Ashra-1 Experiment

H26Kyodo@Kashiwa
Makoto Sasaki
ICRR UTokyo

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)

今年度の使途内訳：

研究費　光学設置治具、消耗品、観測用通信輸送費、など
旅費　国内出張 (会議/試験@柏/明野)など

有効に使わせて頂いております。ありがとうございます。

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IAC : A.Watson,F.Halzen,T.Kifune

ICRR ニュース No. 35 1998. 特集号 東京大学宇宙線研究所

将来計画特集 宇宙線研究のさらなる飛躍をめざして

所長 戸塚洋二

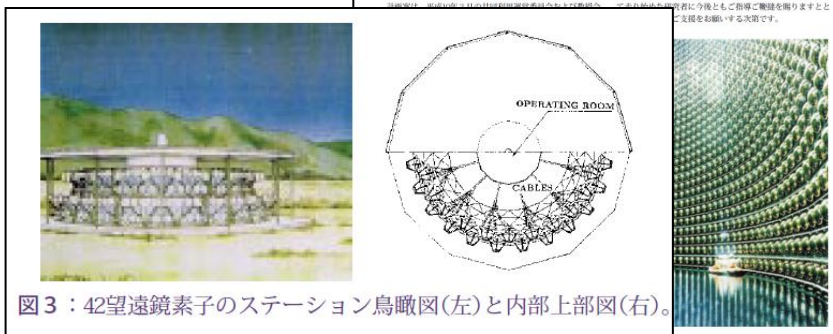
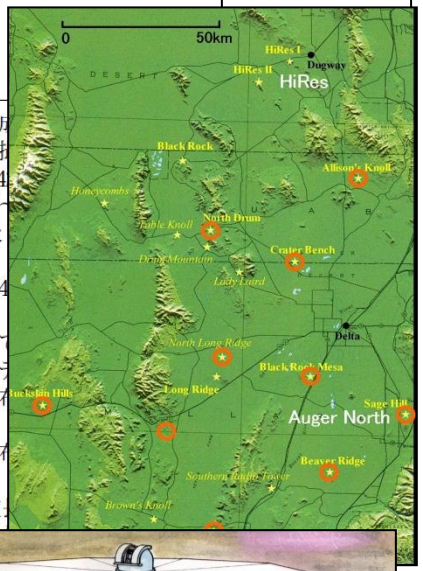


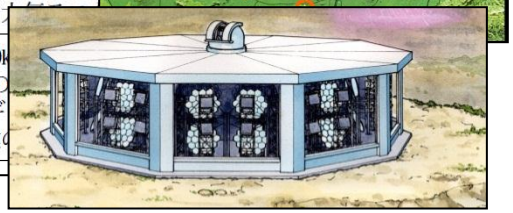
図3：42望遠鏡素子のステーション鳥瞰図(左)と内部上部図(右)。

研究方法

1．テレスコープアレイ検出器仕様

検出原理	空気シャワー電子成
検出器構成	励起蛍光の集光・打
カメラ構成	3m径蛍光望遠鏡4
ステーションの視野	ン・アレイ8台（
シャワー軸再構成	1望遠鏡素子あた
1次エネルギー再構成	光電子増倍管
1次粒子種類同定	方位360°×仰角34
大気透明度較正	ラジアン）
	複数ステーション
	による幾何学的ス
	シャワー縦発達分
	クに積分。
	シャワー縦発達分
	を求め、分類。
	YAGレーザー（波
	ンライン
検出効率（10^{20}eV）	>80,000
分解能	AGASAの
	エネルギ
	大縦発達





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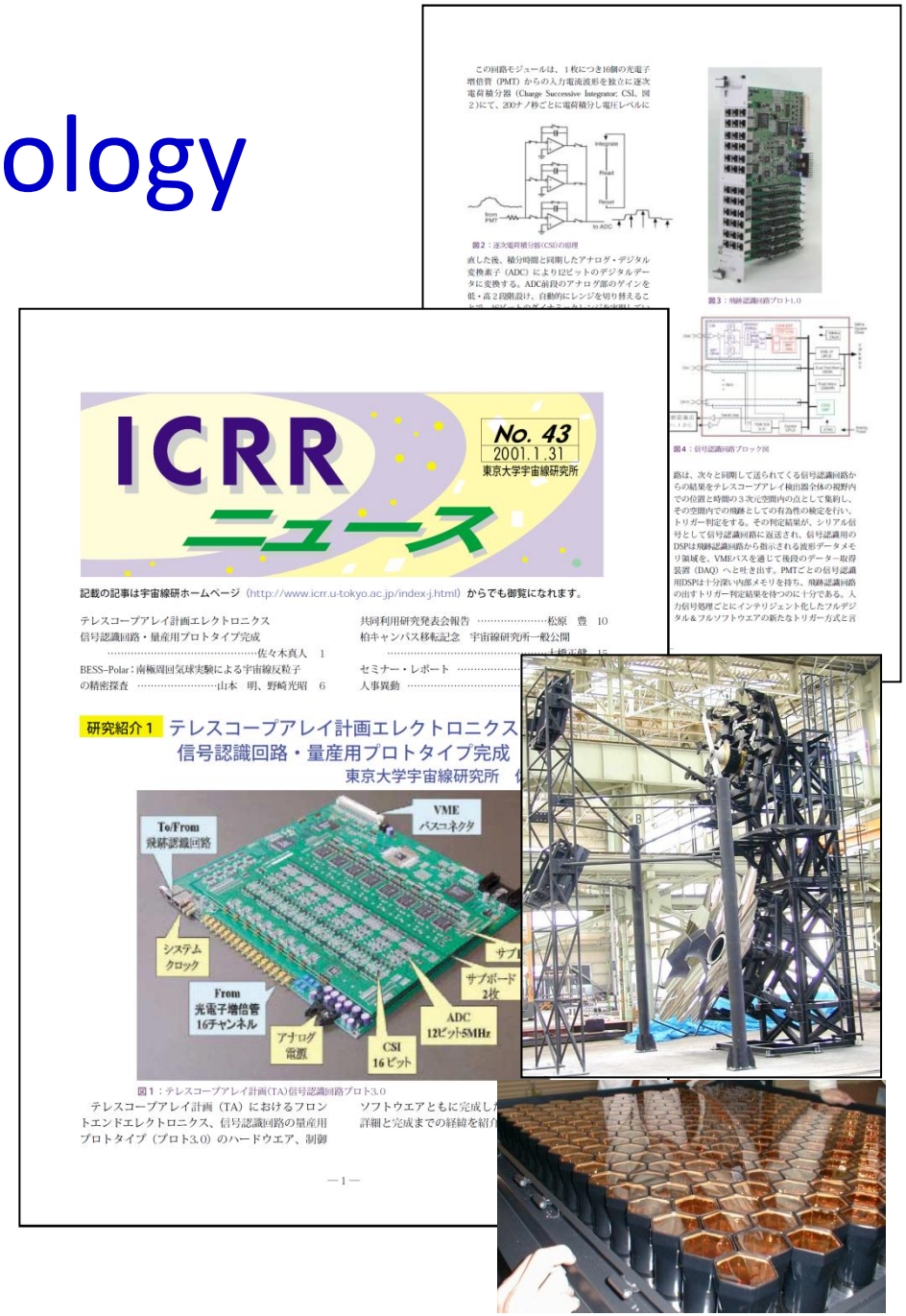

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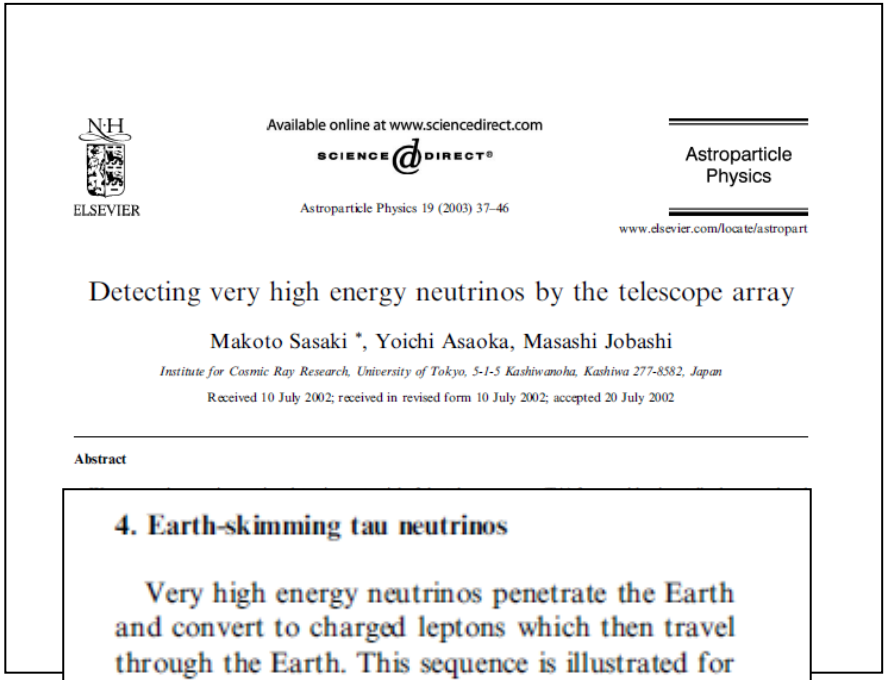

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Astroparticle Physics 19 (2003) 37–46

Astroparticle Physics

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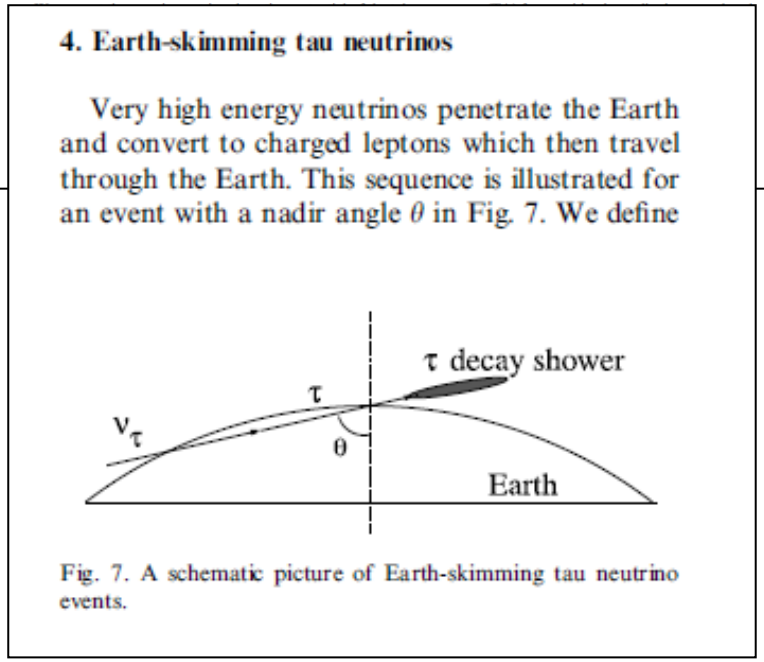
Detecting very high energy neutrinos by the telescope array

Makoto Sasaki *, Yoichi Asaoka, Masashi Jobashi

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

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

Abstract

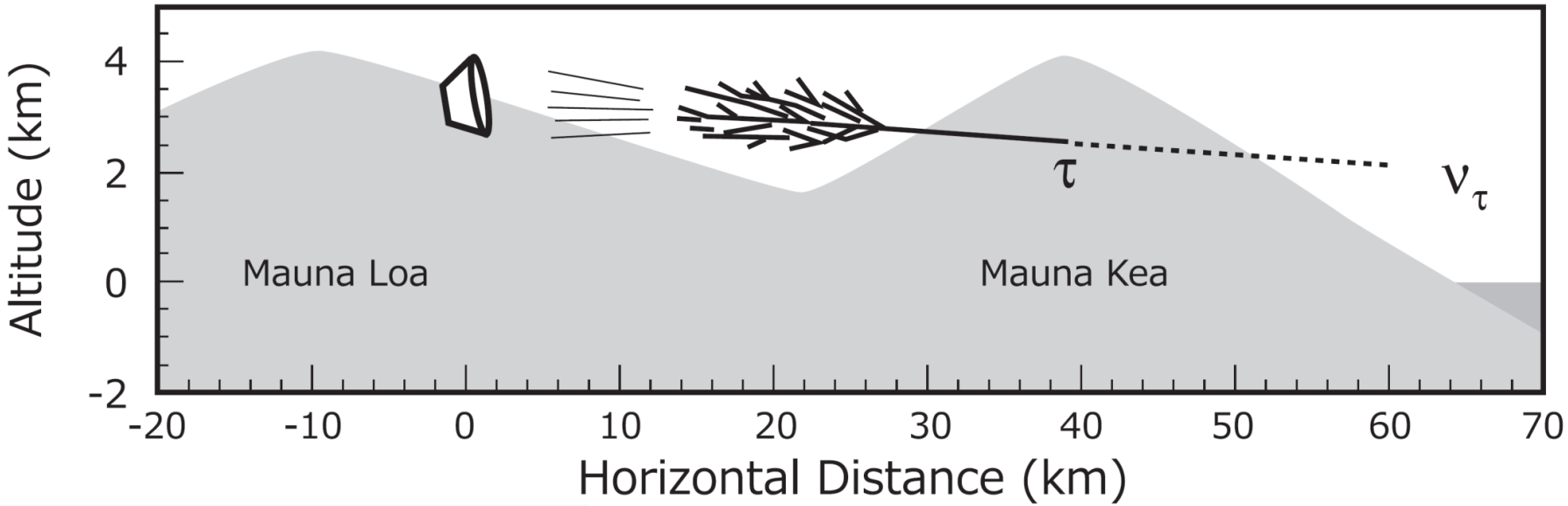


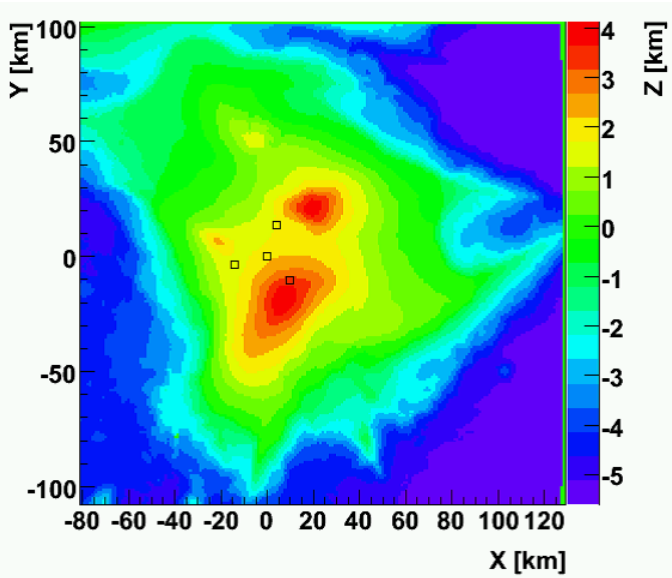
4. Earth-skimming tau neutrinos

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.

Earth Skimming Tau Shower Method





Dist. Ang. w.r.t. Mountain Edge	Expected BG Contamination
0.1 deg	0.08 /yr
0.3 deg	0.55 /yr
1.0 deg	4.3 /yr
3.0 deg	39 /yr

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ICRR-2000 サテライトシンポジューム
「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。
- 稼動率 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、稼動率 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動し、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。

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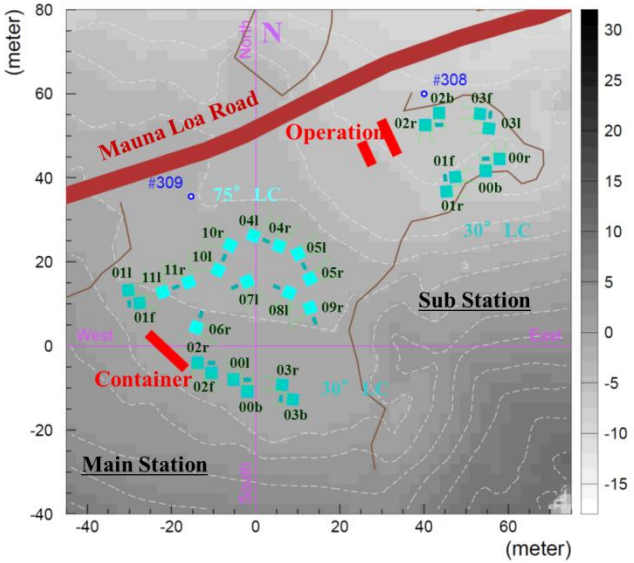

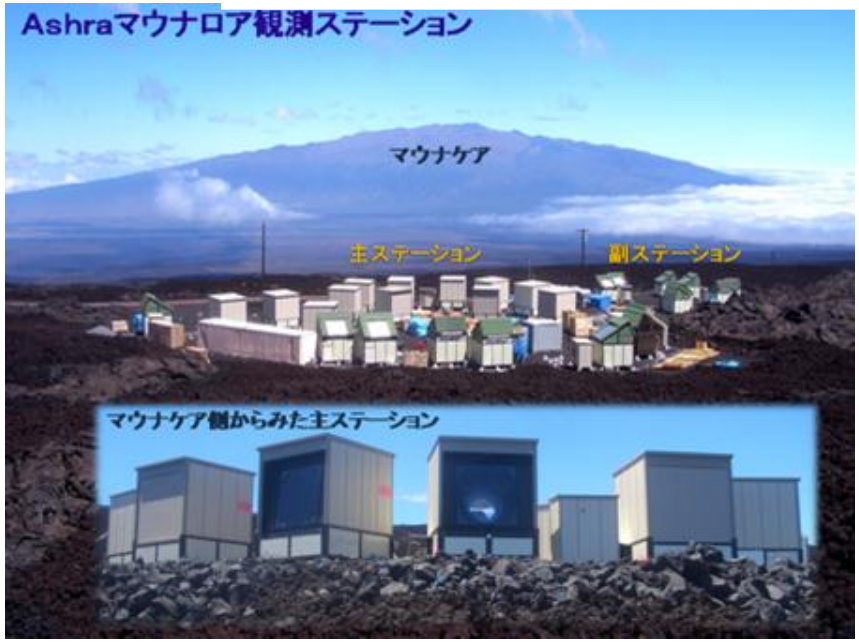

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Neutrino Telescope Array Letter of Intent:

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

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

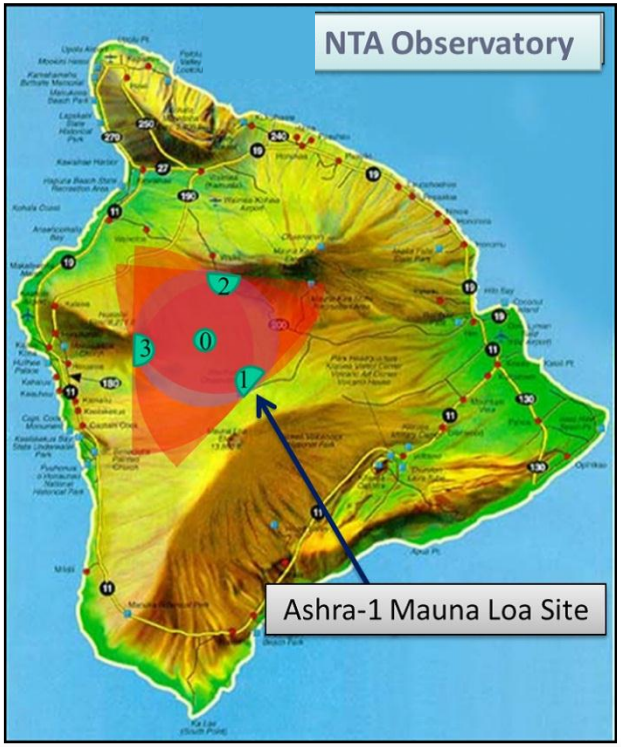
[1] *Institute for Cosmic Ray Research, The University of Tokyo, Kashiwa, Chiba 277-8582, Japan*
[2] *Department of Physics, National Taiwan University, Taipei 10617, Taiwan*
* *E-mail: sasakim@icrr.u-tokyo.ac.jp, wshou@phys.ntu.edu.tw*

the clear discovery and identification of non-thermal hadronic process in the Universe

air shower imaging detector for neutrinos

Ashra-1 Light Collector

NTA Baseline Design



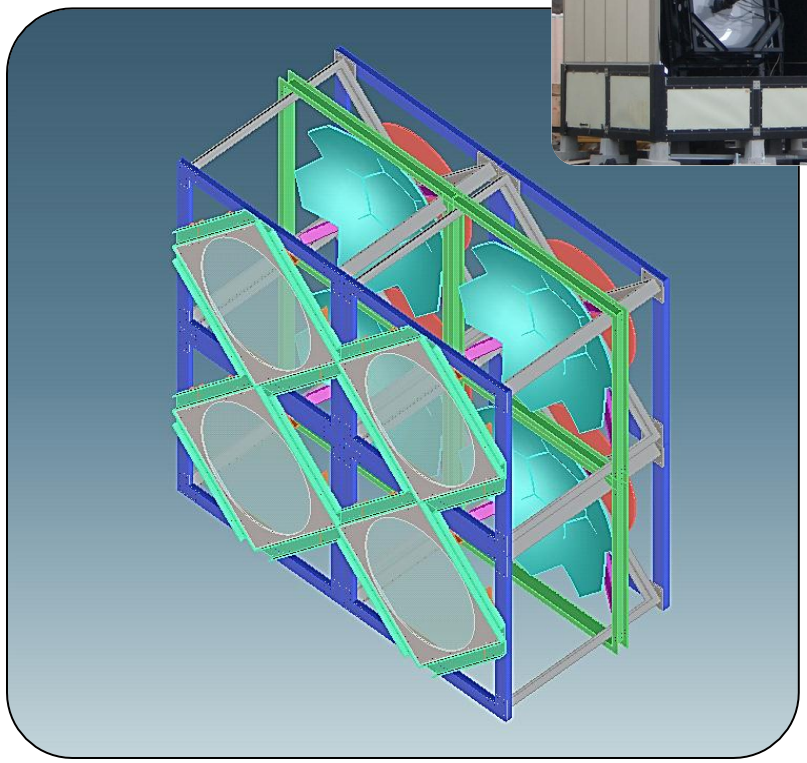


Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

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	$\pi/2$

12 DU's per π coverage

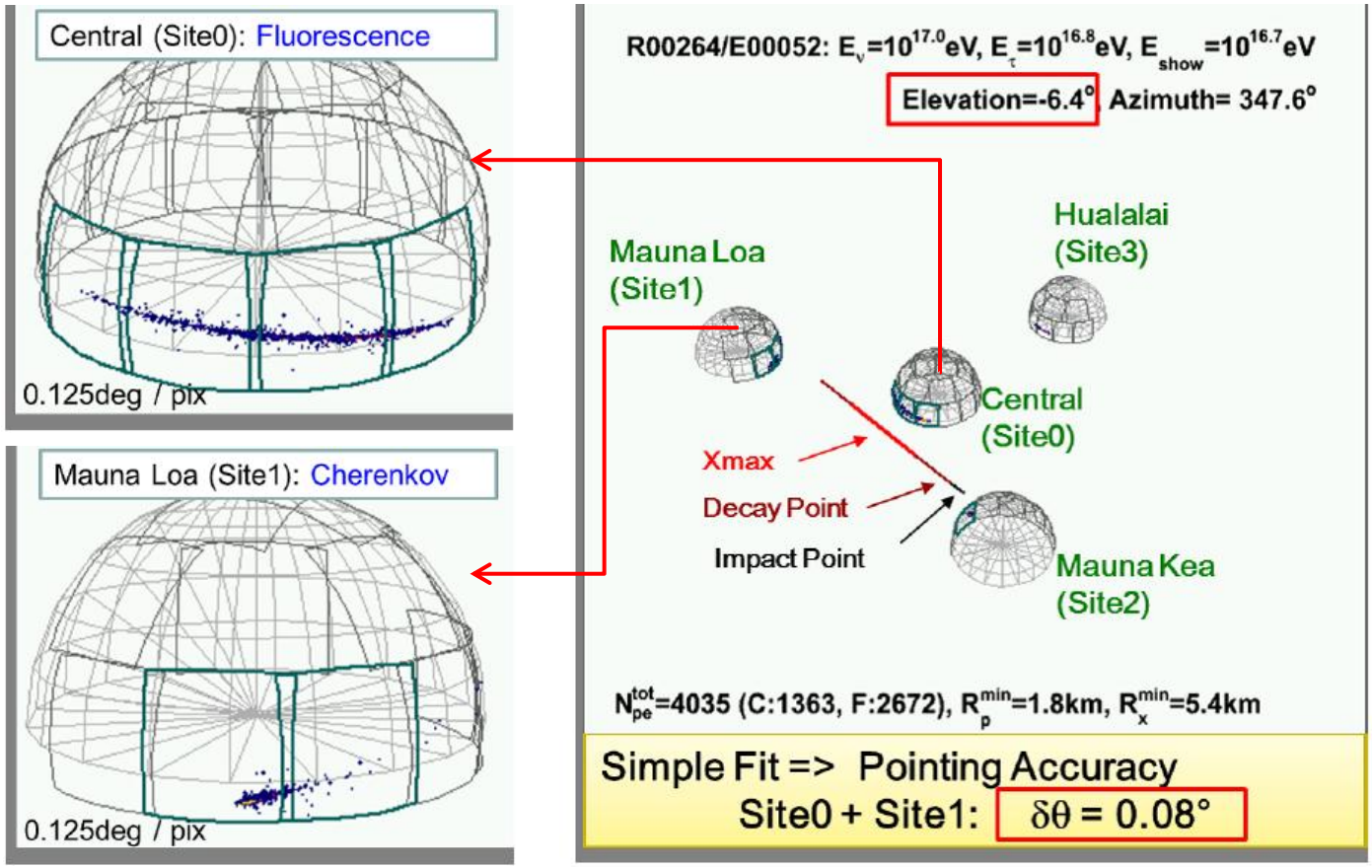
Need at least 30 DU's for Coverage

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

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

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

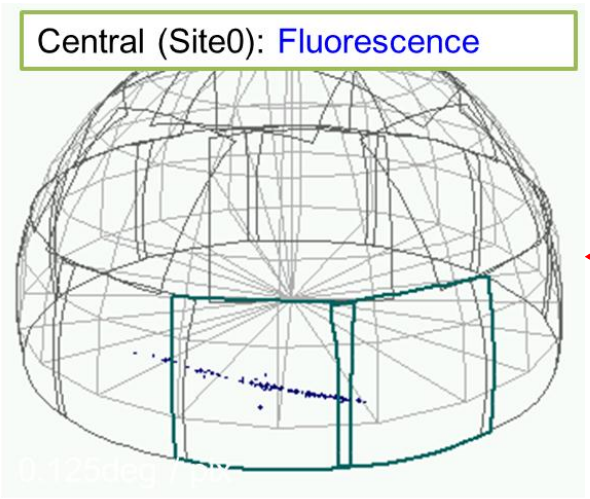
NTA Simulated Event 1

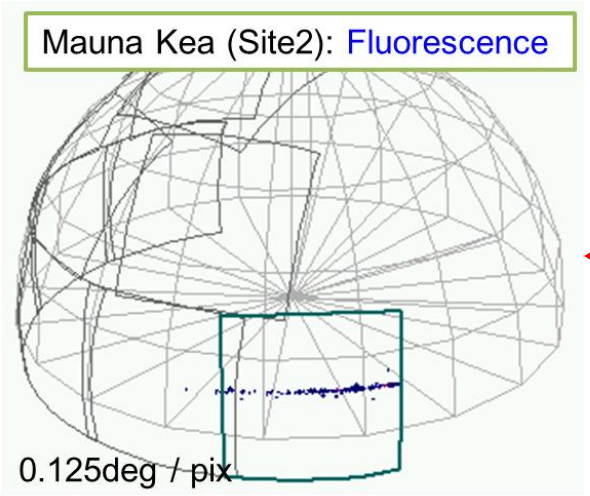


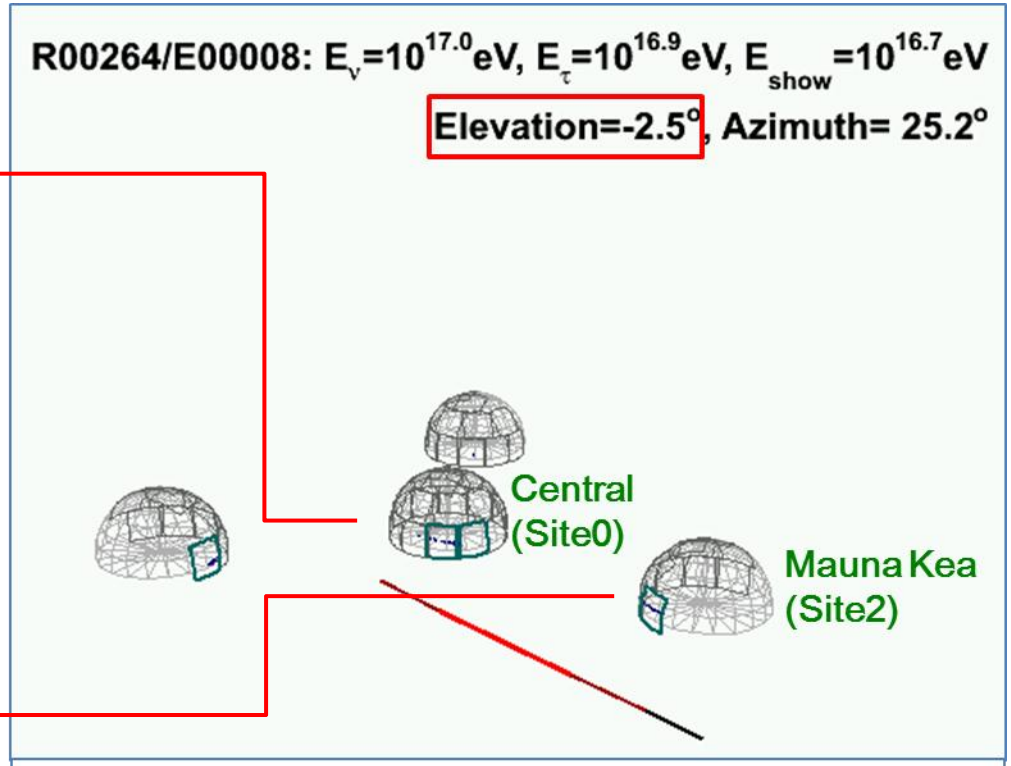
Monostatic Cherenkov => Pointing Accuracy < 0.2deg

(Y. Asaoka and M. Sasaki, Astroparticle Physics 41, 716 (2013).)

NTA Simulated Event 2



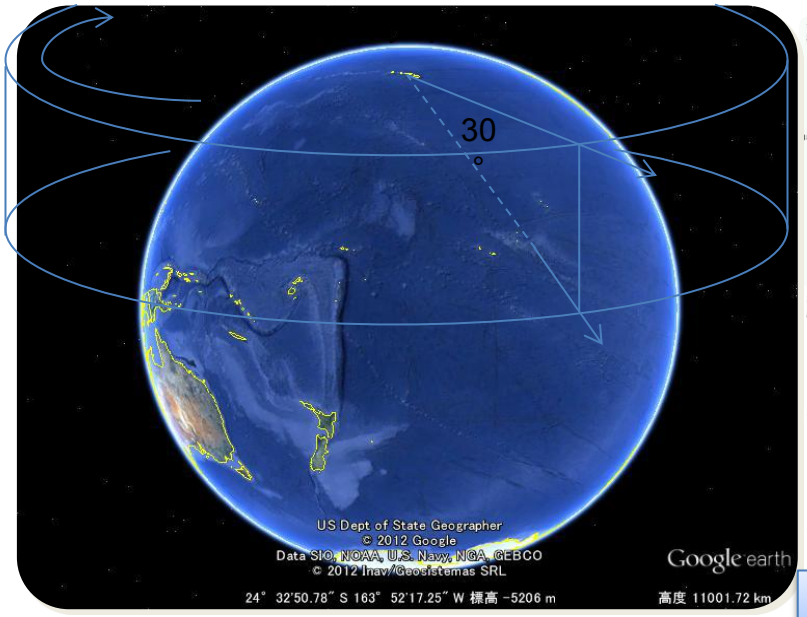


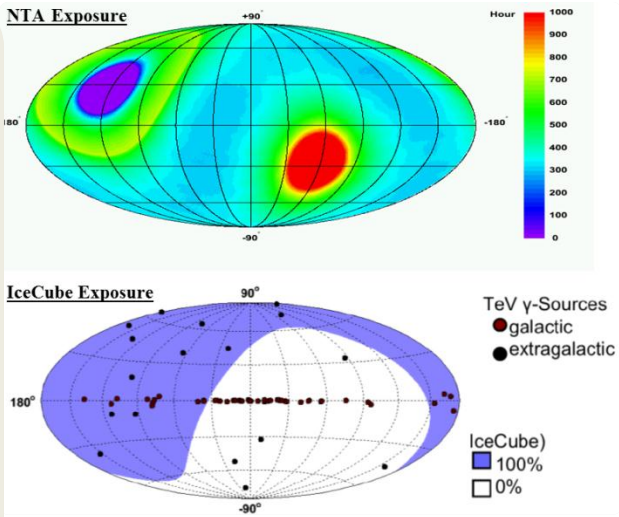


Simple Fit => Pointing Accuracy

Site0 + Site1: $\delta\theta = 0.007°$

NTA ν_τ Survey Performance

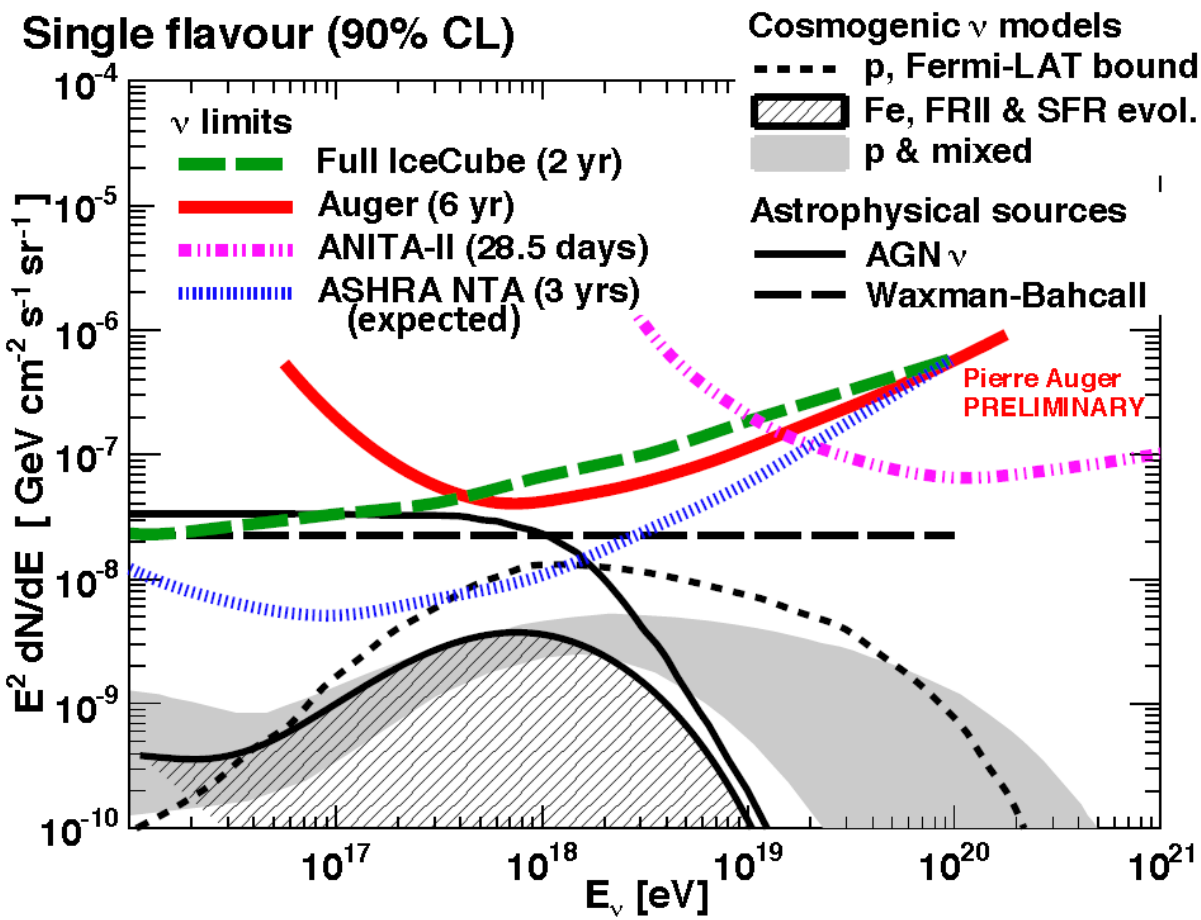




NTA can observe Galactic Center

- Duty 10-20% from Ashra-1
- ν pointing accuracy < 0.2°
- FOV Elevation 30° × Azimuth 360°
- For GRBν
  Survey Depth z < 0.15 (2 Glyr)

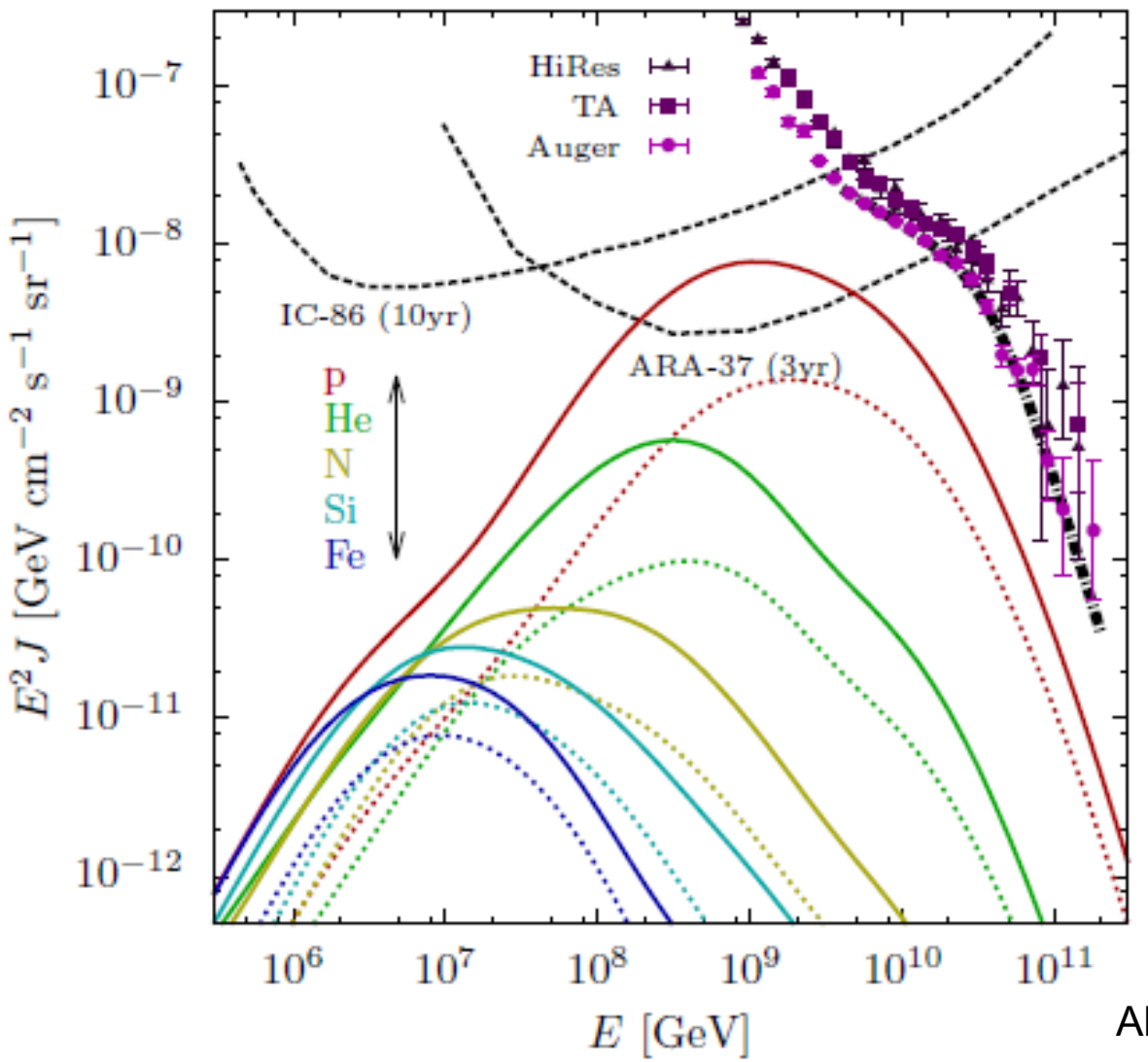
Limits to Diffuse Flux of VHEν



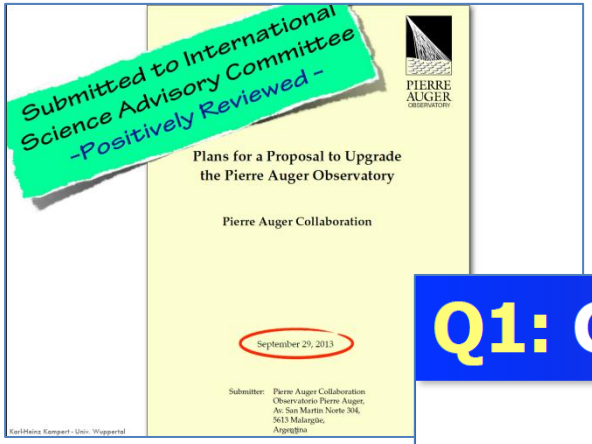
All limits converted to single flavour and given per half a decade of energy

J. Alvarez-Muniz (Auger) VHEPA2014

Cosmogenic ν and UHECR Components

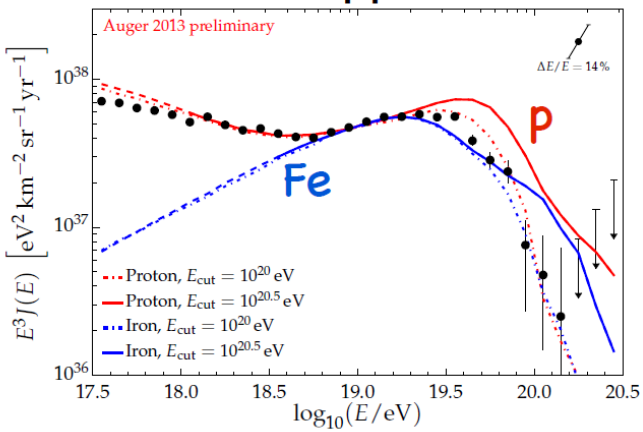


Ahler&Halzen (2012)

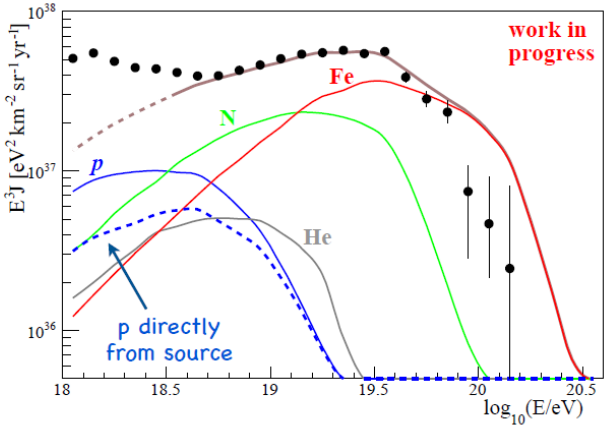


Q1: GZK effect or Exhausted Sources ?

GZK suppression



maxium energy scenario



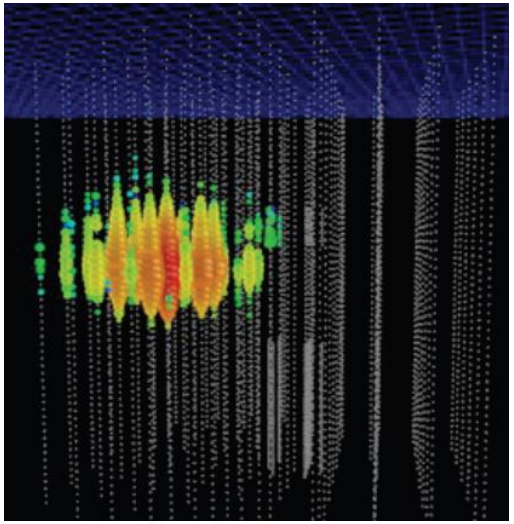
$E_{max}^{p} \sim 10^{18.6}$ eV →

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

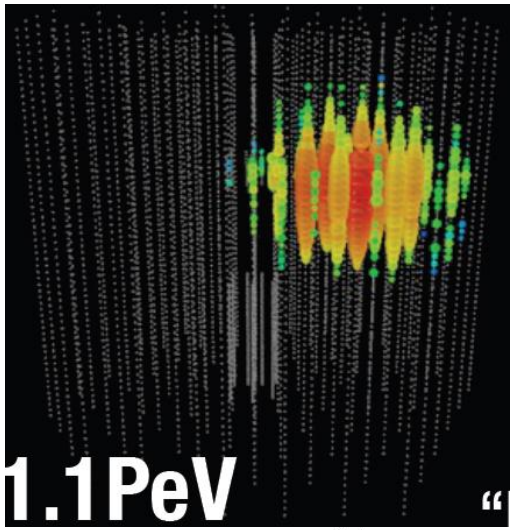
Of fundamental astrophysical importance:
E_{max} of sources ? Standard Fermi acceleration ?

IceCube PeV Events

PRL **111,** 021103 (2013)

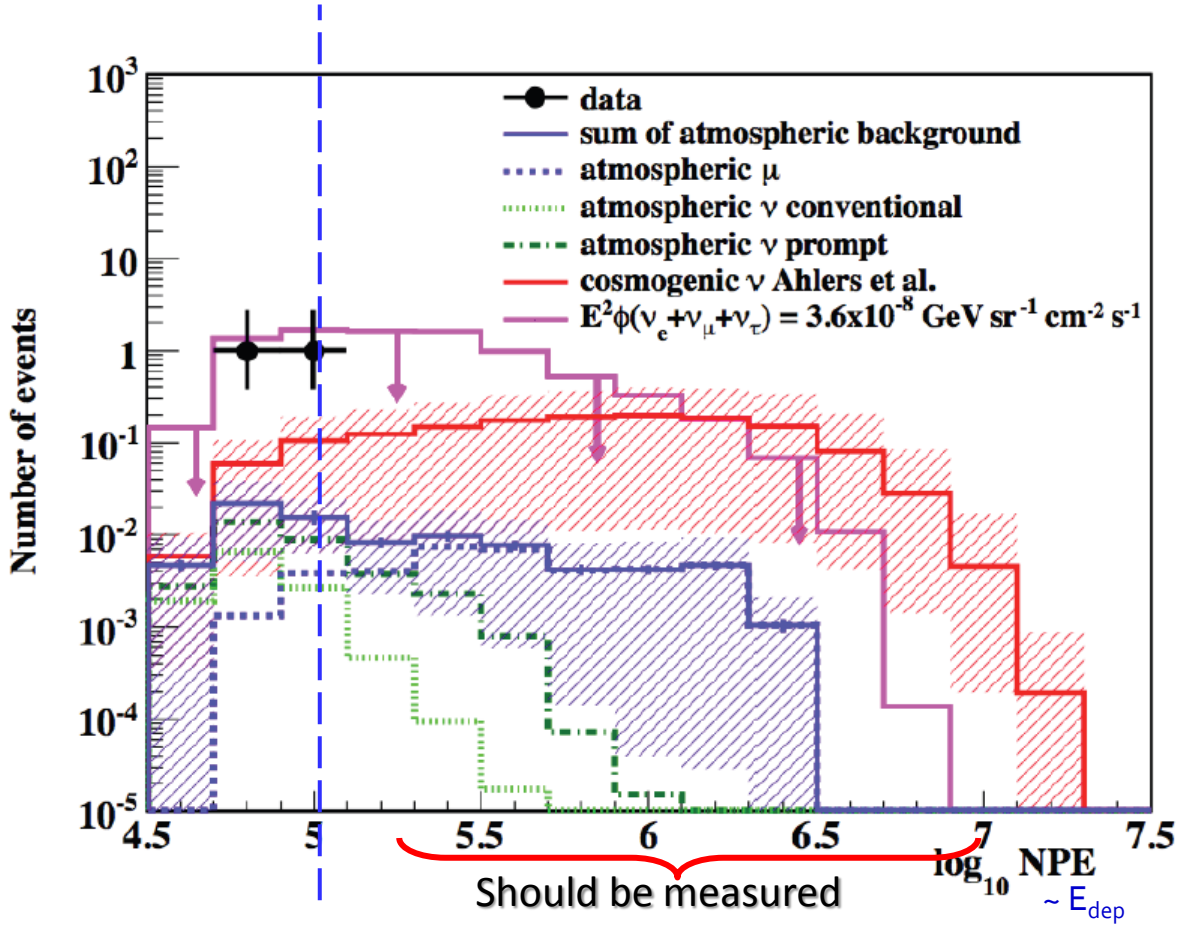


©2013 Sesame Workshop



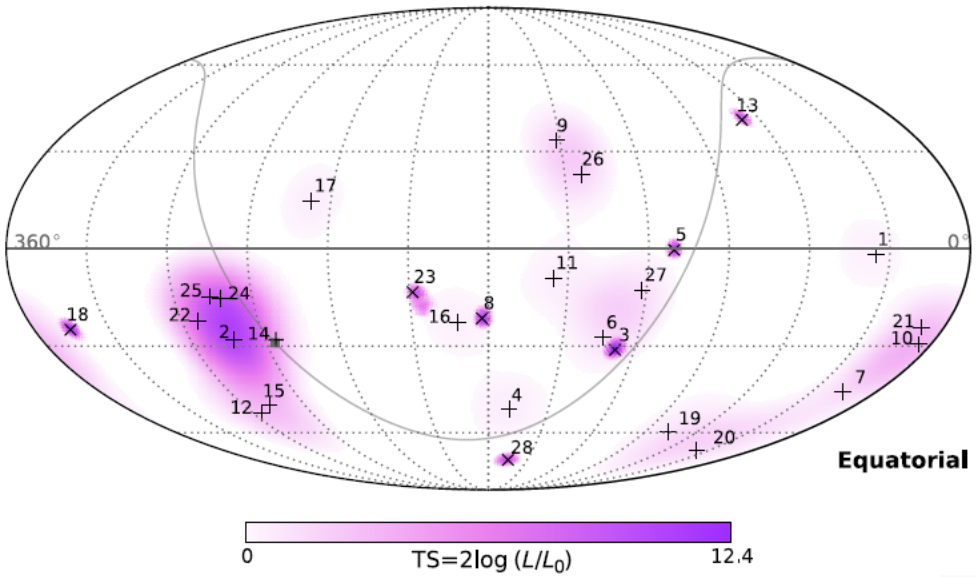
What if one had better Sensitivity
and accurate Pointing Info ?

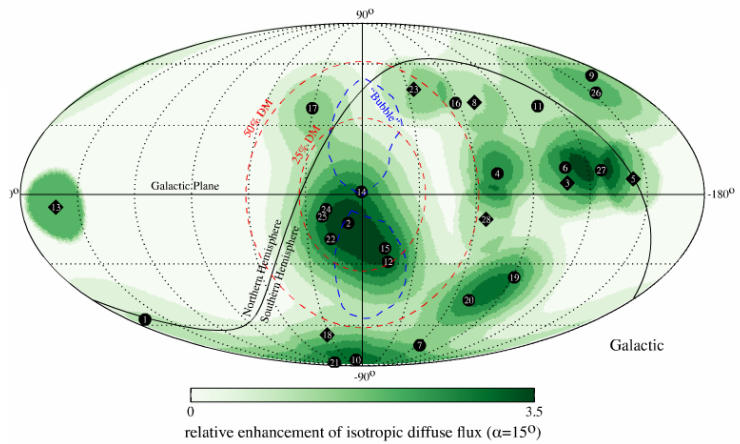
IceCube PeV Events

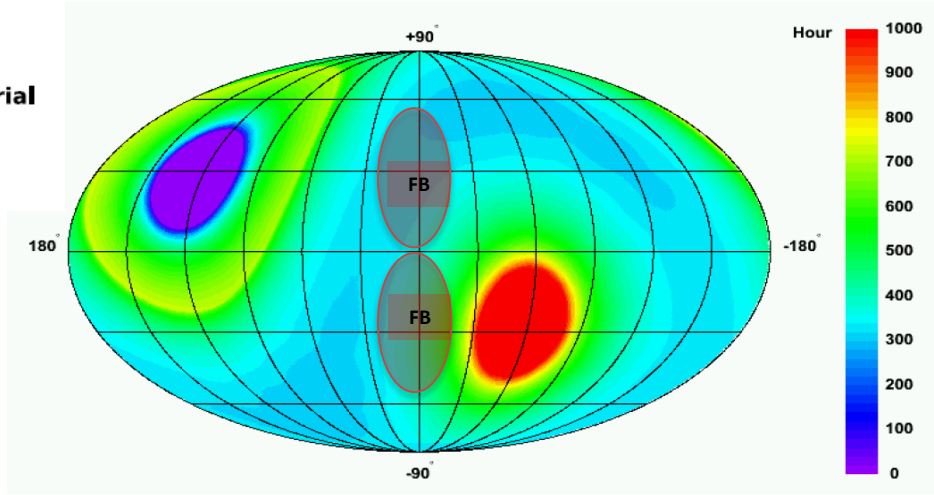


IceCube 28 Events

Ahlers & Murase, PRD (2014).







8% Significance

IceCube, Science 342

2015 → 2016 → 2017 → 2018 → 2019 → 2020 → 2021 → 2022 → 2021

NTA

Funding Request | Construction / Partial Observation | Full Observation

Toward PeV-EeV tau ν Servey

Ashra-1

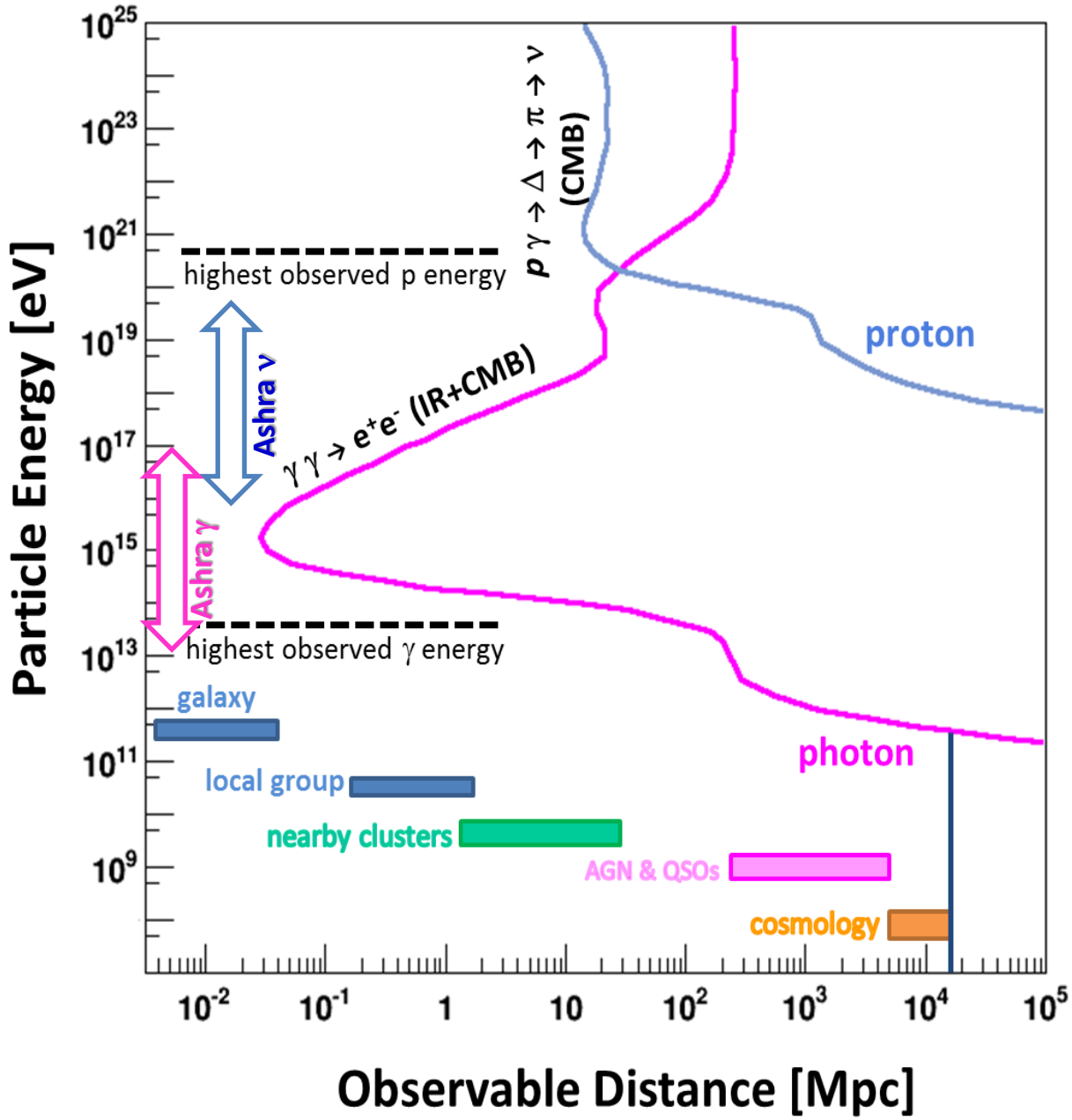
Test Observations / Multi-particle/ Multimessenger

Principal Demonstration

Akeno

Training / Aging / Test Observations

Developments / Assembly

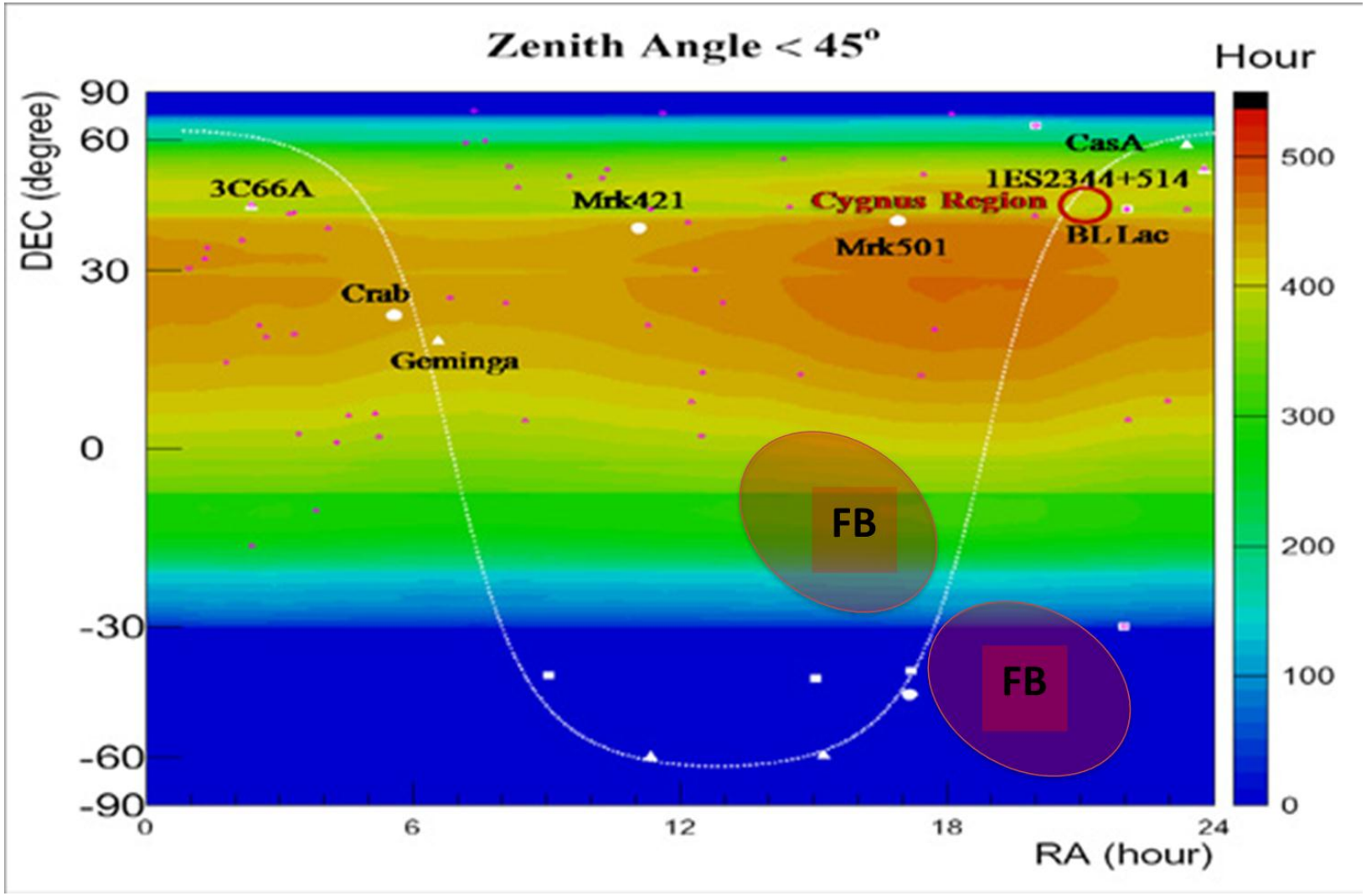


PeV-EeV Universe

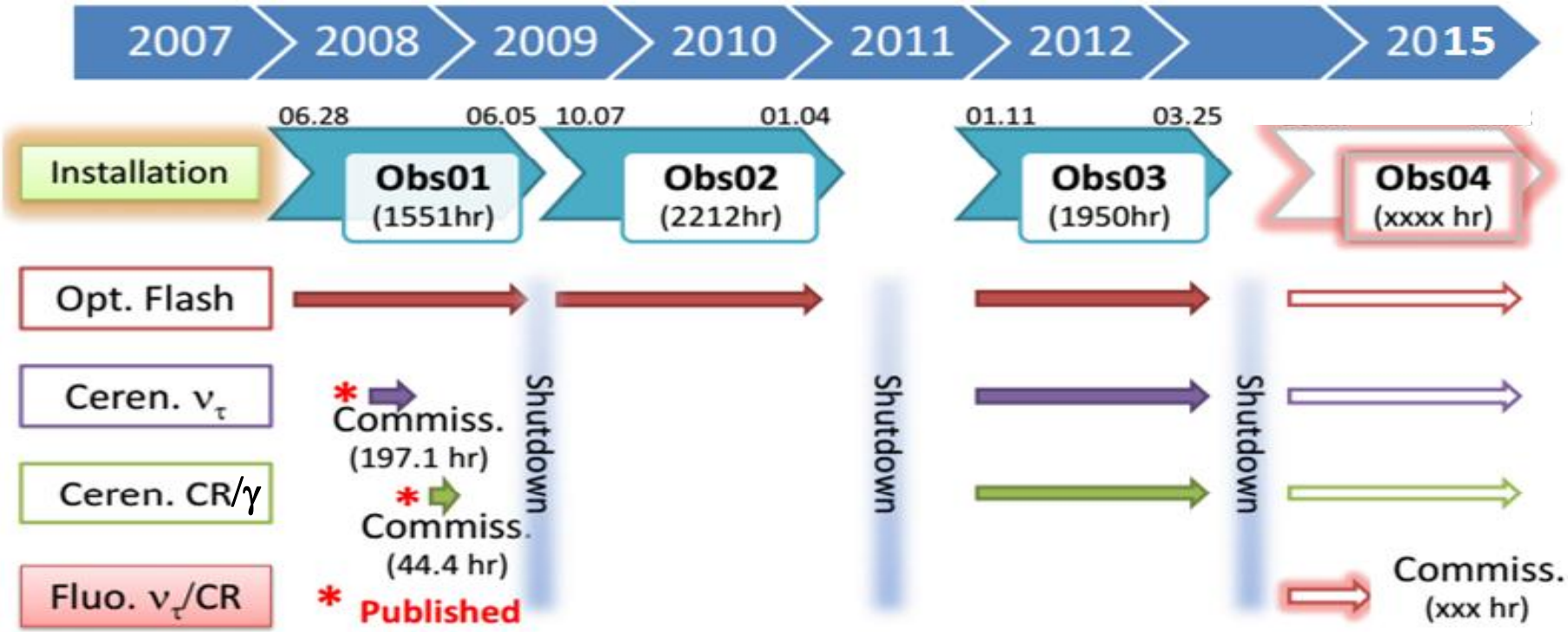
- Nearby (Galactic/Local)
- Multi-particle (Multimessenger)
  - γ
  - ν

Ashra/NTA => PeV-EeV Universe Explorer

Ashra-1 Obs04 γ Exposure



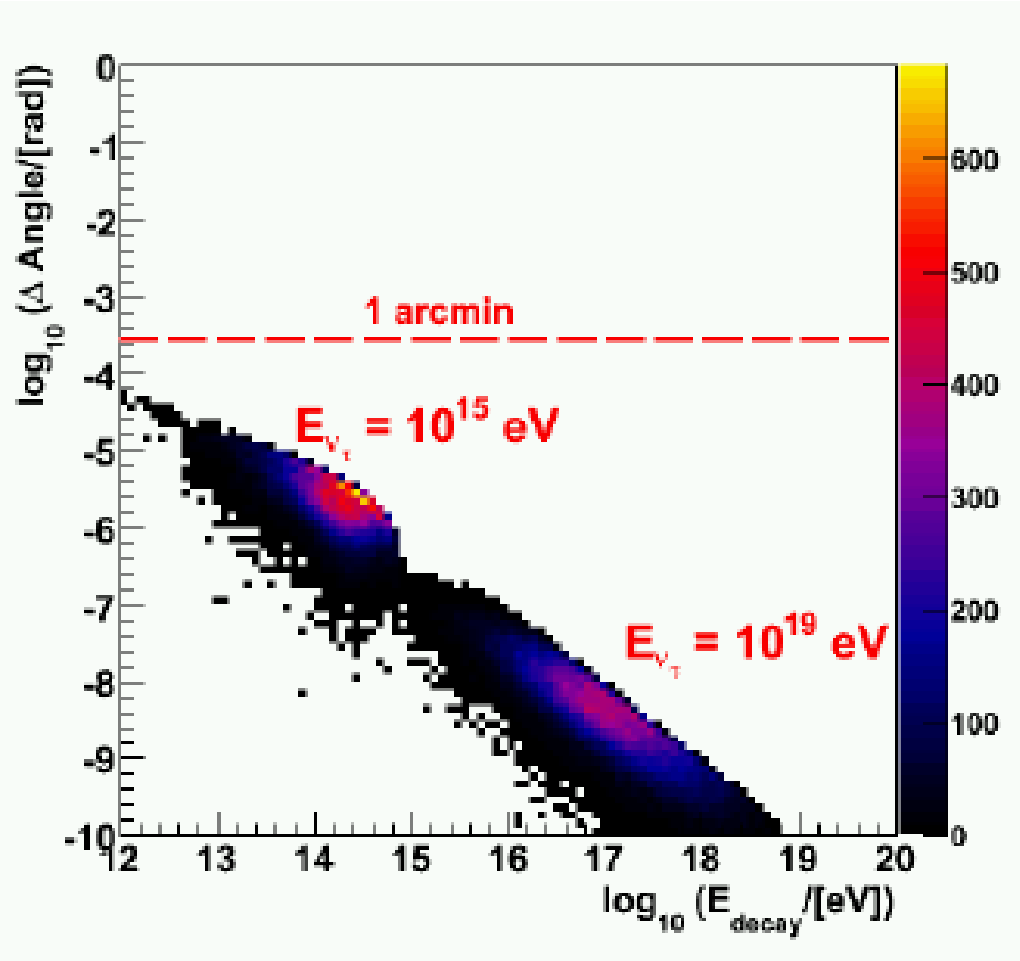
Ashra-1 Observations



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	$-2.7\times10^3 - 4.3\times10^2$

- Obs. Time: 5713hr for Obs01-03 since 2008
- Ave. Duty ~ 20%

Tau Deflection & Decay Energy After Propagation in Rock

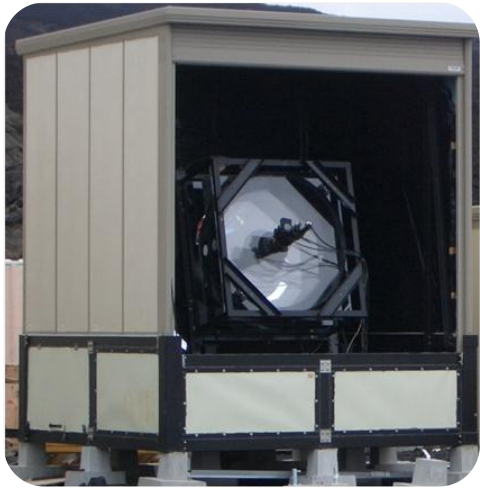


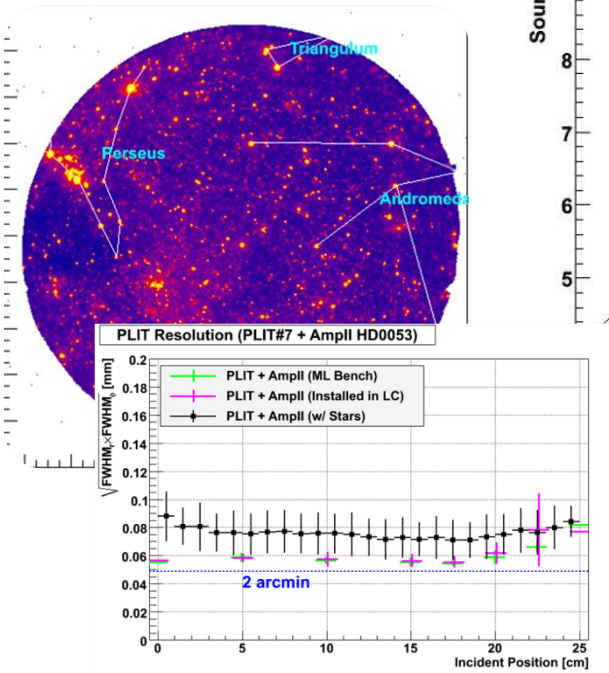
Directional Reconstruction < 0.2deg

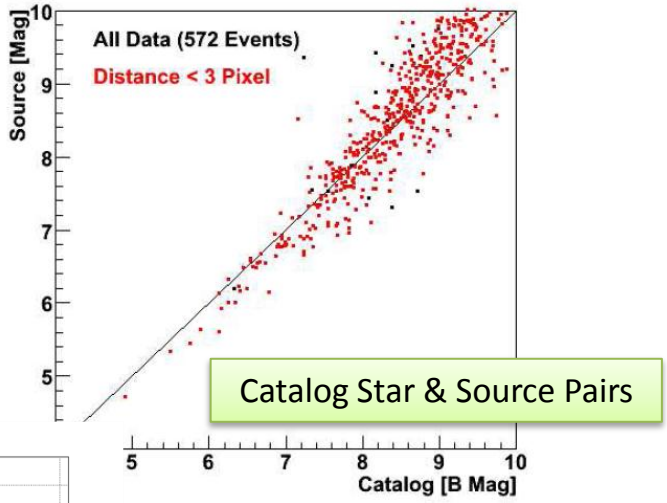
Asaoka & Sasaki, Astropart. Phys. 41 (2013) 7-16

Ashra-1 LC Optical Performance

Ashra-1 Light Collector







Catalog Star & Source Pairs

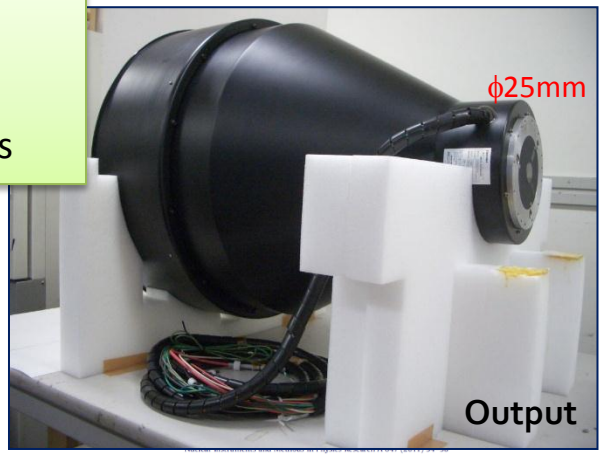
Total Resolution: ~3 arcmin image in 42° FOV

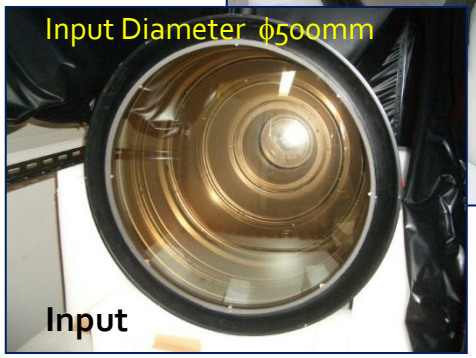
Can cover Mauna Kea surface at 35 km distance

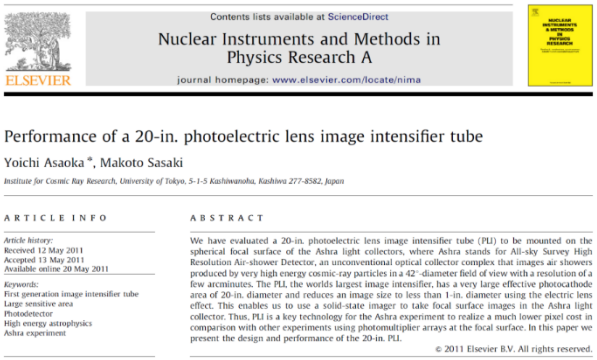
=> Shimizu's Talk

20” Photoelectric Lens Imaging Tube (PLI)

Large : World largest I.I.
Fine : FWHM = 40-60μm @output window
Stable: No performance degradation for 3.5 years







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

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Large sensitive area
Photodetector
High energy astrophysics
Ashra experiment

ABSTRACT

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

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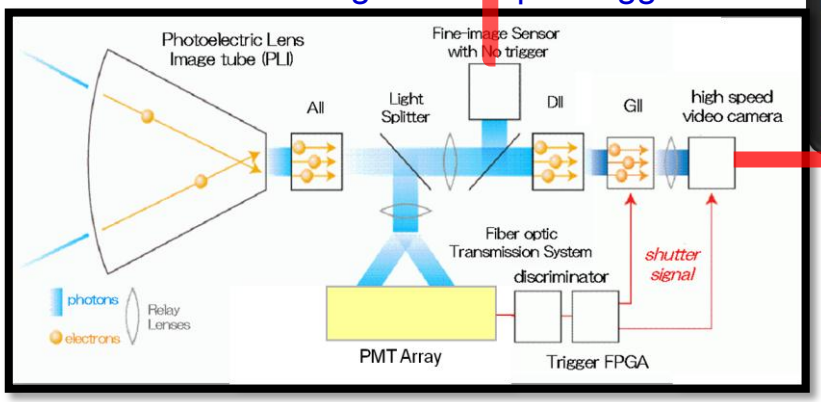
Y.Asaoka, M.Sasaki NIMA 647 (2011) 34

Improving Sensitivity
=> Dev. with HPK

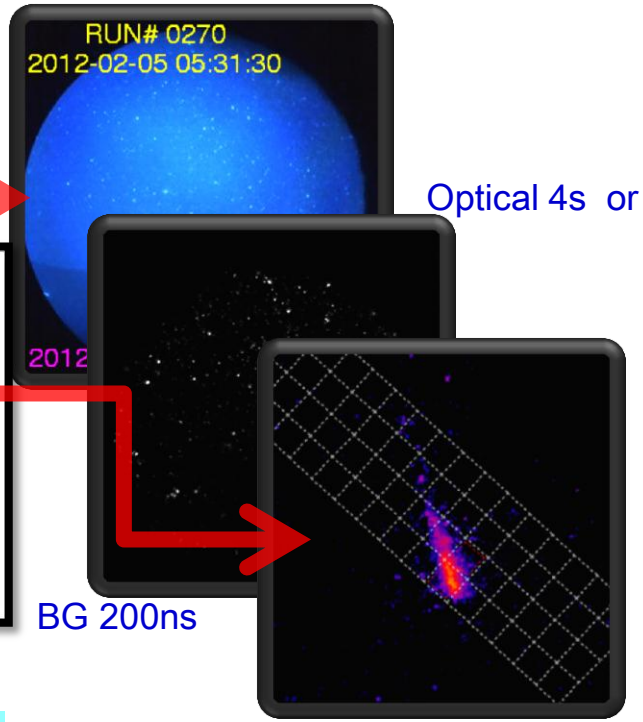
Ashra-1 Pipeline Trigger & Readout

demonstrated

Same Fine Image to Multiple Triggers



Photoelectric Image Pipeline (PIP)



Optical 4s or 1s

BG 200ns

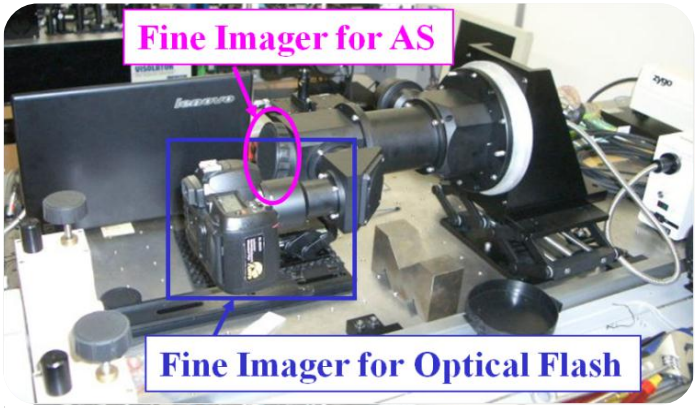
CR 200ns

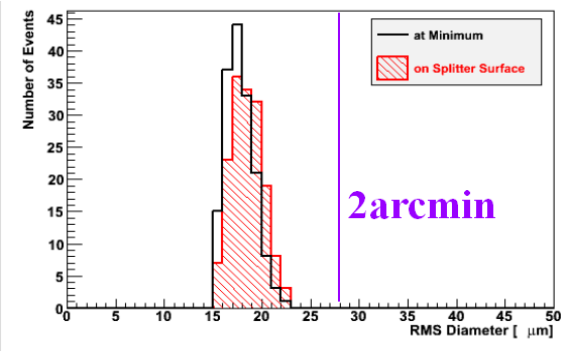
Multi-Messenger Approach with
One Detector System

1st imaging air-shower with self-triggered I.I.

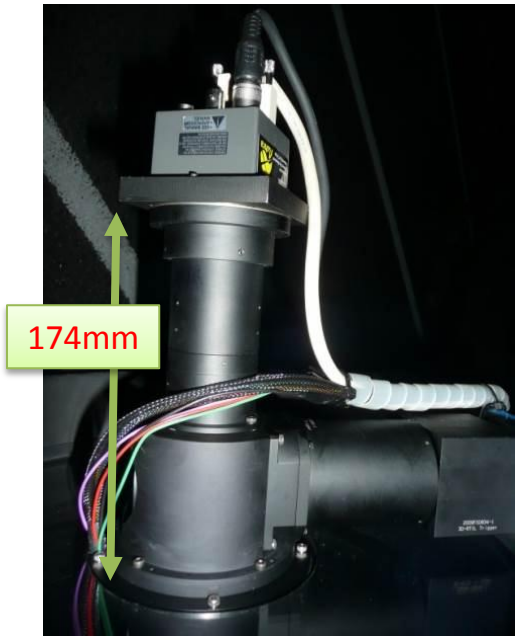
Photoelectric Image Pipeline (PIP)

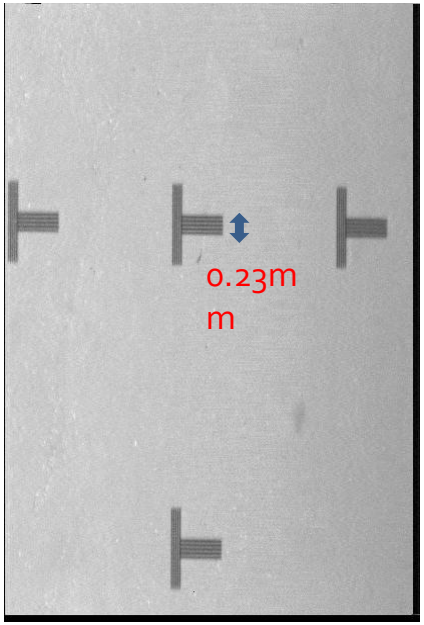
Test of PIP (1st generation)





Mounted PIP (2nd generation)

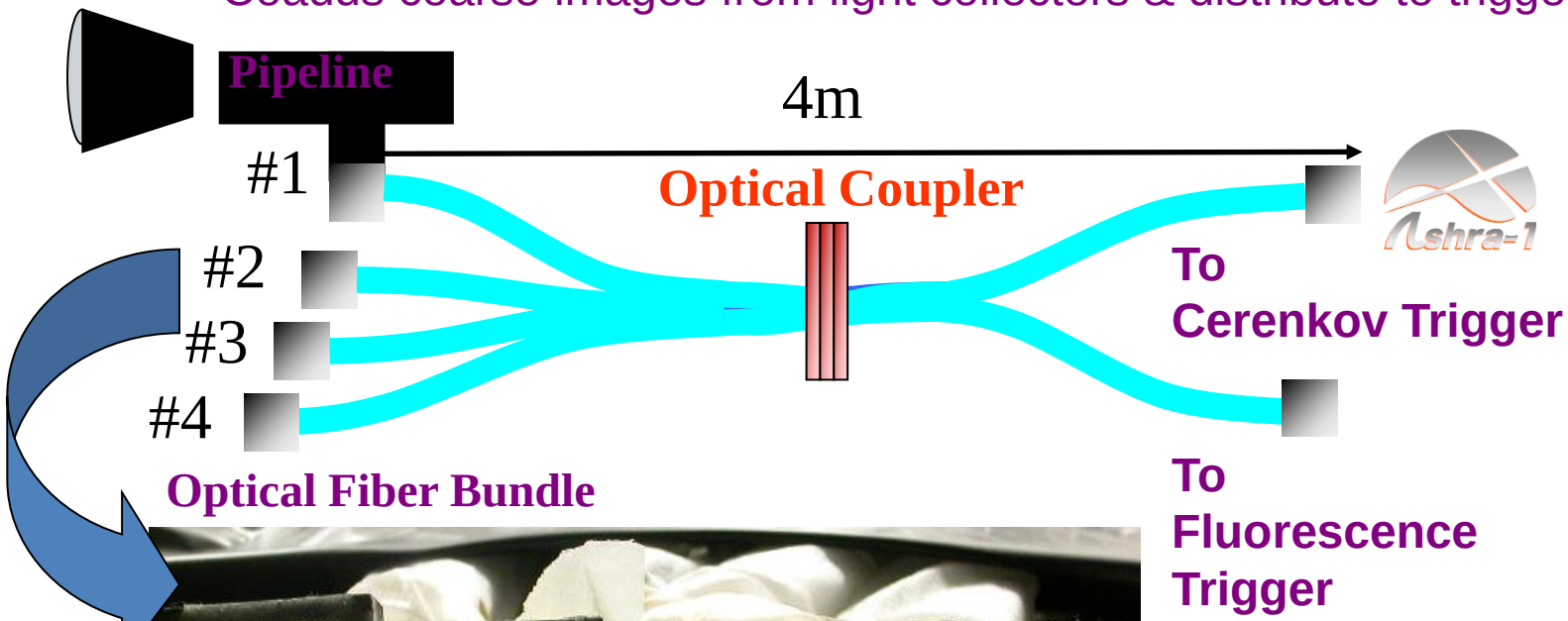


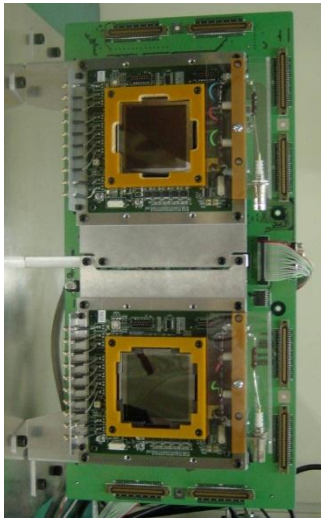


=> 21 LP/mm => ~1arcmin

Optical Fiber Transmission System

Coadds coarse images from light collectors & distribute to trigger sensors





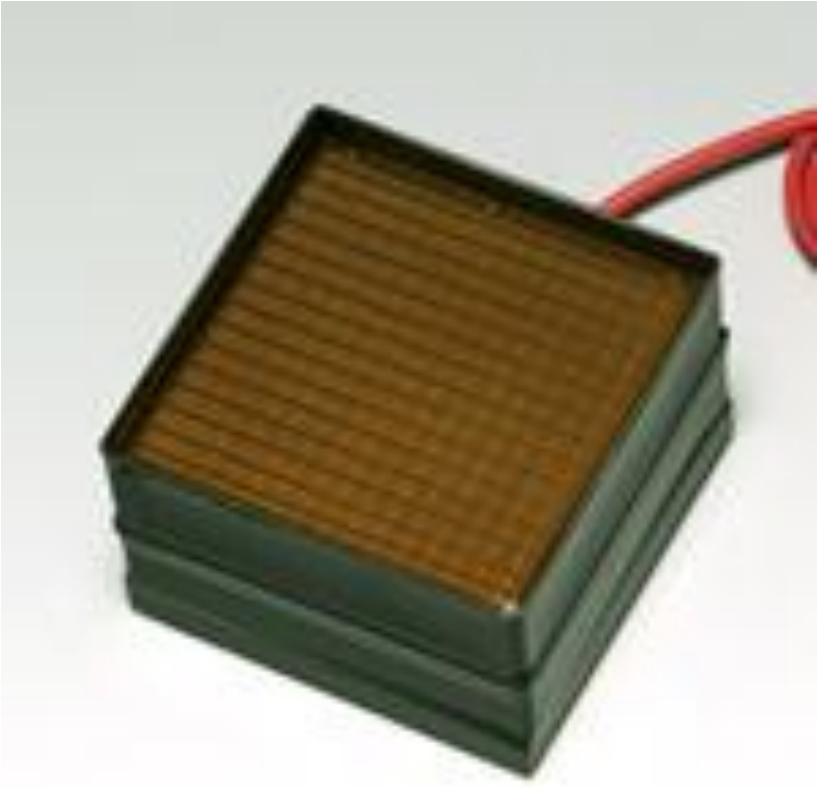
64 × 64 MAPMT

- 64x64 fibers(0.5mmf)
- 0.67deg-FOV / fiber

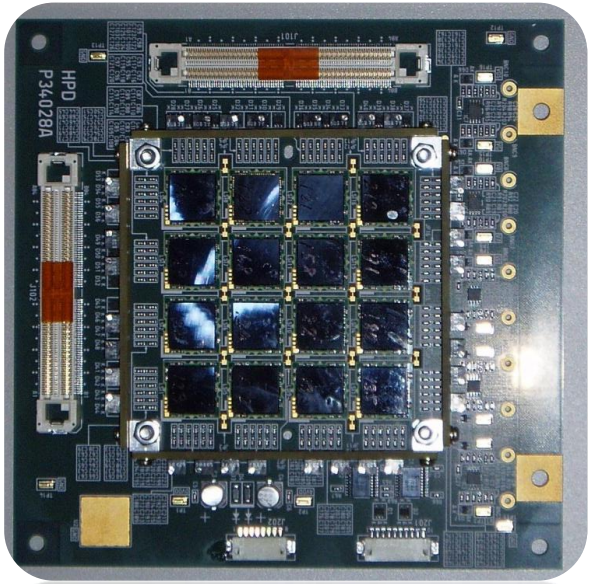
Light collectors can be easily appended to the trigger.

Sensitivity can be reinforced when more budget is available.

Ashra NTA Trigger Sensor

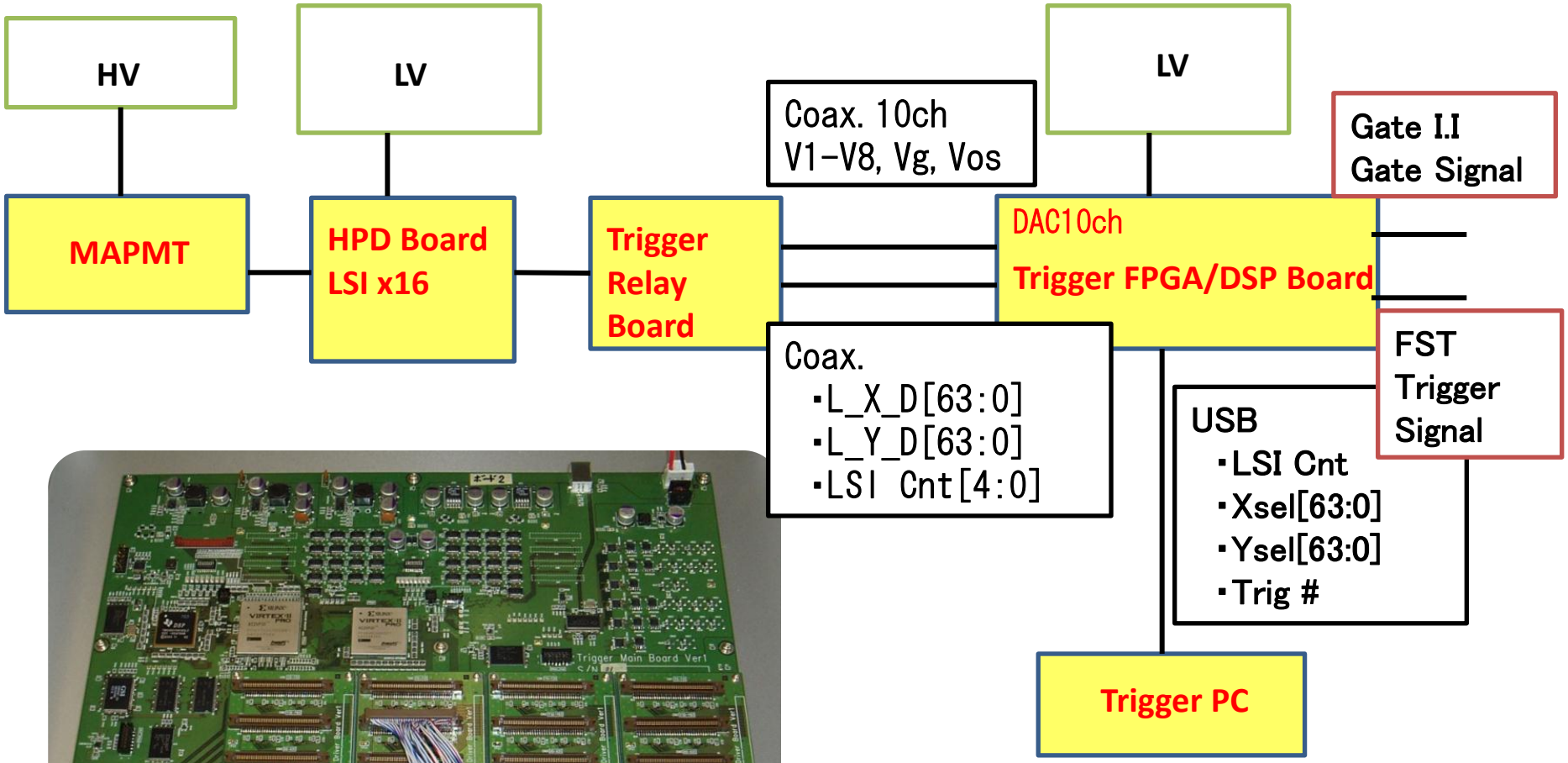


R8400-00-M256 (H9500)



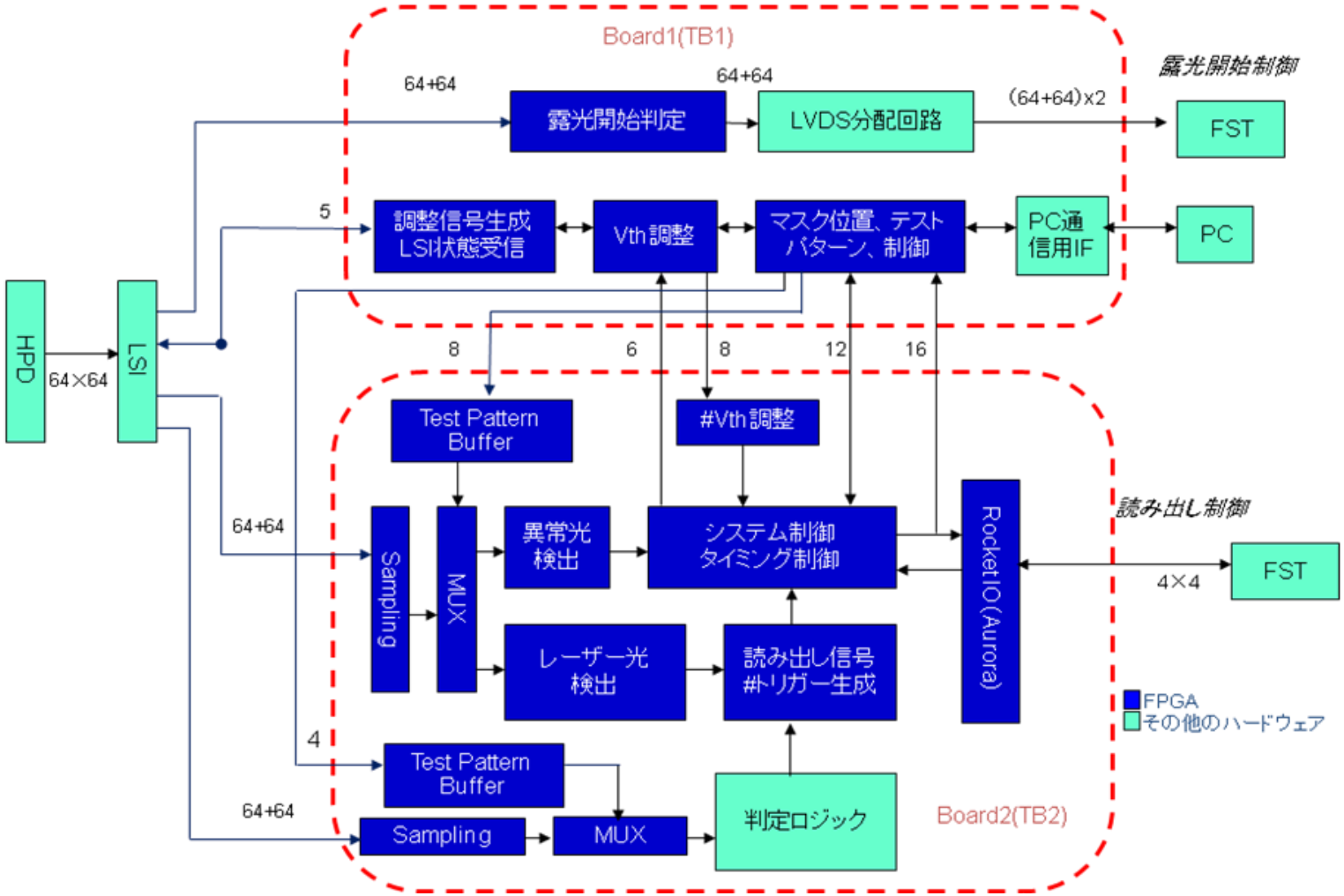
Trigger Sensor Unit (TSU) =
16x16 trigger pixs /chip on R8400-00-M256
followed by Trigger Decision LSIs (ASIC)

4x4 TSUs for 1 Detector Unit

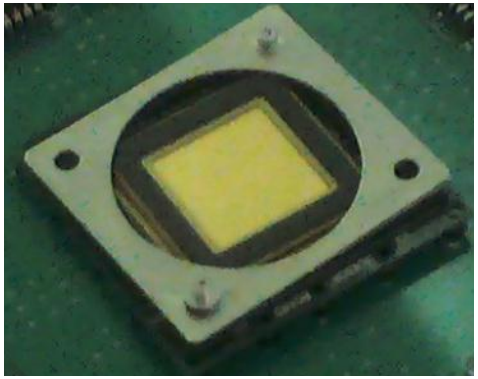


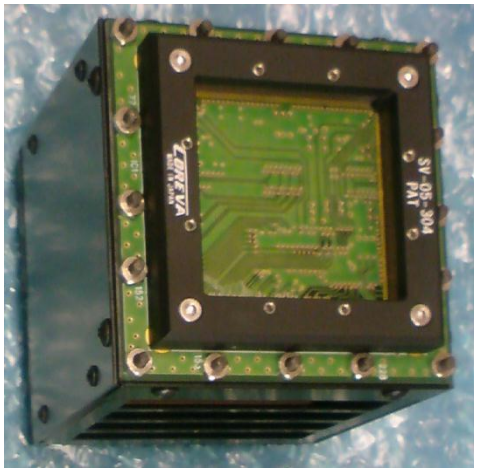
Trigger FPGA/DSP Board

Trigger Board Functions



Performance of FST CMOS Sensor



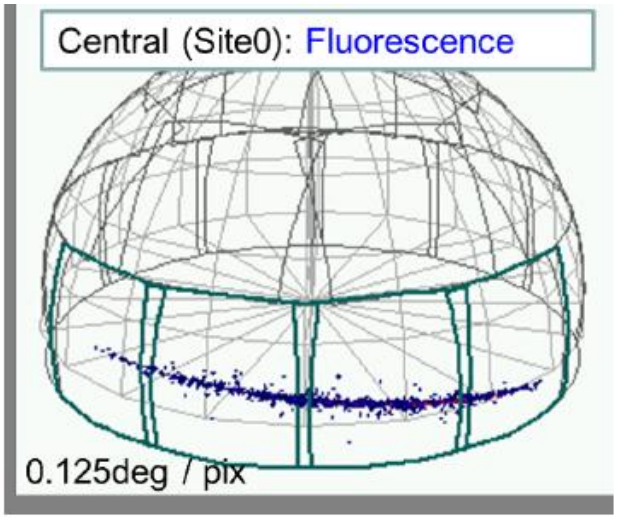


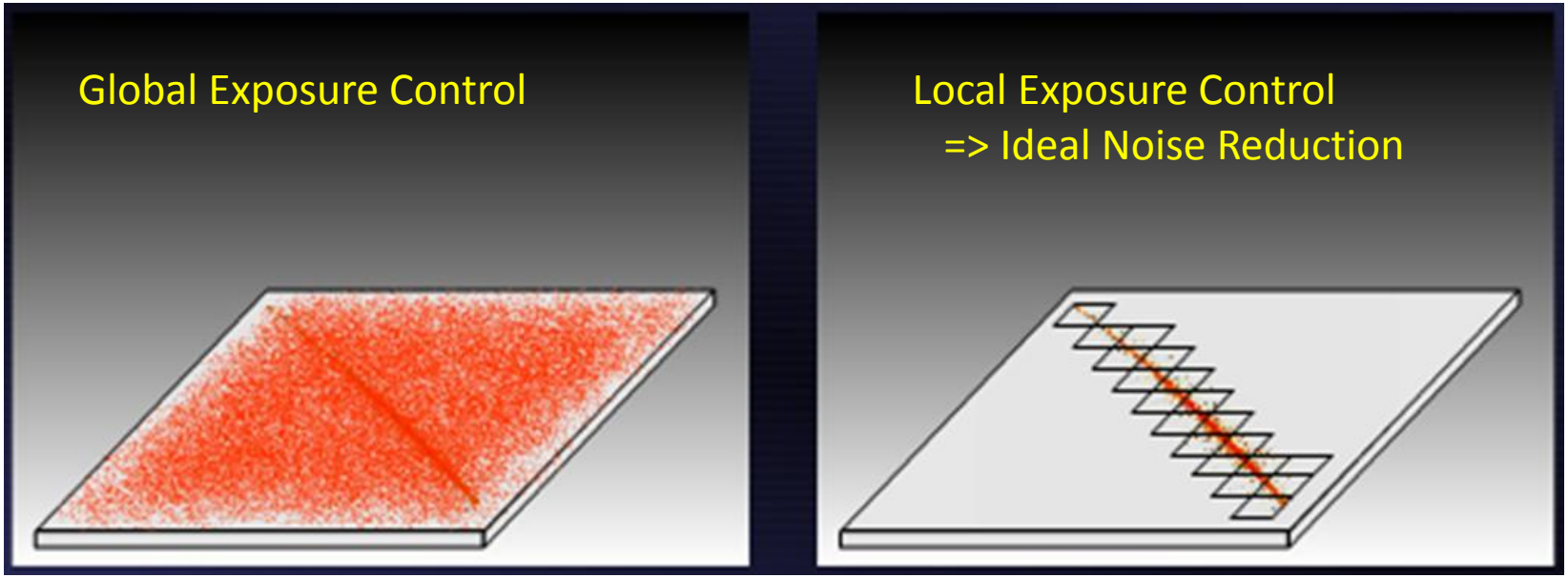
2048x2048 pixels / 19mm x 19mm,
Triggered Regional (64x64 macrocells) Exposure

Parameter	Measured Value
Saturation Capacity	4561 e
Dark Current	636 e/s
Temporal dark noise	16.25 e
Total Quantum Efficiency	58.3 % @525nm
Dark Signal Non-Uniformity*	4.37 %
Photo Response Non-Uniformity*	7.12 %

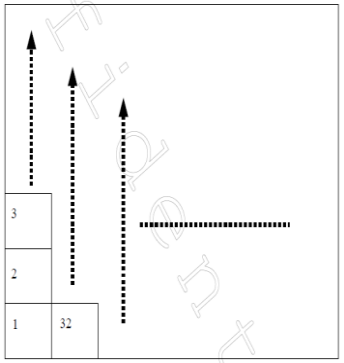
* Careful off chip FPN correction can eliminate them

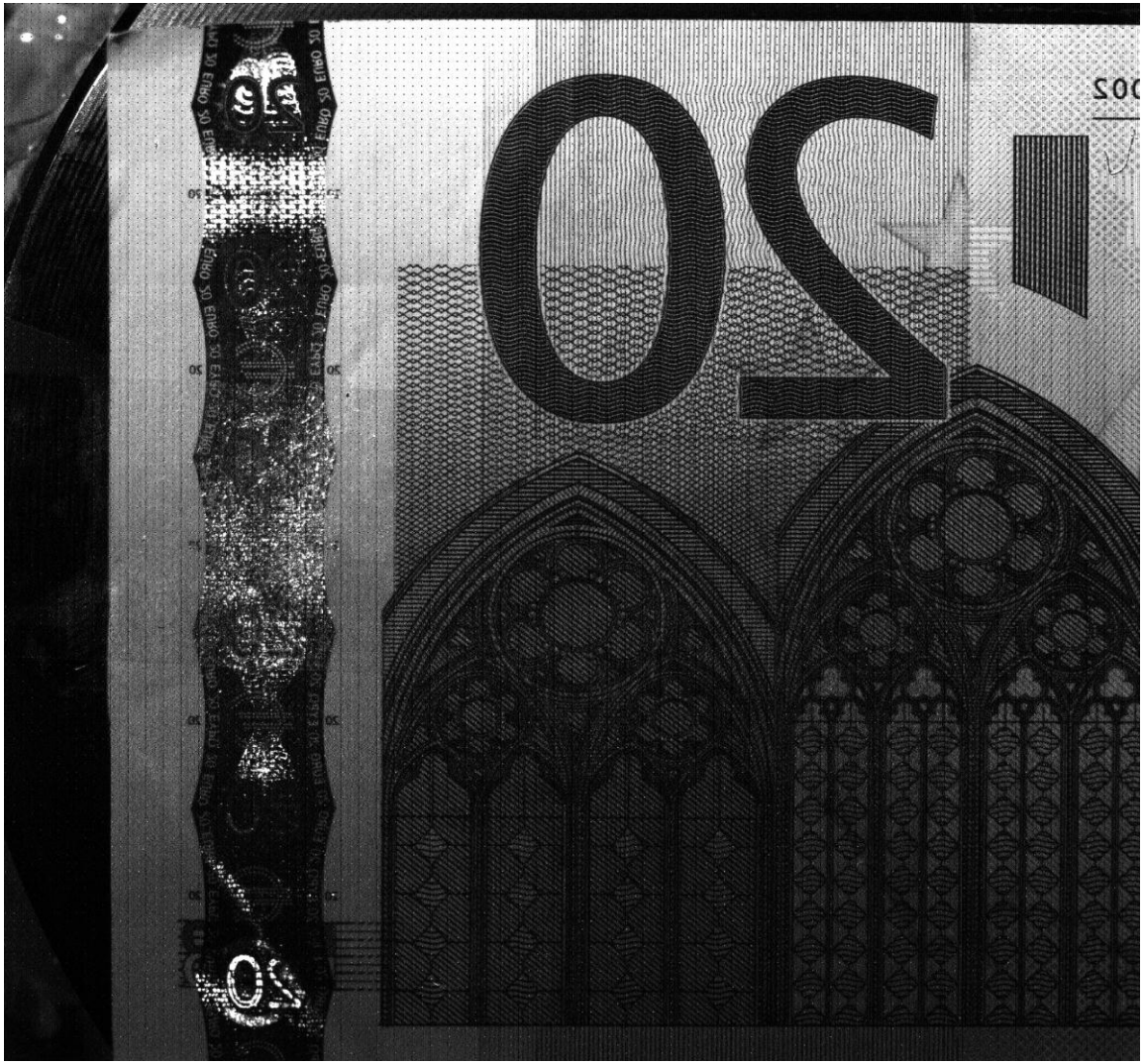
Local Exposure Control





FST Demonstration





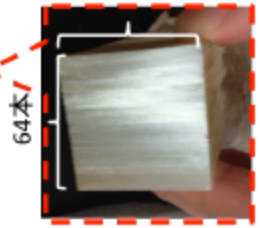
光ファイバー伝送系の光伝送効率

光ファイバー束…光ファイバーを64×64の格子状に束ねたもの。全長3.7m
端面から入力した光を粗画像に変換する。

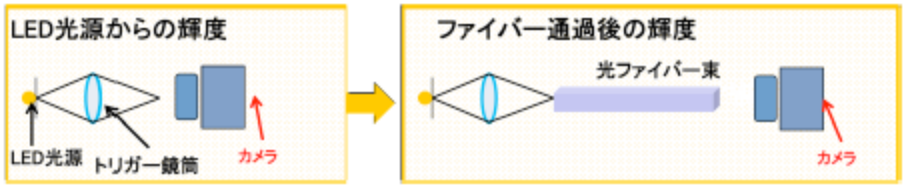
光ファイバー束は、東邦大学にて
研究・製作を行っている。

光ファイバー束

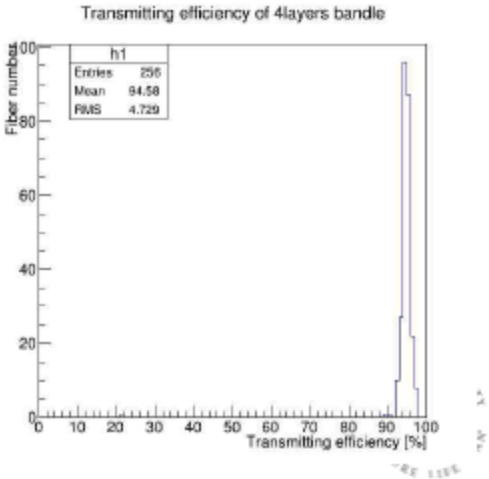
端面



・光ファイバー伝送系の光伝送効率の測定



$$伝送効率[\%] = \frac{ファイバー通過後の輝度}{LED光源の輝度} \times 100$$



→光ファイバー束は光伝送効率90%以上をもつ。
【2014年日本物理学会春季大会29pTS2_安彦】

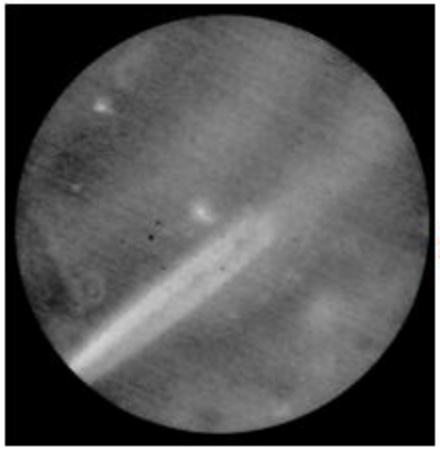
集光器の視野方向とレーザー照射方向

集光器は仰角24.4°, レーザーの射出窓に対して方位角24.0°の方向を向いており、集光器にマウントしたイメージパイプラインは全視野5.5°である。

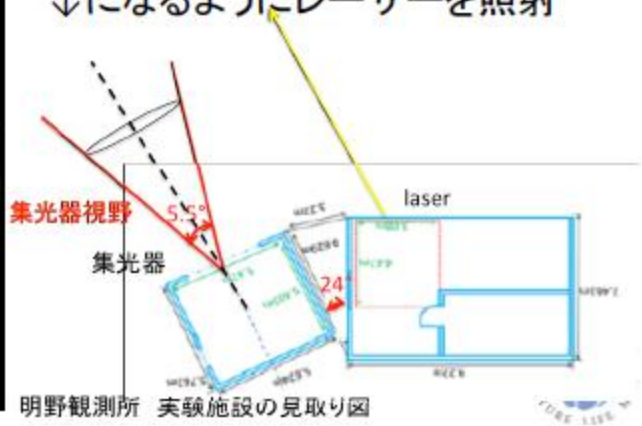
出力3.5Wのレーザーのセットアップを行い、集光器の視野に対して狙った方向にレーザーを照射できるようになった。

レーザーの設置

撮像画像



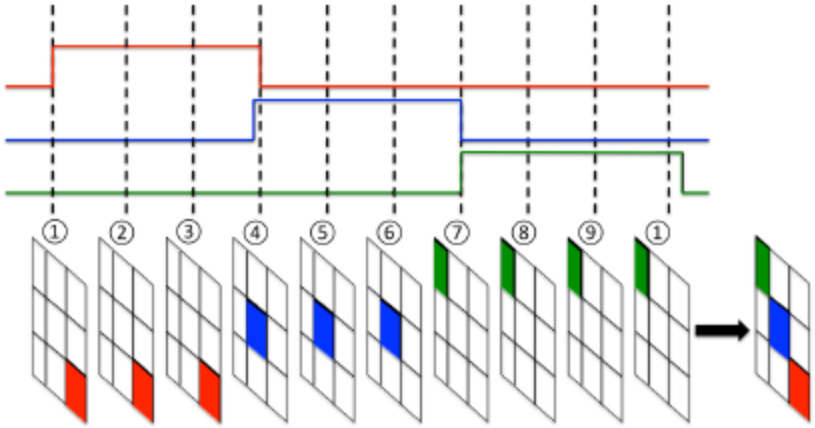
←集光器視野中心と平行付近
↓になるようにレーザーを照射



トリガーロジック(2)_リングバッファー

<u>トリガーロジック(2)</u>

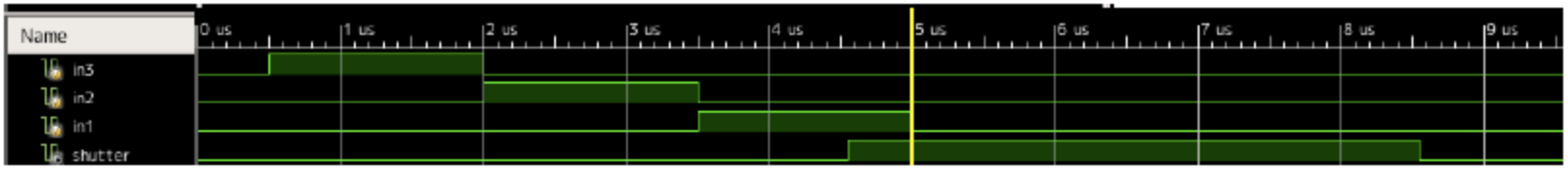
一定の時間間隔で信号を取り込むリングバッファを考え、常に信号パターンを判定させる。任意の回数連続して同じマス目に信号が入力されていて、かつ、信号パターンが条件を満たしている場合にトリガー信号(シャッター信号)を送る。



トリガーロジックのイメージ図

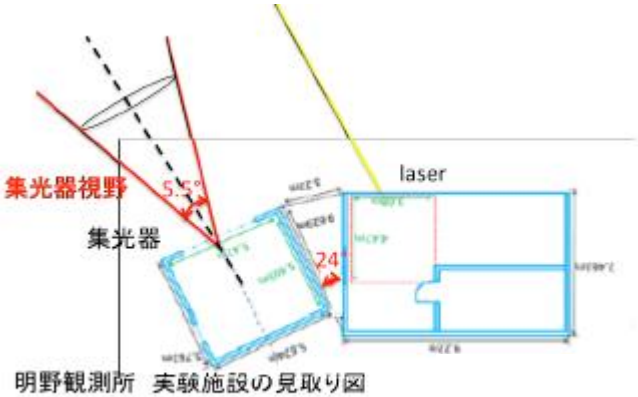
下のタイミングチャートは、それぞれのマスに1.5μsずつ信号が来たときのシミュレーションである。500nsごとにデータをサンプリングし、隣り合う3マスにそれぞれ3回ずつ信号が入力したときにトリガー信号が出力されるように作成した。

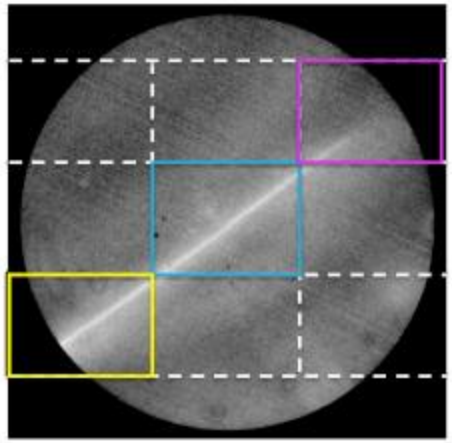
トリガーロジックのシミュレーション



試験的トリガー撮像

レーザーのセットアップを行った後、
集光器の近くにレーザーを照射し、
試験的にトリガー撮像を行った。
レーザーの照射方位角は、集光器の
視野中心に対して方位角3.0°の方向である。

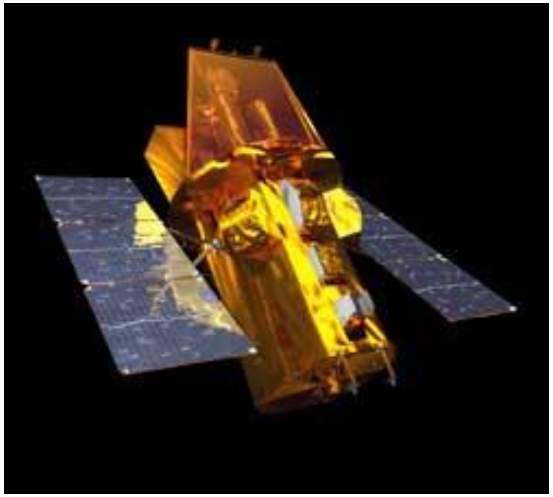




トリガー撮像を行った画像

9分割した視野中において、レーザーの
トラックに沿ったマスを選択して、自律的
にトリガーがかかることを確認した。

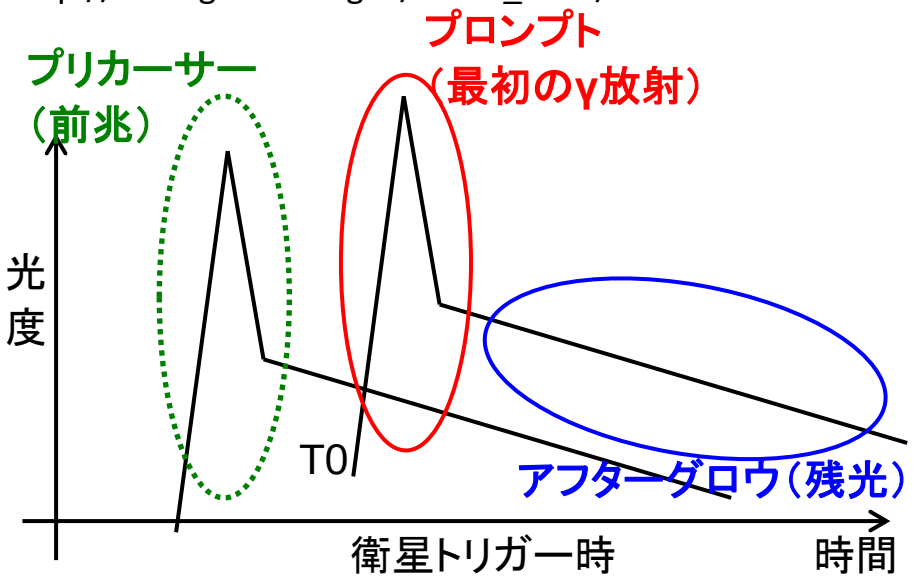
Swift衛星とのクロス観測



http://swift.gsfc.nasa.gov/about_swift/

・NASAのSwift衛星望遠鏡はGRB研究に特化した観測衛星であり、ガンマ線バースト発生時から残光まで観測が可能。

・トリガー信号を送る
Burst Alert Telescopeの位置精度は1～4分角

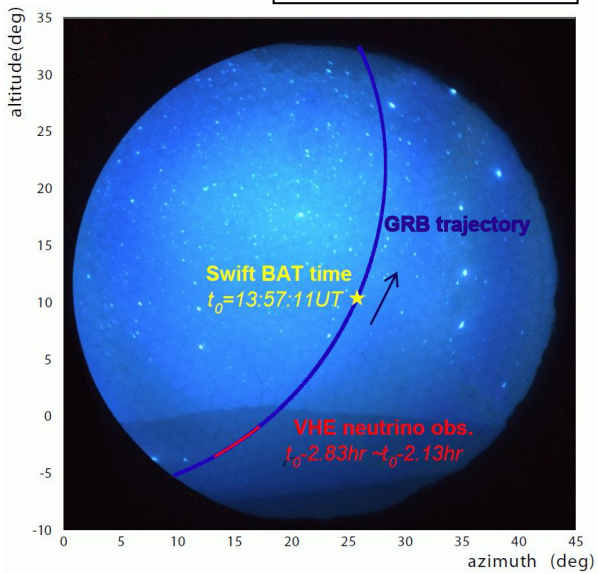


このSwift衛星からGRBの発生時刻（バーストアラート時刻：T_0）及び赤道座標を取得。
Ashra集光器の視野内を確認、解析へともっていく。

過去に行ったGRBの位置同定結果

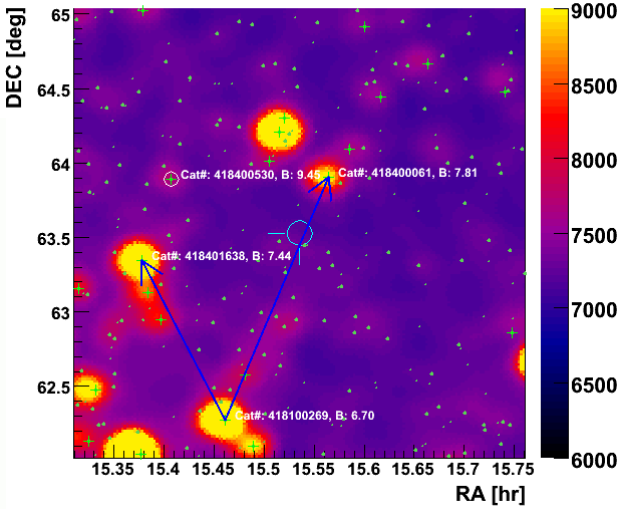
Ashra実験においてGRB発生付近を限定してローカルにGRB 081203Aを同定した結果。

42°　×42°　視野



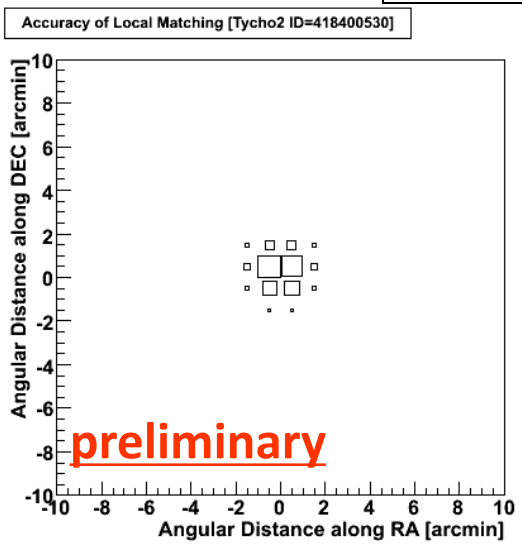
081203 Image#2917

赤道座標



- 基底ベクトルから位置を同定する。
- 精度<2分角

精度



画像全体からの予測位置の補正を用いた上で、精度<2分角のGRB同定を目指す。

GRBが視野内のどのような位置にあっても2分角以内の精度で同定できるよう開発する。

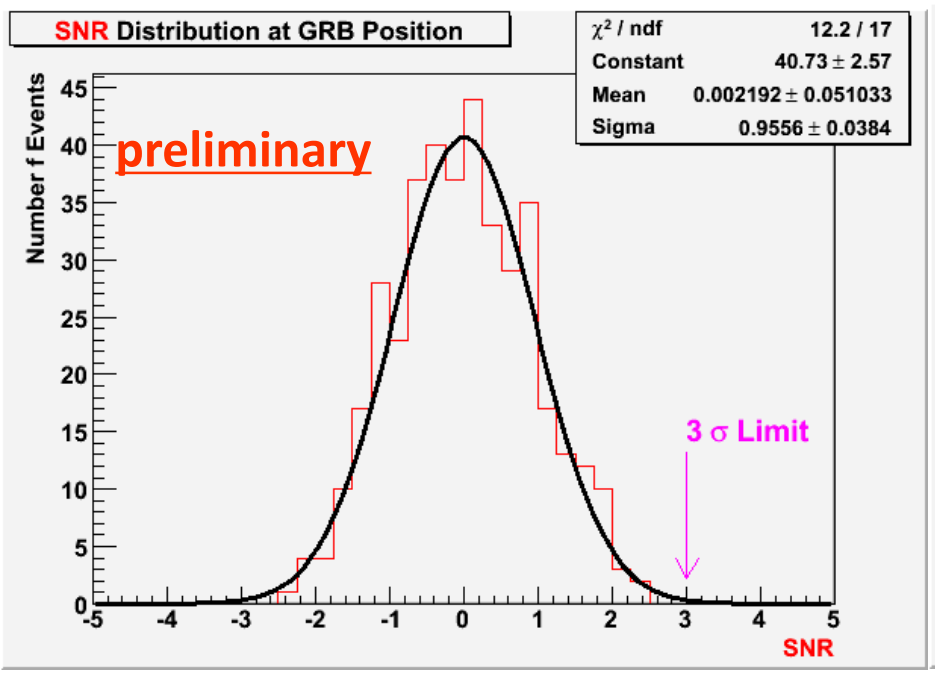
引用：2009年度　日本物理学会春季大会 Ashra報告48：閃光観測（プリカーサの探索）
東京大学宇宙線研究所　長南　勉

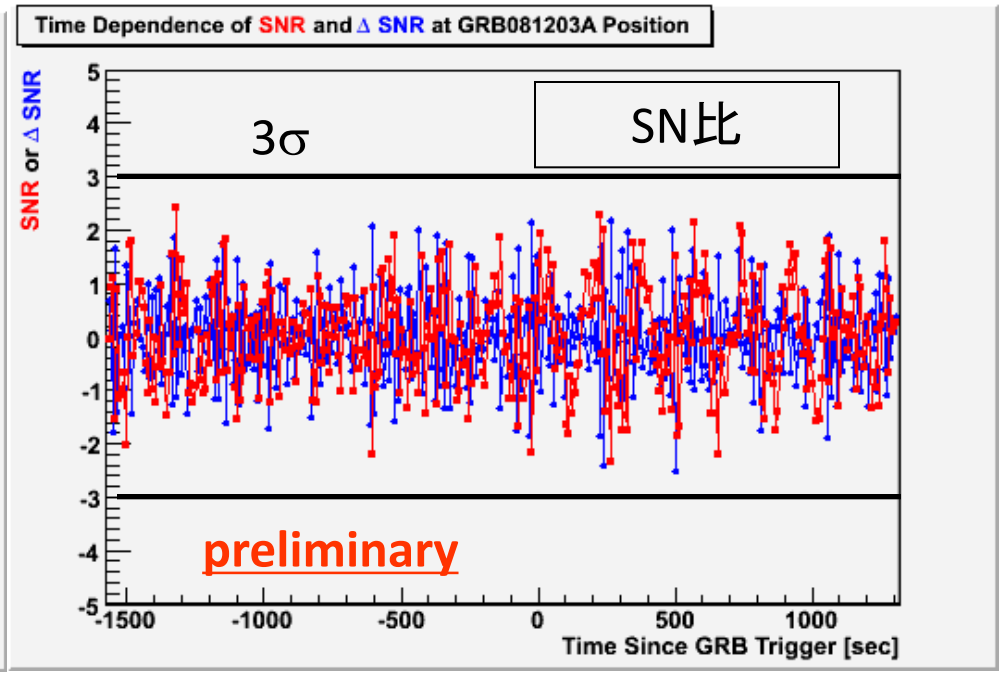
有意度の確認

SNの式：

$$SN = \frac{S}{\sqrt{BG}}$$

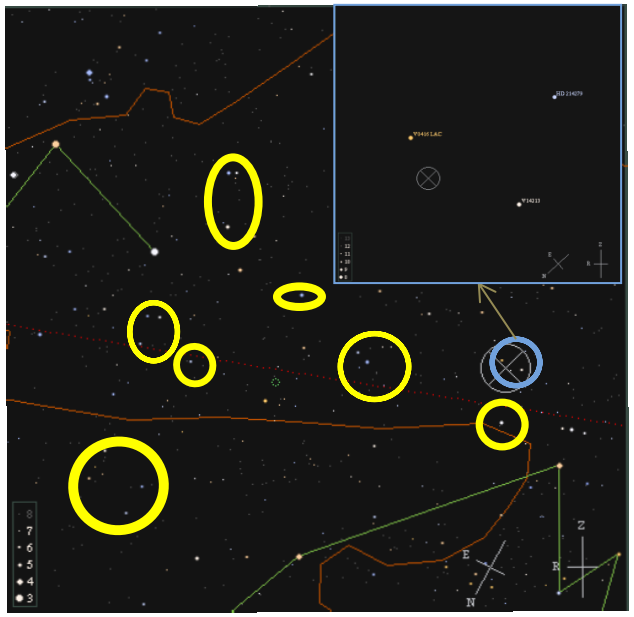
SNの分布から正しく計算していることを確認(σ=1)

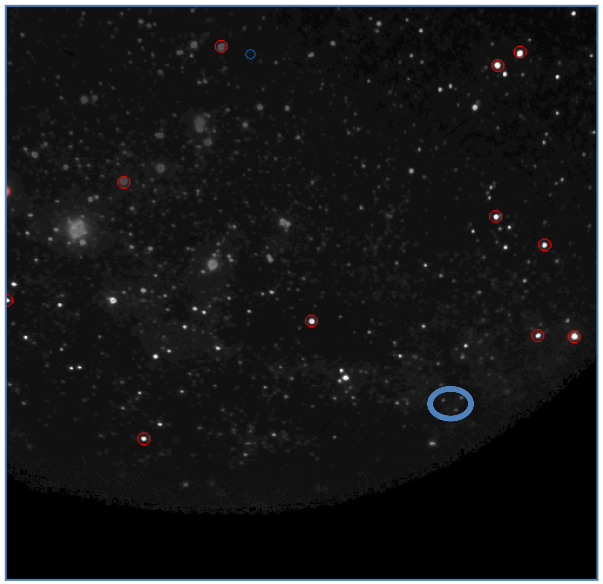




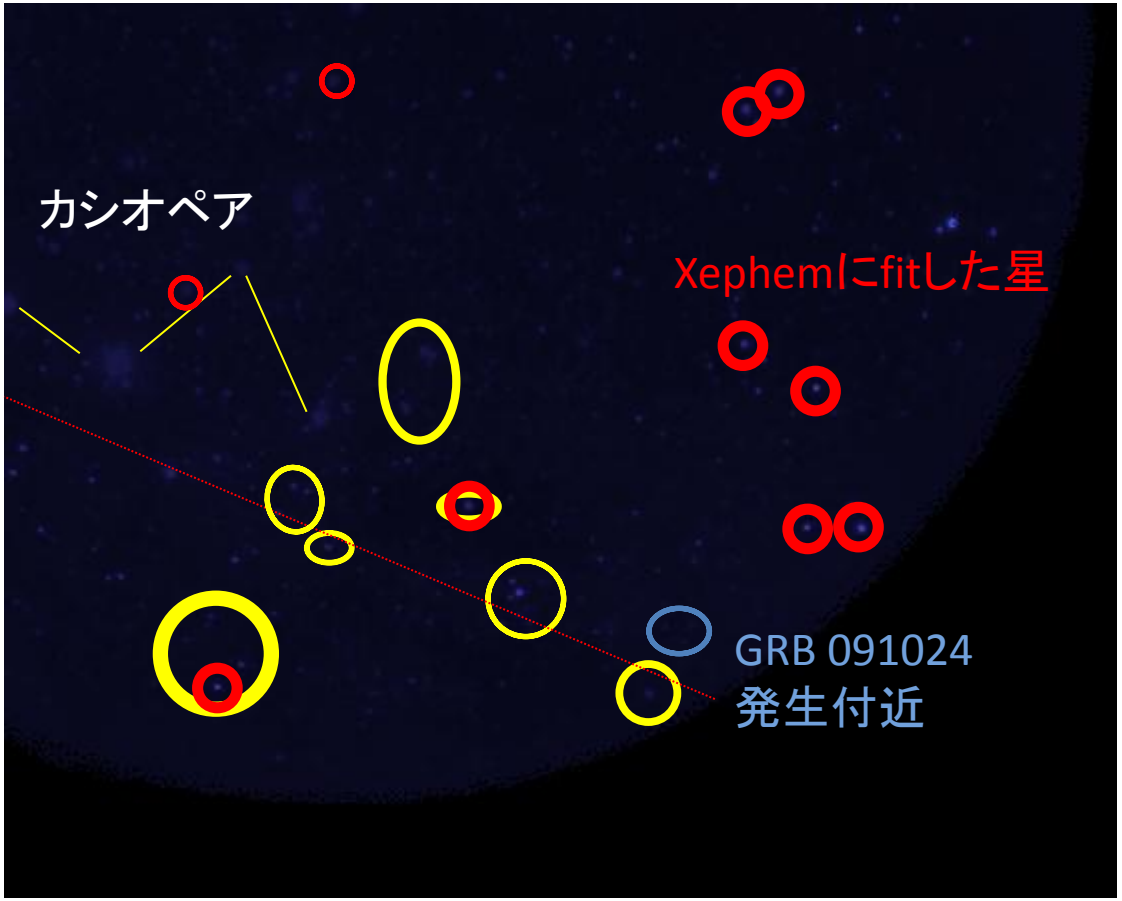
GRB位置での3σを超えるイベント無し

Ashraによって撮影された写真における GRB 091024の位置確認





Xephemの画像(左上図)とfitting画像(左下図)を利用し、T0時に撮影されたGRB091024の発生位置付近を同定。



Conclusions

- Ashra-1/NTA => PeV-EeV Universe Explorer
  Optical Air-shower Technique
  Multi-particle Astronomy (γ,ν)
- Forming NTA collaboration internationally
- Collaborative demonstration running successfully at Akeno with Developed Trigger & Readout for fluorescence and pulse laser System
- About publishing physics results (optical transiensts, ν_τ, CR spectrum, ..) from 5700hr observation with Ashra-1 => ICRC2015
- Almost ready for Obs04 (2015.4-) on Mauna Loa