



Ashra

H27Kyodo ICRR

Makoto Sasaki

ICRR UTokyo



Ashra @ Mauna Loa

査定経費推移：

H16年度 50千円 (佐々木)
H17年度 70千円 (佐々木・渡邊)
H18年度 890千円 (佐々木・渡邊・小川)
H19年度 750千円 (佐々木・渡邊・小川)
H20年度 1000千円 (佐々木・渡邊・小川・木村・家入)
H21年度 1400千円 (佐々木・小川・木村)
H22年度 1420千円 (佐々木・小川・木村)
H23年度 1170千円 (佐々木・浅岡・小川・木村)
H24年度 970千円 (佐々木・浅岡・小川・木村)
H25年度 970千円 (佐々木・浅岡・小川・木村)
H26年度 300千円 (佐々木・小川)

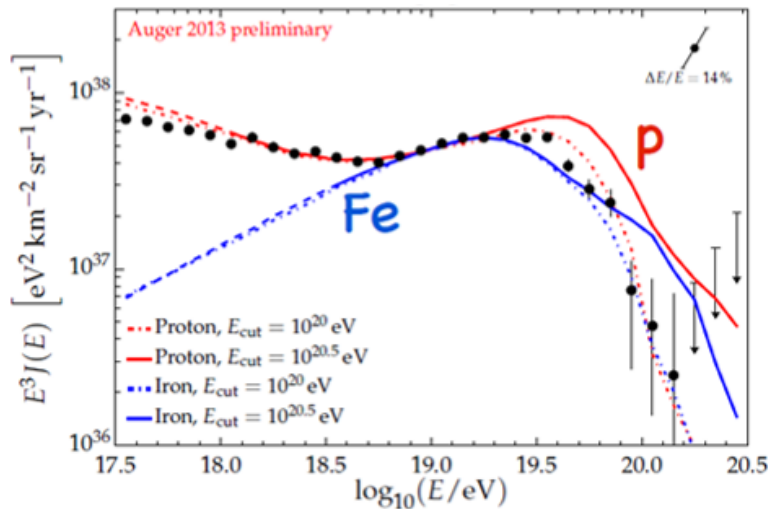
H27年度 300千円 (佐々木・小川)

今年度の使途内訳：

研究費 光学要素、設置治具、消耗品、ソフトアプリ、など
旅費 国内出張 (会議/試験@柏/明野)、など

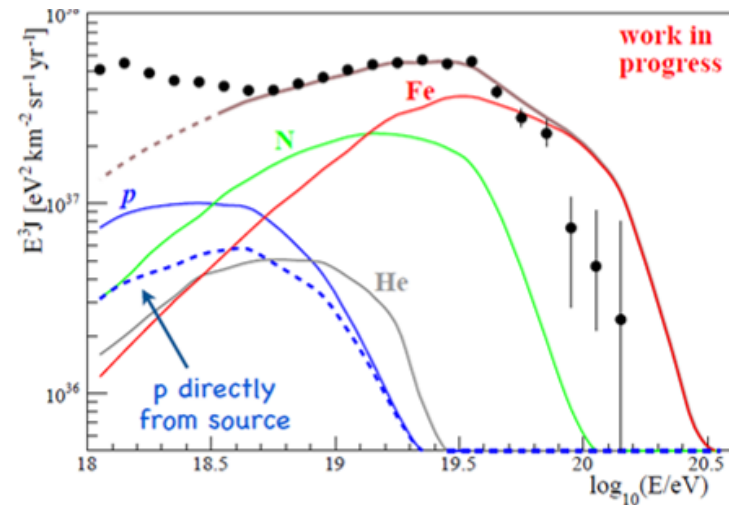
Hadron: Cutoff exists but what makes it?

GZK suppression?



K-H. Kampert, VHEPA2014

maximum energy scenario?



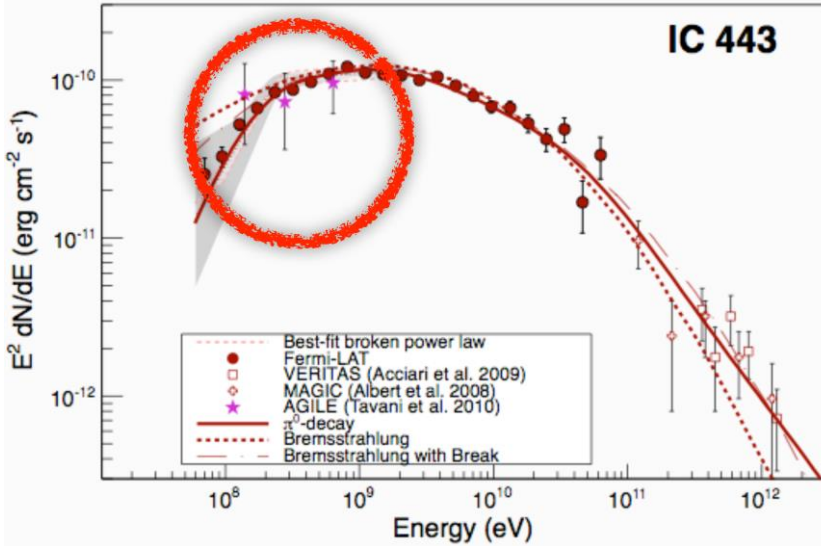
$$E_{\text{max}}^p \sim 10^{18.6} \text{ eV} \rightarrow$$

$$E_{\text{max}}^{\text{Fe}} \sim 10^{20} \text{ eV}$$

- ⇒ 1. CR Origins must be nearby within GZK horizon ($\sim 40\text{Mpc}$) or our galaxy.
- ⇒ 2. Hadrons cannot be probes for sources outer side of GZK horizon or our galaxy.

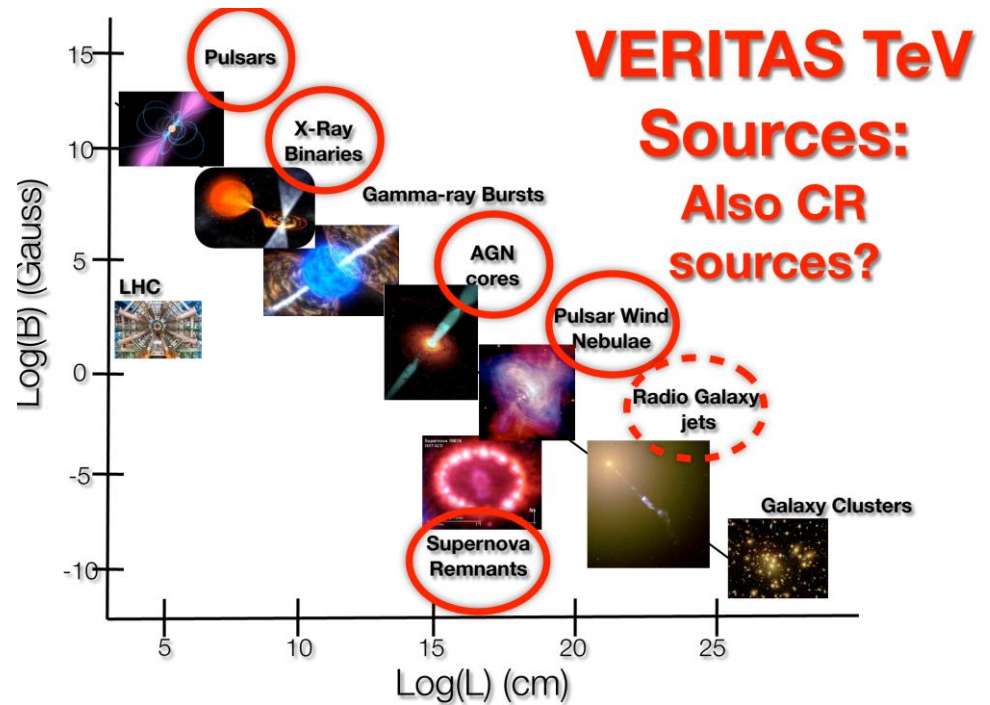
Photon: Indicates Hadron Accelerators

Fermi-LAT: cutoff around 200 MeV



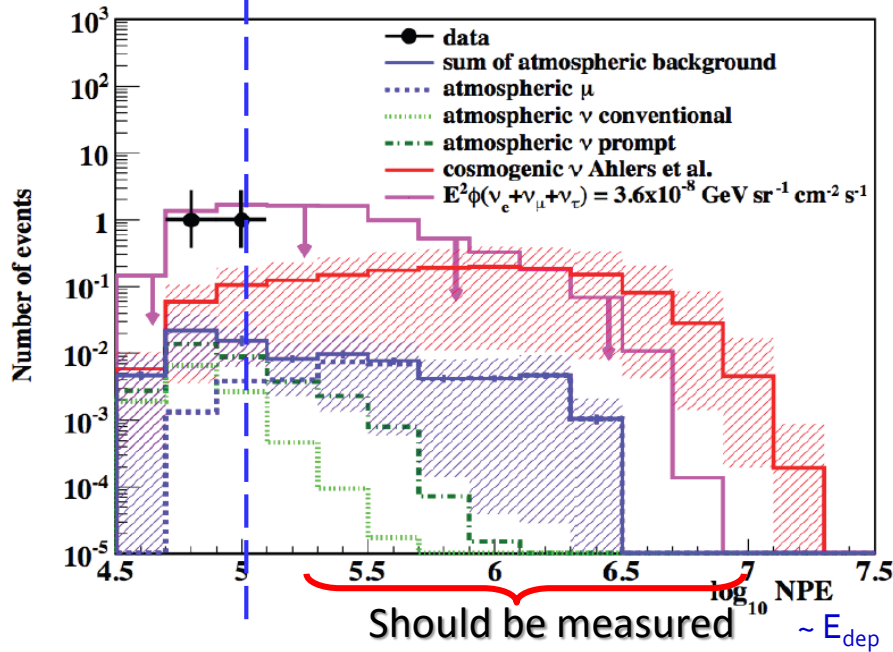
Fermi-LAT, Science 339 (2013)

TeV- γ : many spectra favors hadronic models



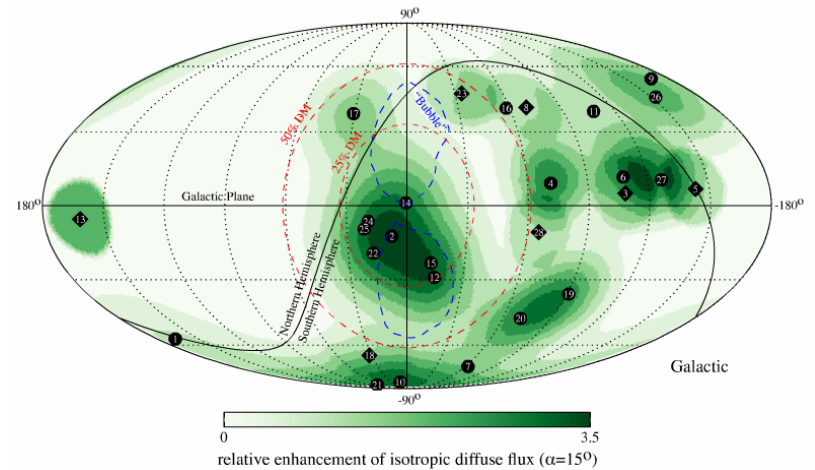
Neutrino: Indicates PeV emitters

IceCube: PeV events



IceCube, PRL 111 (2013) 021103

IceCube: 28 events $E_{\text{dep}} > 30 \text{ TeV}$



Ahlers & Murase, PRD (2014).
IceCube, Science 342

Exploring PeV-EeV Universe *for and beyond* CR Origins

Strategies:

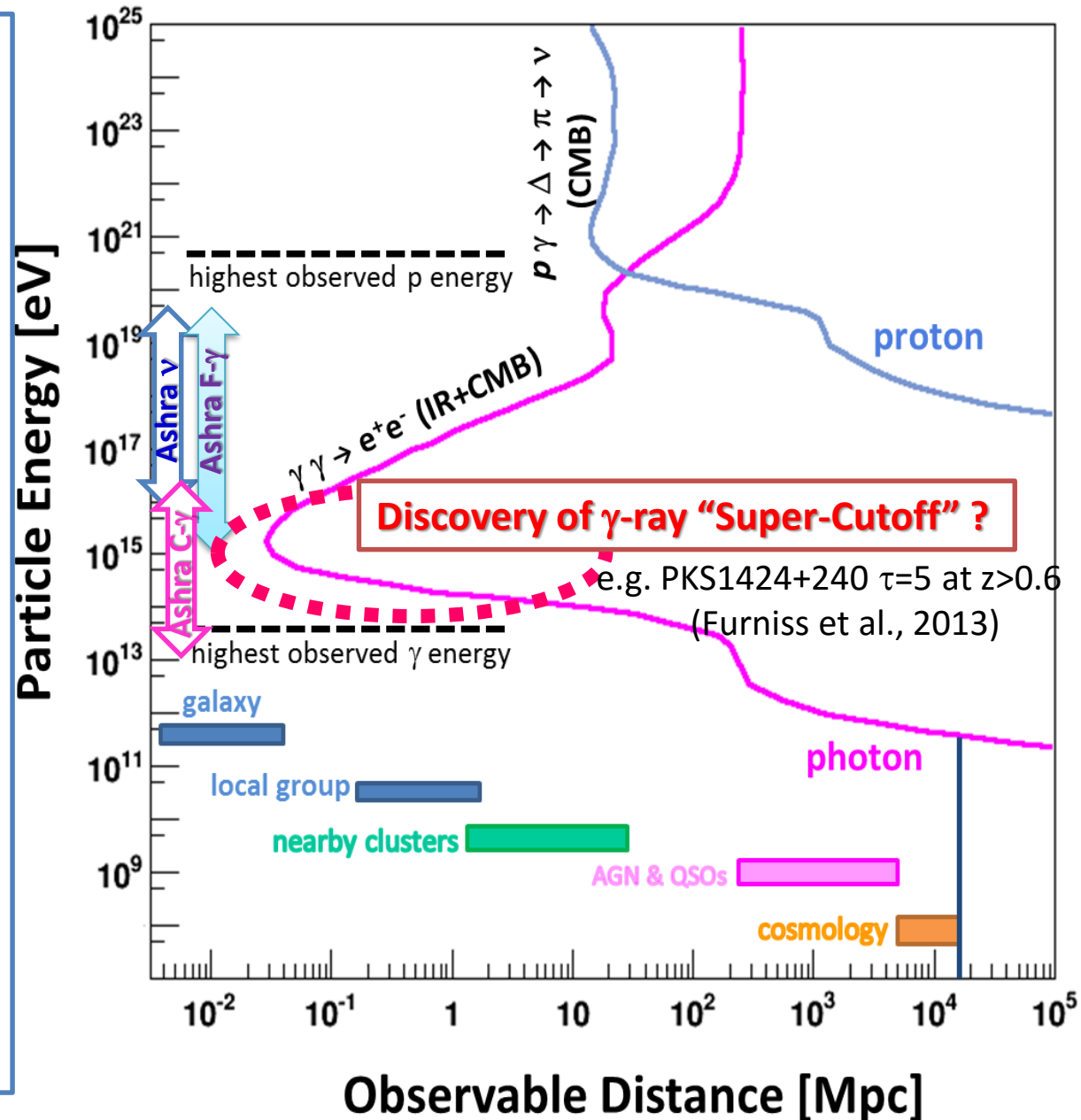
1. *Pin down PeV-EeV ν_τ sources with fine point-back resol.*

=> Direct evidence of hadron accelerators or CR origins

2. *Check PeV-EeV ν and γ -ray fluxes*

=> Id. and discover breaks of basic physics and lows e.g. pp/p γ ?, Super-cutoff, Lorentz invariance, etc.

VHE Universe "Labo."



Chronology

1997: TA grand design
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2002: renamed into Ashra
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2014: VHEPA2014 @ Kashiwa
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IAC: A.Watson, F.Halzen, T.Kifune
2015: NTA-meet @ ICRC2015 Hague
2016: VHEPA2016 @ Honolulu, Jan.7-9



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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

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Received 10 July 2002; received in revised form 10 July 2002; accepted 20 July 2002

Abstract

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

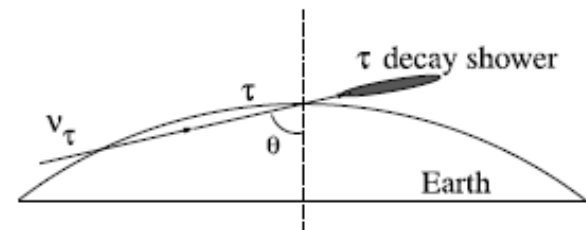


Fig. 7. A schematic picture of Earth-skimming tau neutrino events.

Chronology

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ICRR-2000 サテライトシンポジウム
「高エネルギー宇宙の総合的理解」

多波長観測から多粒子観測へ
高エネルギーニュートリノ

宇宙線望遠鏡計画改良案(NTA)の概要

2002年1月

東京大学宇宙線研究所
佐々木 真人

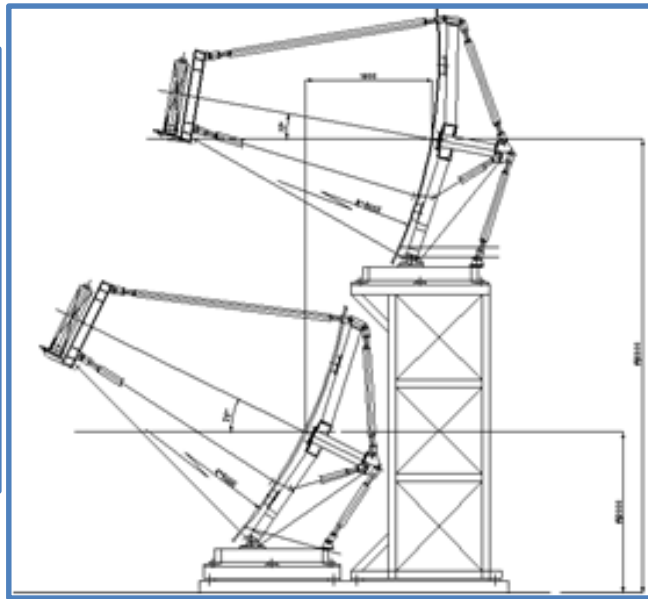
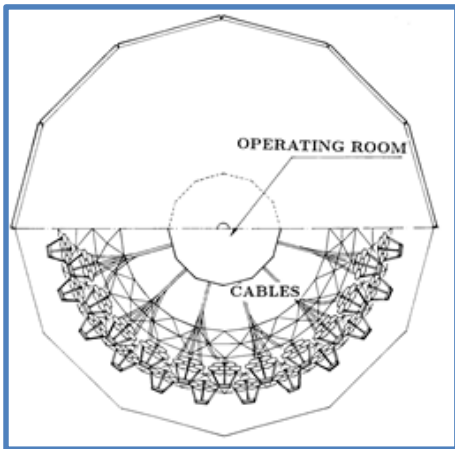
1. はじめに

本稿では宇宙線望遠鏡計画(TA)とその現状を振り返り、その問題点を明らかにして、抜本的な基本設計上の改善策を提案する。

2. TA とその現状

- TA は日本が 8 ステーション(64 億円)、米国+豪州が 2 ステーション (16 億円)を貢献し、合計 10 ステーション(80 億円)からなる。
- 1 ステーションは 3.3m 径反射鏡と 1.1m 角の 256 本の光電子増倍管(PMT)からなるカメラによる光学望遠鏡 40 台から成る。全読み出し数=102,400 チャンネル。
- 1 ステーションで方位角 360 度、水平から高さ 32 度の視野(全天の約半分)を覆う。
- AGASA 等が示唆した最高エネルギー宇宙線(UHECR)起源同定を行う事を旨とする。
- 稼働率 10% ならば、AGASA の 60 倍の UHECR 検出率を持ち、AUGER と同等。
- 大気蛍光法を採用し 1 次粒子同定に優れる。そのため、UHECR 起源を宇宙論的か天体加速か峻別する能力に秀でる。
- 行政の構造改革の影響により、日本側 64 億円の概算要求の見通しが悲観的。
- 平成 14 年度科研費「特定領域研究」(32 億円)と「特別推進研究」(25 億円)にて基本的に TA の一部分 3 ステーションのみを予算申請した。
- これにより、稼働率 10% ならば、AUGER の 1/4 の UHECR 検出率。稼働率は HiRes の実例から 7% 程度が現実的なので、AUGER の 1/6 以下の検出率となる公算が高い。
- また、AUGER の建設は順調に進んでおり、2003 年度には申請規模の半分、2004 年度には全検出器が稼働し、成果が出だす公算が高い。
- 平成 14 年度科研費により TA の一部 3 ステーションの予算化が成功しても、建設終了後、全検出器によるデータが出るのは 2006 年度以降である。

Records of Design & Development of TA Fluorescence Detector



Records of Design & Development of Ashra Wide & Fine Imaging Detector

Progress of Optics

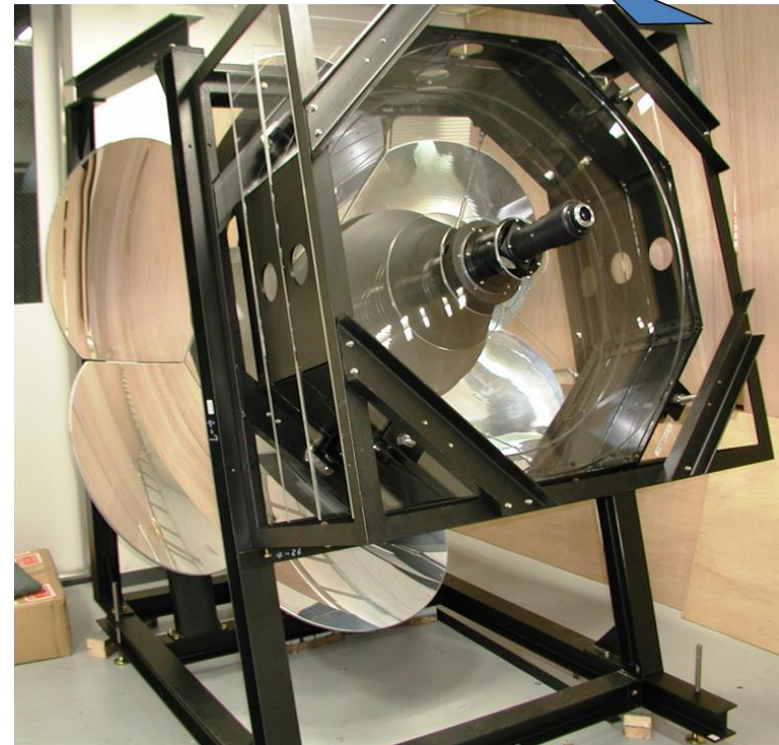
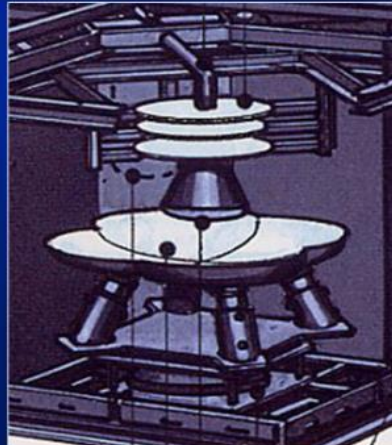
• TA ... Davies-Cotton

- FOV $\sim 16^\circ$ / Telescope
- Focal spot size $\sim 0.3^\circ$



• ASHRA ... Baker-Nunn

- FOV $\sim 50^\circ$ / Telescope
- Focal spot size $\sim 0.01^\circ$

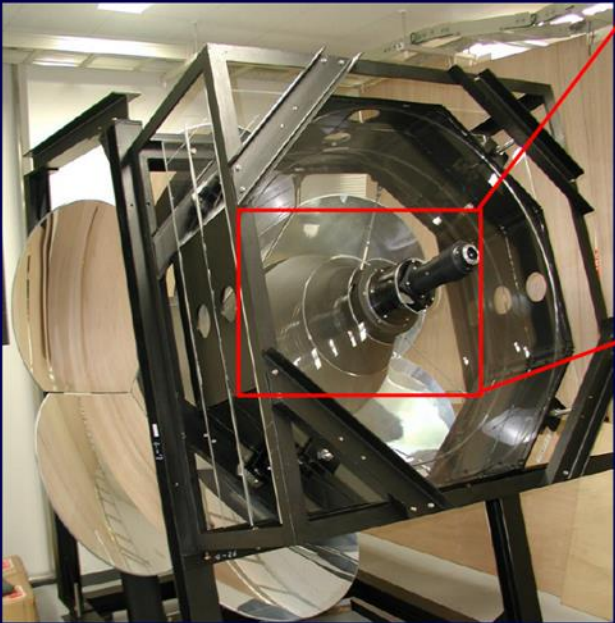
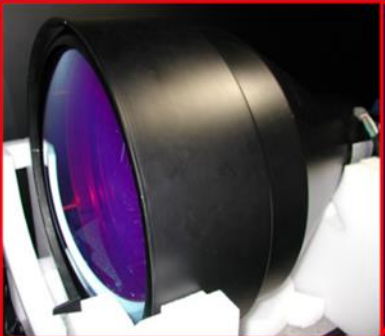
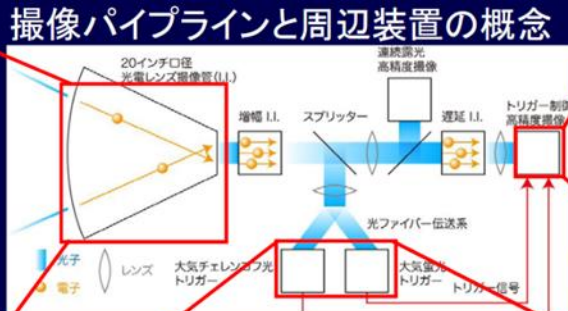
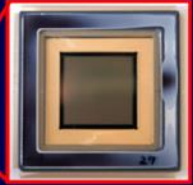



M.Sasaki, CosPA2003, Taipei

2-3 arcmin. resolution over 42deg FOV

2007: Installation on Mauna Loa

Ashra-1 LC Components

撮像パイプラインと周辺装置の概念

20インチ口径
光学レンズ増倍管(I.I.)

増幅 I.I. スプリッター 連続露光 高精度撮像

遅延 I.I. トリガー制御 高精度撮像

光ファイバー伝送系

光子 電子

レンズ 大気チェレンコフ光 トリガー 大気蛍光 トリガー トリガー信号

CMOSセンサ回路 (4.2Mpxl)

トリガー信号を受信し、
精細な画像を撮影する。

**20インチ
イメージンシファイア**

光電子増倍管と異なり、**位置情報を保ったまま輝度増幅+画像収縮**。

光電面が青く見えているのは、波長300-400nmのバンドパスフィルターを蒸着しているため。紫外領域の感度が向上している。

トリガセンサ回路

超高エネルギー素粒子観測では、いつシャッターを切るかを自動的に判断する仕組みが必要。大気チェレンコフや大気蛍光のみデータ画像を取得する高速撮像、判断、結果の配布。

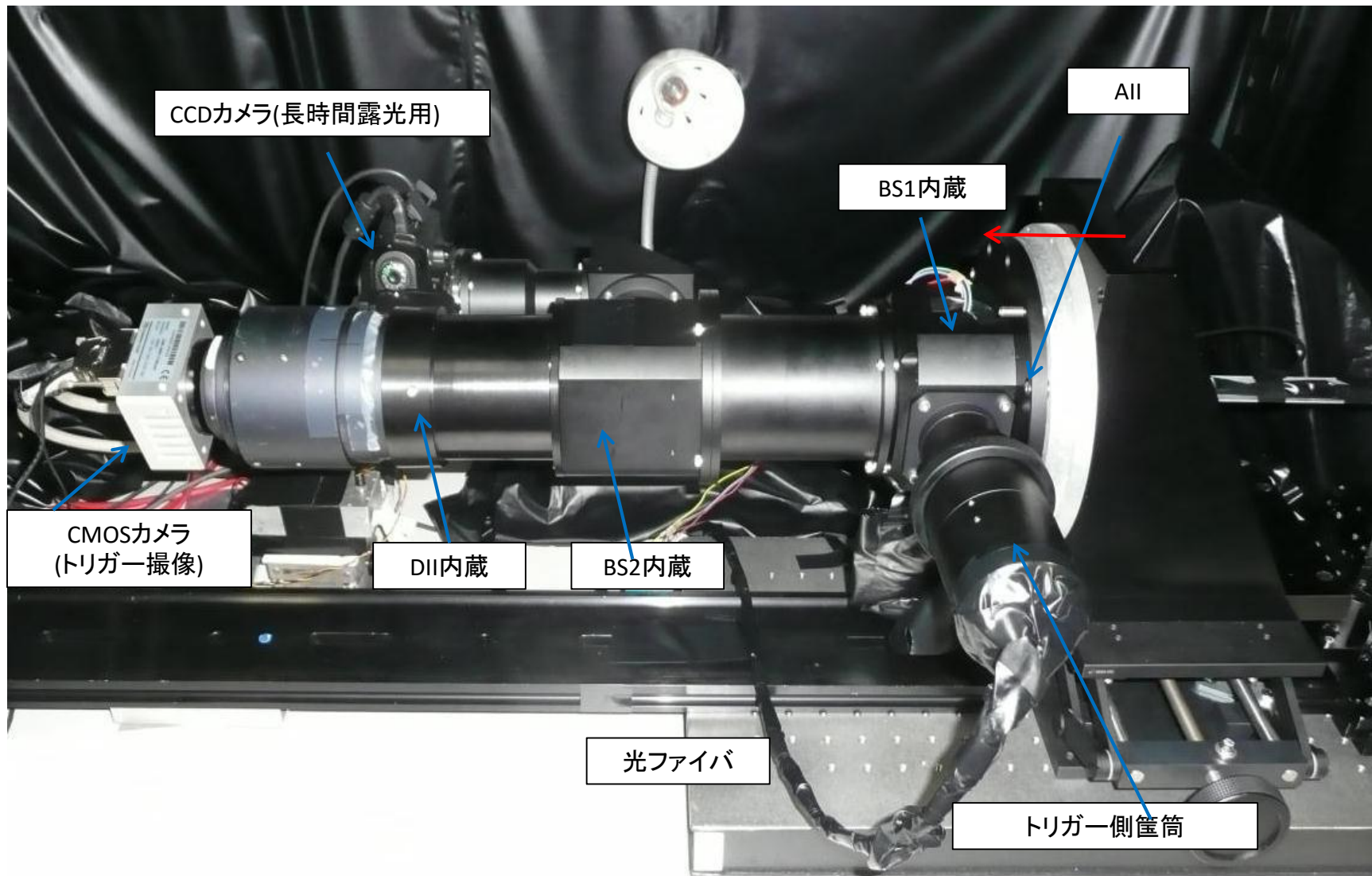
Ashra -1 集光器光学系

3枚の補正レンズ(有効径1.2m)を通過した光は7分割反射鏡でII(イメージンシファイア)に集光

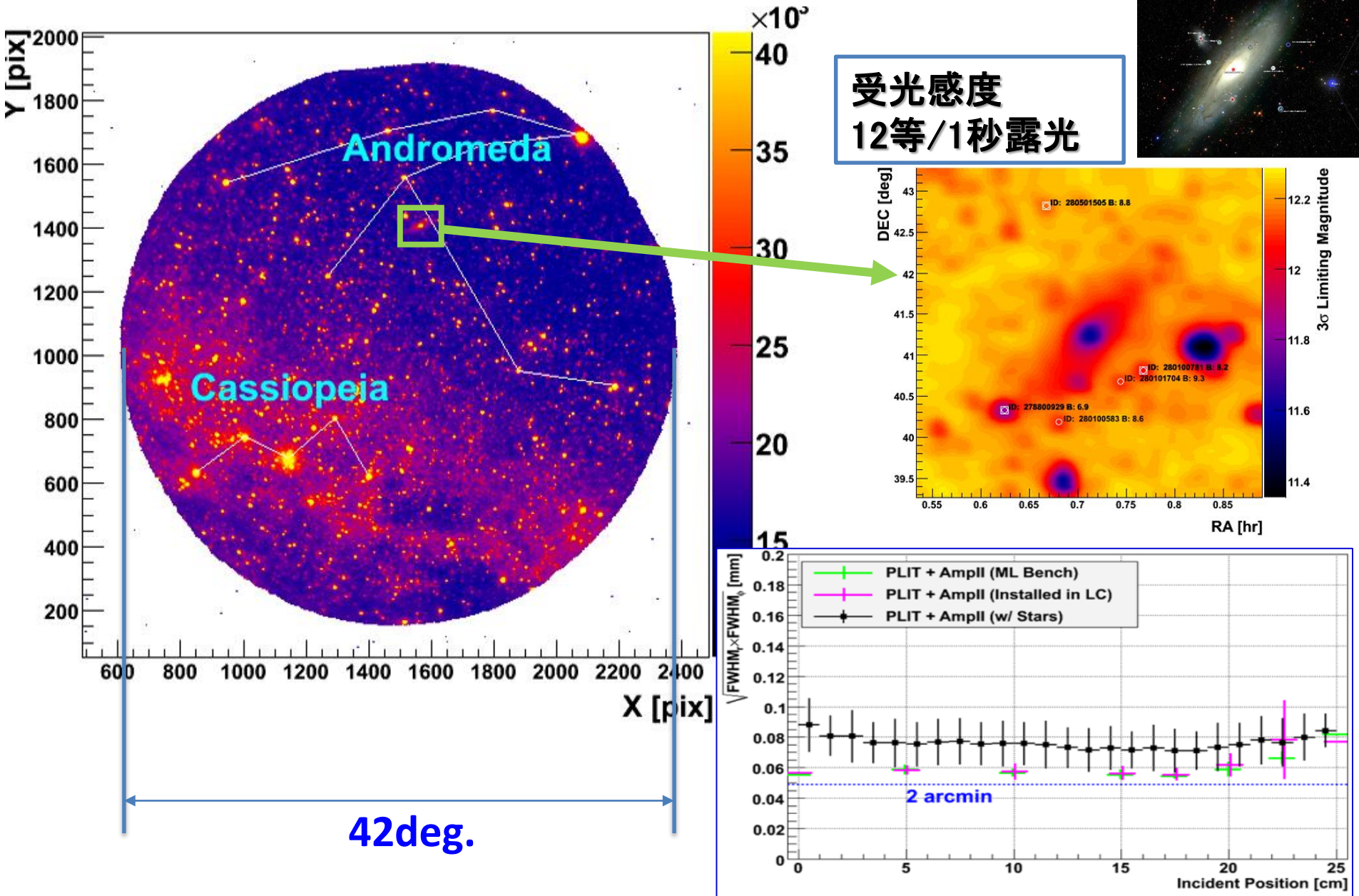
42度の視野を光だけでなく電子静電レンズも協働させ1インチまで収縮することに成功

- ①広視野、②高解像度、③マルチトリガー (for 多粒子天文)

Ashra-1 光電撮像パイプライン (PIP)

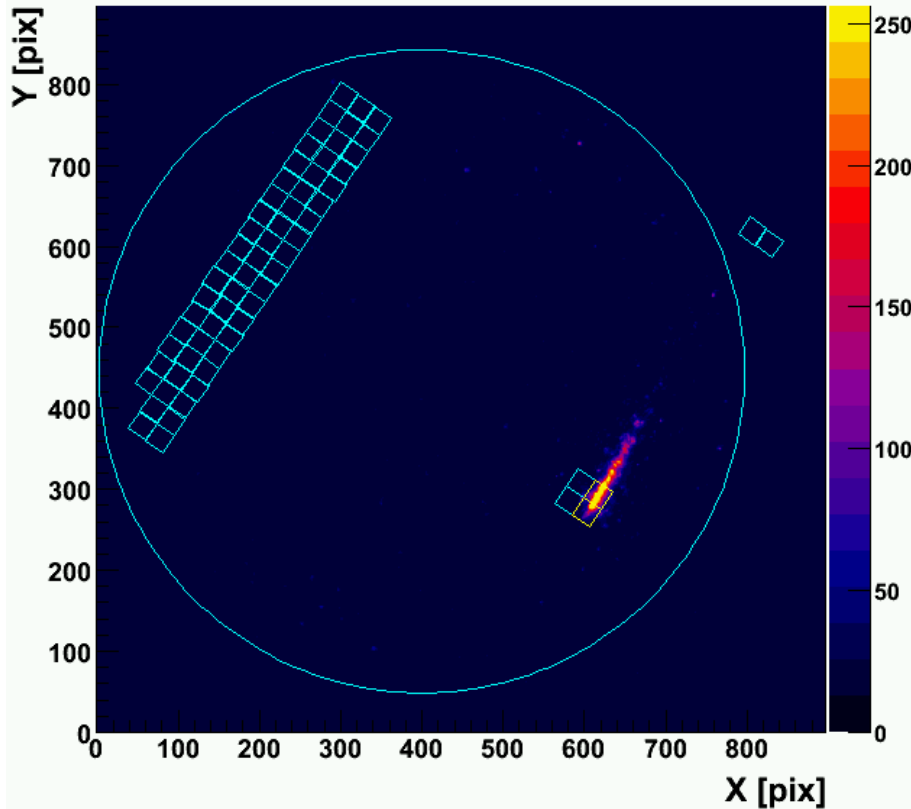


2-3 arcmin. Resol. Over 42deg FOV

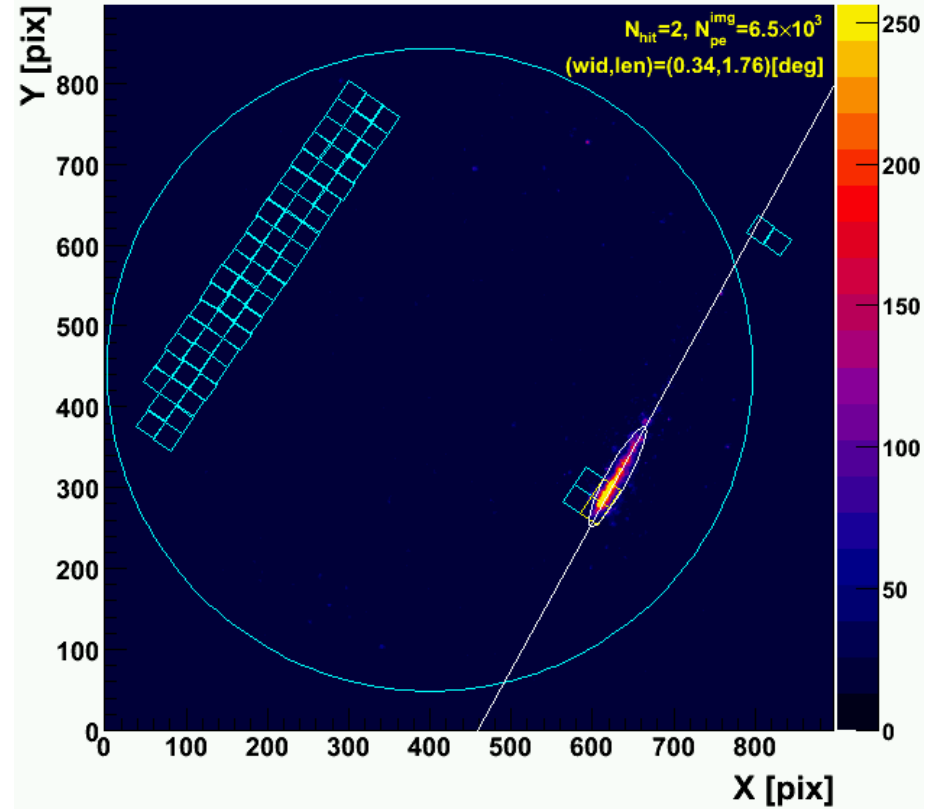


Real Shower Images

R0000847/E075258 120328 UT 13:30:44.356585



R0000847/E075258 120328 UT 13:30:44.356585



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

NTA Baseline Design

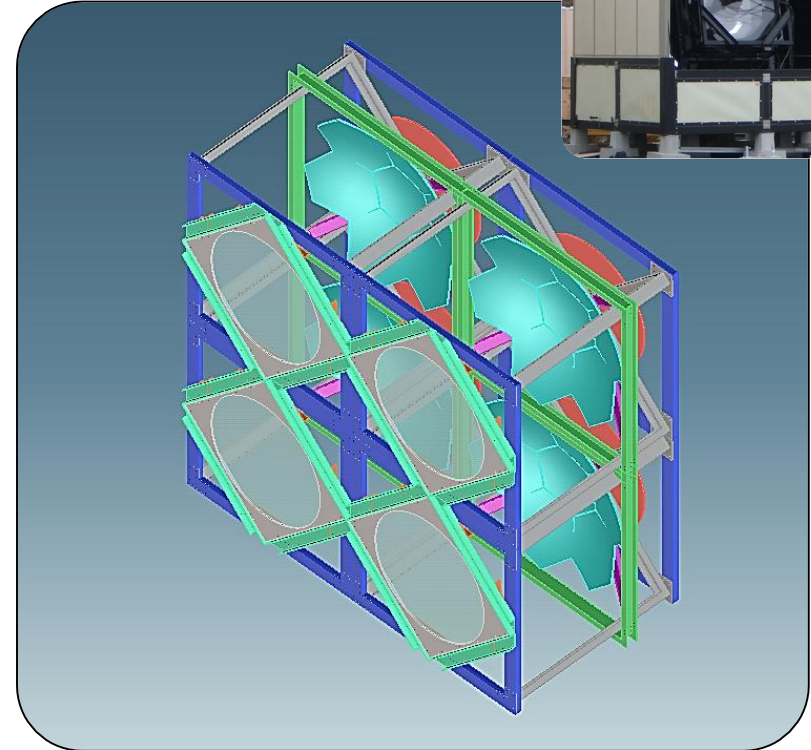
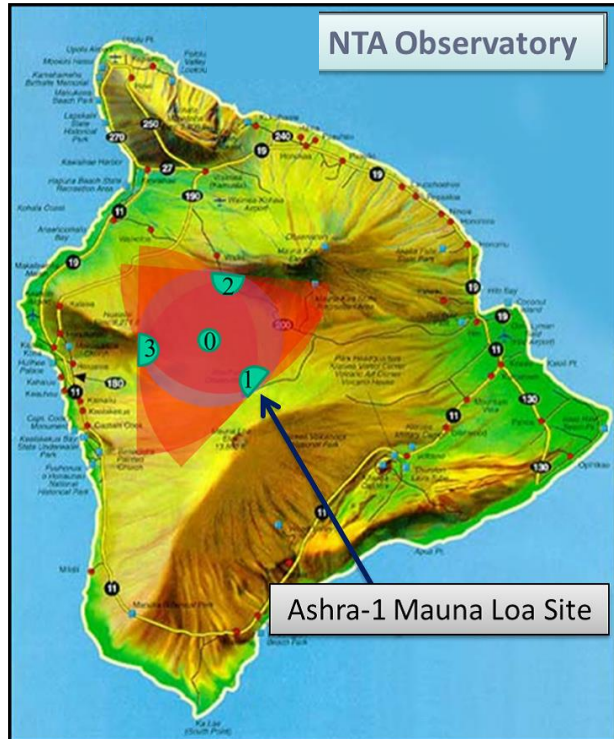
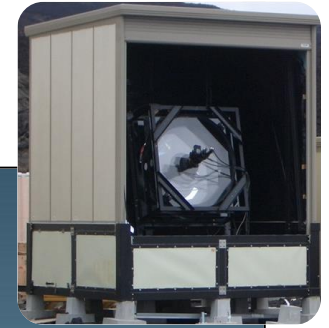


Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

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	$\pi/2$

⇒ Concept:

Ashra-1 x 1.5 scaled-up
+ same **trigger & readout**

Light Collector (LC)

Optics with $\phi 1.5\text{m}$ pupil
FOV 28° = focal sphere $\phi 50\text{cm}$

Detector Unit (DU)

4 LCs watching same FOV
Superimposed 4 images

⇒ **Effective pupil = $\phi 3\text{m}$**

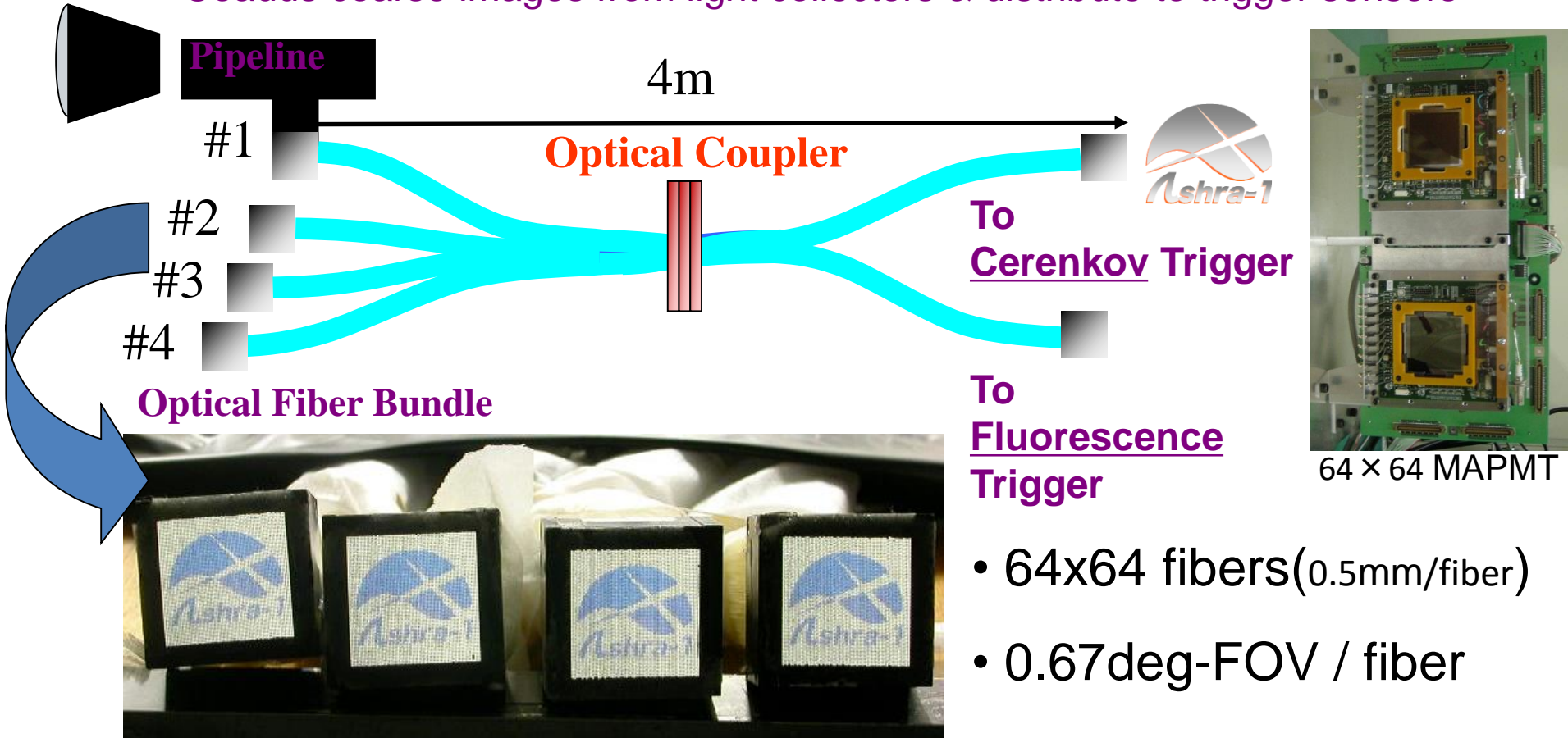
12 DU's per π coverage

~1000km² stereo

Need at least 30 DU's for Coverage

Optical Fiber Transmission System

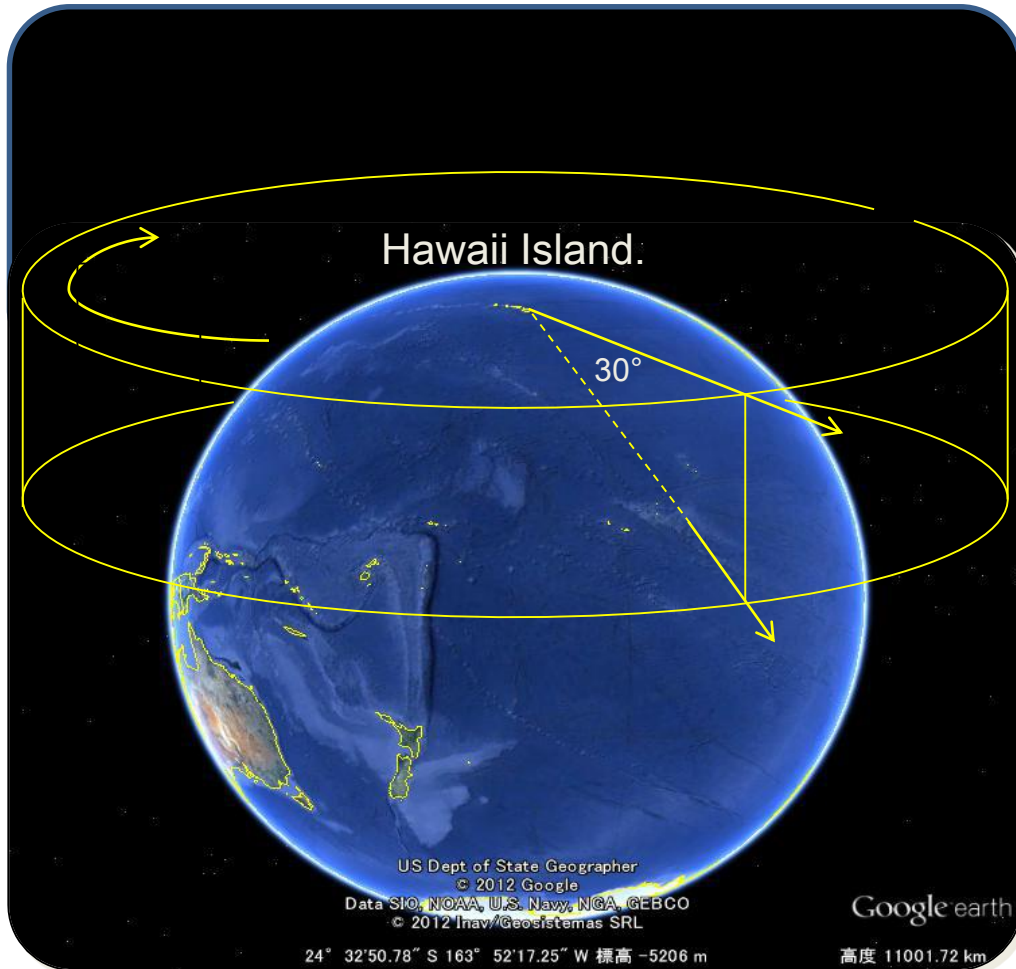
Coadds coarse images from light collectors & distribute to trigger sensors



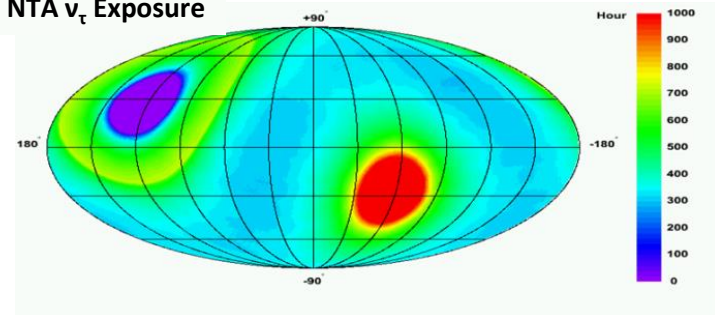
Light collectors can be easily appended to the trigger.

Sensitivity can be reinforced when more budget is available.

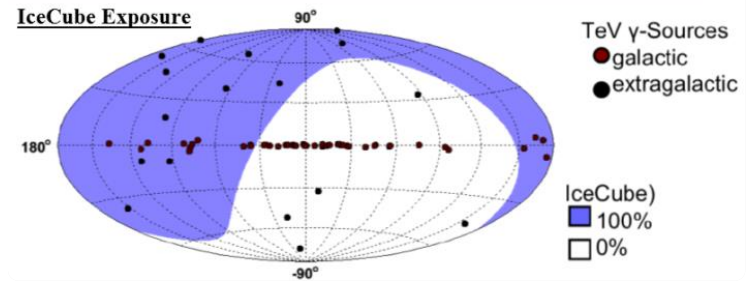
NTA ν_τ Survey Performance



NTA ν_τ Exposure



IceCube Exposure



Duty 10-20% from Ashra-1

ν pointing accuracy $< 0.2^\circ$

FOV Elevation $30^\circ \times$ Azimuth 360°

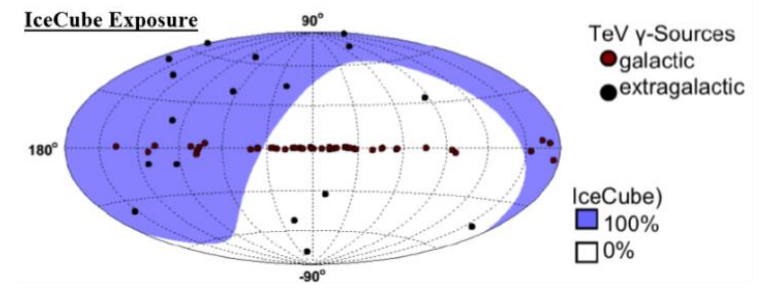
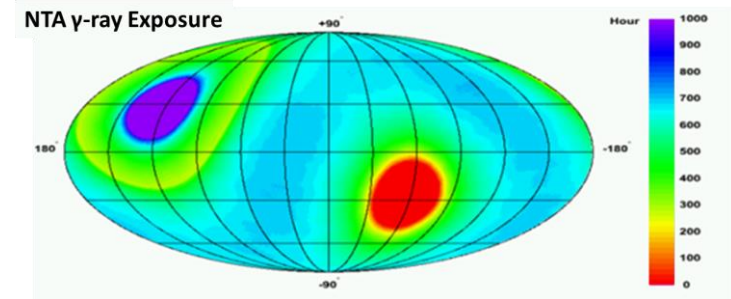
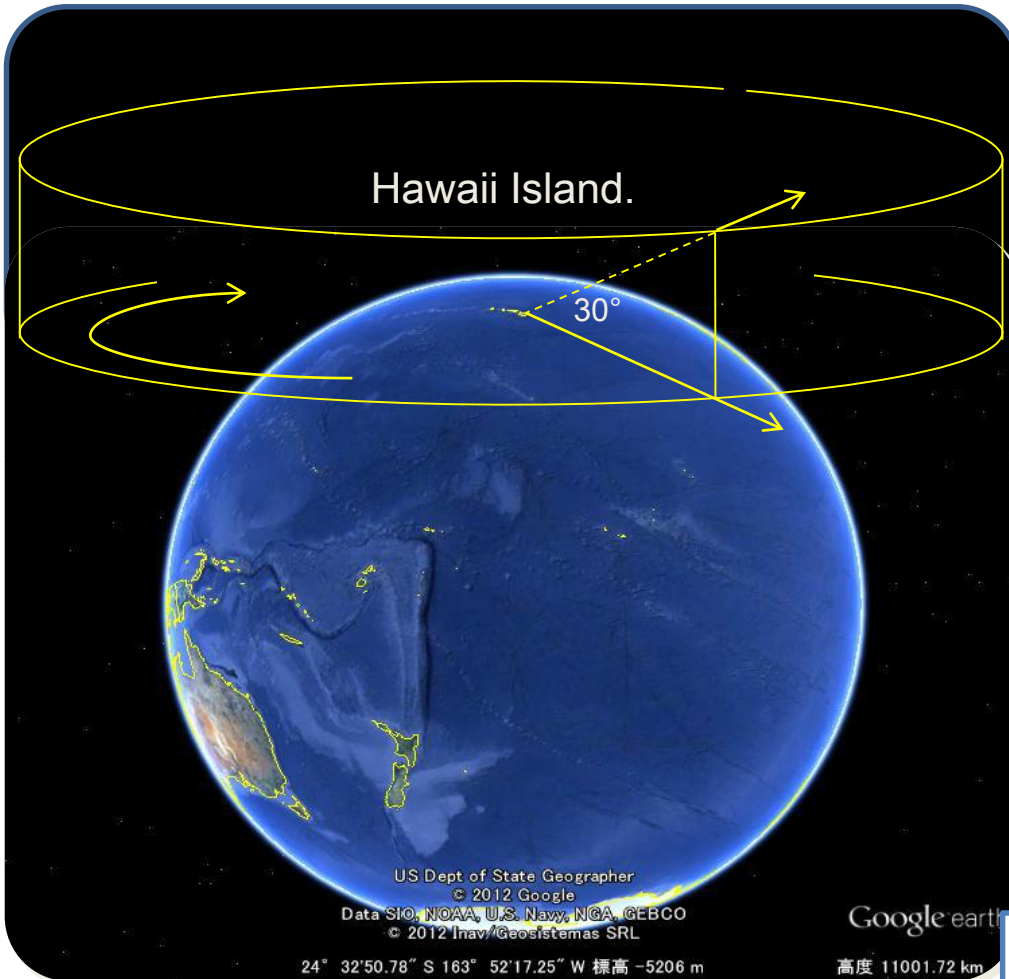
For GRB ν (Hummer et al. 2012)

Survey Depth $z < 0.15$ (600Mpc)

NTA ν_τ can observe Galactic Center

Wide & fine survey up to 15 x GZK-radius.

NTA γ -ray Survey Performance



- Duty 10-20% from Ashra-1
- γ -ray pointing accuracy $< 0.2^\circ$
- FOV Elevation $30^\circ \times$ Azimuth 360°
- Large zenith \Rightarrow PeV γ -ray aperture

NTA γ -ray can also observe Galactic Center

**Fine image in wide FOV @ large zenith,
 Cherenkov & Fluo. indep. triggers
 \Rightarrow γ -ray obs. in PeV-EeV range**

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2016: VHEPA2016 @ Honolulu, Jan. 7-9



The 9th International workshop on Very High Energy Particle Astronomy (VHEPA) will be held Jan 7-9, 2016 at the University of Hawaii at Manoa in the East-West Center (EWC).

This workshop will focus on future projects to measure very high energy particles and cosmic rays including the NTA (Neutrino Telescope Array) proposal for the Big Island of Hawaii, ANITA, ARA, ARIANNA, AUGER, CTA, GRAND, HAWC, IceCube-Gen 2, JEM-EUSO, KM2NET, LHAASO, and TA. In particular, following the observation of astrophysical neutrinos by IceCube, there is world-wide interest in measuring neutrinos in the energy range above IceCube and below the range covered by Auger, TA and other experiments. Although ANITA observed ultra-high energy cosmic rays, neutrinos in the GZK energy range have not yet been detected either. There are no confirmed point sources of neutrinos or high energy cosmic rays. Ample time for informal technical discussion of these issues will be planned at the workshop.

Confirmed speakers:

Jim Beatty
John Belz
Mauricio Bustamante
Peter Gorham
Sadakazu Haino
Francis Halzen
Jordan Hanson
Kael Hanson
George Hou
Brian Humensky
Albrecht Karle
Uli Katz
Kohta Murase
Angela Olinto
Nepomuk Otte
Makoto Sasaki
Gordon Thomson
Michael Unger
Amanda Weinstein
Lawrence Wiencke
Tolga Yapici

**For Ashra-1,
NTA = *internationalized* Ashra-2**

International Advisory Committee: Francis Halzen, Tadashi Kifune, Alan Watson, George Wei-Shu Hou

Local Organizing Committee: Philip von Doetinchem (chair), Veronica Bindi, Tom Browder, Peter Gorham, Jason Kumar, John Learned, Danny Marfatia, Bob Morse, Jan Bruce, Jacky Li and Josie Nanao.





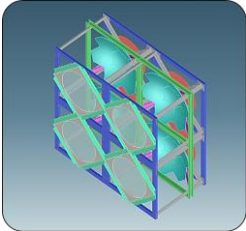
NTA

Funding Request

Construction / Partial Observation

Full Observation

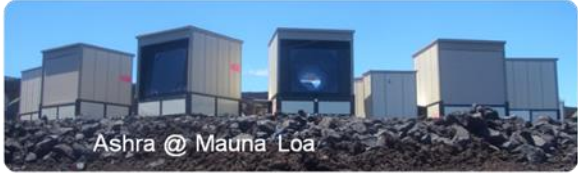
Toward PeV-EeV tau ν & γ -ray survey



Ashra-1

Test Observations / Multi-particle/ Multimessenger

Principal Demonstration



Akeno

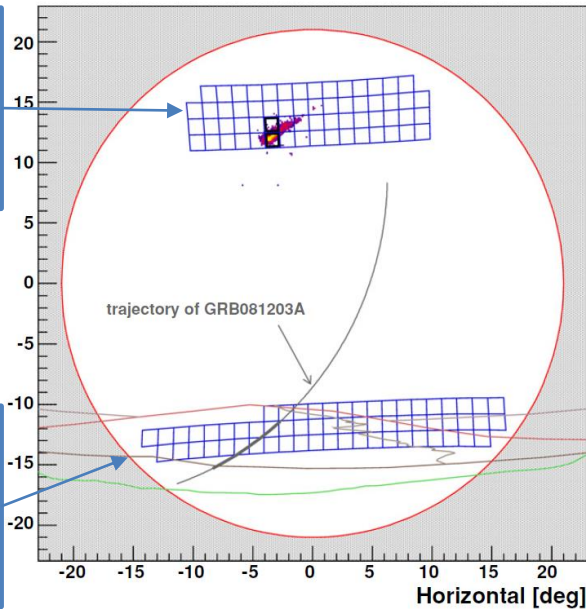
Training / Aging / Test Observations

Developments / Assembly



Obs01 (2008-2009):

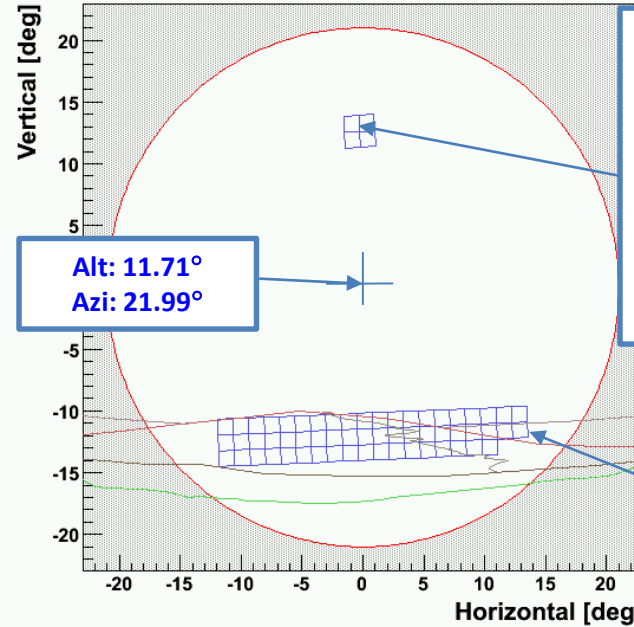
Trigger Pixels
for CR:
62 trig. pixels
44.4 hrs



Trigger Pixels
for Taus
62 trig. pixels
197.1 hrs

Obs03 (2012-2013):

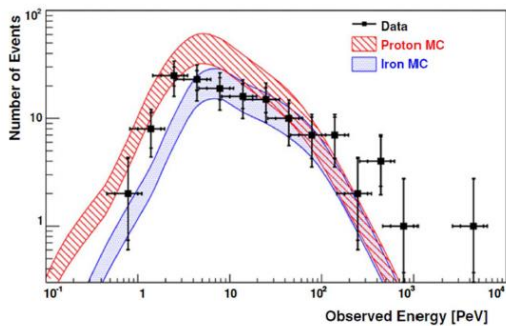
Trigger Pixels
for CR:
4 trig. pixels
1884 hrs
Alt: $14.63^\circ \pm 1.29^\circ$
Azi: $21.99^\circ \pm 1.29^\circ$
Fine Pix: $0.05^\circ/\text{pix}$



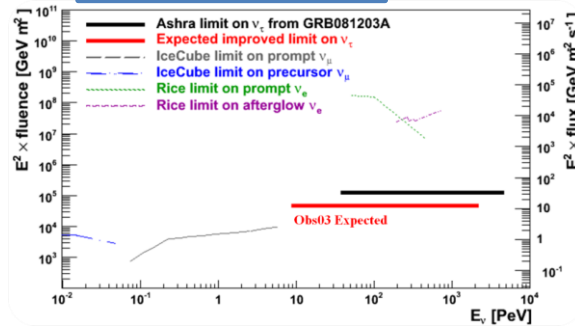
Alt: 11.71°
Azi: 21.99°

Trigger Pixels
for Taus
58 pixels
1950 hrs

CR Spectrum



GRB ν_τ Limit



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

Satellite	GRB Name	Flux Range
Swift	GRB0812	
Fermi	GRB0904	
Fermi	GRB0904	
Swift	GRB091024	$-1.6 \times 10^3 - 3.3 \times 10^2$
Fermi	GRB100216A	$-4.0 \times 10^3 - 1.1 \times 10^4$
Swift	GRB100906A	$-1.0 \times 10^4 - 4.0 \times 10^3$
Fermi	GRB120120	$-1.4 \times 10^3 - 8.9 \times 10^3$
Fermi	GRB120129	$-1.6 \times 10^3 - 6.7 \times 10^3$
Fermi	GRB120327	$-9.9 \times 10^3 - 8.2 \times 10^1$
Swift	GRB120911	$-2.4 \times 10^4 - 6.8 \times 10^1$
Fermi	GRB121019	$-1.7 \times 10^3 - 7.3 \times 10^3$
Swift	GRB121212A	$-5.8 \times 10^3 - 2.6 \times 10^4$
Fermi	GRB130206	$-3.3 \times 10^3 - 7.5 \times 10^4$
Fermi	GRB130215	$-2.7 \times 10^3 - 4.3 \times 10^2$

[1] Aita et al., 2011, ApJ, 736, L12

To be updated

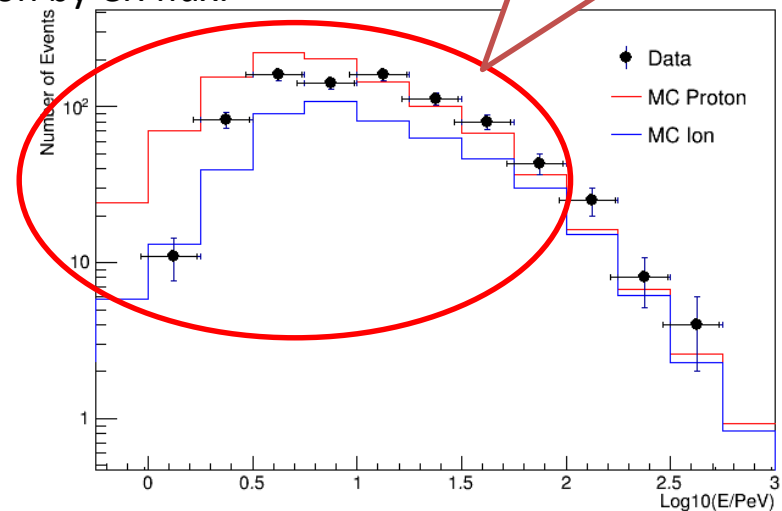
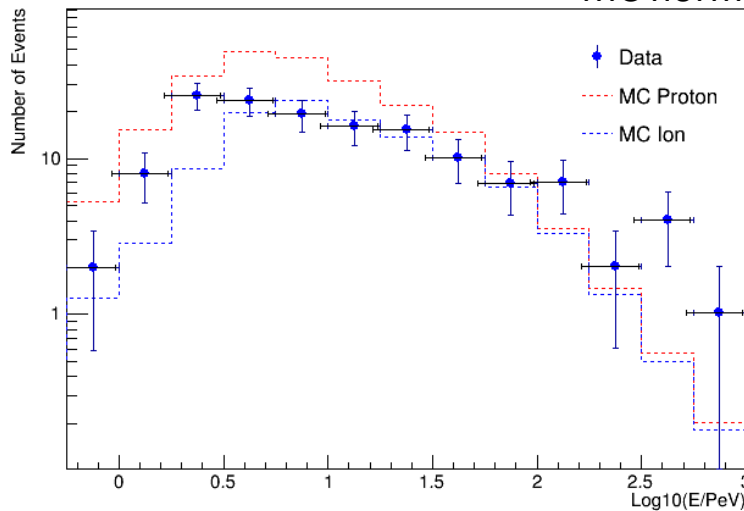
CR E_{obs} Spectrum

Obs01: **140** events

Obs03: **824** events

Interesting discrepancy bet. MC Iron and Proton

MC normalization by CR flux.

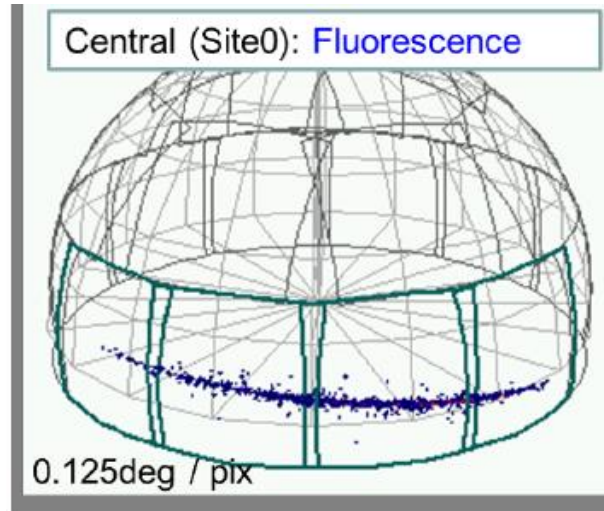


Source of Systematics	Error [%]
Trigger Threshold	19
Atomsphere & Optics	21
DAQ Efficinecy	6.3
Weather Condition	6.4
Sensitivity Total	30
Fine Image Gain	30

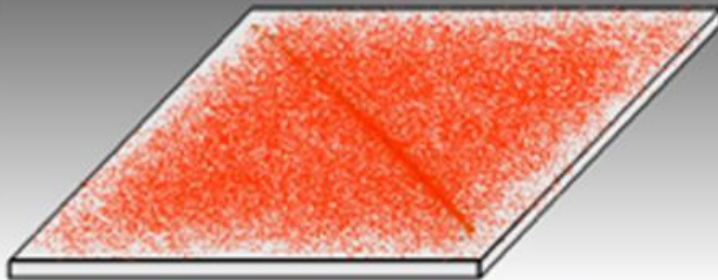
Updated **Very Preliminary**

Become negligible due to LED flusher calibration

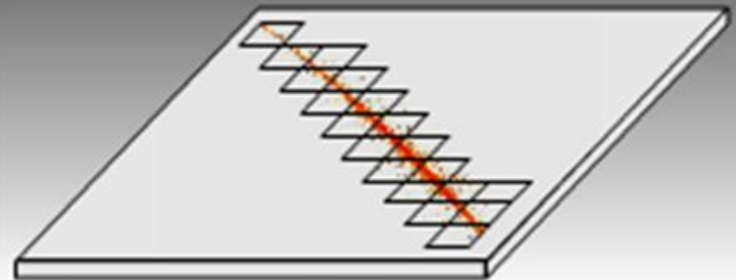
Local Exposure Control



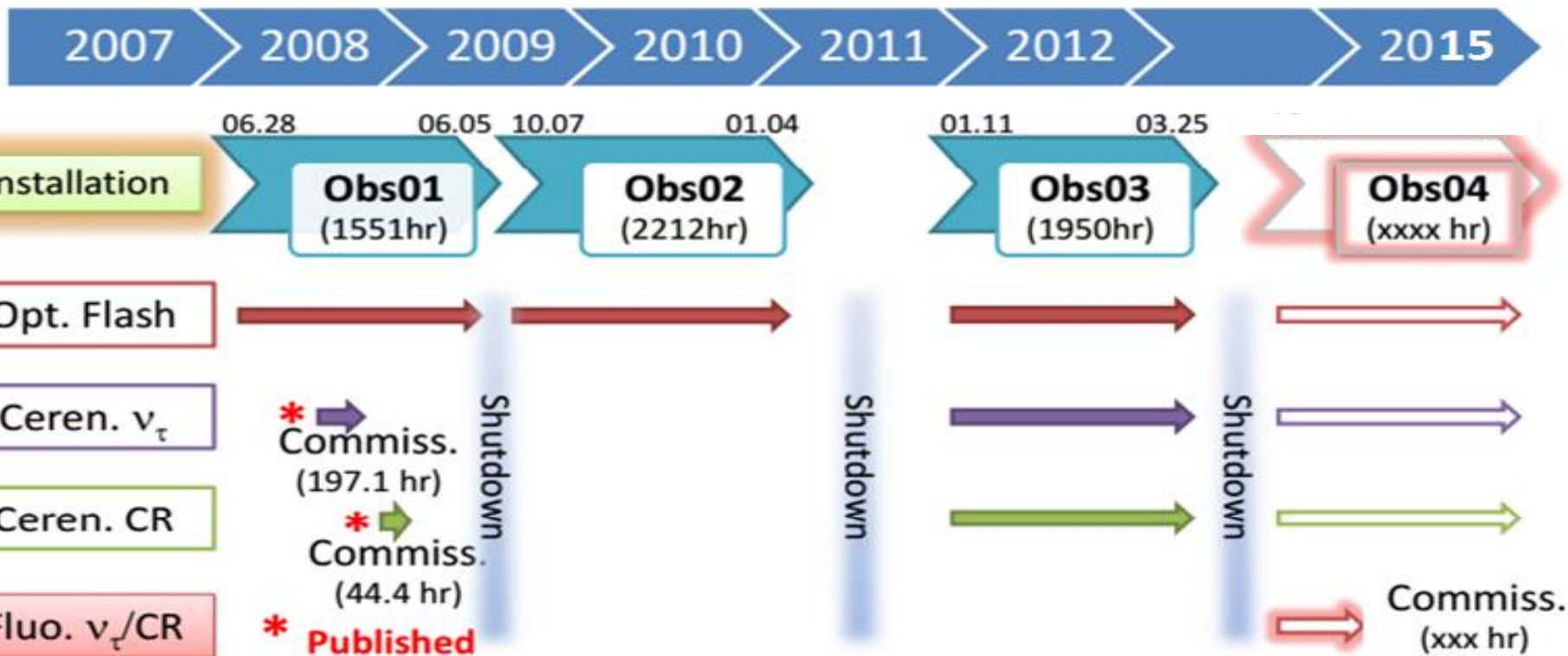
Global Exposure Control



Local Exposure Control
=> Ideal Noise Reduction



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	$-1.2 \times 10^4 - 5.6 \times 10^3$
Fermi	GRB090428	$-8.1 \times 10^3 - 5.9 \times 10^3$
Fermi	GRB090429C	$-4.1 \times 10^3 - 1.7 \times 10^3$
Swift	GRB091024	$-1.6 \times 10^3 - 3.3 \times 10^2$
Fermi	GRB100216A	$-4.0 \times 10^3 - 1.1 \times 10^4$
Swift	GRB100906A	$-1.0 \times 10^4 - 4.0 \times 10^3$
Fermi	GRB120120	$-1.4 \times 10^3 - 8.9 \times 10^3$
Fermi	GRB120129	$-1.6 \times 10^3 - 6.7 \times 10^3$
Fermi	GRB120327	$-9.9 \times 10^3 - 8.2 \times 10^1$
Swift	GRB120911	$-2.4 \times 10^4 - 6.8 \times 10^1$
Fermi	GRB121019	$-1.7 \times 10^3 - 7.3 \times 10^3$
Swift	GRB121212A	$-5.8 \times 10^3 - 2.6 \times 10^4$
Fermi	GRB130206	$-3.3 \times 10^3 - 7.5 \times 10^4$
Fermi	GRB130215	$-2.7 \times 10^3 - 4.3 \times 10^2$

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

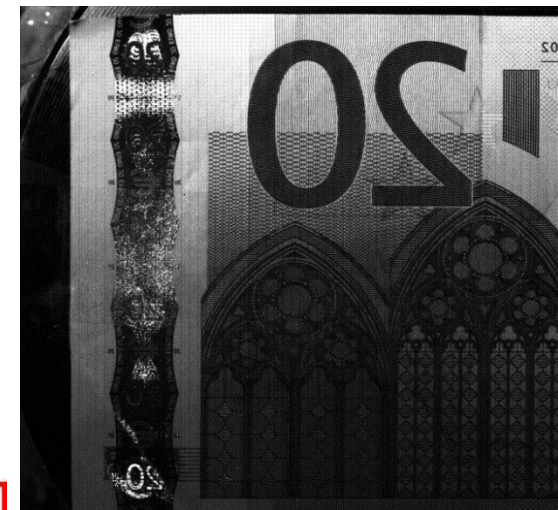
Ashra-1 高速撮像カメラ (FST)



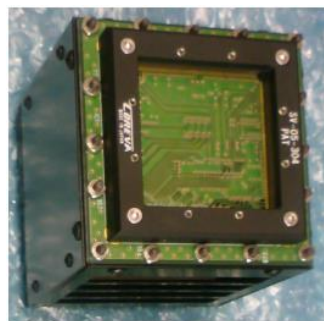
トリガー論理判定回路 (FPGA
ボード) との接合動作試験



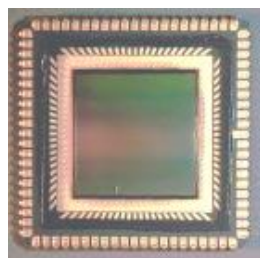
ファイセンサーの撮像試験



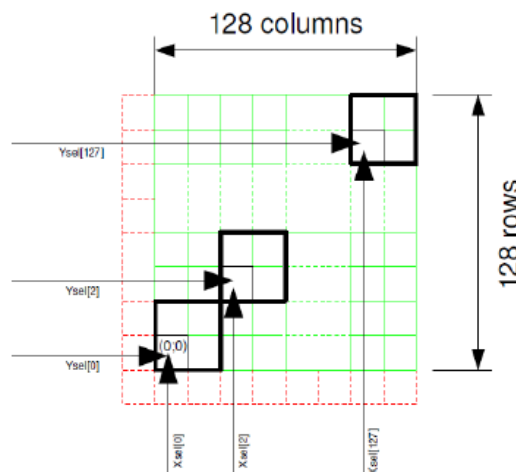
露光 読み出しされた画像



ファインセン
サーカメラモ
ジュール



Ashra
ファインセン
サー



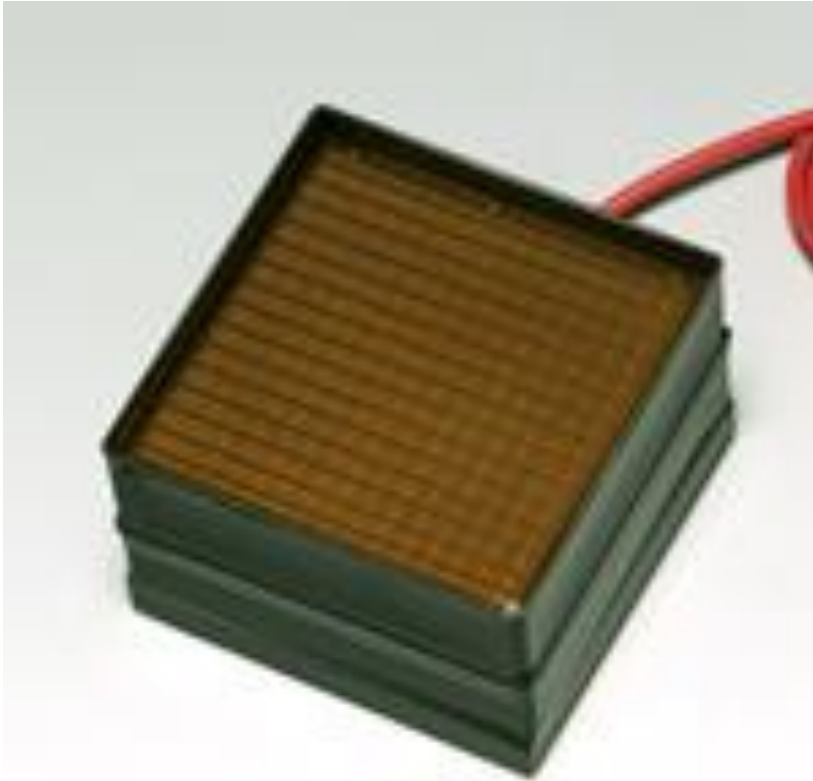
トリガーセンサーアドレス

Ashraファインセンサーの特徴
2048x2048 pixels/19mmx19mm
128x128 セルの
個別露光 読み出し可能

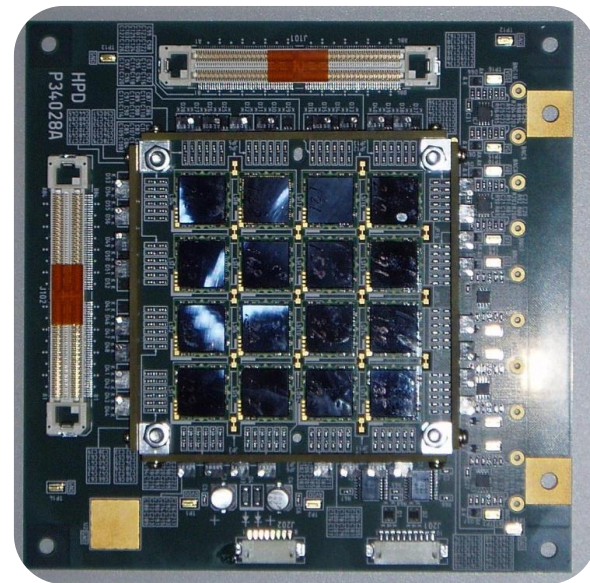
動的撮像試験

最終動作確認中

Ashra-1 / NTA Trigger Sensor

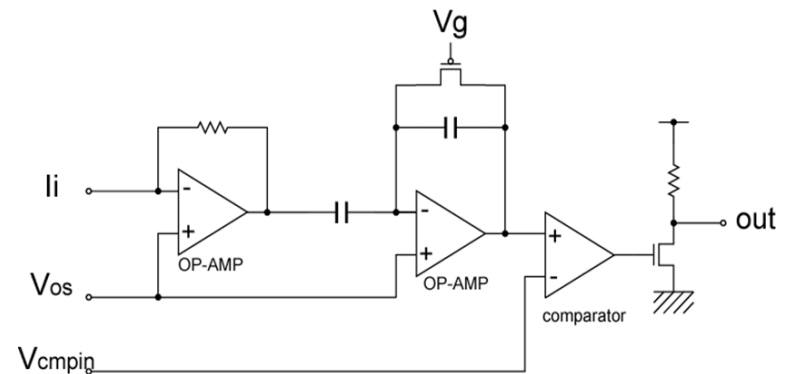


R8400-00-M256 (H9500)



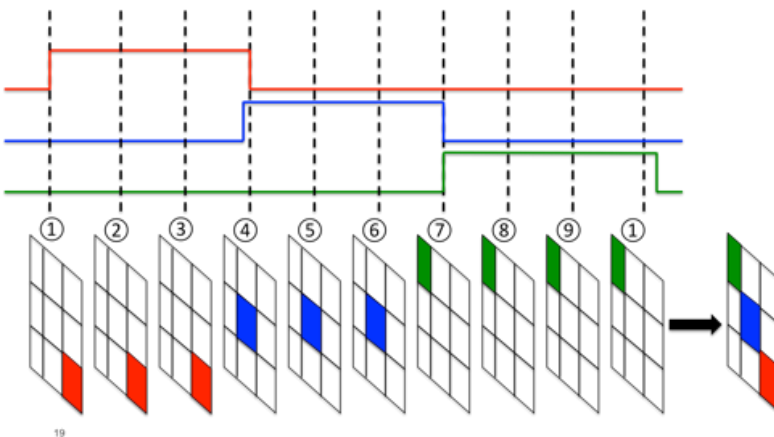
- Trigger Sensor Unit (TSU) = 16x16 trigger pixs /chip on R8400-00-M256 followed by Trigger Decision LSIs (ASIC)
- 4x4 TSUs for 1 Detector Unit

Pixel Circuit Diagram



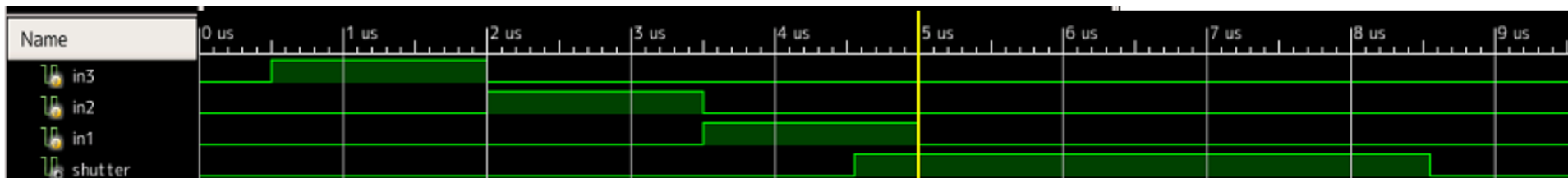
大気蛍光用論理判ロジック (Track Finding)

論理判定回路



Obs3で使用したチェレンコフ光判定に
大気蛍光判定を付け加える
複数のFPGA、DSP、メモリーが搭載

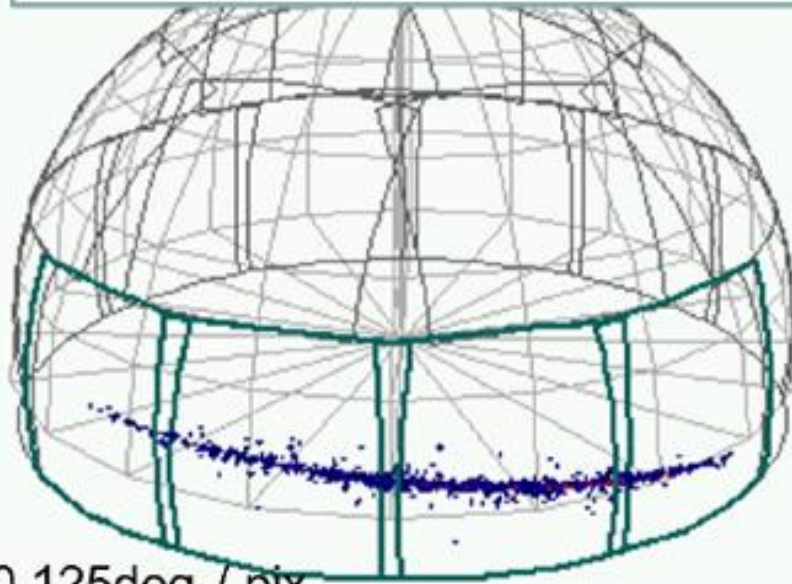
MAPMT、閾値判定回路を通された信号を
サンプリングリングバッファに蓄積し
随時判定を行う
判定後 ファインセンサーから読み出しを行う



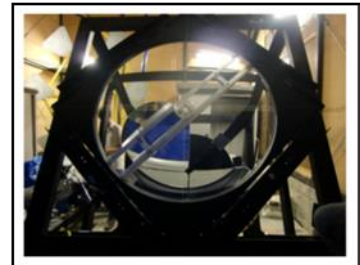
論理判定 シミュレーション波形

Trigger Test with Laser Tracks

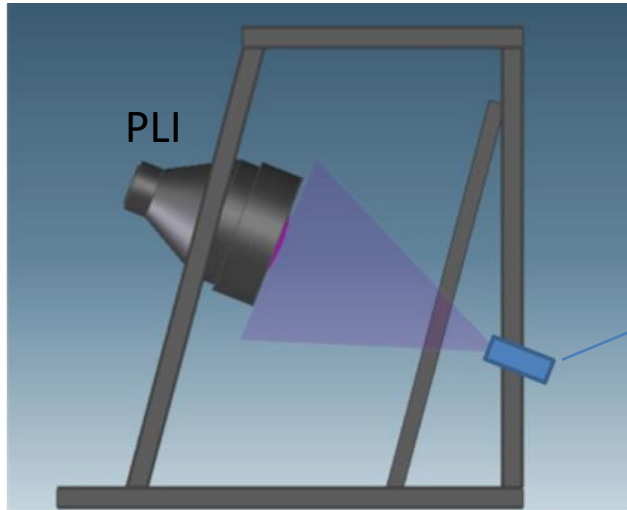
Central (Site0): Fluorescence



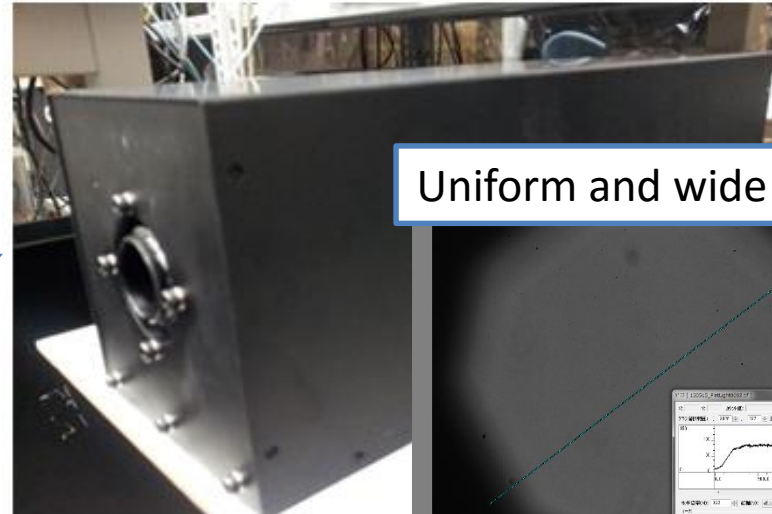
Laser Track Triggered with Track Finding, 9.6mJ/pulse @532nm



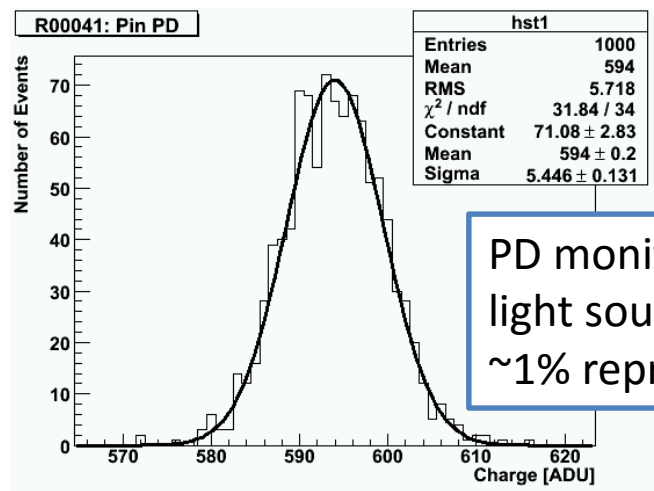
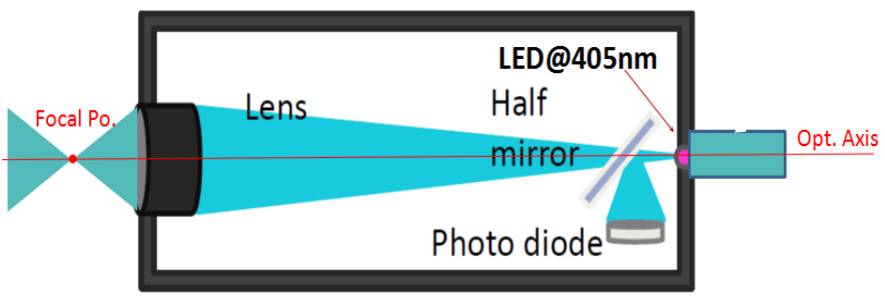
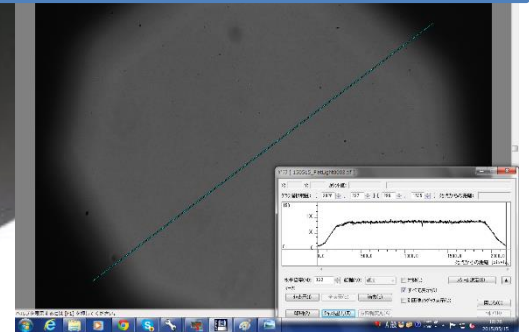
LED Flasher for Gain Calibration



PLI+PIP Trigger Readout can be calibrated even during Physics Run (e.g. 0.01Hz)



Uniform and wide ($\pm 20^\circ$)



PD monitors LED light source stability. $\sim 1\%$ reproducibility

Rehabilitation Jan. – Mar. 2015

The Washington Post

Capital Weather Gang

White Christmas in Hawaii? Snow falls on Big Island peaks, Blizzard Warning issued

ハワイでホワイト・クリスマス? ハワイ島の峰で降雪があり、ブリザード警報が発令

By Jason Samenow December 23 at 4:00 PM |

gatecam Tue Dec 23 08:59:59 2014



2015.12.16

@ Mauna Loa Observation Site



Summary

- We are now just one step away from clearly identifying CR origins and more.
- Ashra/NTA: PeV-EeV Universe Explorer with ν & γ rays for and beyond CR origins.
- Validation for ν_τ based on updated CR Spectrum OK
 - => Soon following analyses will be completed:
 - Diffuse ν_τ flux search
 - ν_τ s from many GRBs passed through Ashra-1 FOV
- CR E_{obs} Spectrum has physics potentials:
 - Composition as a function of E_{obs}
 - Need more statistics and to eliminate systematics
- We would increase trigger pixel coverage (statistics) and start stereo observation (systematics) for ν_τ and CRs. => Demo. for NTA physics potential.



Same orientation
-> stereo-analysis will be possible
with more distant separation

Ashra-1 Collaboration

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Ibaraki Univ. ^F, Kanagawa Univ. ^G



Ostracism