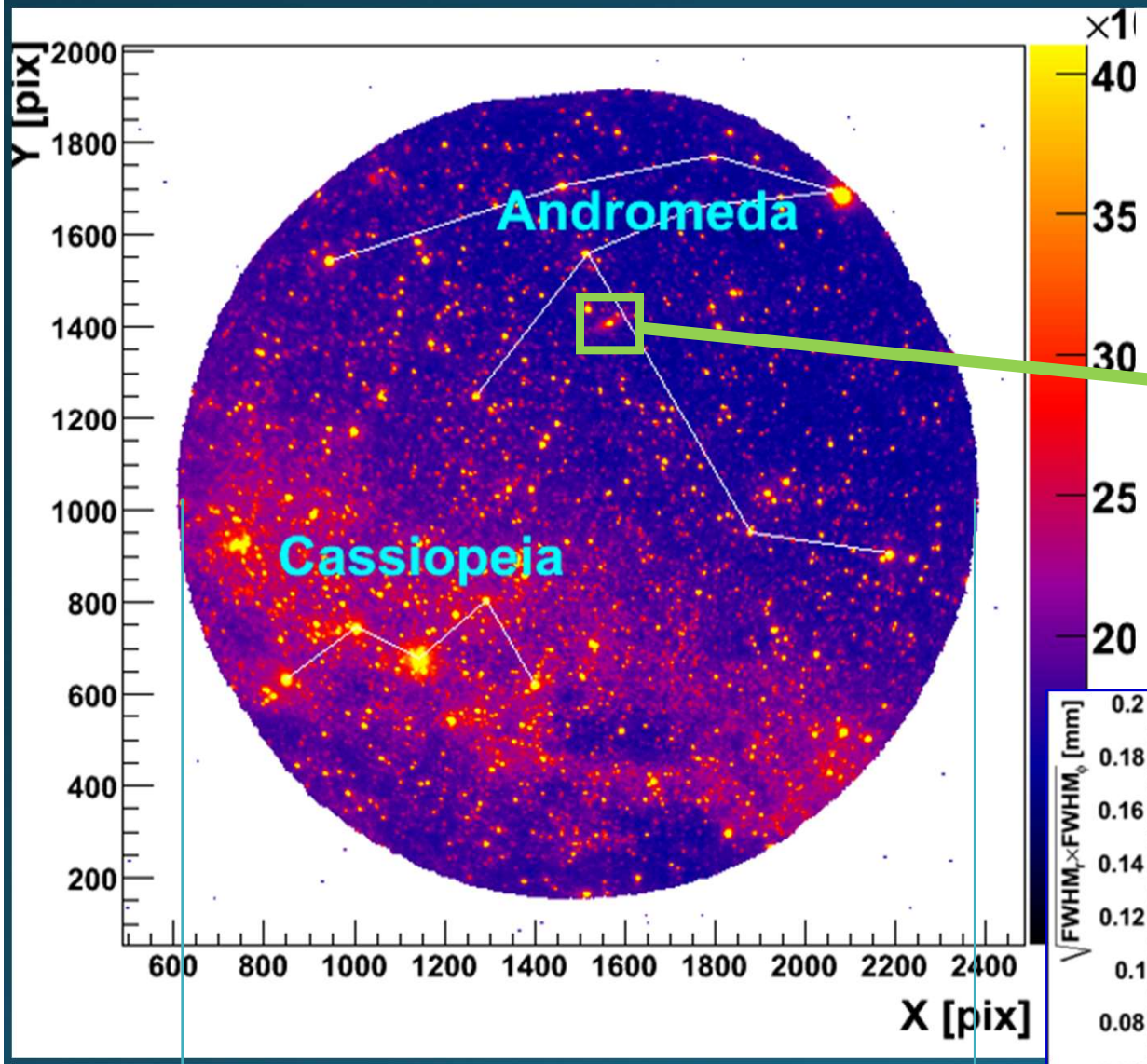
Imaging Resolution Chart on Input Window

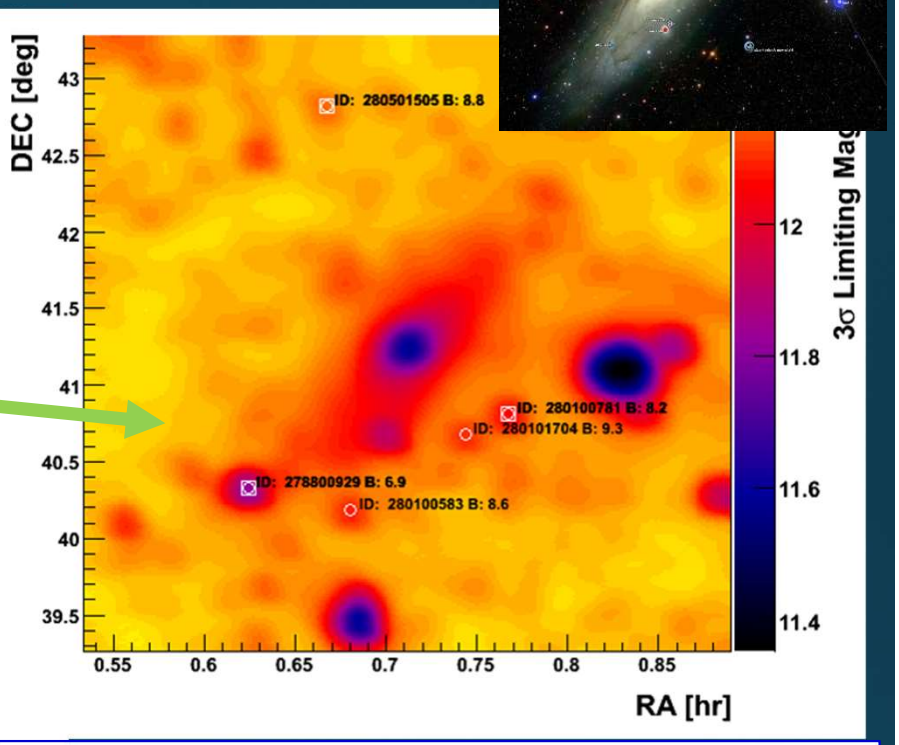
PSF < 0.4mm on in put window

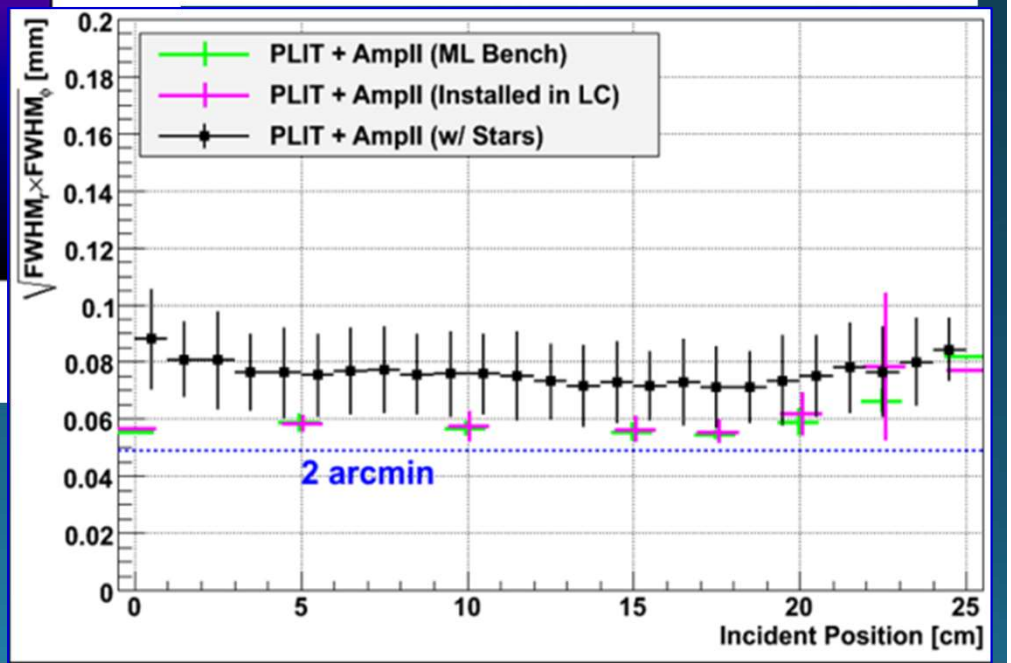
Y.Asaoka, M.Sasaki NIMA 647 (2011) 34



resolution of 3 minutes within a 42° FOV with Ashra-1 LC



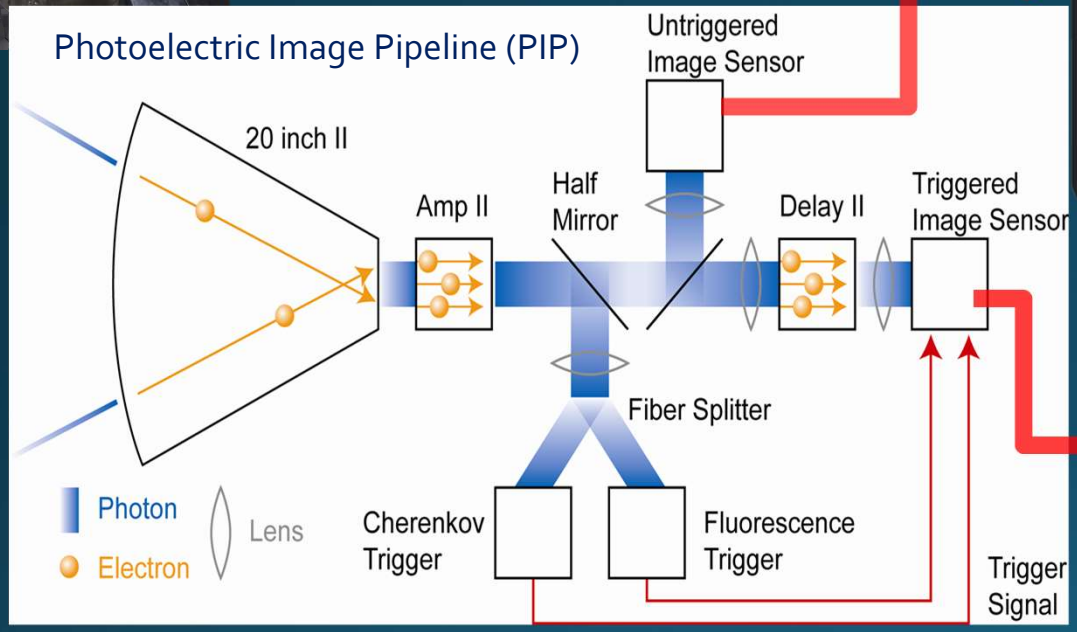


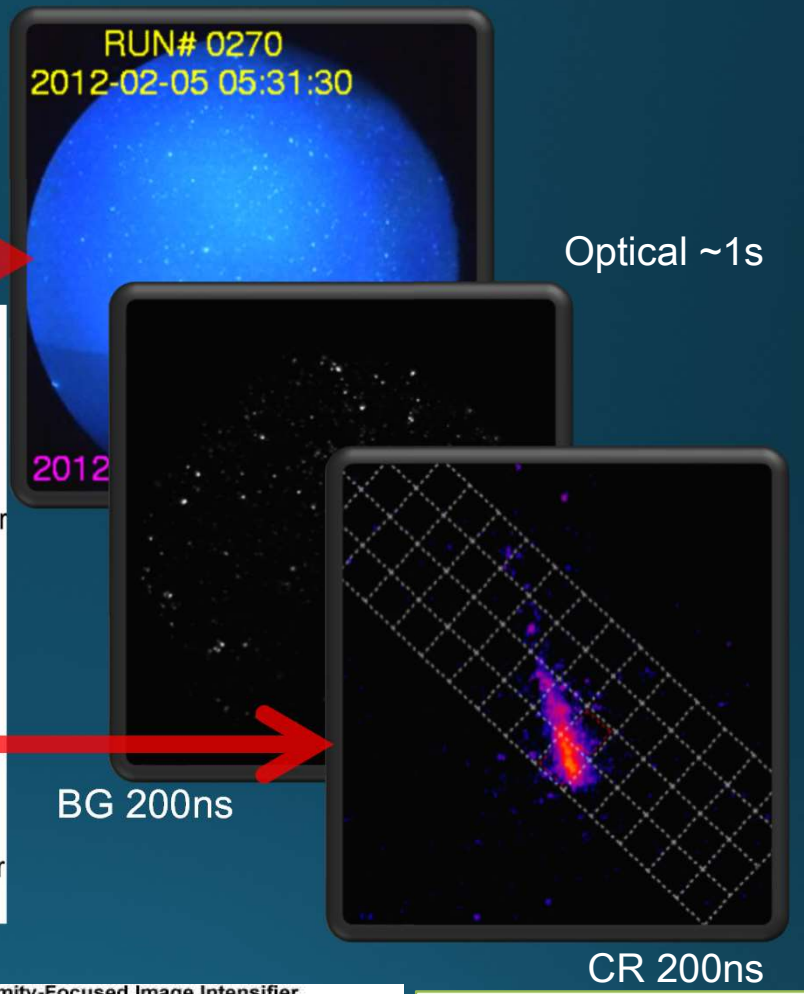


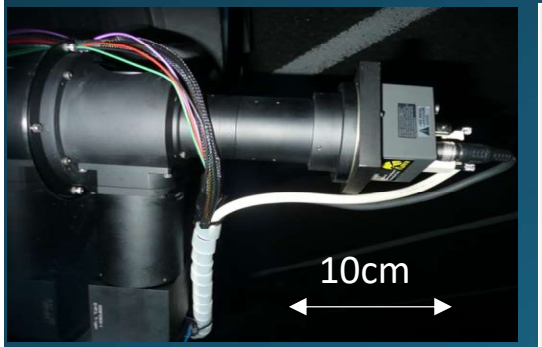
Pipeline Trigger & Readout

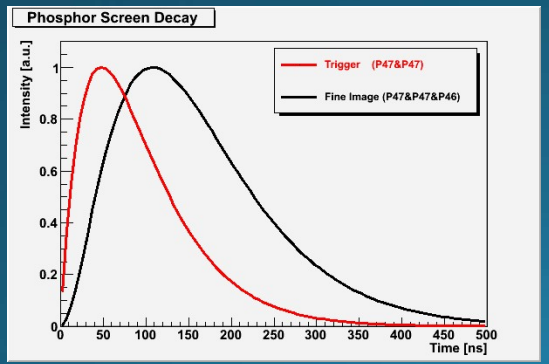
Multi-Messenger Approach with One Detector System

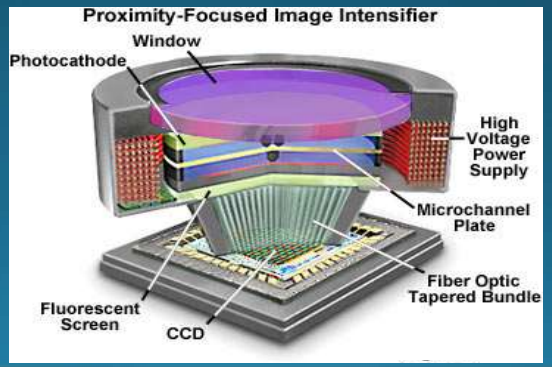
Same Fine Image to Multiple Triggers







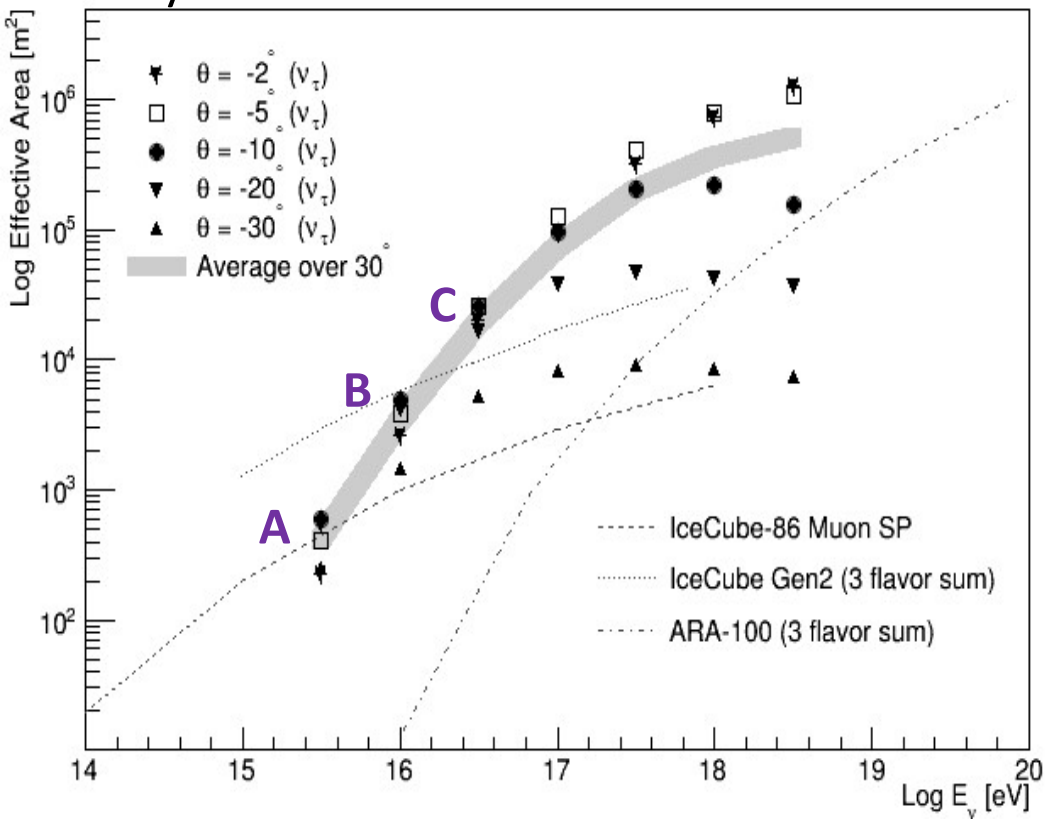


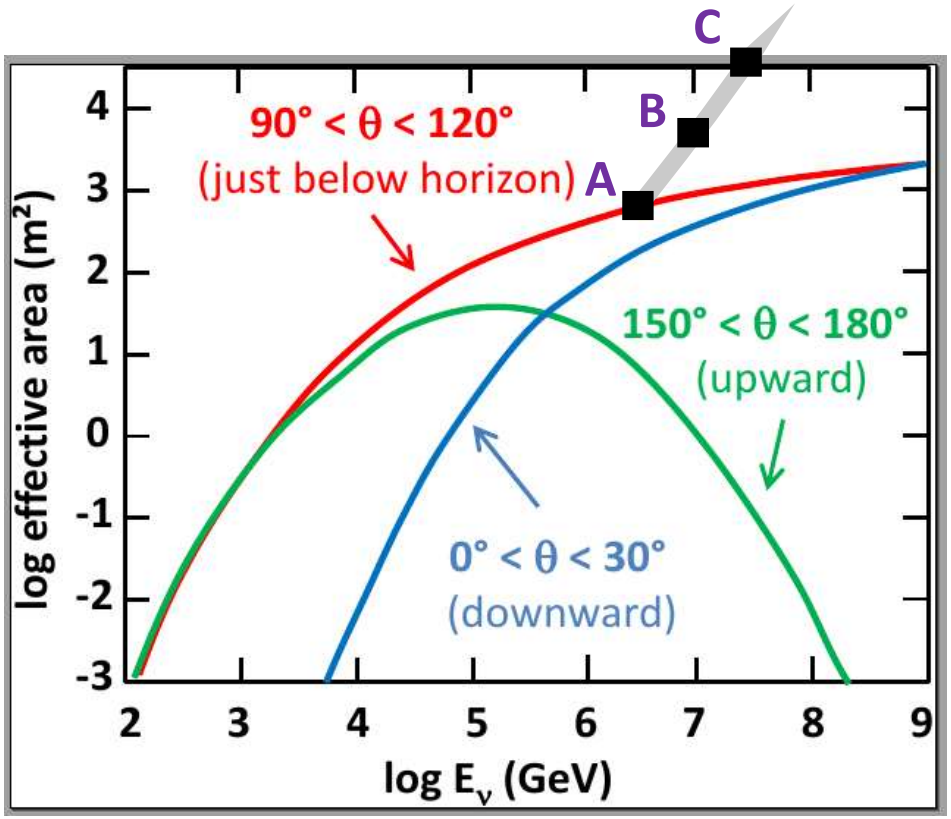


1st air-shower imaged with self-triggering find solid state sensor

Advantage of tau air shower

NTA summit array effective area (m^2)
only with fluorescence detection





PDG, Prog. Theor. Exp. Phys. **2022**, 083C01 (2022)

Tau appearance → separation of target mass from luminous material air.
Air is far more transparent than ice.

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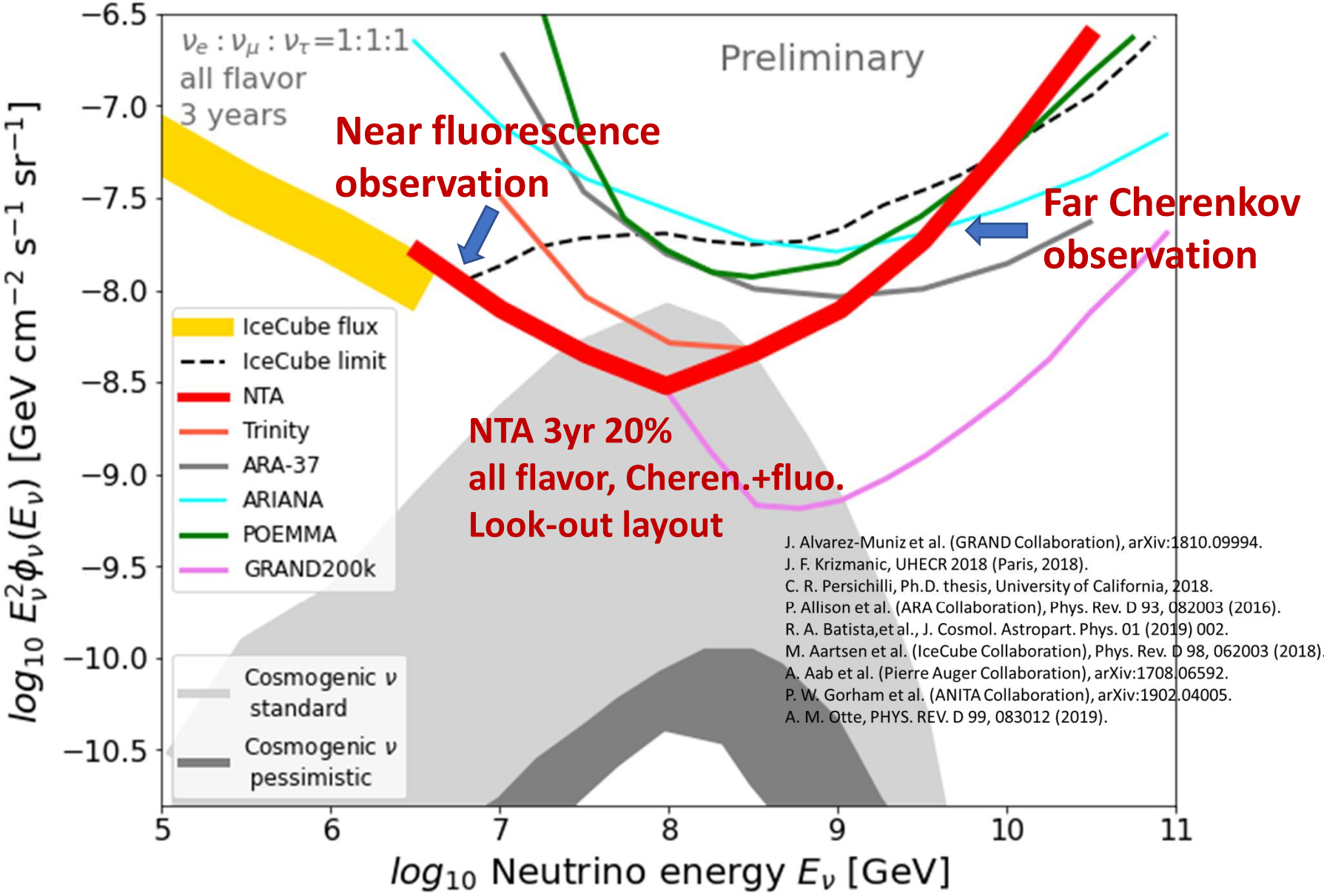
Diffuse υ sensitivity



J. Alvarez-Muniz et al. (GRAND Collaboration), arXiv:1810.09994.
J. F. Krizmanic, UHECR 2018 (Paris, 2018).
C. R. Persichilli, Ph.D. thesis, University of California, 2018.
P. Allison et al. (ARA Collaboration), Phys. Rev. D 93, 082003 (2016).
R. A. Batista,et al., J. Cosmol. Astropart. Phys. 01 (2019) 002.
M. Aartsen et al. (IceCube Collaboration), Phys. Rev. D 98, 062003 (2018).
A. Aab et al. (Pierre Auger Collaboration), arXiv:1708.06592.
P. W. Gorham et al. (ANITA Collaboration), arXiv:1902.04005.
A. M. Otte, PHYS. REV. D 99, 083012 (2019).

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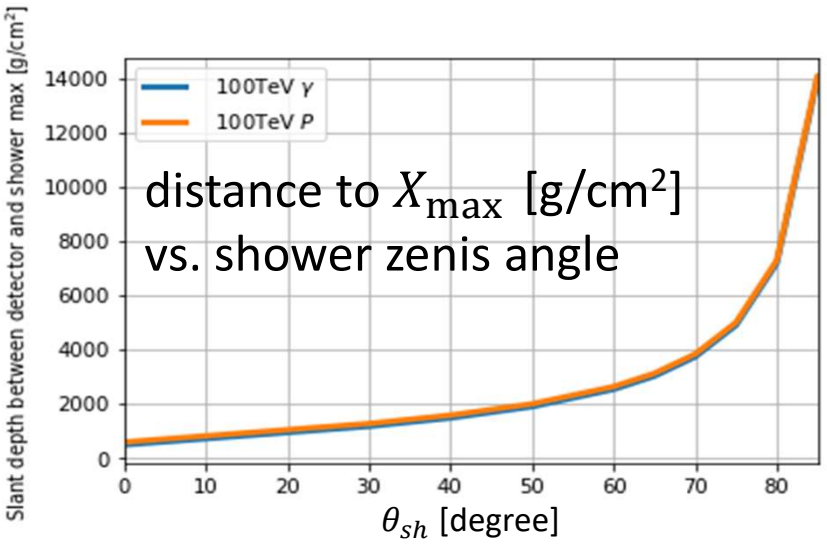
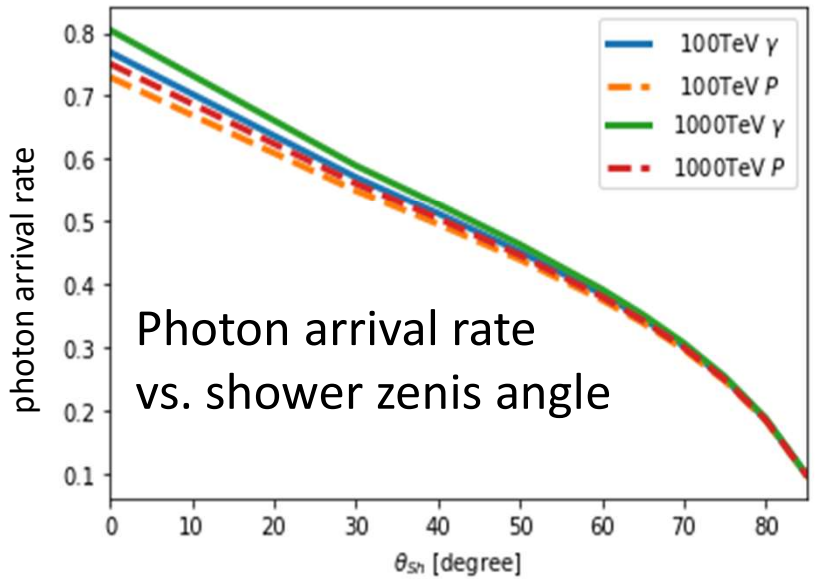
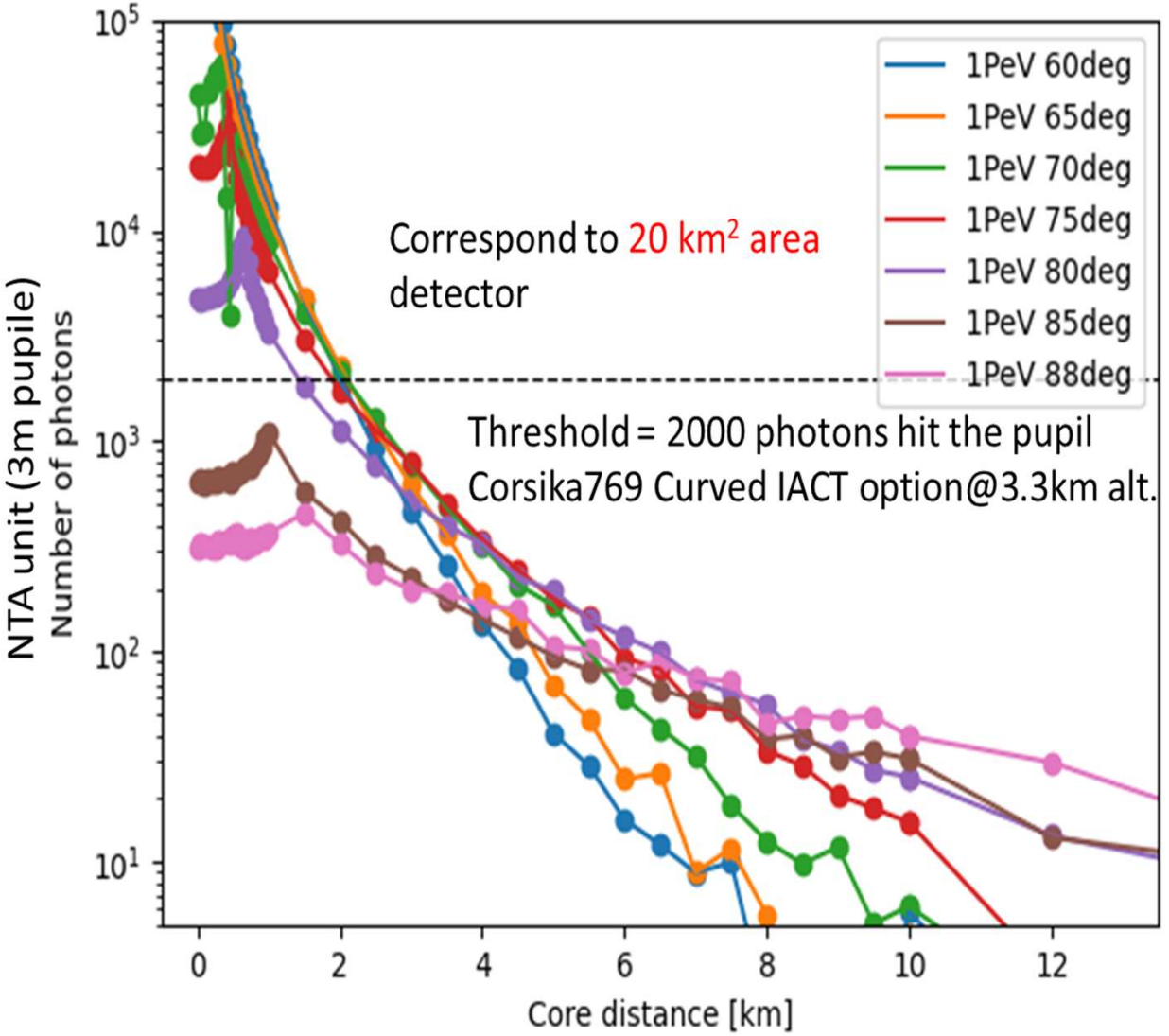
LZA Cherenkov Lateral Profile

LZA Cherenkov provides an effective area equivalent to a 5 km scale IACT array.







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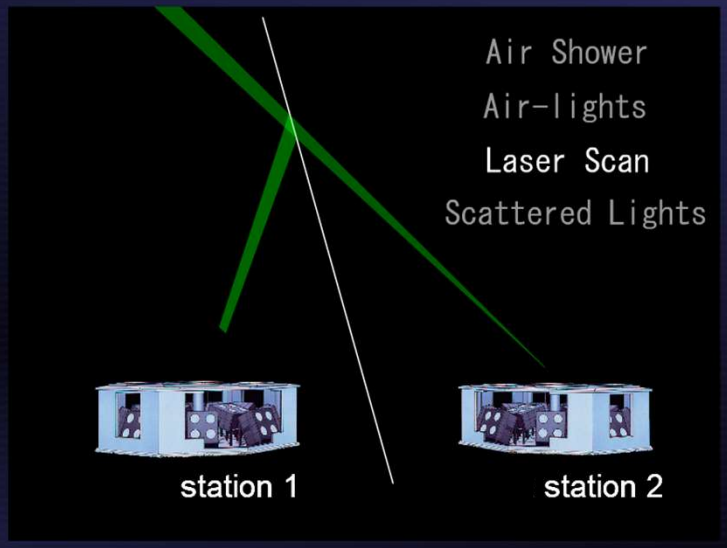
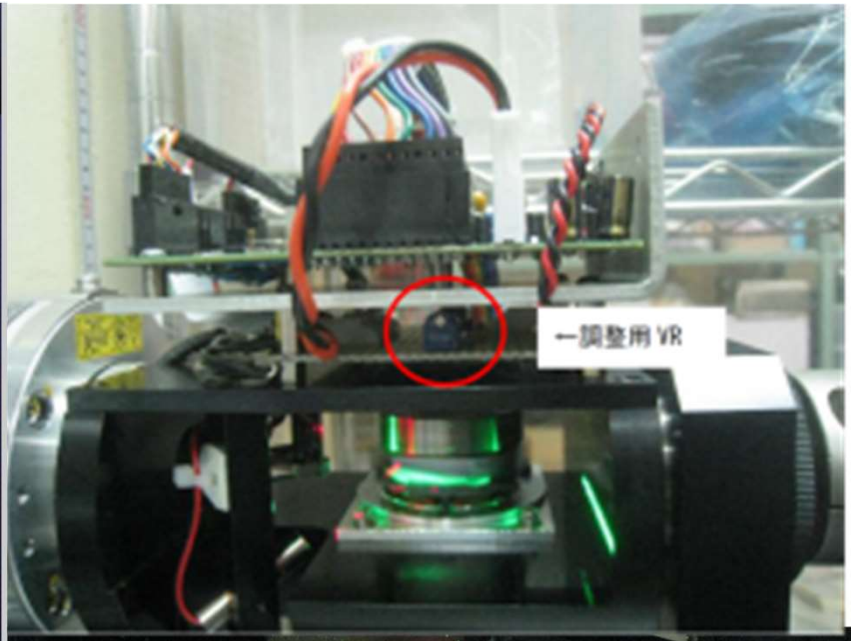
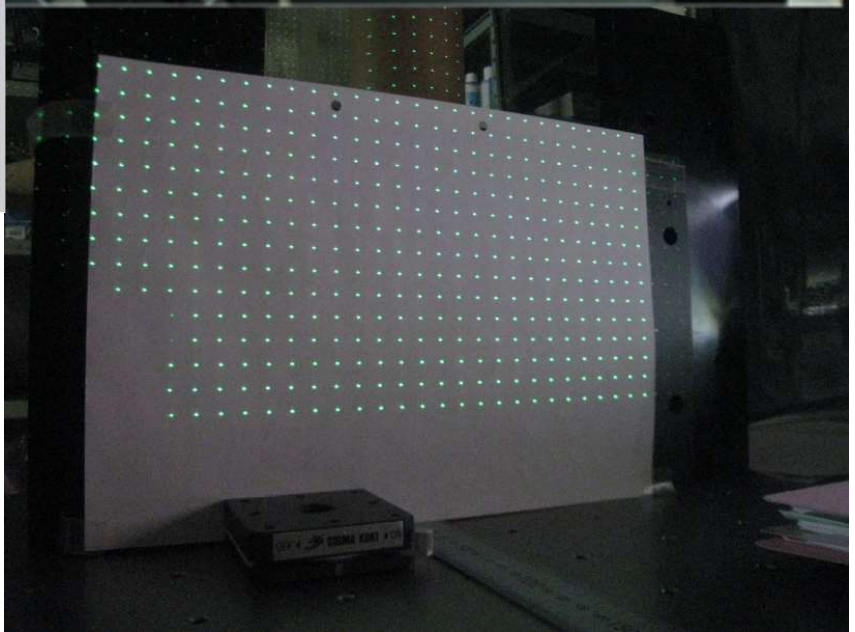
Event driven RT imaging LIDAR

application of LIDAR Remote Sensing



Remote Sens. ➡ Atmospheric Monitor
➡ Primary Energy





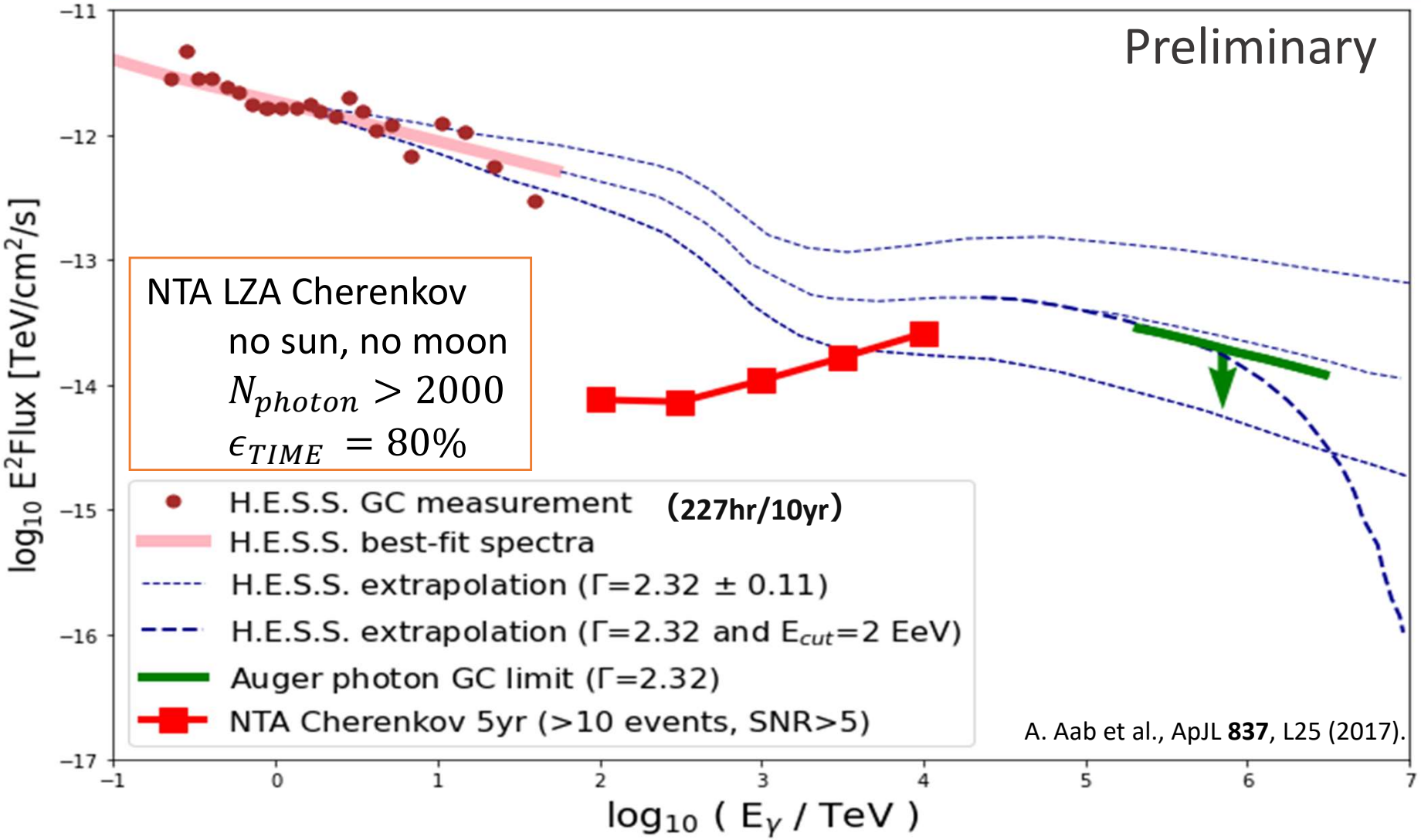
Same NTA units + fast laser scanning for far triggered AS

Scanning system with oscillating polygon mirror

Laser pulse at 40 KHz in any direction 80° x 80° with an absolute accuracy of 0.02°

Photons from Galactic center

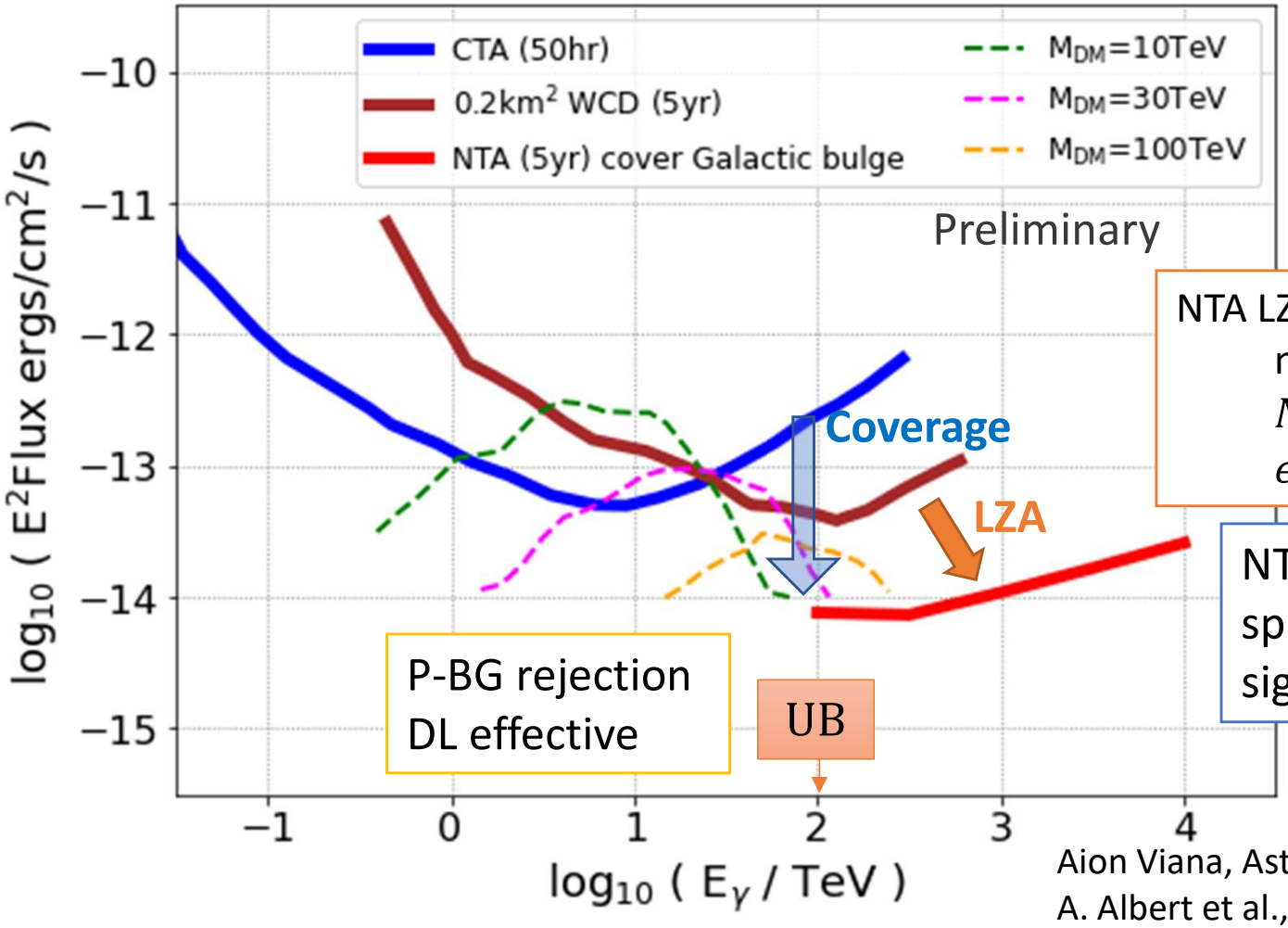
Take over important results from TeV. More developed results to EeV.



DM search (photon probe)

NTA sensitive for super heavy DM around the unitarity bound

e.g. D. J. H. Chung, E. W. Kolb, and A. Riotto, Phys. Rev. D 59, 023501 (1998).



NTA LZA Cherenkov
no sun, no moon
$N_{photon} > 2000$
$\epsilon_{TIME} = 80\%$

NTA can utilize both spectral and morphology signals.

Aion Viana, Astro2020 Science White Paper
A. Albert et al., arXiv:1902.08429.

Conclusion

The era of synergy between HEP and VHEP.
The energy front around the unitarity bound interesting e.g. super heavy DM.

Combined detection of PeV tau and photon; key to VHEPA.

NTA most sensitive to PeV tau (υ) and photon, with good coverage and accuracy.
Take over important results from TeV. More developed results to EeV.

The NTA will open up more comprehensive studies of VHEP and VHEA
by combining VHE tau and photon probes for detection.

Thank you.