Ashra-1 for NTA

VHEPA2015@NTU in Taipei
2015.04.09
Makoto Sasaki
ICRR UTokyo

Outline

- Chronology of Ashra-1 Group
- Detector Designs and Performances
- Prospects for NTA => G.Hou's talk

Chronology

[1997: TA grand design](#)
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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

うものです。
各界各位におかれましては、すでに将来計画の実現に向けて走り始めた研究者に今後ともご指導ご鞭撻を賜りますとともに、ご理解とご支援をお願いする次第です。

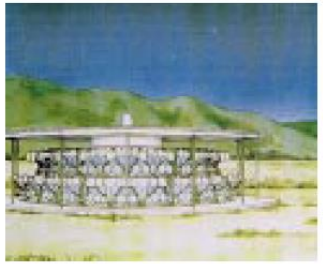
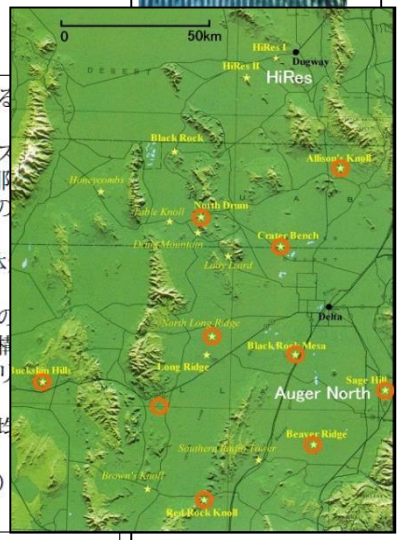


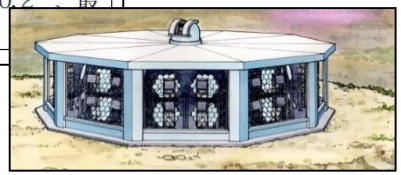
図3：42望遠鏡素子のステーション鳥瞰図(左)と内部上部図(右)。

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分による励起蛍光の集光・撮像
検出器構成	3m径蛍光望遠鏡42素子のステレオ・アレイ8台（～30km間隔）
カメラ構成	1望遠鏡素子あたり256本の光電子増倍管
ステーションの視野	方位360°×仰角34°（立体ラジアン）
シャワー軸再構成	複数ステーションでの飛跡による幾何学的ステレオ再構
1次エネルギー再構成	シャワー縦発達分布をカロリクに積分。
1次粒子種類同定	シャワー縦発達分布から平均を求め、分類。
大気透明度較正	YAGレーザー（波長355nm）オンライン大気モニター。
検出効率（10^{20}eV）	＞80,000km^{2}str×～10%（稼動効率）。
分解能	AGASAの50－100倍。エネルギー20%、到来方向0.2°、最大縦発達の深さ30g/cm^2





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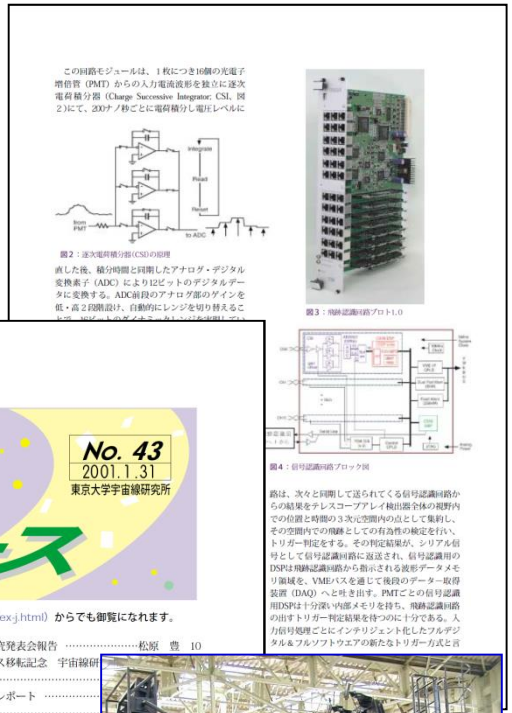
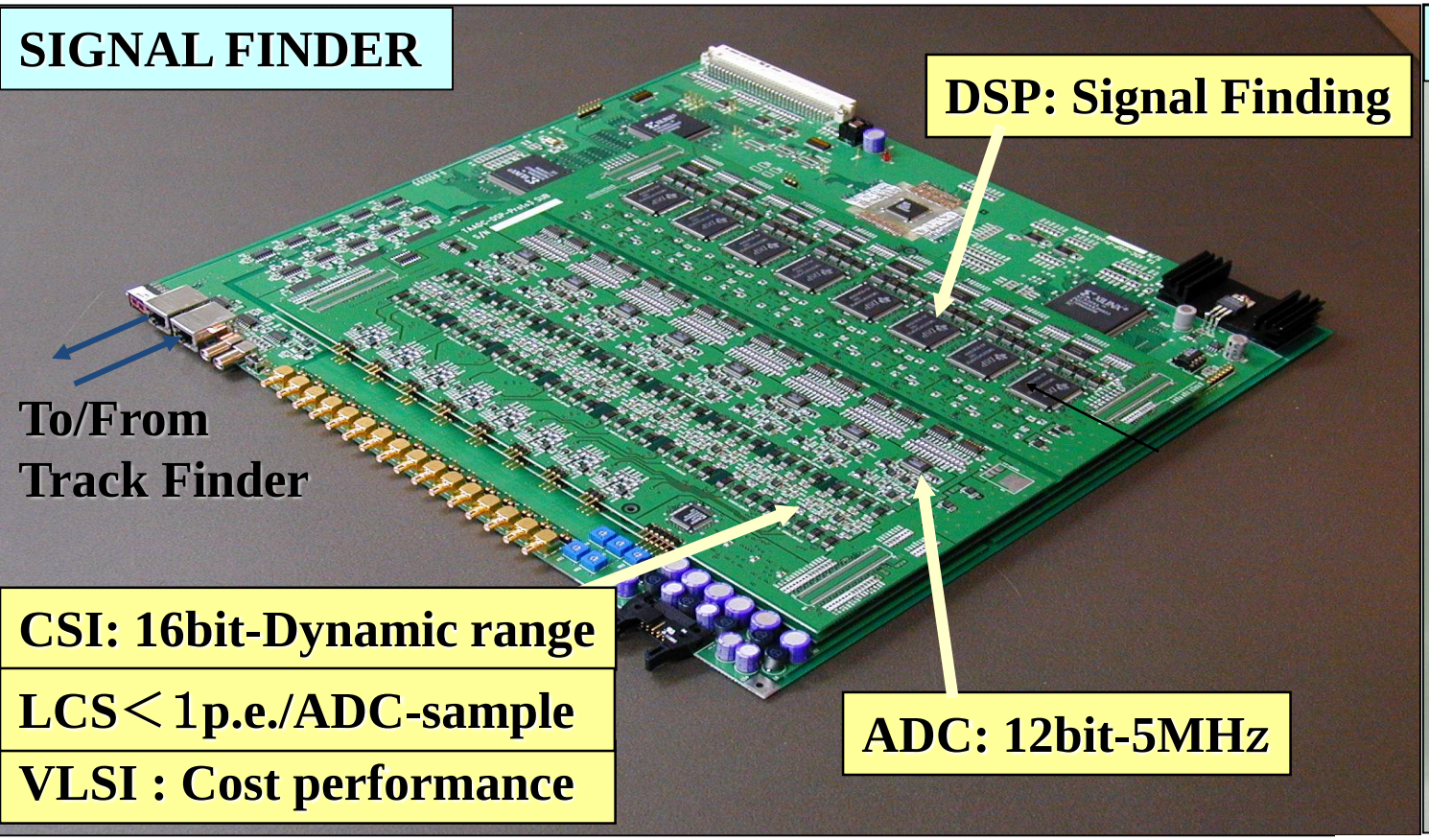


Front-end Signal Process Scheme

SIGNAL FINDER

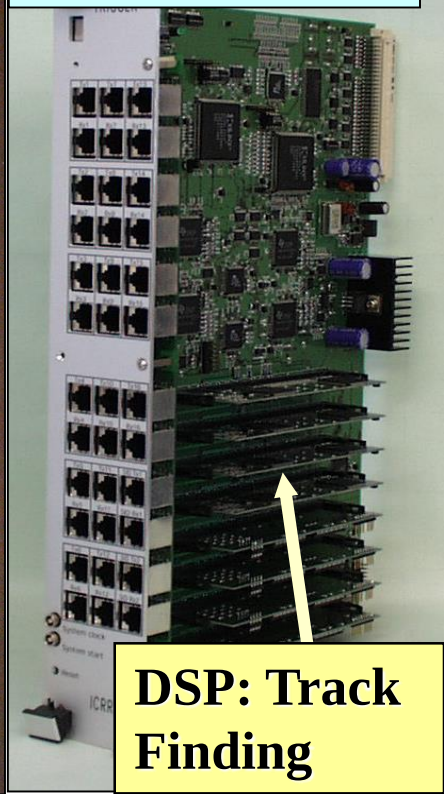


CSI: 16bit-Dynamic range

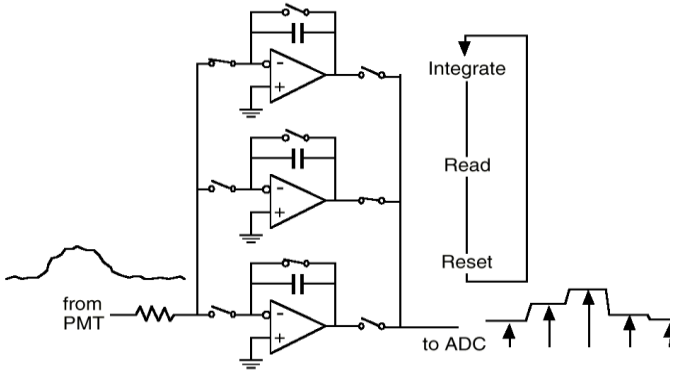
LCS＜1p.e./ADC-sample

VLSI : Cost performance

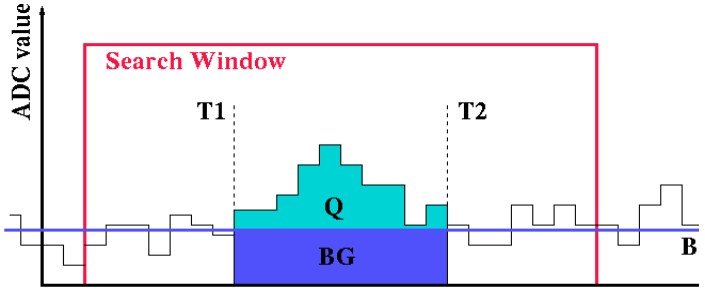
TRACK FINDER



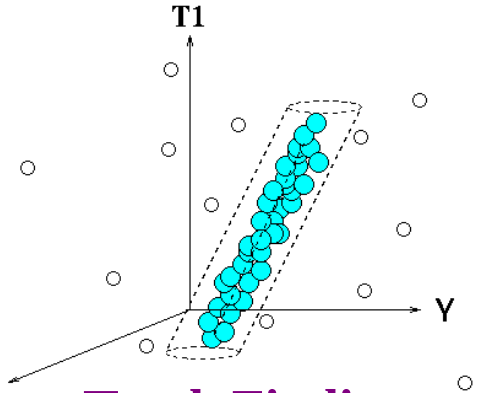
Charge Successive Integrator



Signal Finding



$$S/N(T1,T2) = \frac{Q}{BG^{1/2}}$$



Track Finding

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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

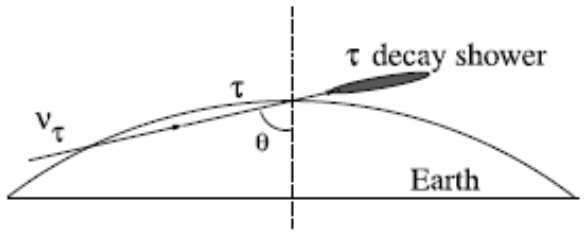
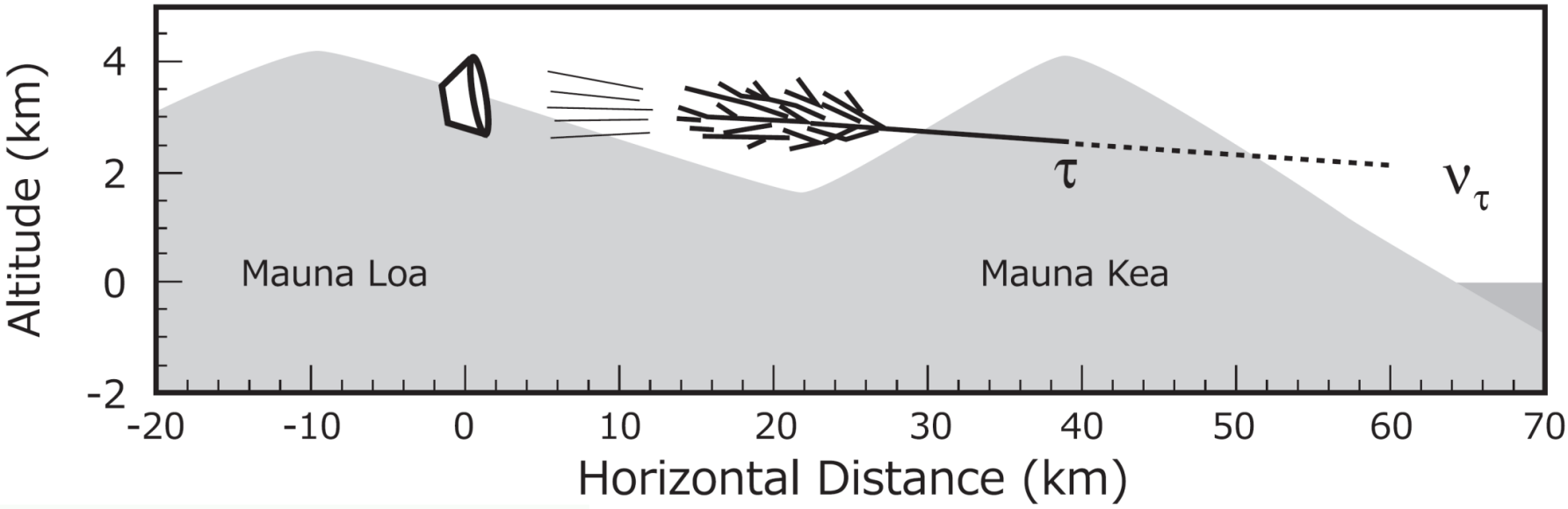
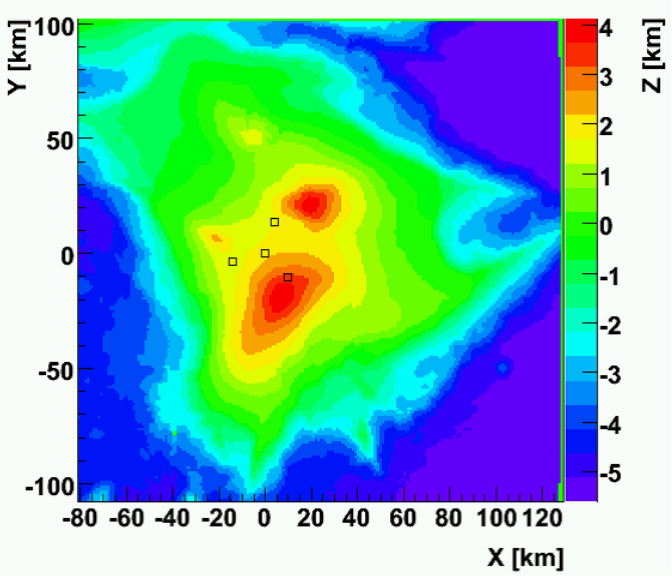


Fig. 7. A schematic picture of Earth-skimming tau neutrino events.

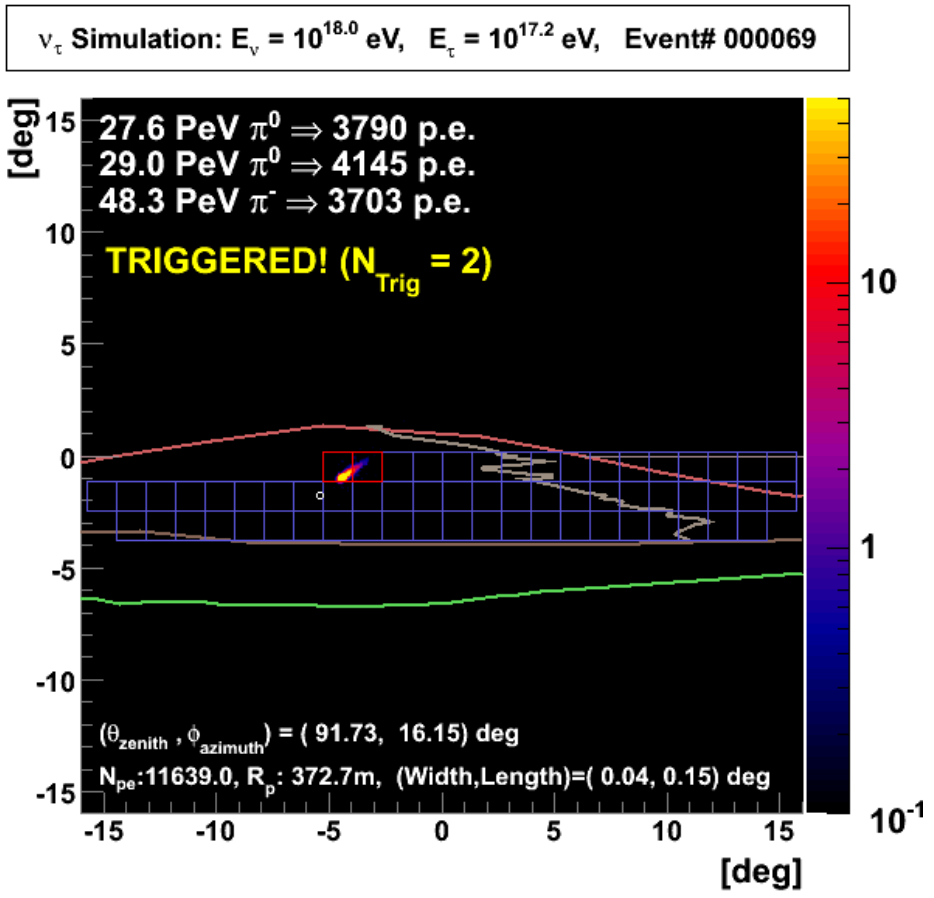
Earth Skimming Tau Shower Method



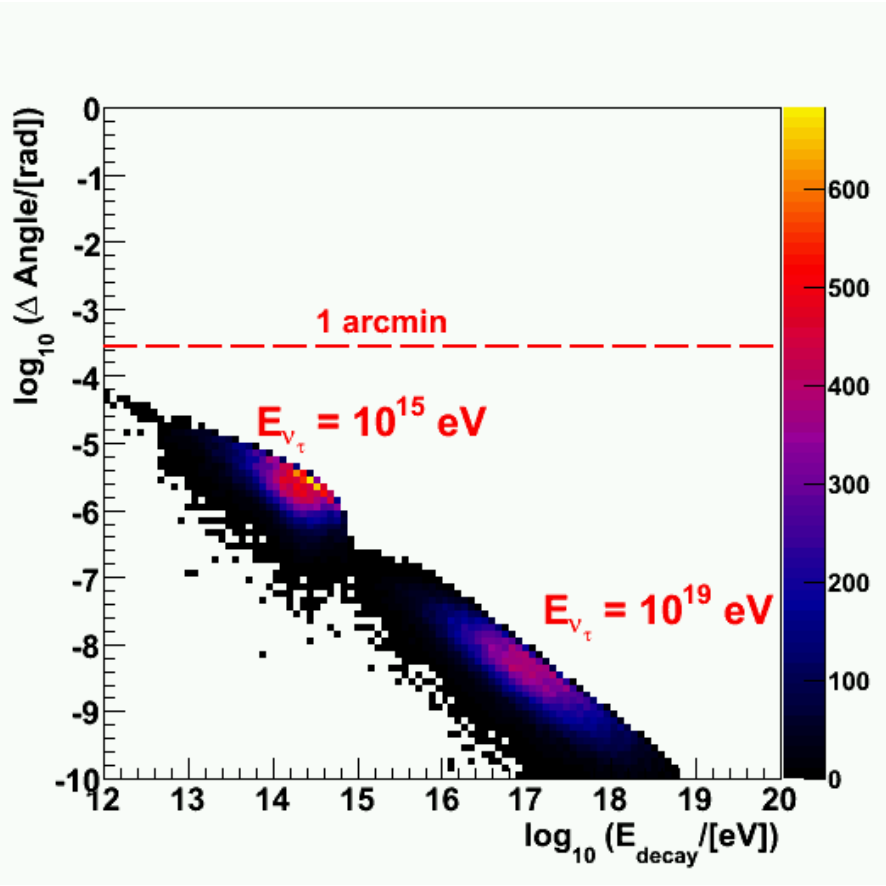


Dist. Ang. w.r.t. Mountain Edge	Expected misrecon. BG
0.1 deg	0.08 /yr
0.3 deg	0.55 /yr
1.0 deg	4.3 /yr
3.0 deg	39 /yr

Tau Deflection & Decay Energy After Propagation in Rock



MC Simulation of Tau Decay



Highly Boosted =>Thrust Axis of Tau Decay Remembers ν_τ Direction < 0.1mrad (~0.3arcmin) @ > 1PeV

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

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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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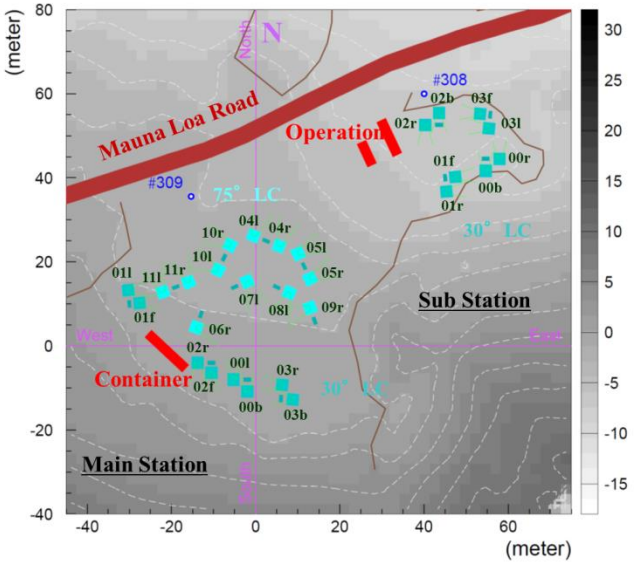
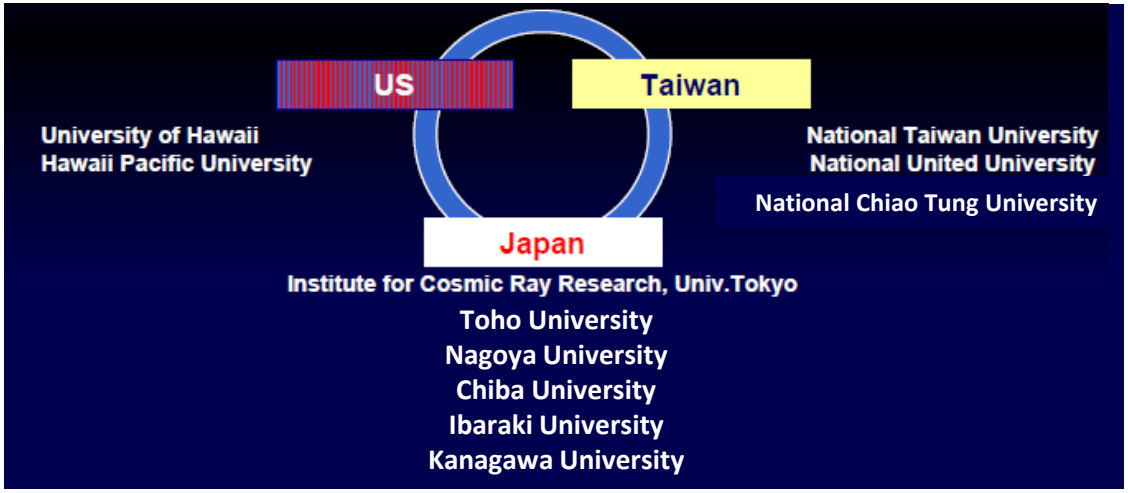
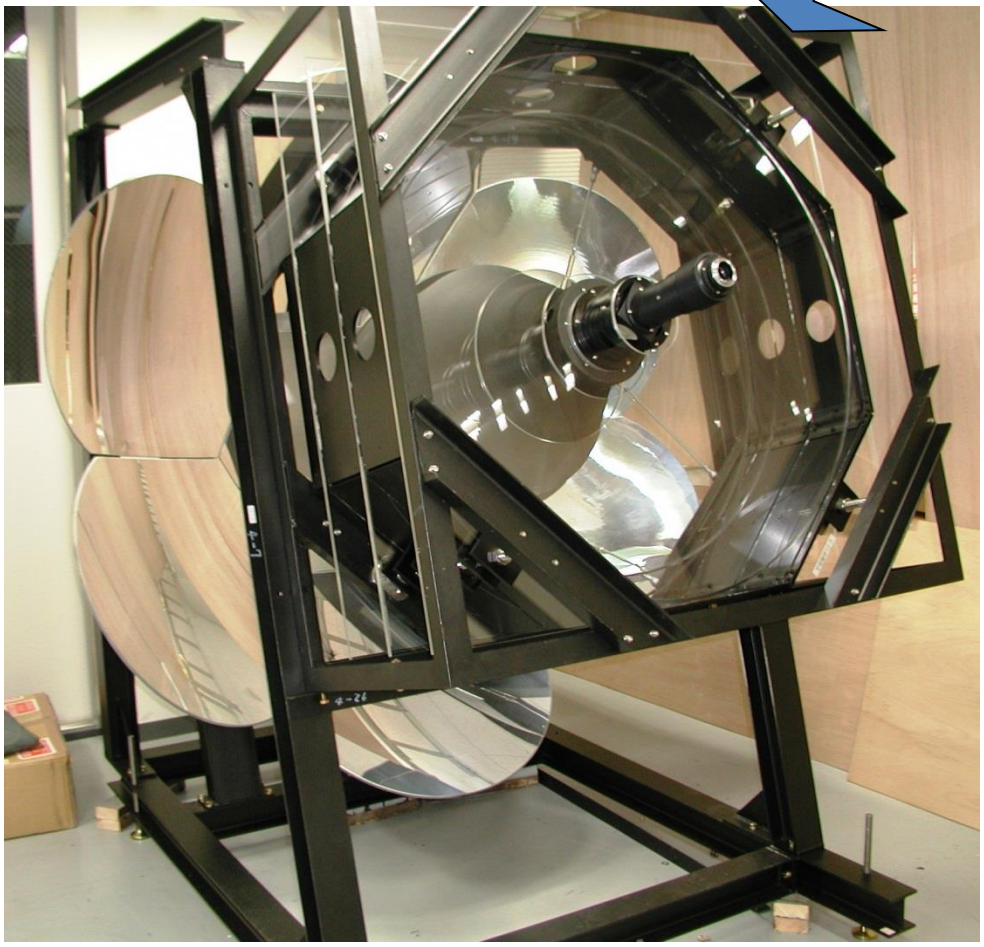


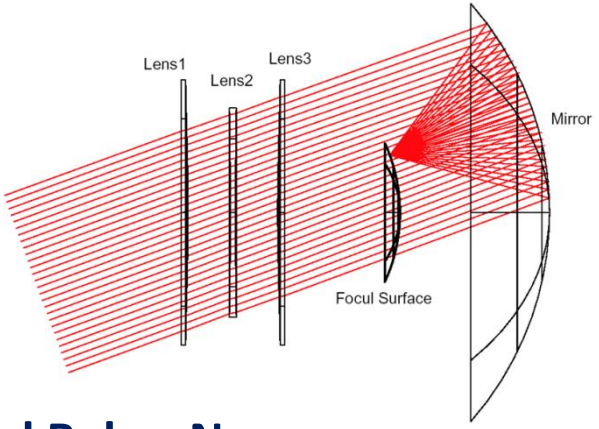
Ashra-1 Collaboration (2004)



Ashra Collaboration Meeting In 2004

Light Collector





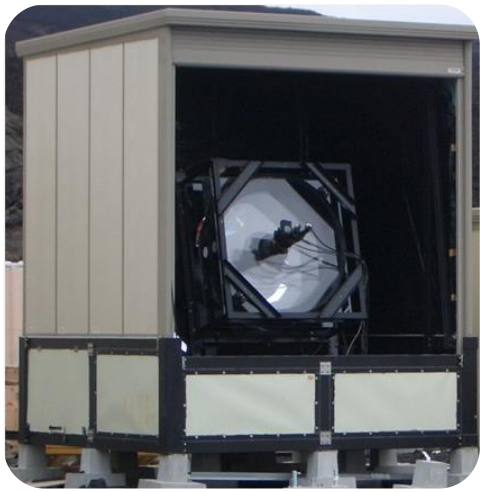
- Optics:
  - **Modified Baker-Nunn**
- Components:
  - **Correcting lens** (1.0~1.2mϕ) with 3 acrylic cut plates
  - **Spherical mirror** (2.2mϕ) with 7 curved glass plates on adjustable tables.
  - **Photoelectric lens IT** (0.5mϕ) on focal sphere suspended with Stewart platform mechanism
  - **Mount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

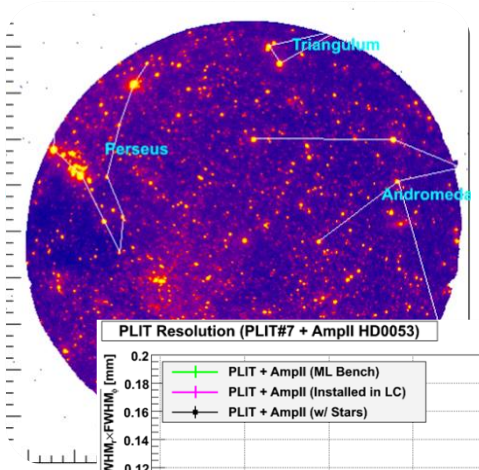
=> arcmin. resolution over 42deg FOV

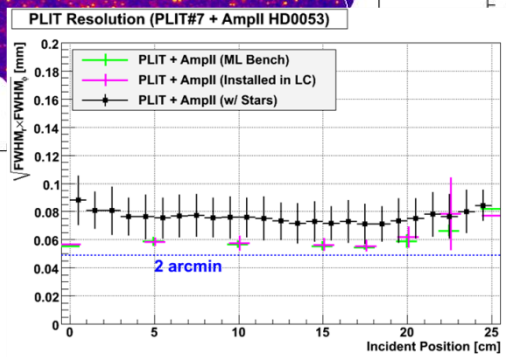
=> Very cost-effective

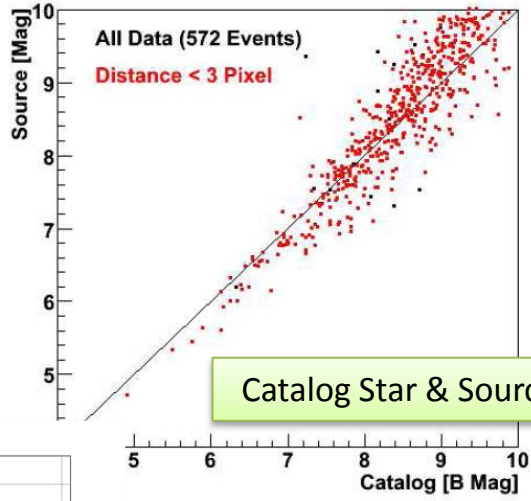
Ashra-1 LC Optical Performance

Ashra-1 Light Collector









Catalog Star & Source Pairs

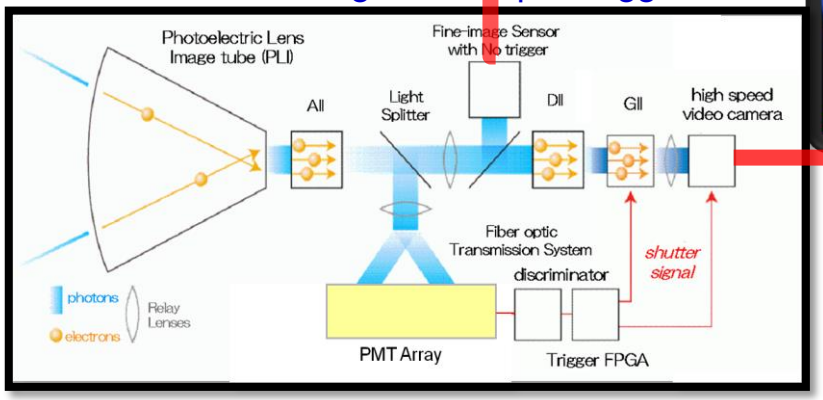
Total Resolution: ~3 arcmin image in 42° FOV

Can cover Mauna Kea surface at 35 km distance

Ashra-1 Pipeline Trigger & Readout

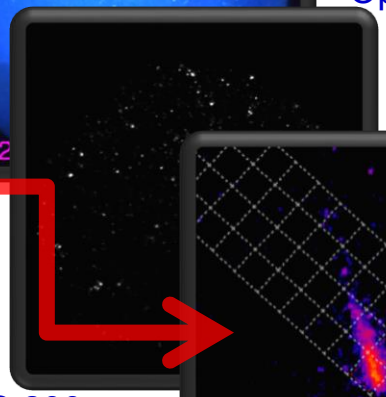
demonstrated

Same Fine Image to Multiple Triggers

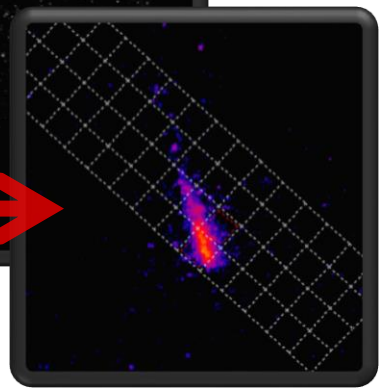


Photoelectric Image Pipeline (PIP)

Optical 4s or 1s



BG 200ns



CR 200ns

Multi-Messenger Approach with
One Detector System

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

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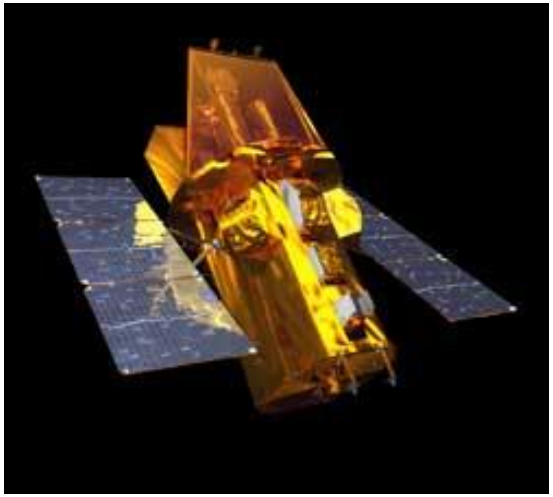
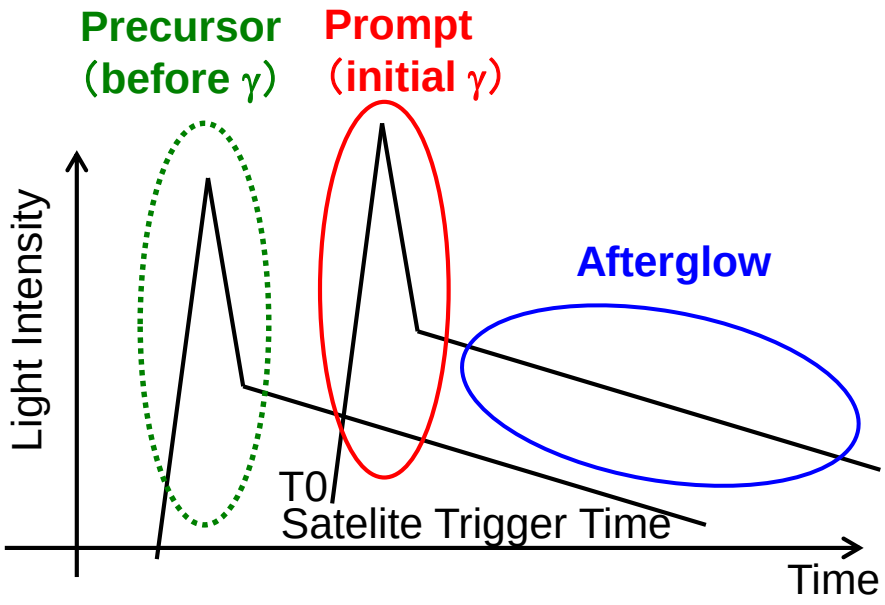
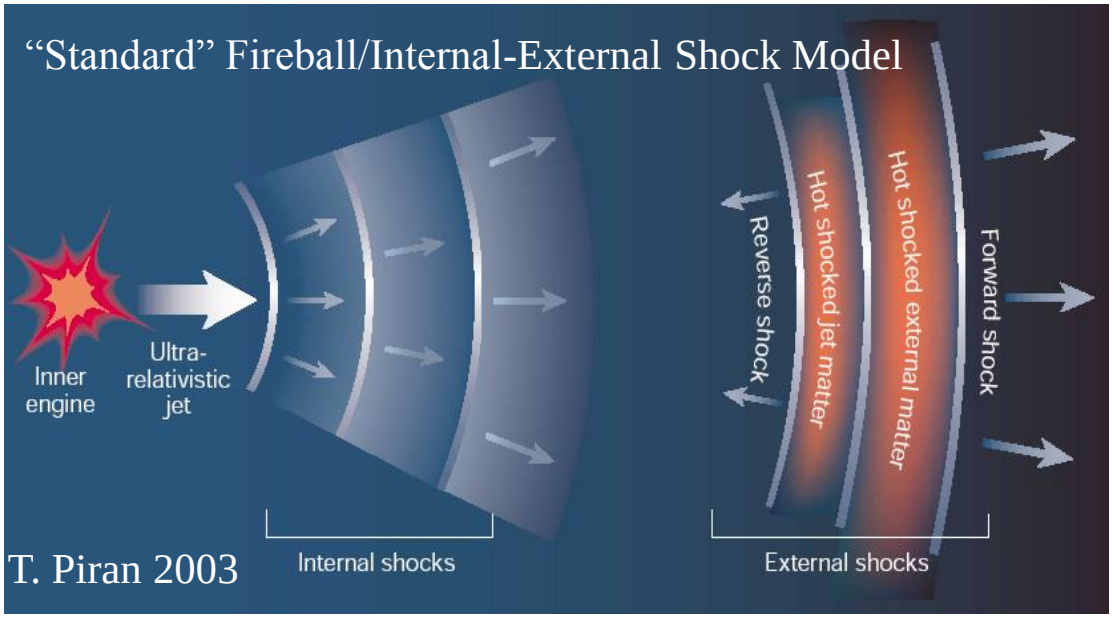


http://swift.gsfc.nasa.gov/about_swift/



Astronomical Multi Particle Object: GRB



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

$$p + \gamma \rightarrow \pi^0 + p$$
$$\hookrightarrow \gamma + \gamma + p$$

VHE Gammas

$$\rightarrow \pi^+ + n$$

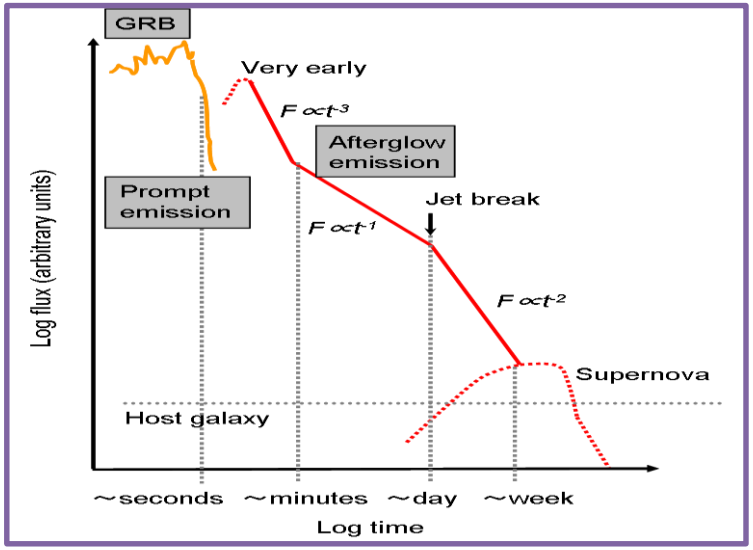
Cosmic Rays

$$\hookrightarrow \mu^+ + \nu_\mu + n$$

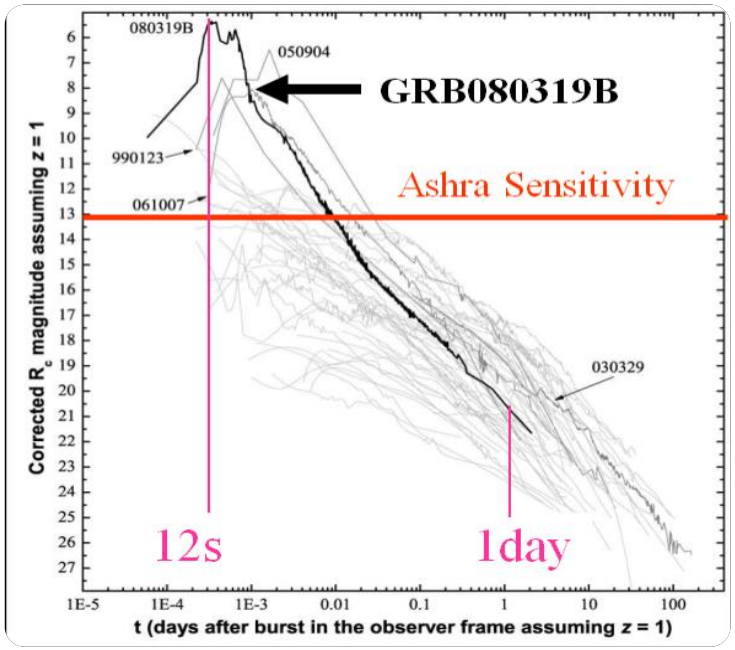
VHE Neutrinos

$$\hookrightarrow e^+ + \nu_{\bar{\mu}} + \nu_e + \nu_\mu + n$$

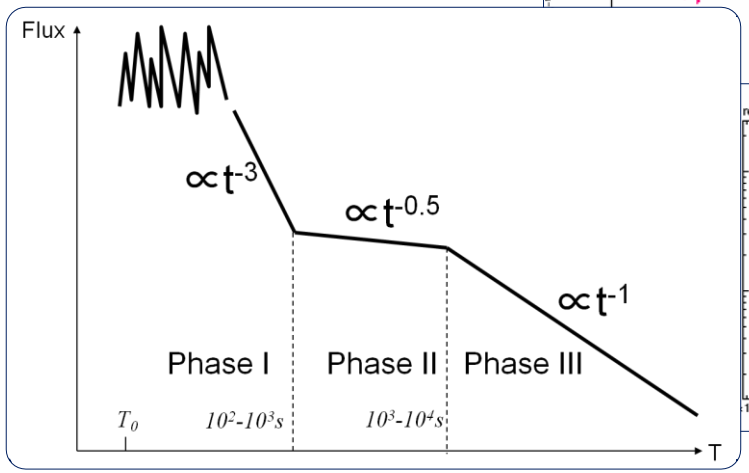
External Reverse Shock => Prompt Optical Flash



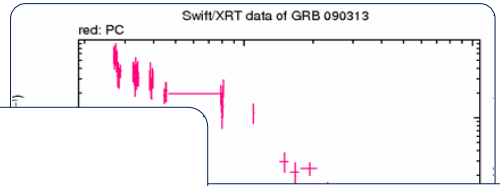
Optical & X-ray Problems to Solve

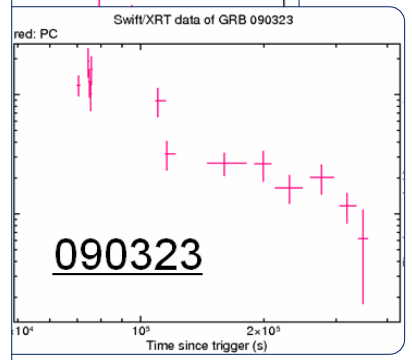


Reverse Shock Optical Flash
[Sari&Piran, ApJ 520 (1999) 641]



X-ray Canonical Behavior
[Nousek et al. ApJ 642 (2006) 389]



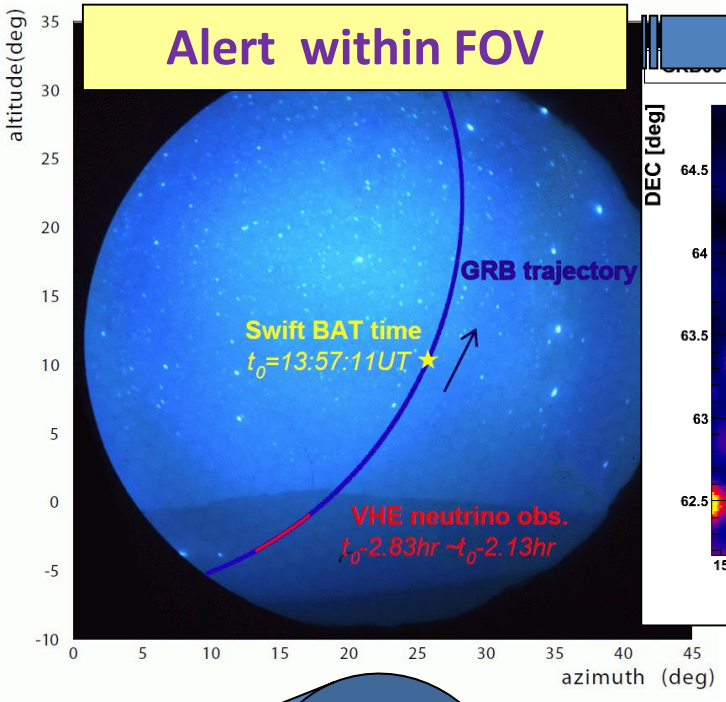


X-ray Precursor
[Burlon et al., ApJ 685 (2008) L19]

Delayed Gamma-ray (GeV)
[DePasquale et al., ApJ 709 (2010) L146]

Diverseness beyond GRB SM => New Observations

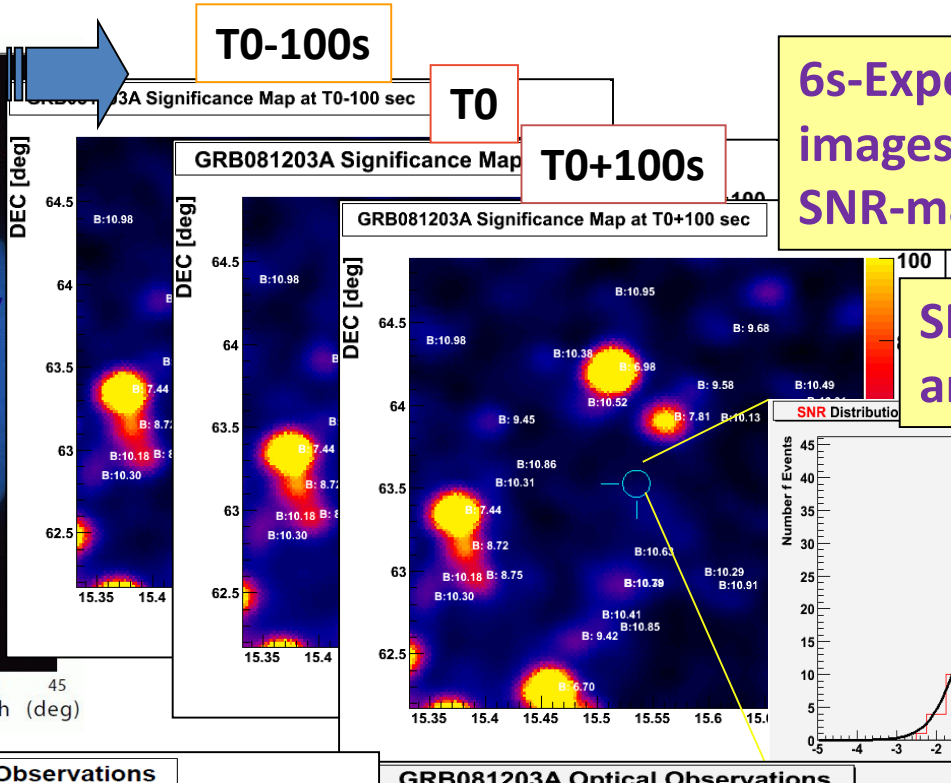
Process of Analysis of GRB Optical Flash Search (GRB081203A)



T0-100s

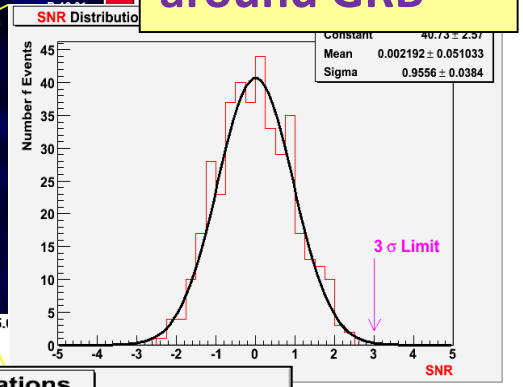
T0

T0+100s

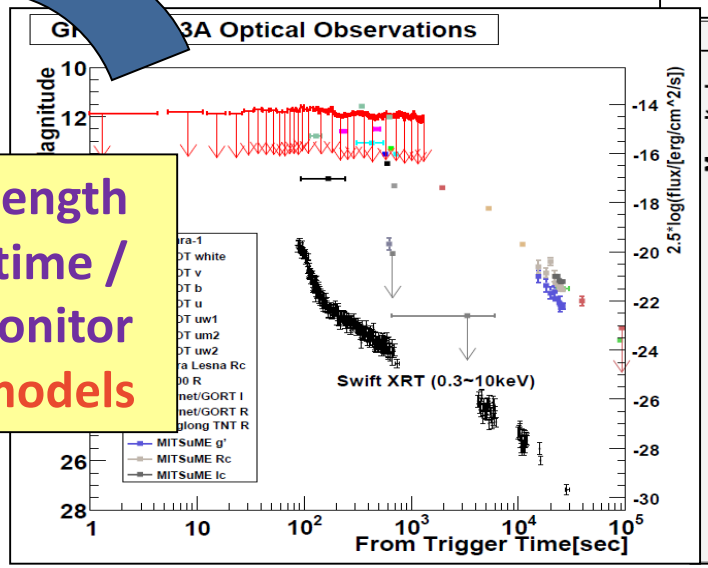


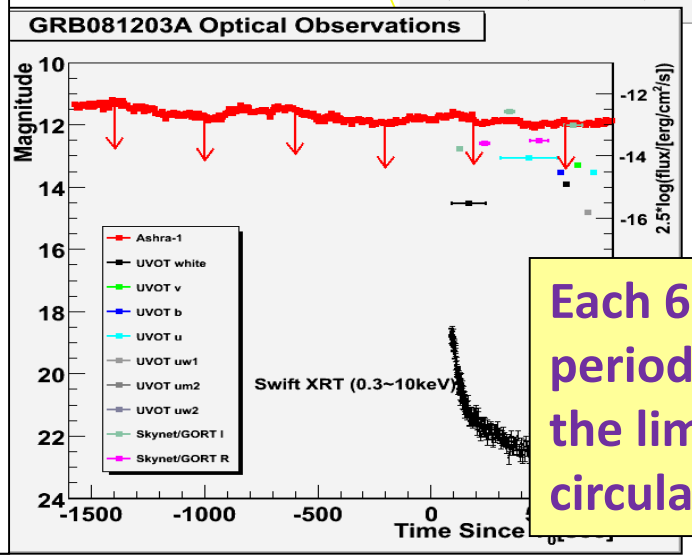
6s-Exposure images ⇒ SNR-map

SNR histo around GRB



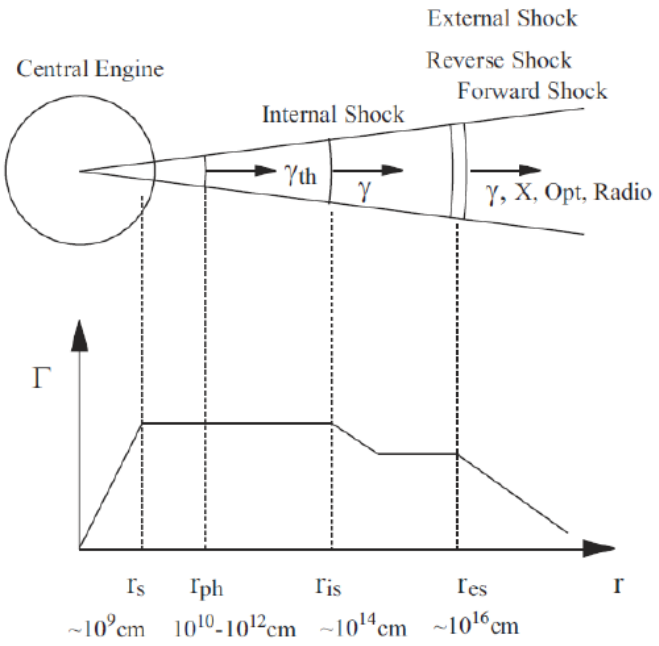
Multi-wavelength ＋Ashra Ontime / Precursor monitor ⇒ Restrict models





Each 6s-period , plot the limits => circular #8632

Initial Lorentz Factor Restricted by Optical Flash Search



$$\gamma_\times = \min[\eta, \eta_c]$$

$$\eta_c \sim 190\ n_0^{-1/8} \left(\frac{1+z}{3.3}\right)^{3/8} \left(\frac{T}{100\mathrm{sec}}\right)^{-3/8} \left(\frac{E_{52}}{5.6}\right)^{1/8}$$

$$t_\times \sim \left(\frac{\gamma_\times}{\eta_c}\right)^{-8/3} T$$

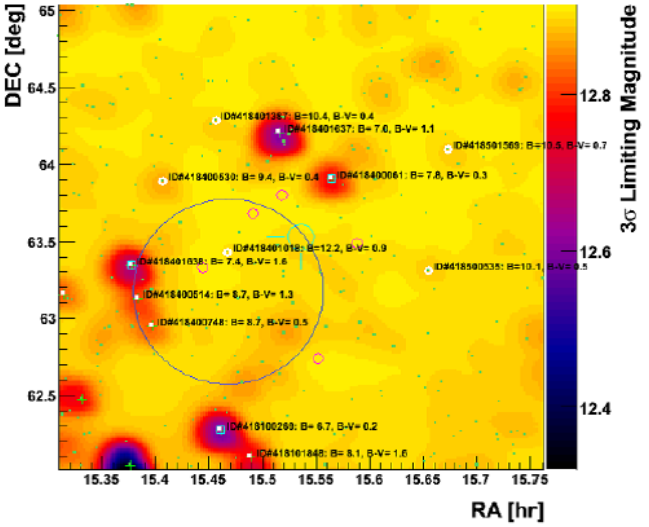
$$\nu_{c,r}(t_\times) \sim \nu_{c,f}(t_\times)$$

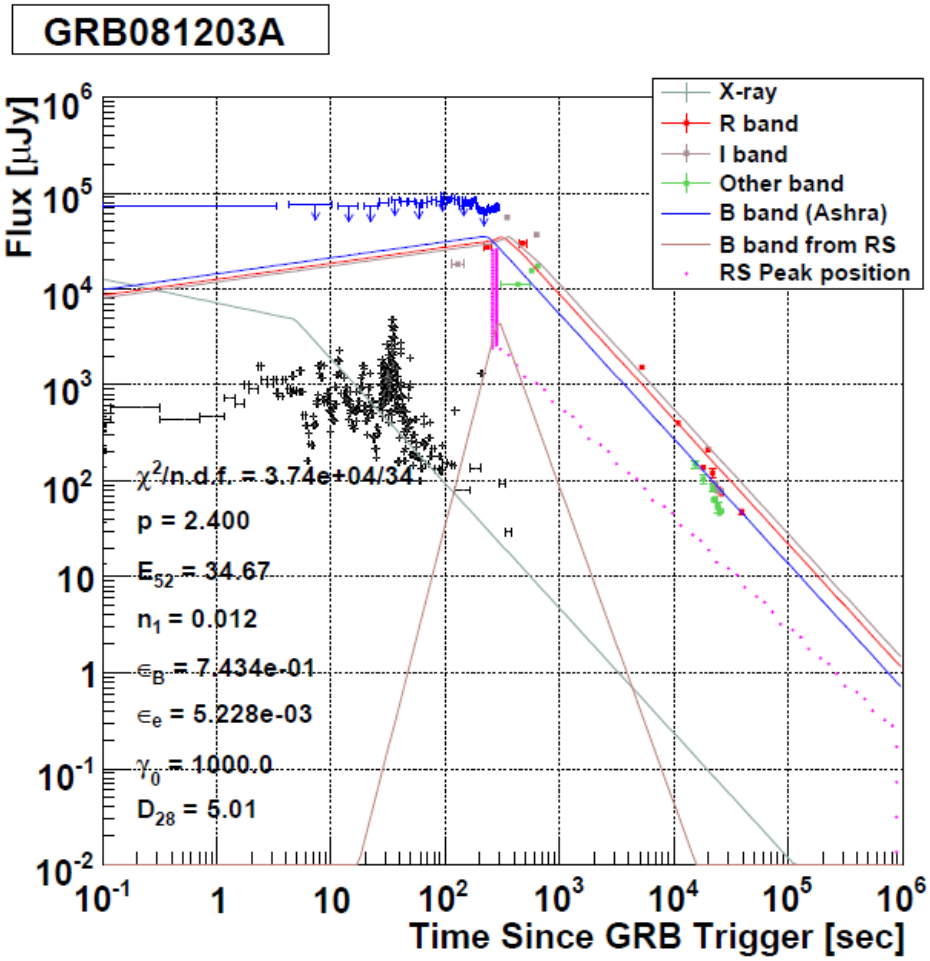
$$\nu_{m,r}(t_\times) \sim \frac{\eta^2}{\gamma_\times^4}\ \nu_{m,f}(t_\times).$$

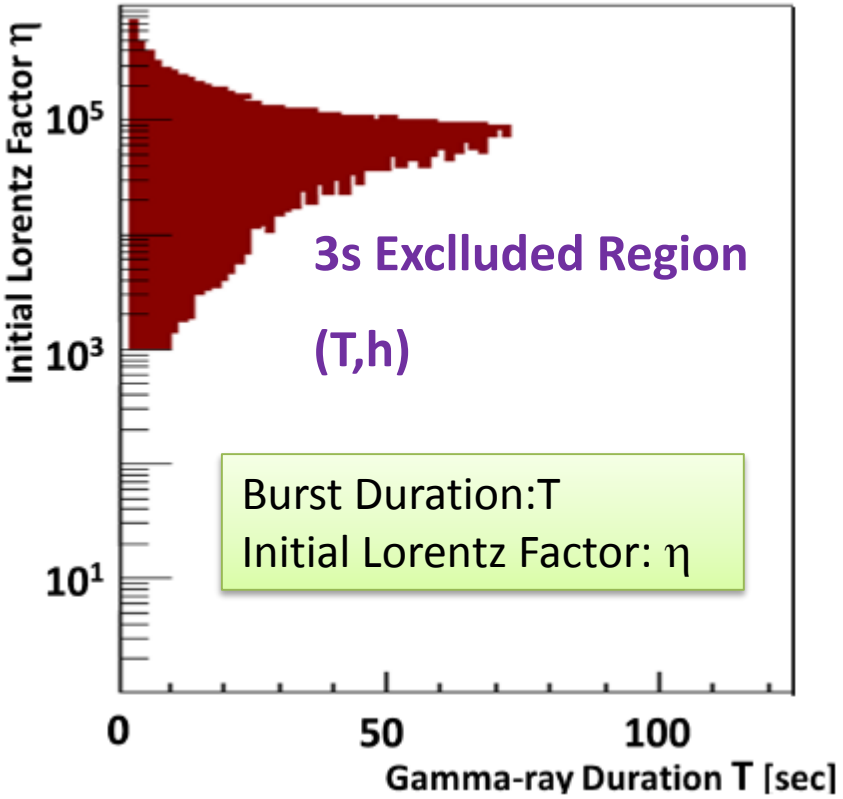
$$F_{\nu,\max,r}(t_\times) \sim \frac{\gamma_\times^2}{\eta} F_{\nu,\max,f}$$

Kobayashi & Zhang ApJ 582 (2003) L75

Initial Lorentz Factor Restricted with Optical Flash Search



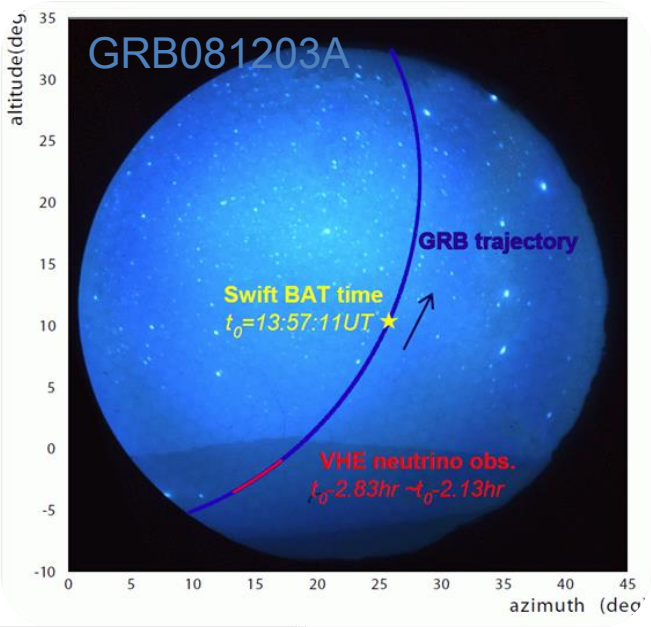


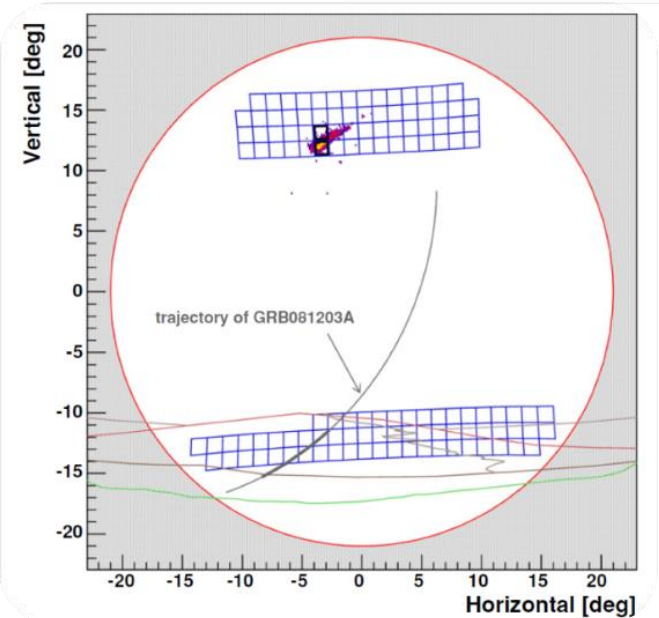


Chronology

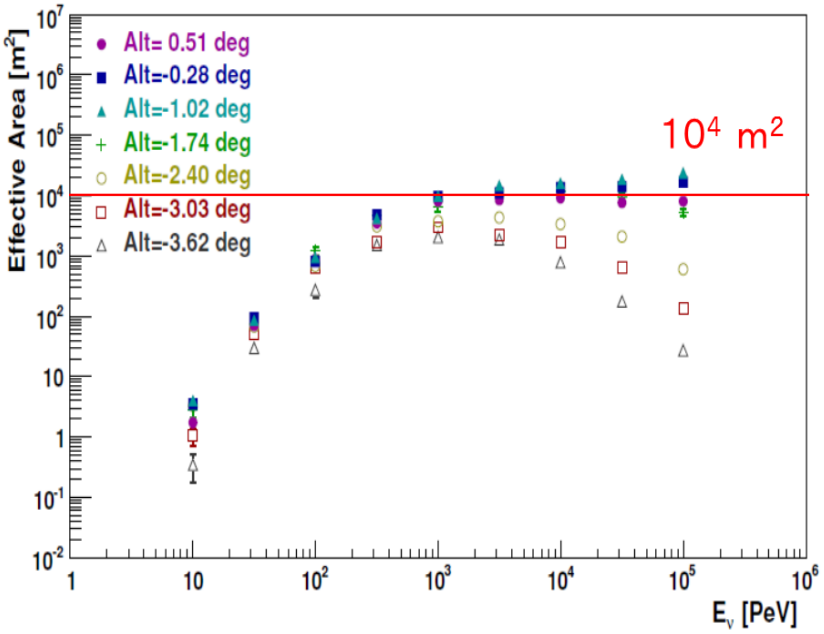
1997: TA grand design
2000: Signal/Track Finder
2000: PAO funded
2002: ES ν_τ AS method
2002: NTA proposed (with TALE)
2002: renamed into Ashra
2003: Ashra-1 funded
2004: 1st search for OpF on GRB
2008: 1st search for ES ν_τ on GRB
2013: NTA LoI
2014: VHEPA2014 @ Kashiwa
2015: VHEPA2015 @ Taipei?

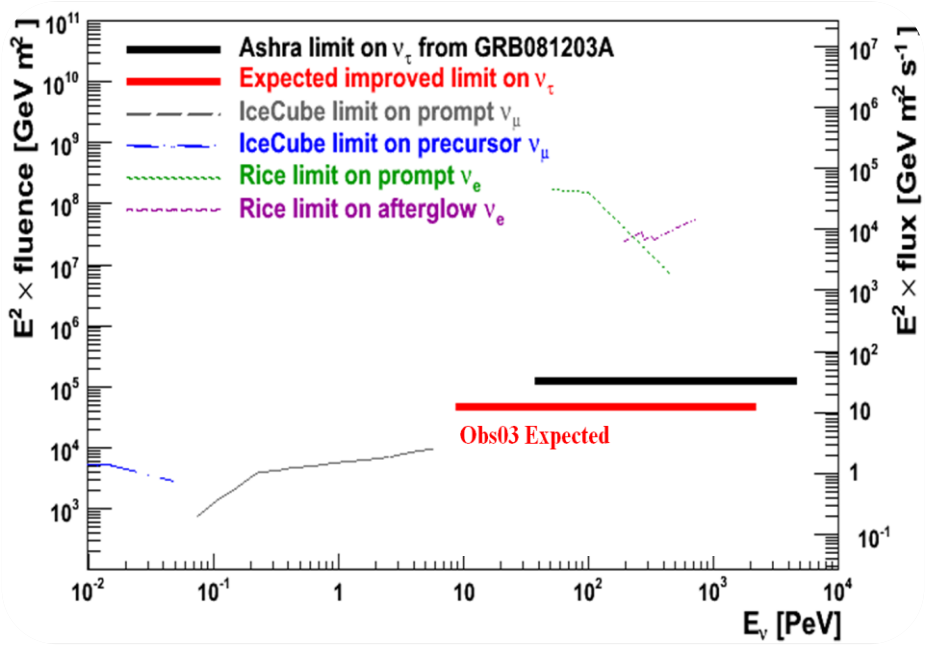
IAC : A.Watson,F.Halzen,T.Kifune

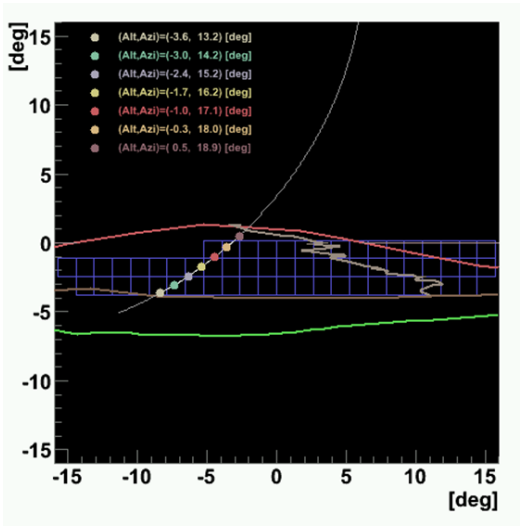




First GRB ν_τ Search Limit

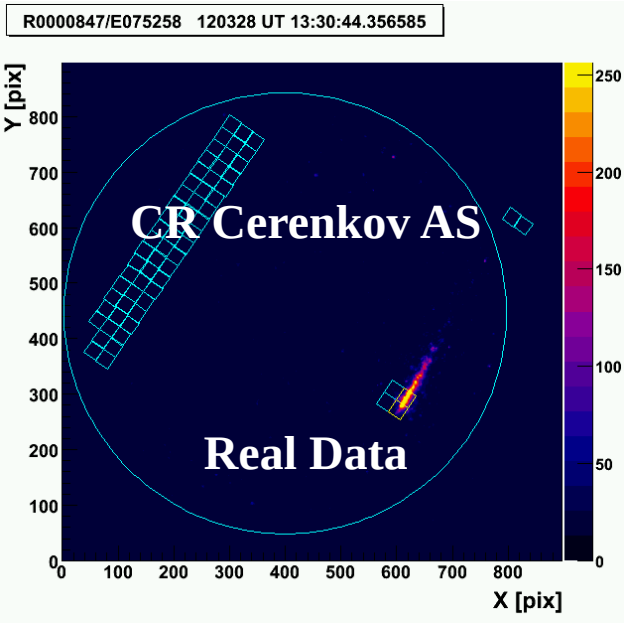


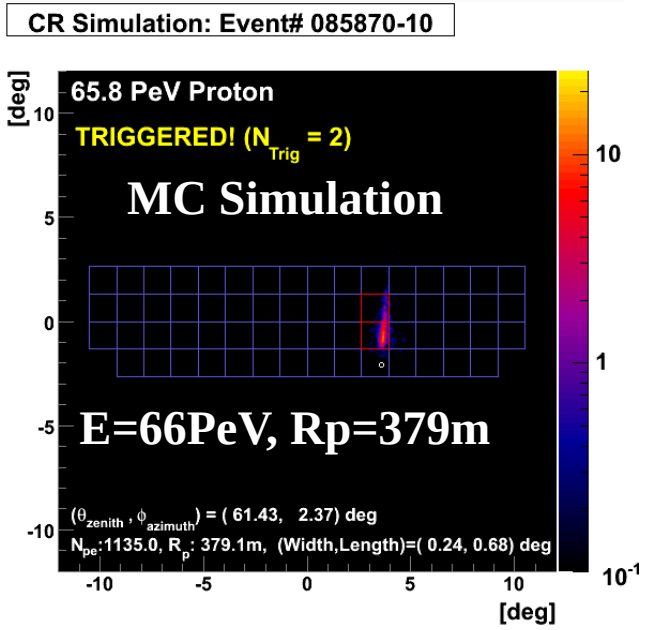




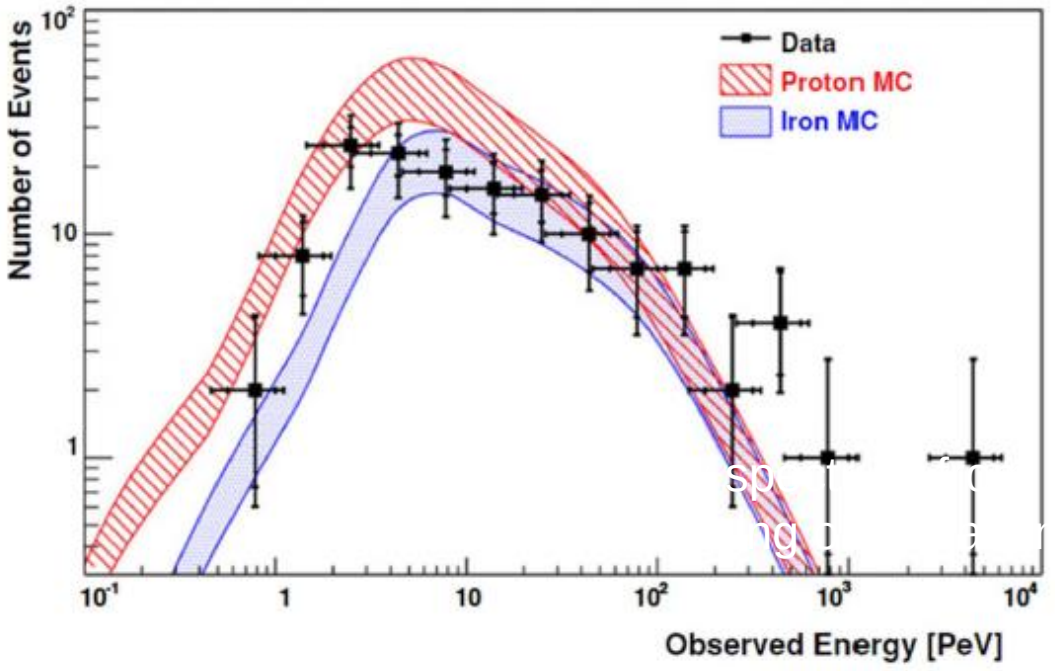
- Swift GRB Alert during Commissioning in 2008
- First Check for PeV-EeV Tau Neutrino from a GRB (ApJ, 736 (2011) L12)
- Even Commissioning 100x Better than Rice
- Started Obs03 Runs Approaching to IceCube Area

Cosmic Ray Studies





- Important to verify detector sensitivity and calibration
- Measure energy spectrum (hint on composition)
- Test MC by event comparison



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IAC : A.Watson,F.Halzen,T.Kifune
April 8-9, 2015, National Taiwan Univ.
www.icrr.u-tokyo.ac.jp/~ashra/VHEPA2015ntu

Neutrino Telescope Array Letter of Intent:

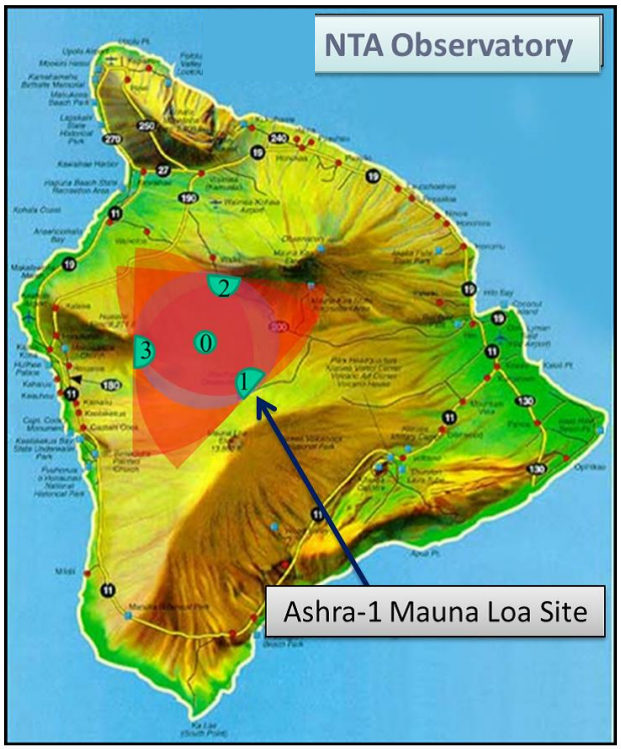
A Large Array of High Resolution Imaging Atmospheric Cherenkov and Fluorescence Detectors for Survey of Air Showers from Cosmic Tau Neutrinos in the PeV-EeV Energy Range

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

NTA Baseline Design



Ashra-1 Light Collector

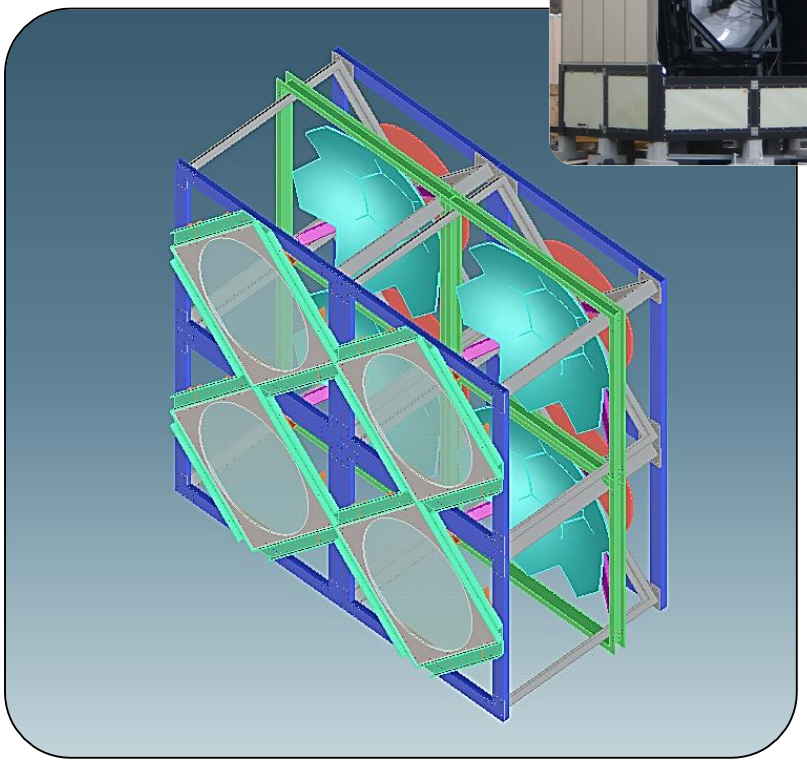


Table 1. Coordinates and FOV coverage of the Ashra NTA sites.

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

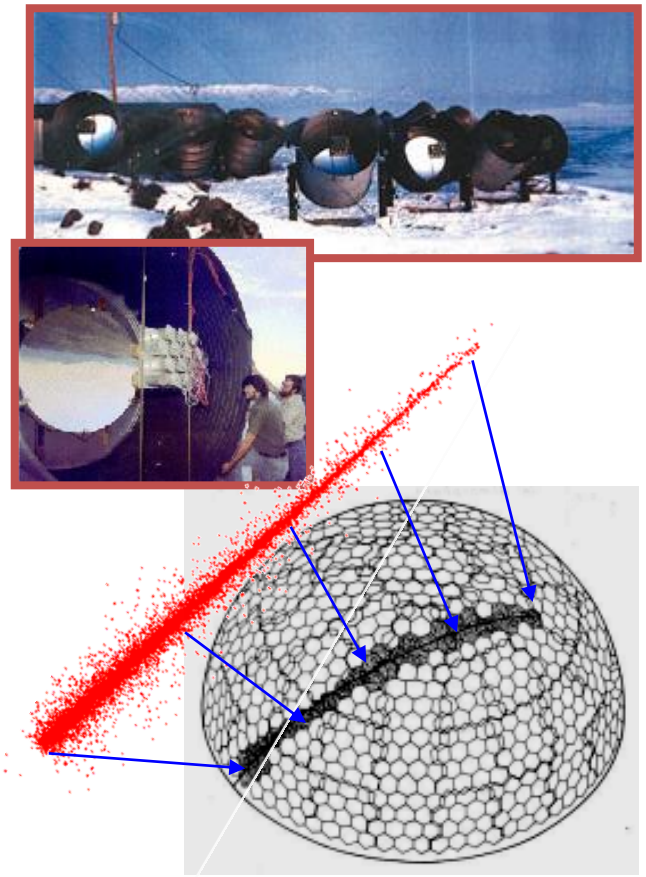
Outline

- Chronology of Ashra-1 Group
- Detector Designs and Performances
- Prospects for NTA => G.Hou's talk

Optical Air-shower Detector

Progress of Resolution × FOV

Fly's Eye (1981-1993)



4deg/pix × All-sky

P M T

HiRes (1994-2006)

1deg/pix × 28deg

P M T

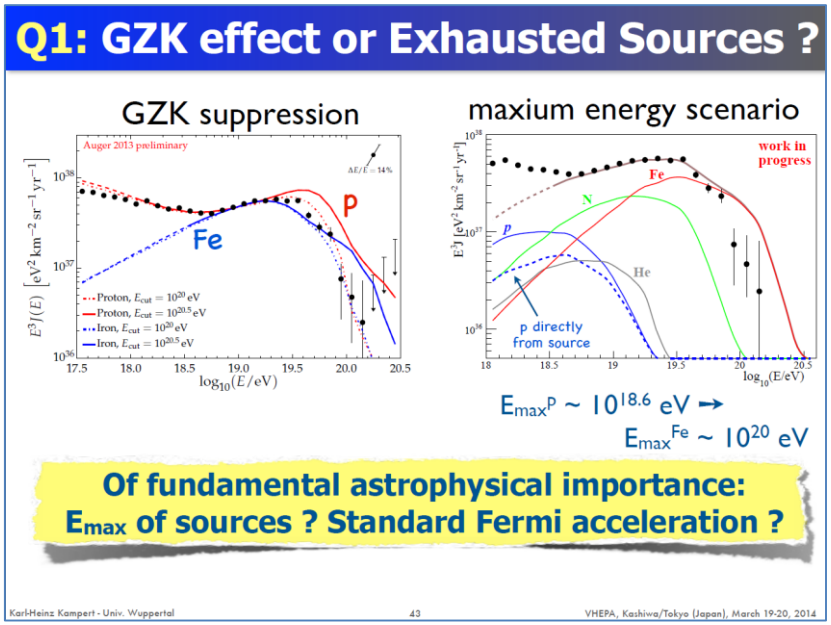
Ashra-1

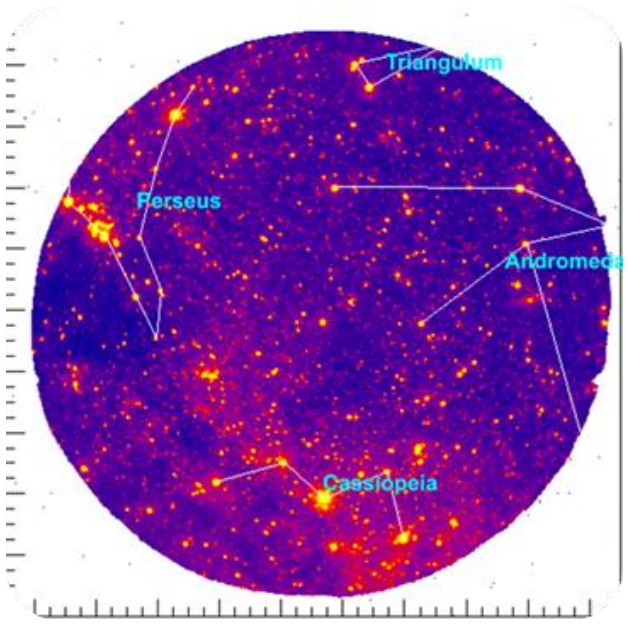
1.2min/pix × All-sky

Image Tube＋CMOS

Spectroscopy with CR

+ Astrometry with ν & γ



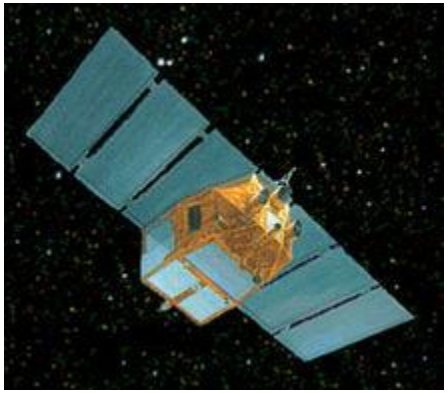


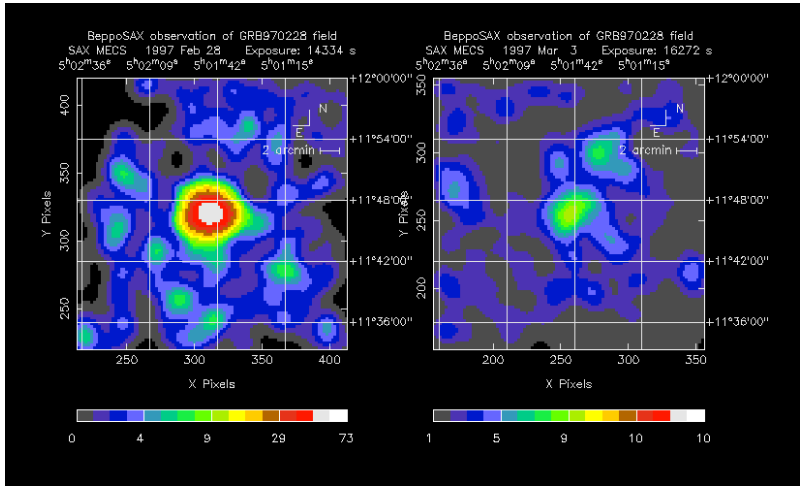
Karl-Heinz Kampert, VHEPA, Kashiwa/Tokyo (Japan), March 19-20, 2014

Optical Image with Ashra-1 Light Collector (LC)

VHE Particle Astronomy (VHEPA)

Arcmin Resolution -> Multi-Messenger



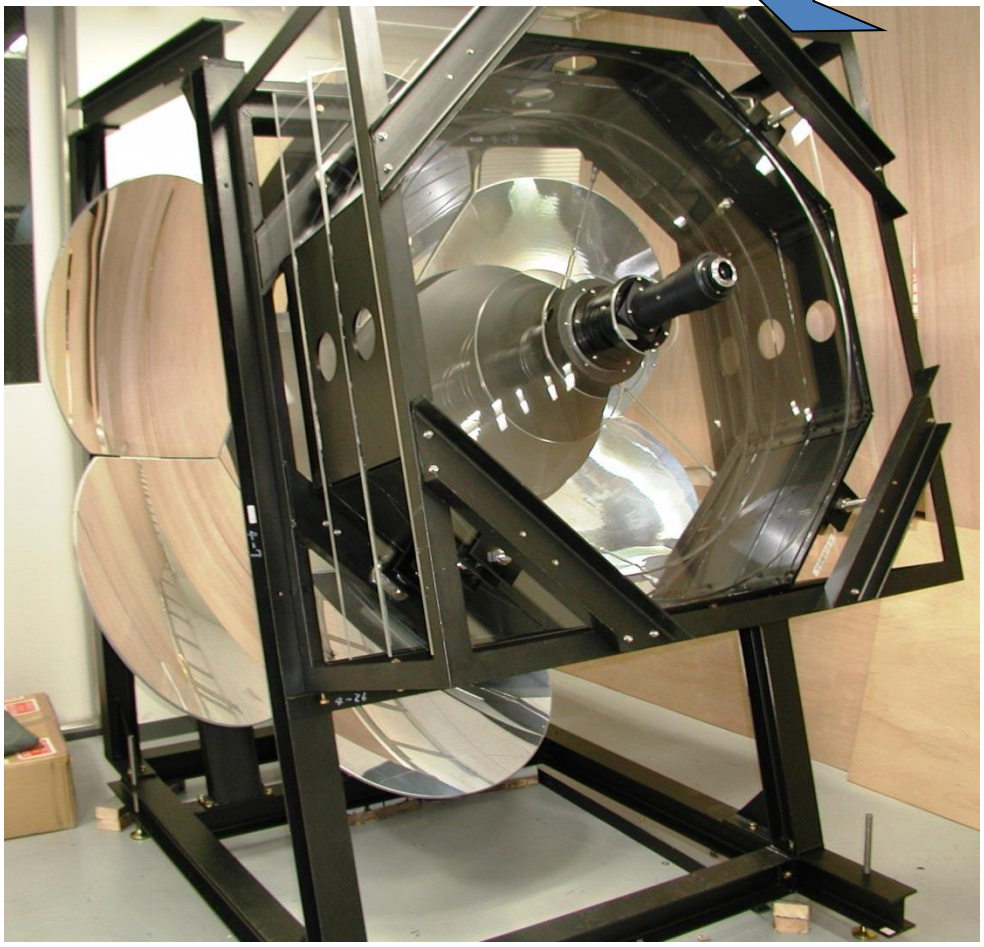


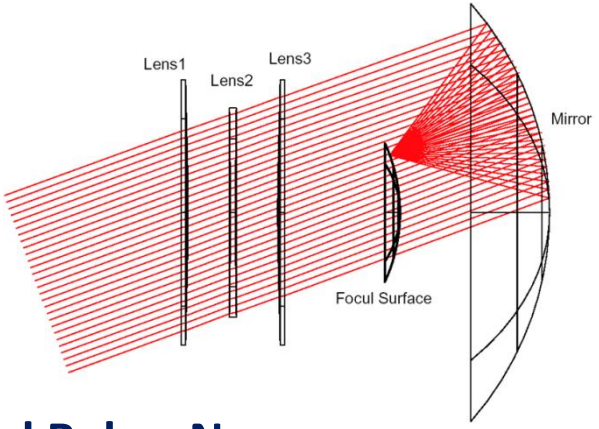
- **GRB 970228:**
  the first GRB for which an afterglow was observed

- BeppoSAX
  - GRBM (40-700keV):
  - WFCs (2–26 keV, FOV=40deg) :
    burst's position within 3arcmin

- optical images taken with the
  William Herschel Telescope on La Palma
  => visible and IR arcsec images

Light Collector



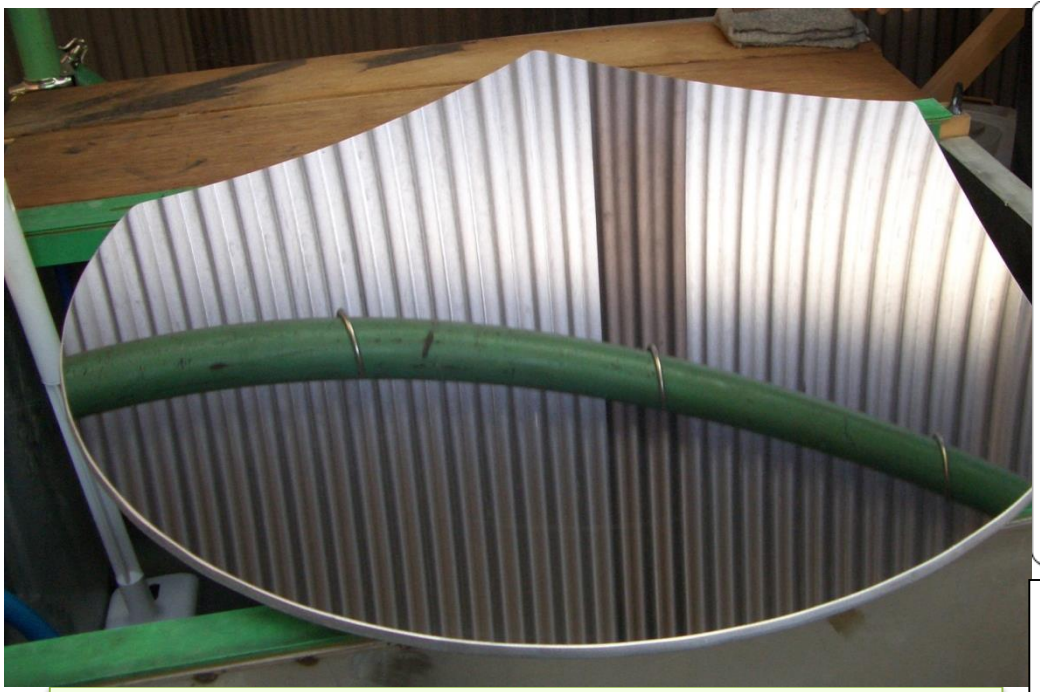


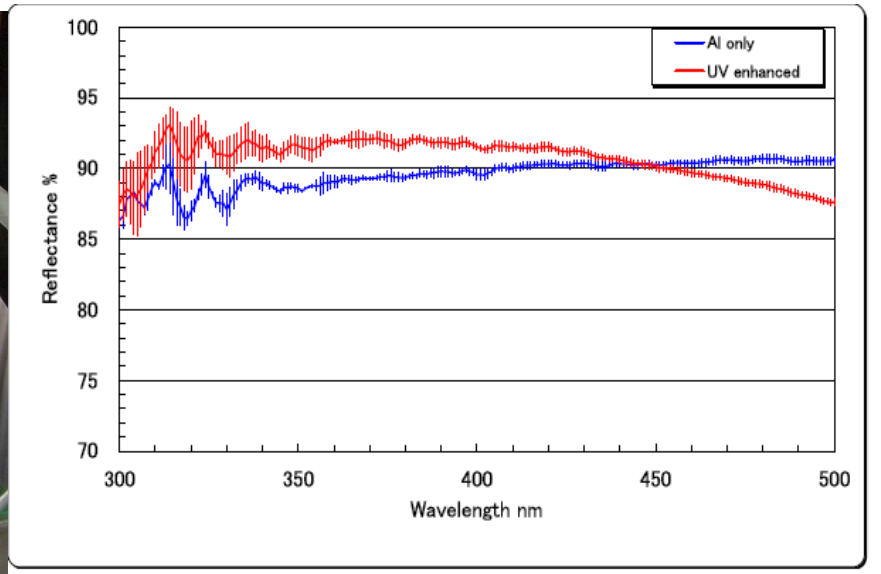
- Optics:
  - **Modified Baker-Nunn**
- Components:
  - **Correcting lens** (1.0~1.2mϕ) with 3 acrylic cut plates
  - **Spherical mirror** (2.2mϕ) with 7 curved glass plates on adjustable tables.
  - **Photoelectric lens IT** (0.5mϕ) on focal sphere suspended with Stewart platform mechanism
  - **Mount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

=> arcmin. resolution over 42deg FOV

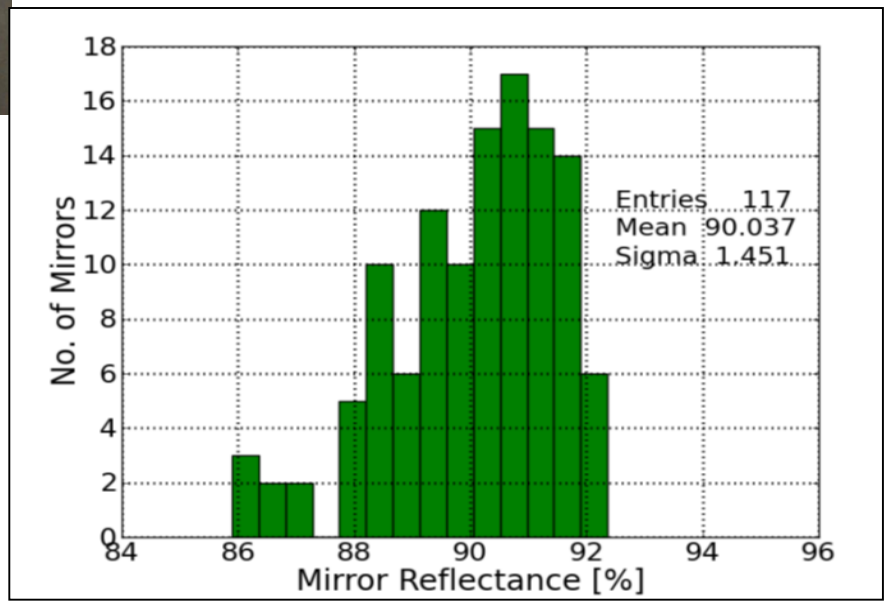
=> Very cost-effective

Segment Mirror



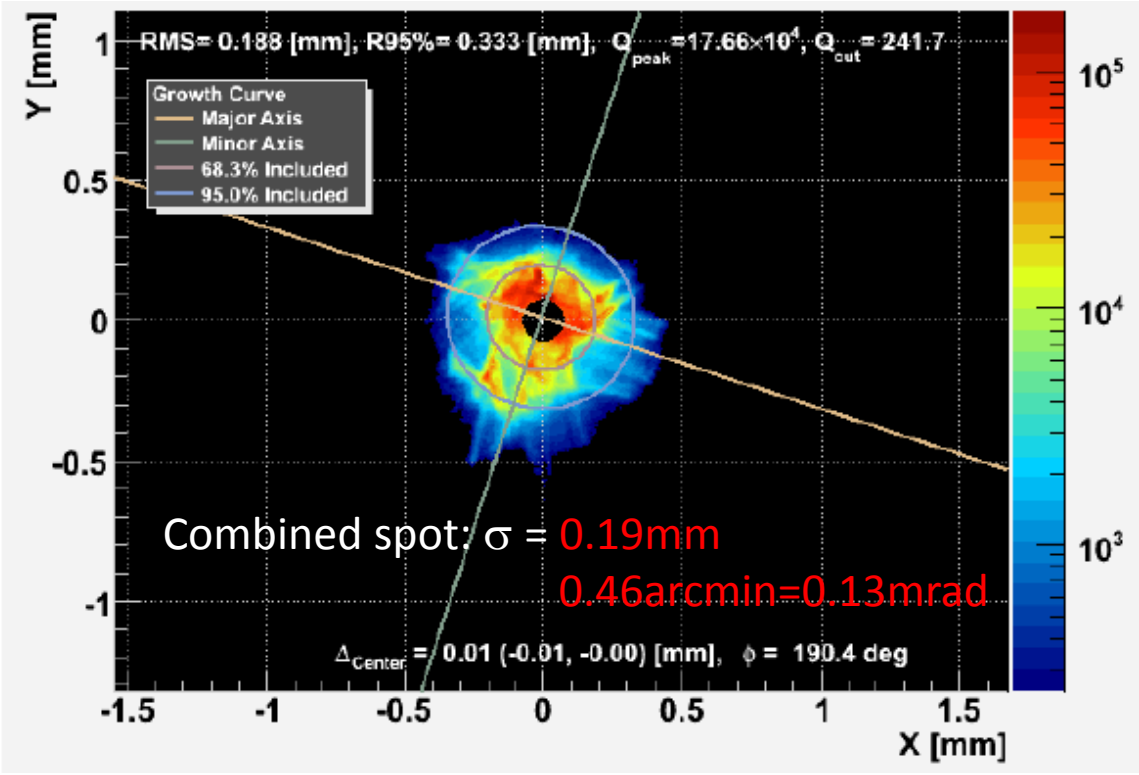


1. Float glass curved mirror:
   ϕ850 x t8 Cut => 10 kg / seg . piece
   Total 7seg / LC => ϕ2.2m & ~70kg.
2. Evaporation of Al + Al_2O_3 coating
   => UV enhanced
3. On-site test just before installation:
   all segments (~200 pieces) OK:
   >85% @ 470nm => >88% @ <400nm



Mirror Adjustment

Installation of Segment Mirror on Mount @ Ashra Mauna Loa Site



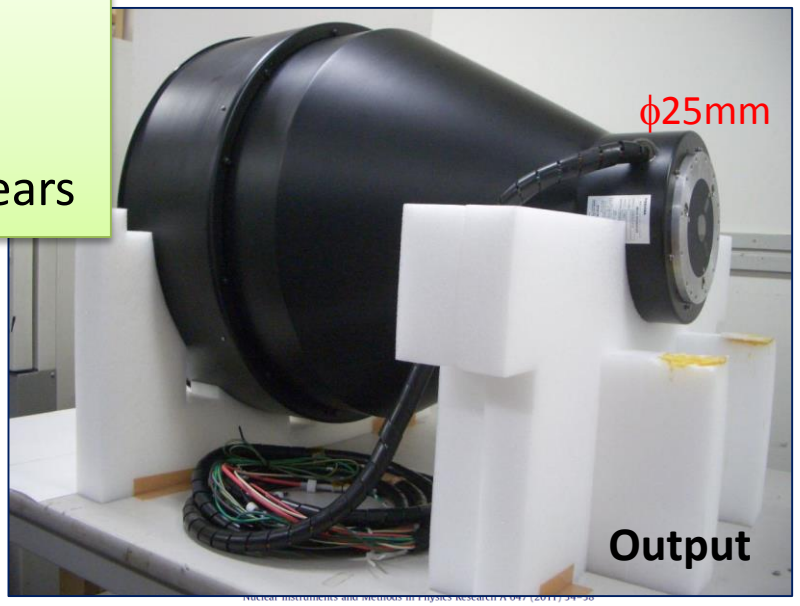
- Total spot size measured after adjusting 6 segment mirrors on mount:
  => Combined spot σ = 0.19mm
  => corresponding to 0.46arcmin = 0.13mrad

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

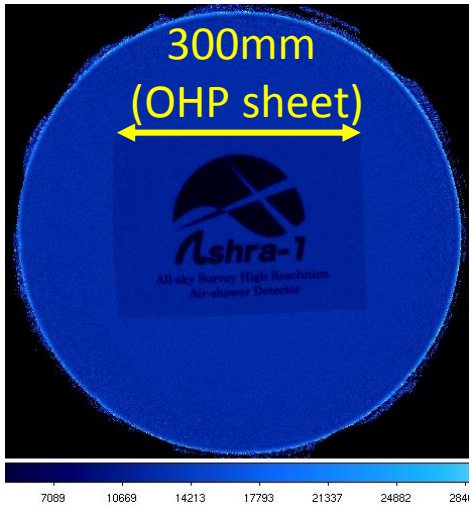
ABSTRACT

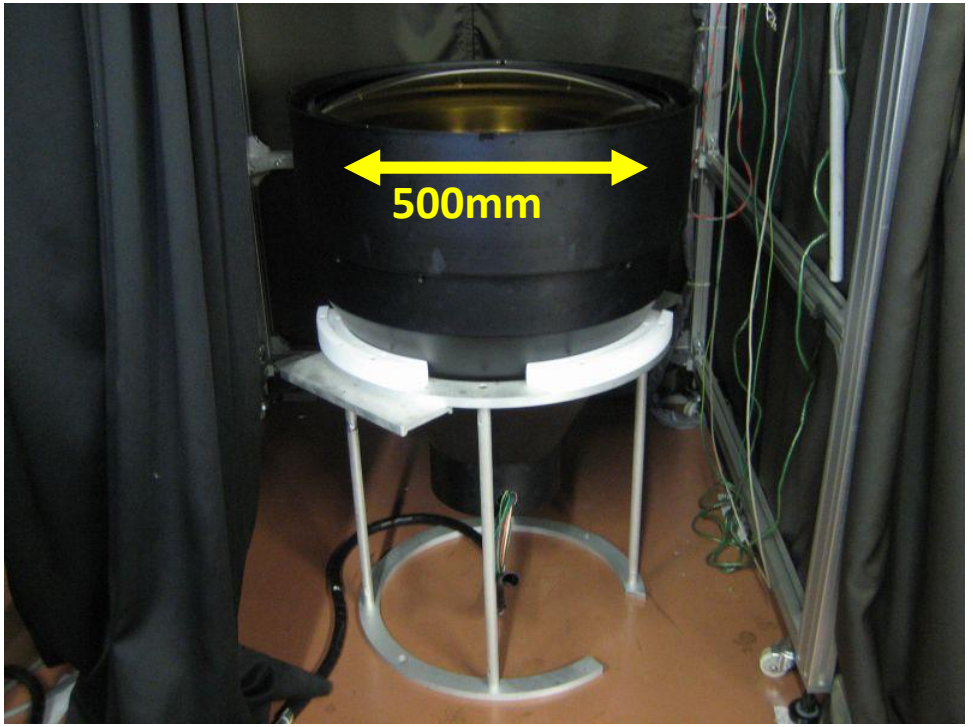
We have evaluated a 20-in. photoelectric lens image intensifier tube (PLI) to be mounted on the spherical focal surface of the Ashra light collectors, where Ashra stands for All-sky Survey High Resolution Air-shower Detector, an unconventional optical collector complex that images air showers produced 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.

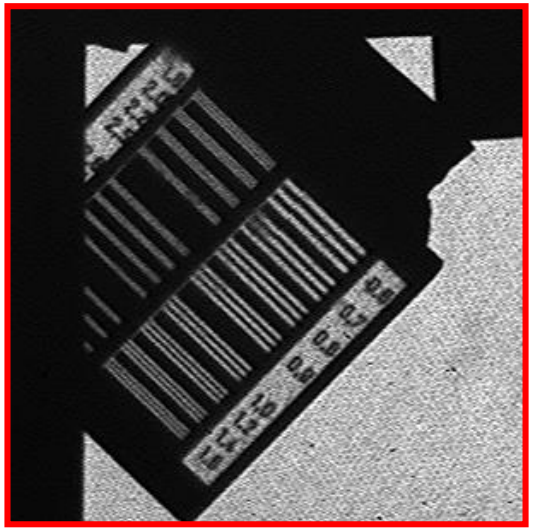
Y.Asaoka, M.Sasaki NIMA 647 (2011) 34

Imaging Test of 20” PLI

Output Image Example



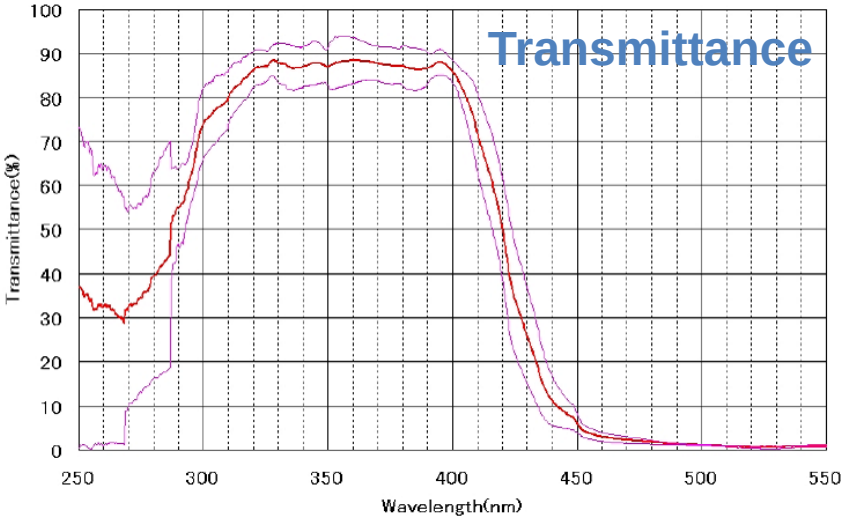


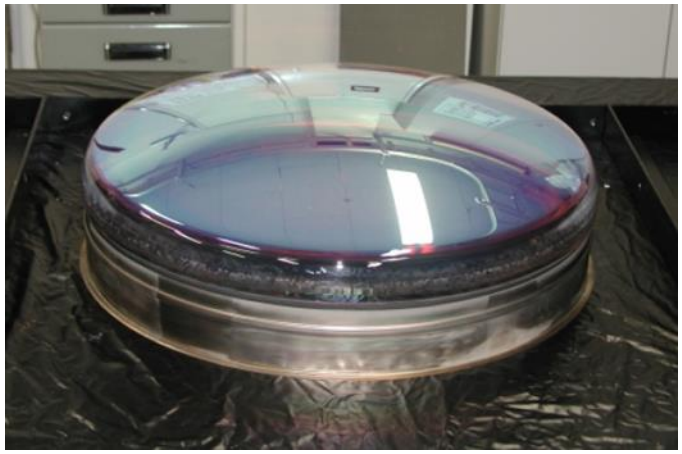


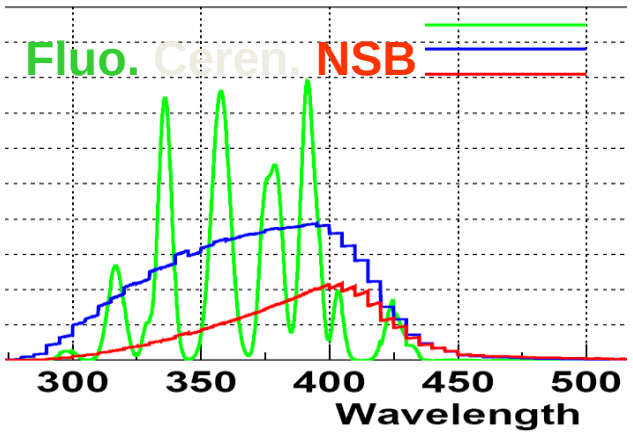
Imaging Resolution Chart on Input Window

20” Lens-IT & Filter

20”φ Prod.ver.





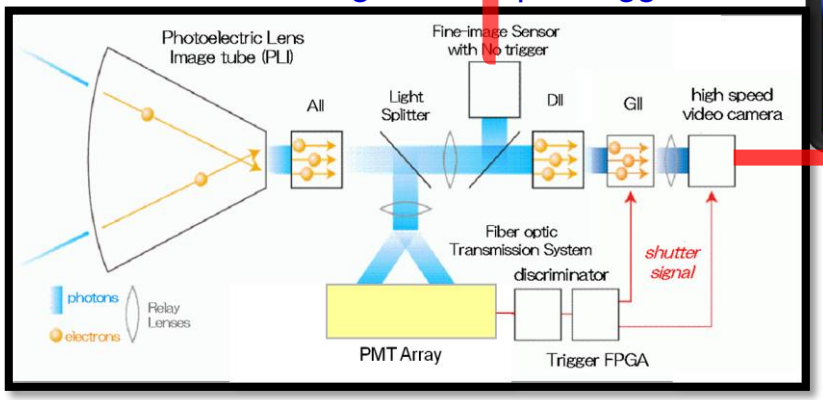


- Input window is coated with multi(40-)layer thin film filter to cut λ>450nm
- Keep good S/N of fluorescence and Cerenkov lights against NSB

Ashra-1 Pipeline Trigger & Readout

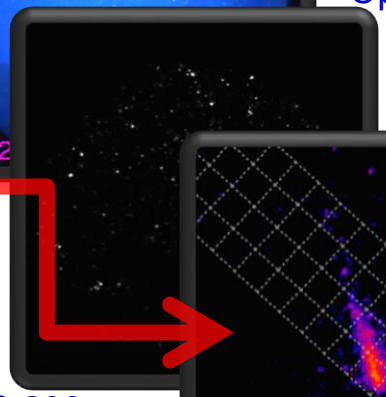
demonstrated

Same Fine Image to Multiple Triggers

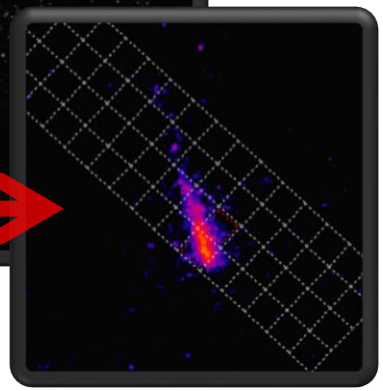


Photoelectric Image Pipeline (PIP)

Optical 4s or 1s



BG 200ns



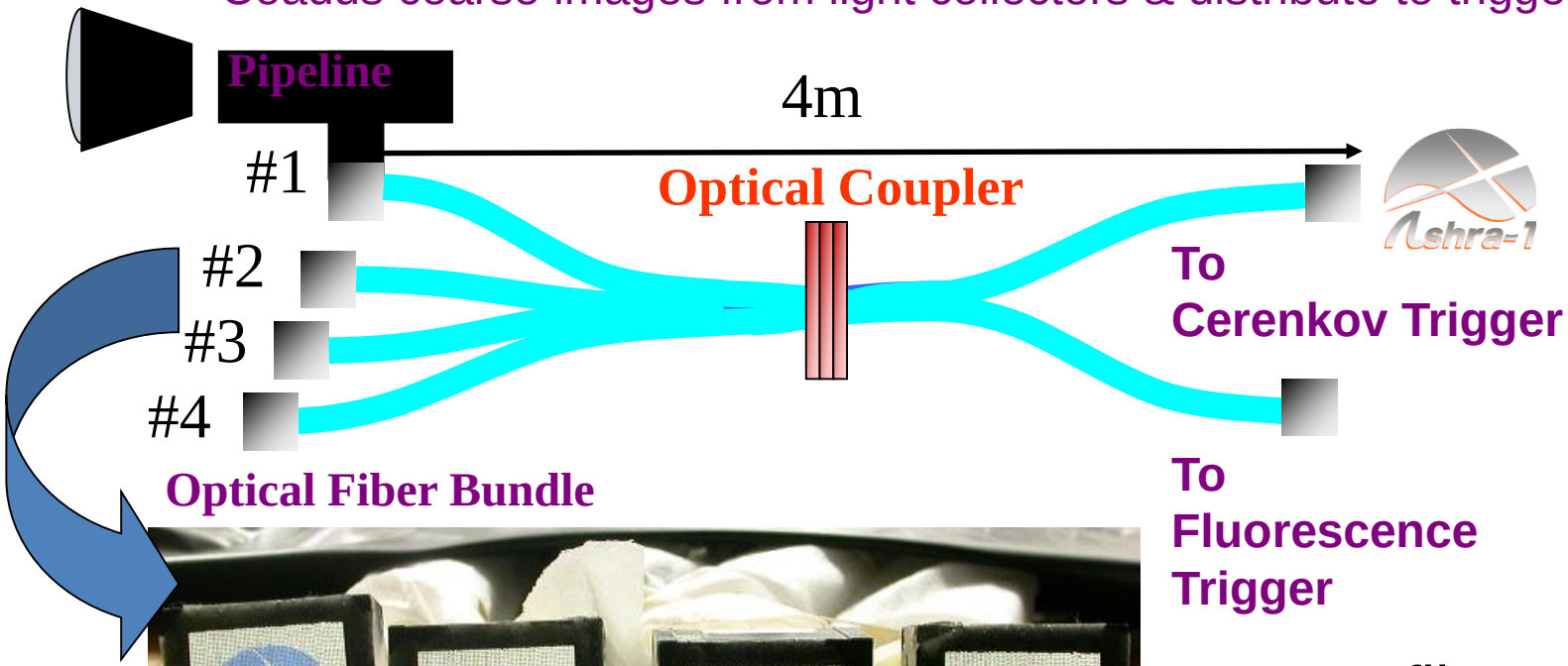
CR 200ns

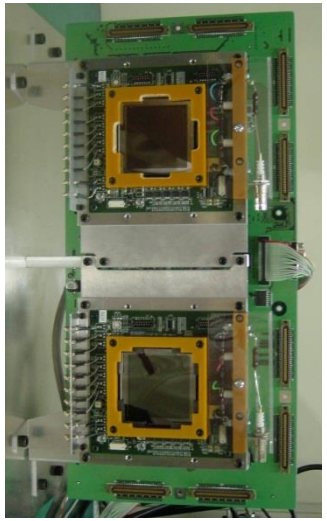
Multi-Messenger Approach with
One Detector System

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

Optical Fiber Transmission System

Coadds coarse images from light collectors & distribute to trigger sensors





64×64 MAPMT

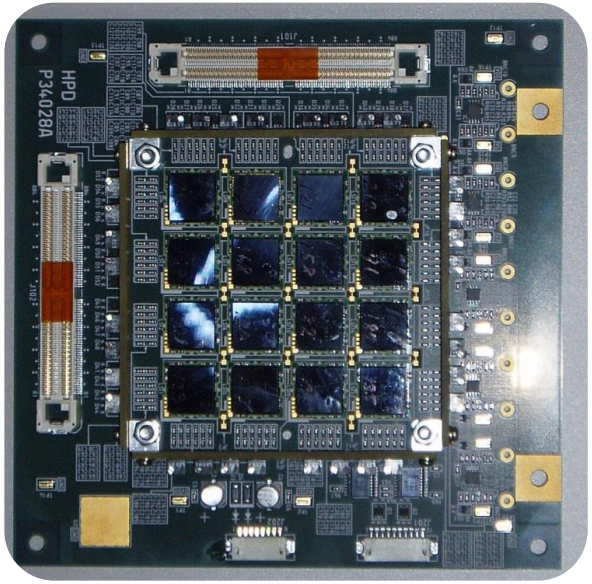
- 64x64 fibers(0.5mmf)
- 0.67deg-FOV / fiber

Light collectors can be easily appended to the trigger.

Sensitivity can be reinforced when more budget is available.

Ashra-1 / NTA Trigger Sensor

R8400-00-M256 (H9500)

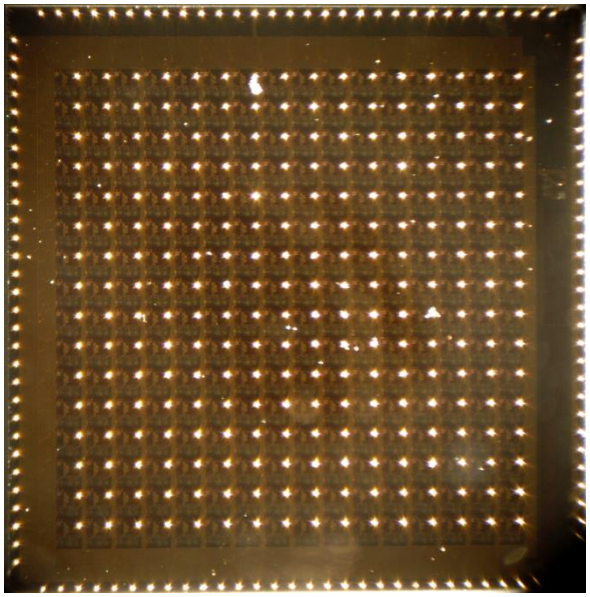


Trigger Sensor Unit (TSU) =
16x16 trigger pixs /chip on R8400-00-M256
followed by Trigger Decision LSIs (ASIC)

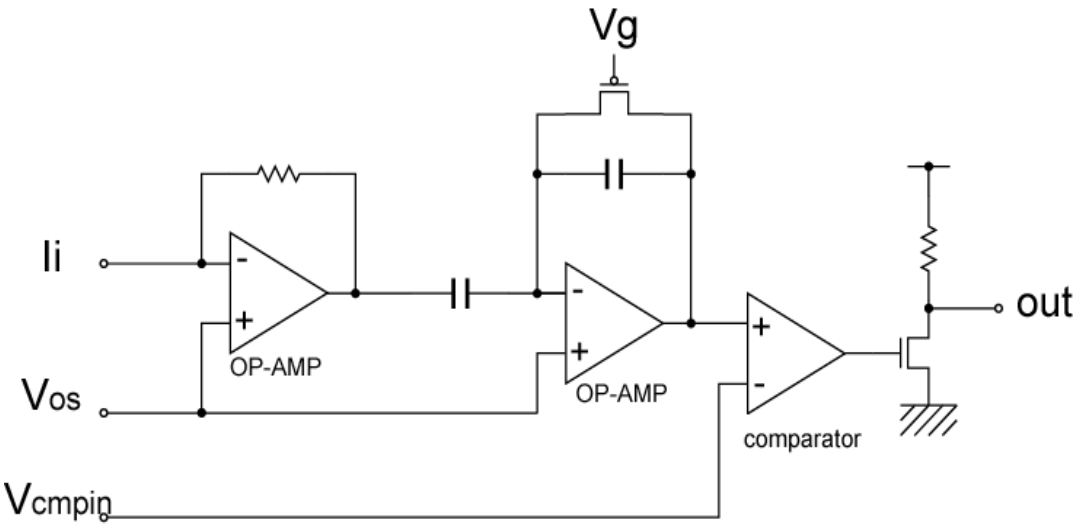
4x4 TSUs for 1 Detector Unit

Trigger Sensor LSI

16x16 discriminator array equipped on the back of MAPMT



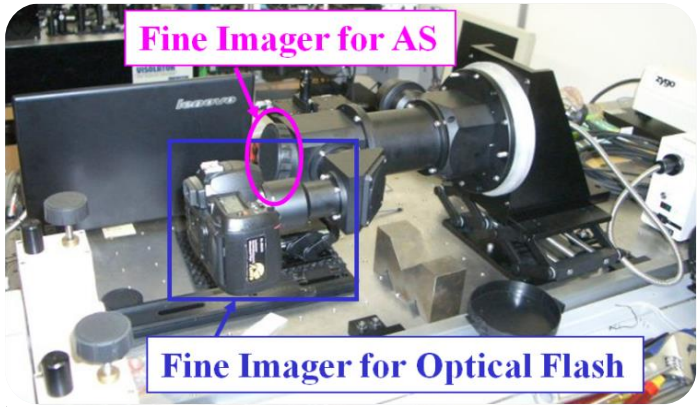
Pixel Circuit Diagram

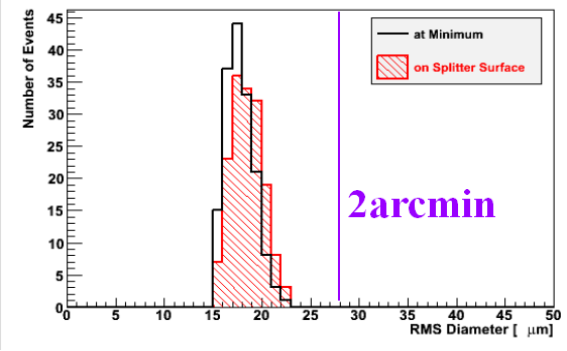


- Pixel includes I/V transformer、filter、and comparator in the size of 500μm□
- 16×16 pixel array / LSI chip ⇒ 64×64 trigger generated with 4×4 LSI chips
- LSI size: 9.8mm□

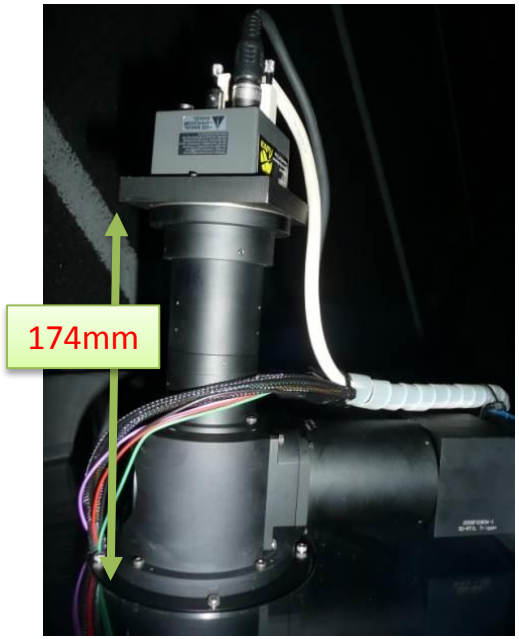
Photoelectric Image Pipeline (PIP)

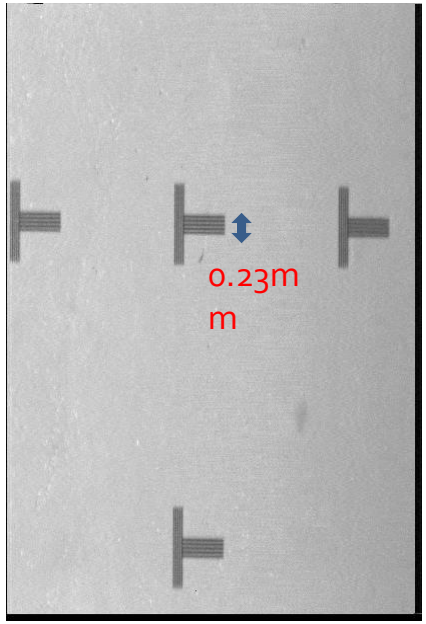
Test of PIP (1st generation)





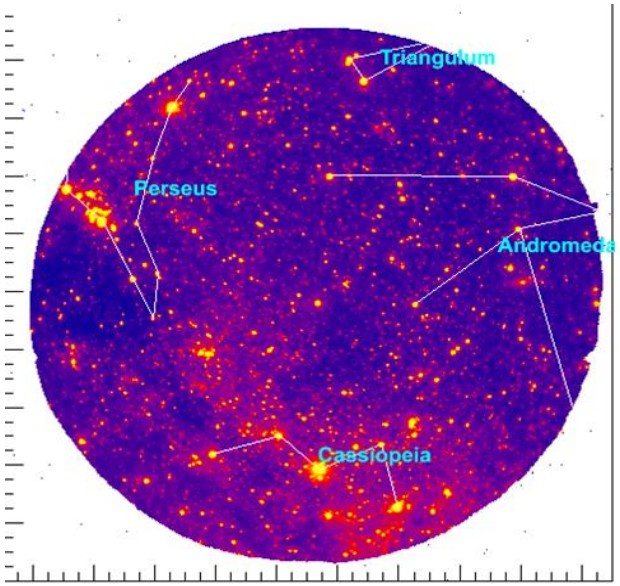
Mounted PIP (2nd generation)

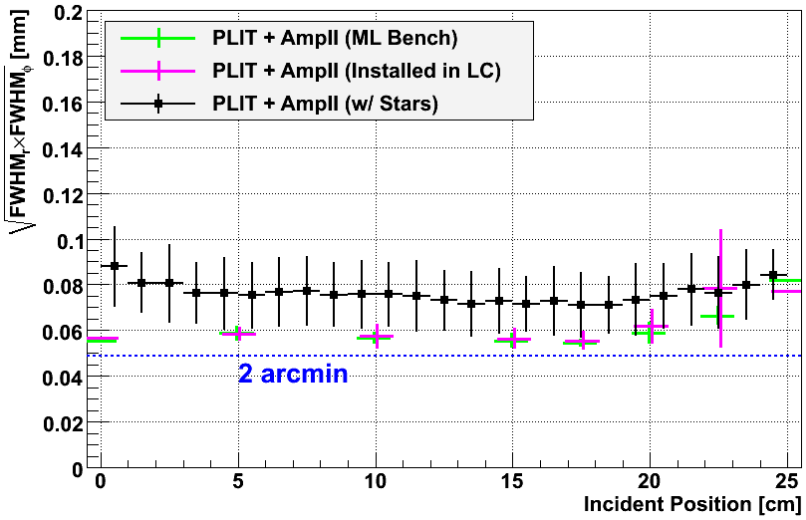




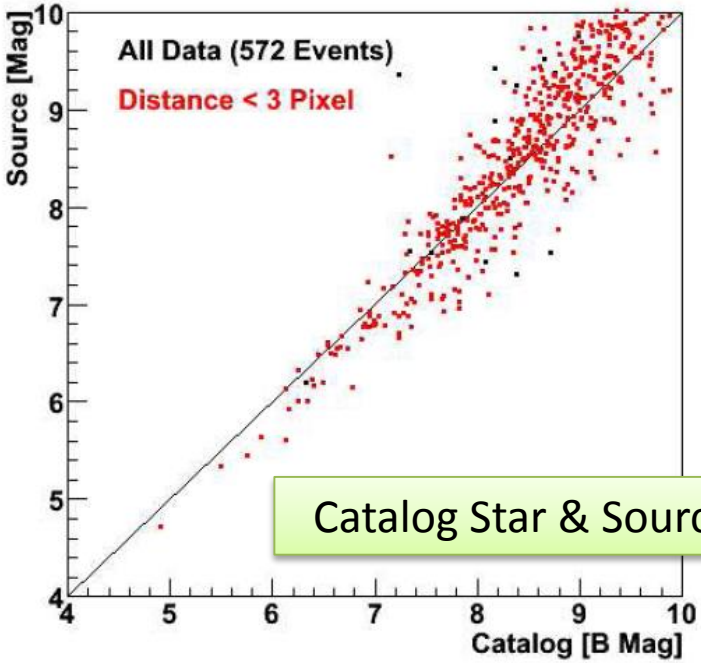
=> 21 LP/mm => ~1arcmin

Performance for Astrometry & Photometry

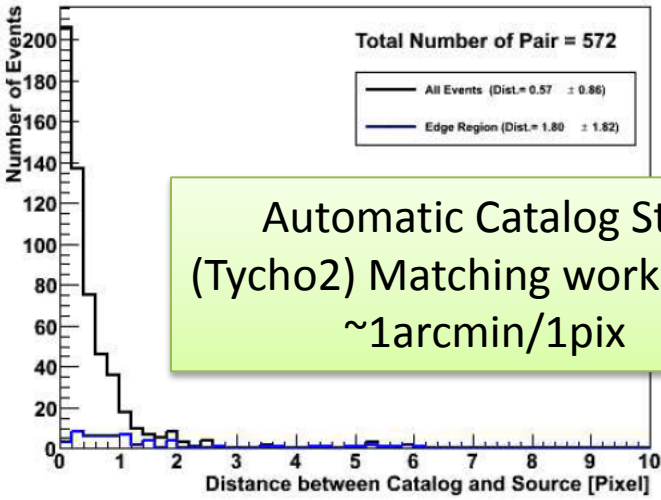




~3 arcmin over 42 deg FOV after all adjustments



Catalog Star & Source Pairs



Automatic Catalog Star (Tycho2) Matching works well. ~1arcmin/1pix

Trigger FPGA/DSP Board

HV

LV

MAPMT

HPD Board
LSI x16

Trigger
Relay
Board

Coax. 10ch
V1-V8, Vg, Vos

LV

Gate I.I
Gate Signal

DAC10ch
Trigger FPGA/DSP Board

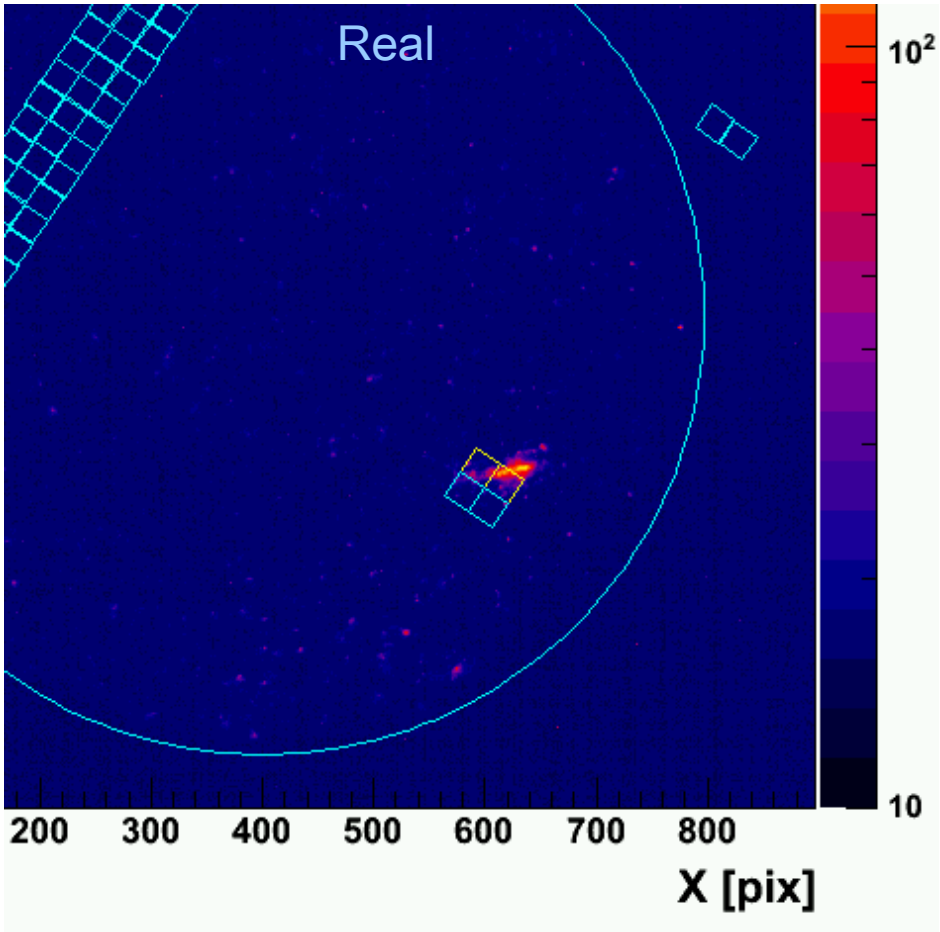
FST
Trigger
Signal

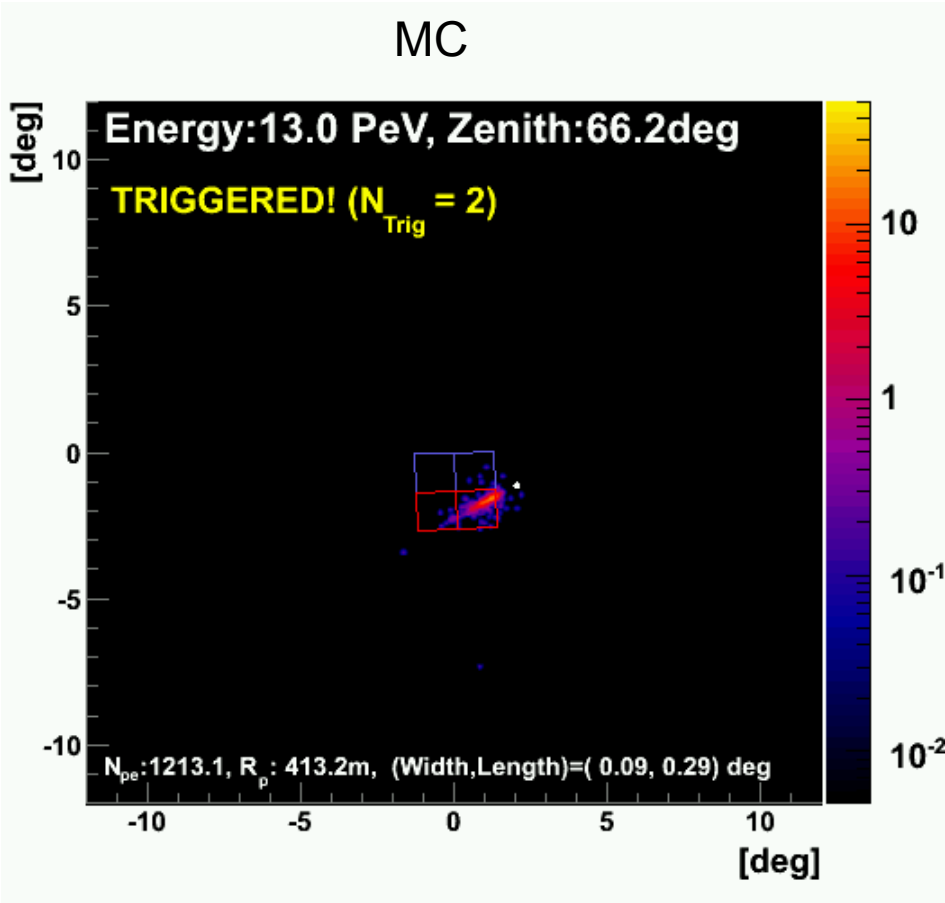
Coax.
- L_X_D[63:0]
- L_Y_D[63:0]
- LSI Cnt[4:0]

USB
- LSI Cnt
- Xsel[63:0]
- Ysel[63:0]
- Trig #

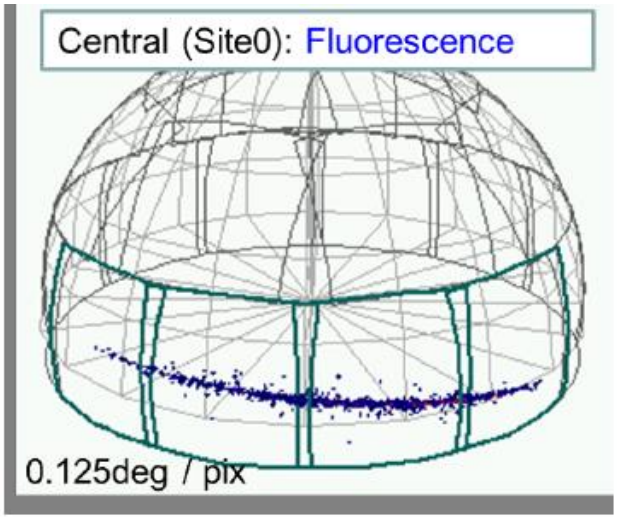
Trigger PC

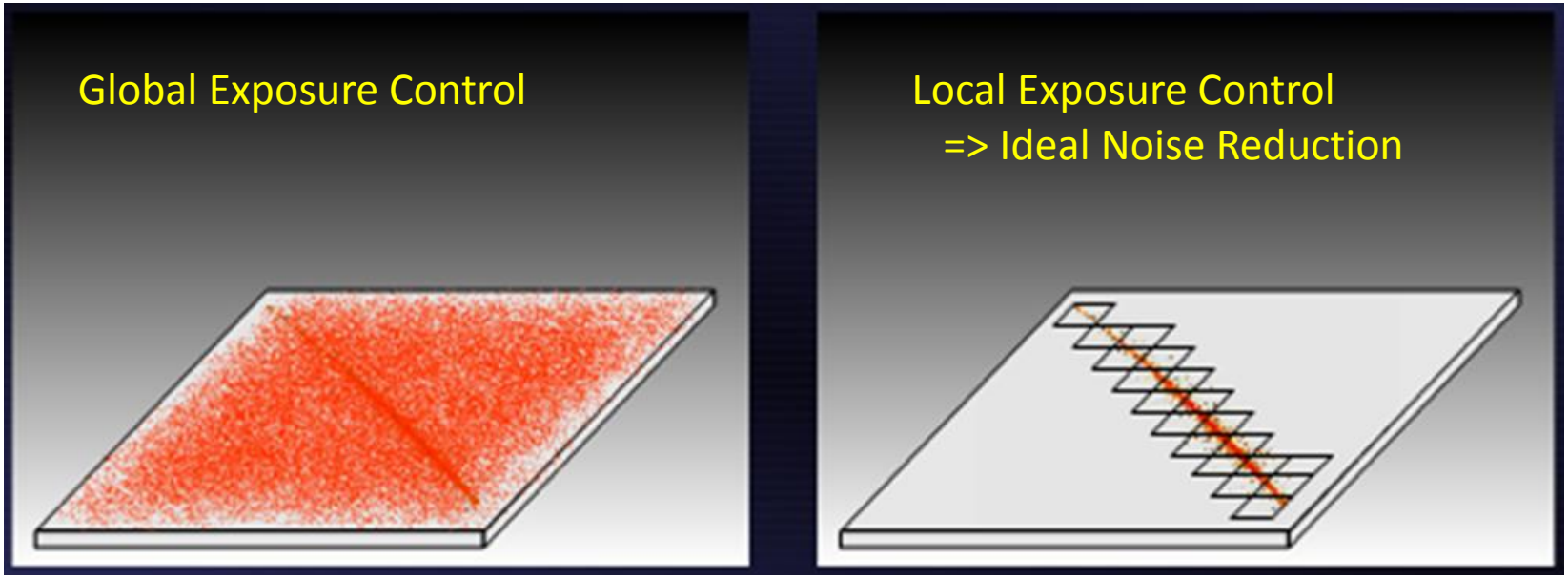
Ashra-1 R0000941/E115513 Triggered Shower and MC



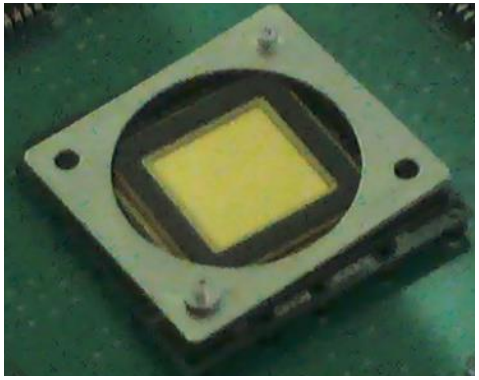


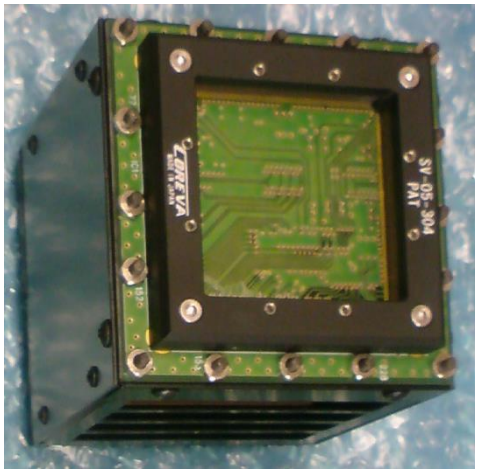
Local Exposure Control





Performance of FST CMOS Sensor



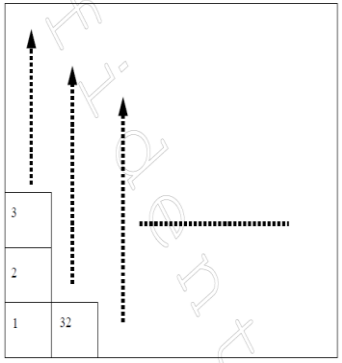


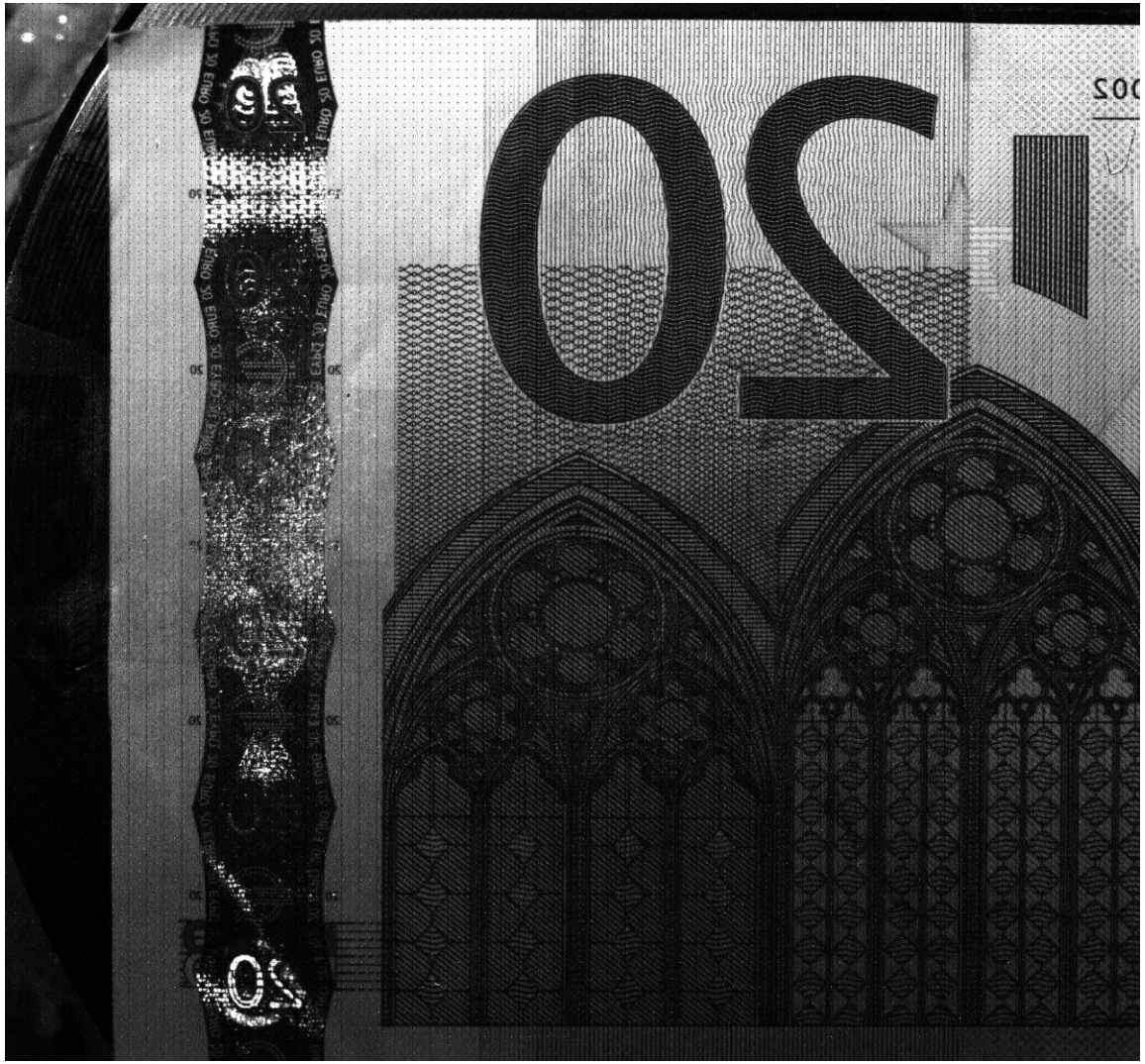
2048x2048 pixels / 19mm x 19mm,
Triggered Regional (64x64 macrocells) Exposure

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

FST Demonstration





Outline

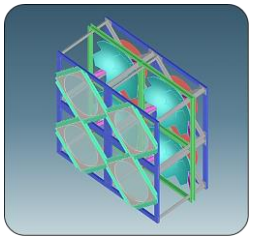
- Chronology of Ashra-1 Group
- Detector Designs and Performances
- Prospects for NTA => G.Hou's talk

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

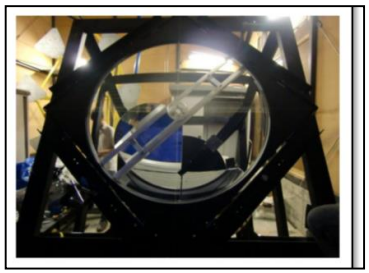
Test Observations / Multi-particle/ Multimessenger

Principal Demonstration

Akeno

Training / Aging / Test Observations

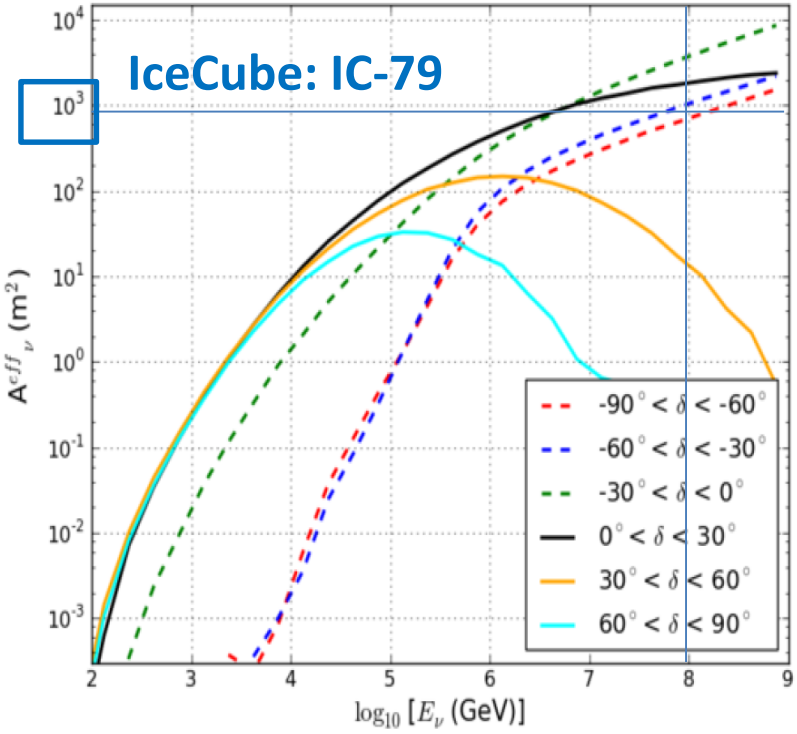
Developments / Assembly

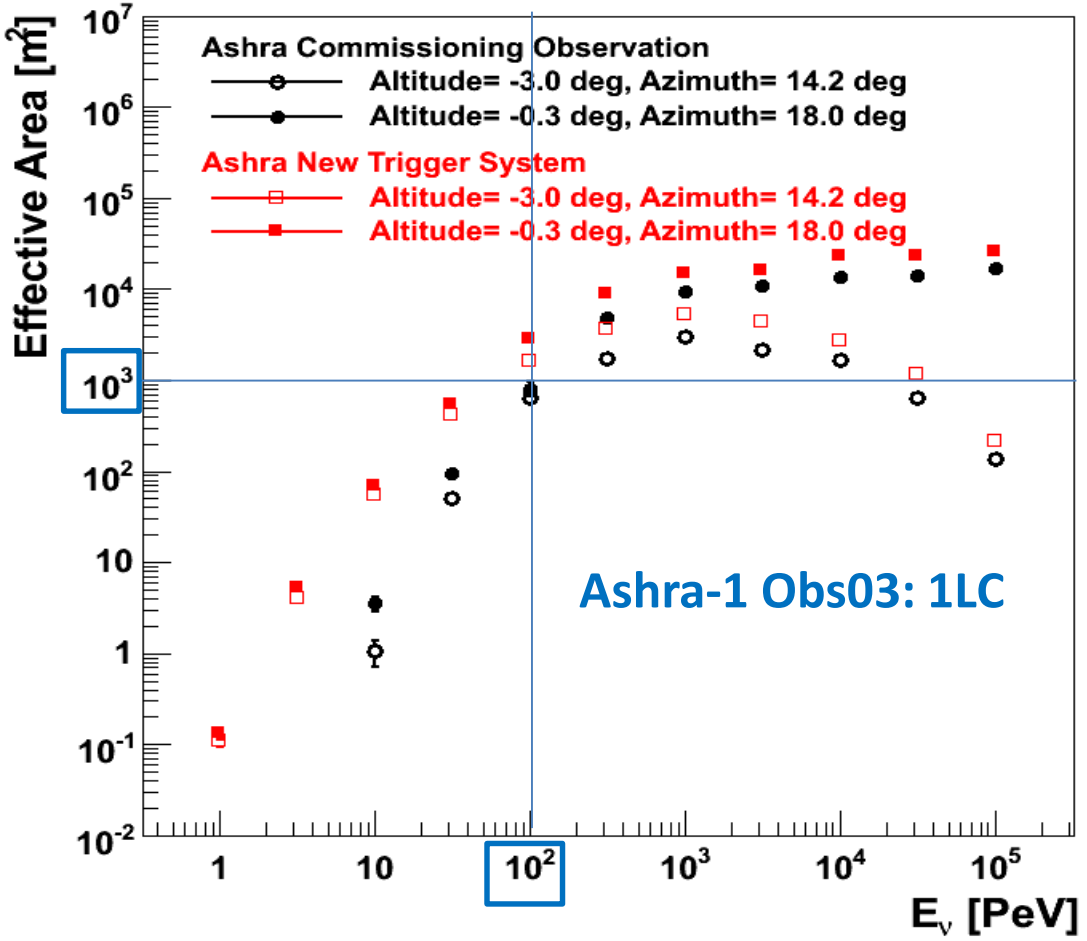


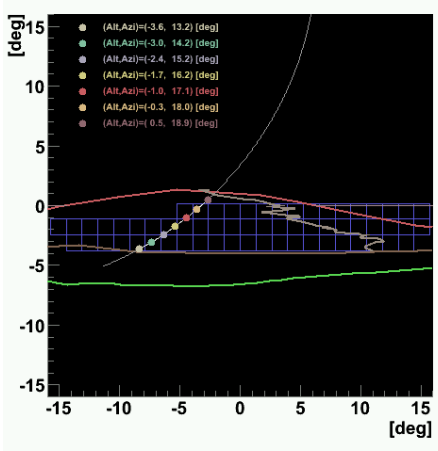
Sensitivity (A^{eff}_{ν})

J.A.Aguilar, Nucl.Phys.B 237-238 (2013) 250-252

10^2 PeV



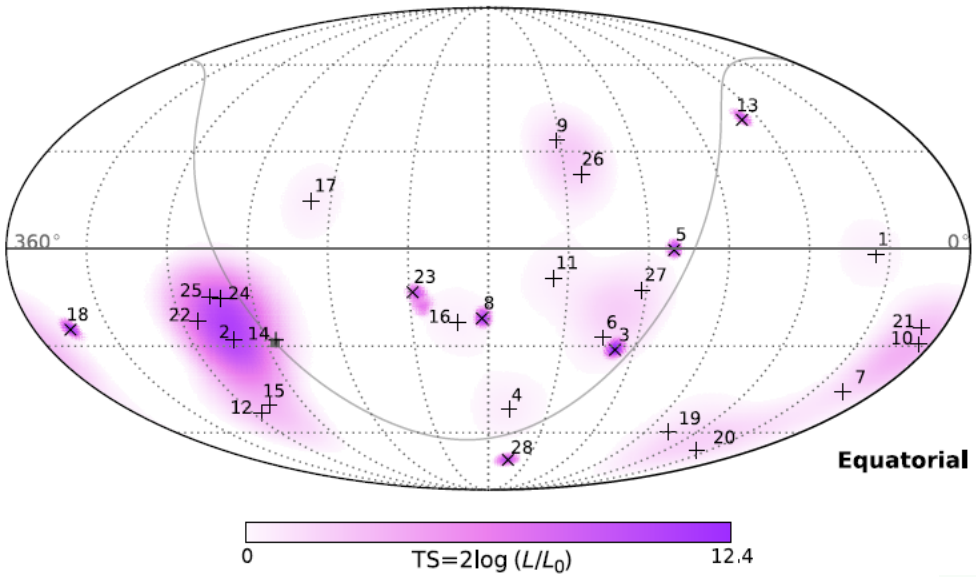


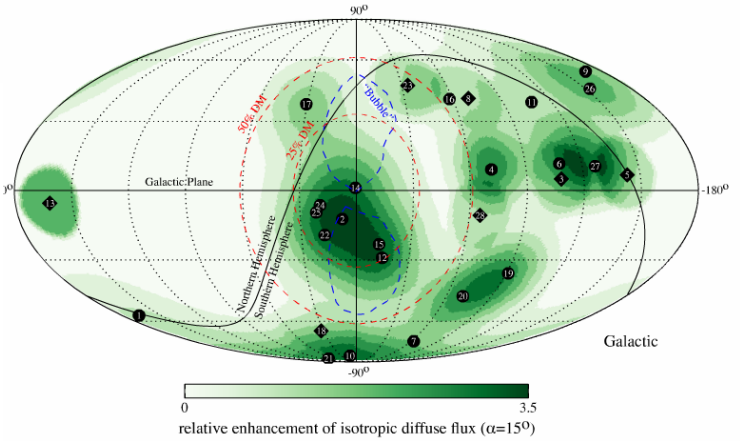


- Ashra-1 1LC compatible with IceCube @ 10^2 PeV
- IceCube indicated flax $E^2\phi=1.2\times10^{-8}$GeV sr^{-1} s^{-1} cm^{-2}
  => Fluence x E^2 = 8.7 GeV cm^{-2}
- Ashra-1 1LC: 49 ν_τ s @-3.0deg, 77 ν_τ s @-0.3deg
- Small ES angle limits chance => NTA improves

IceCube 28 Events

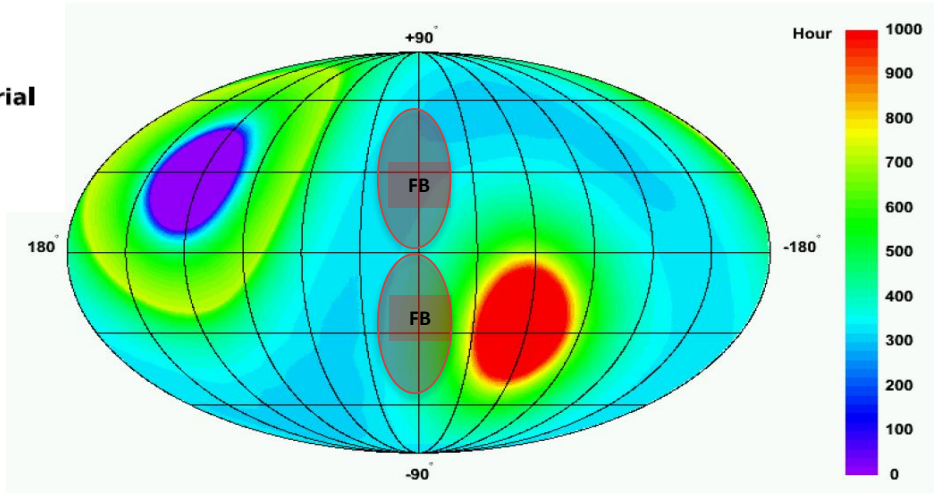
Ahlers & Murase, PRD (2014).



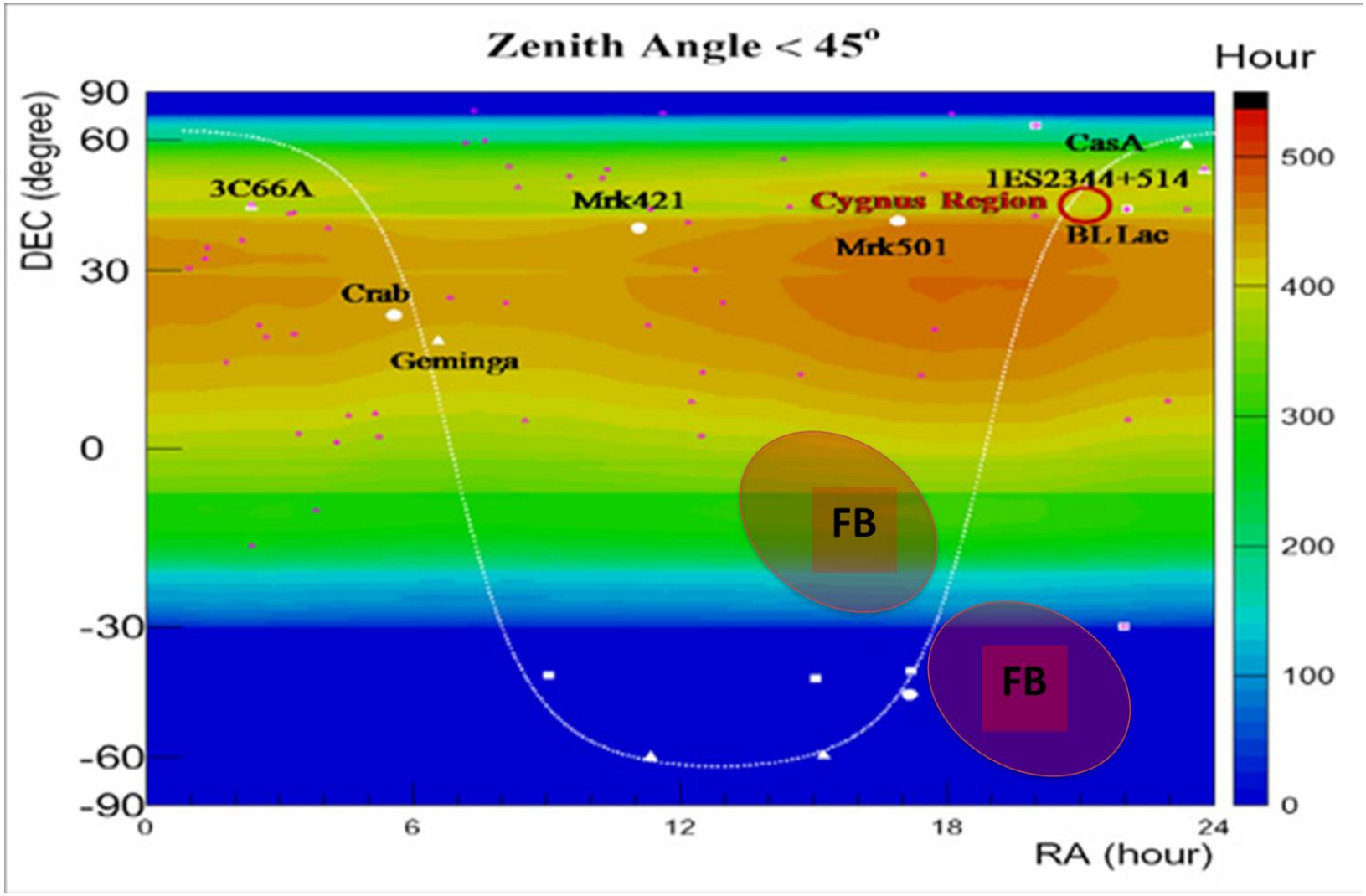


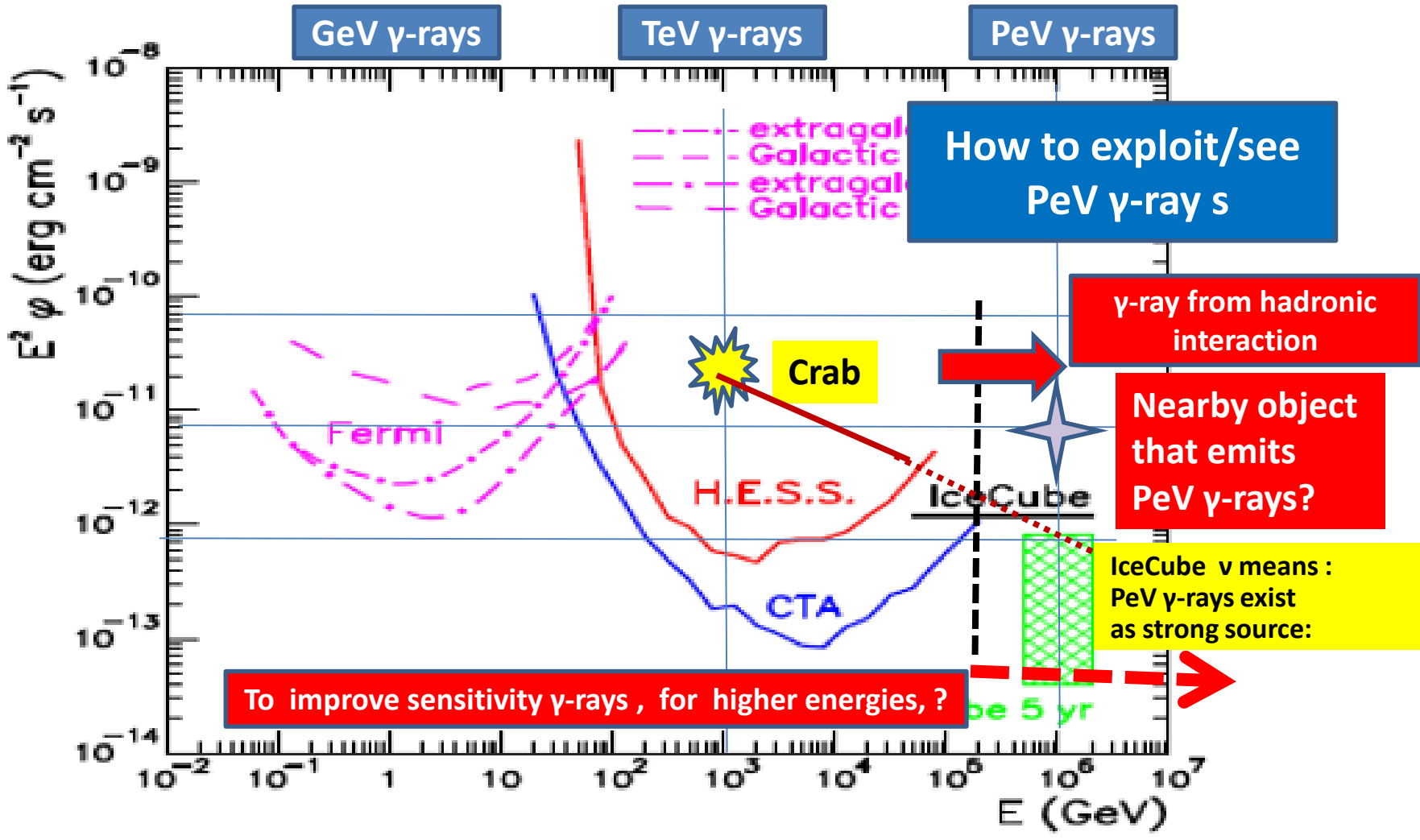
8% Significance

IceCube, Science 342



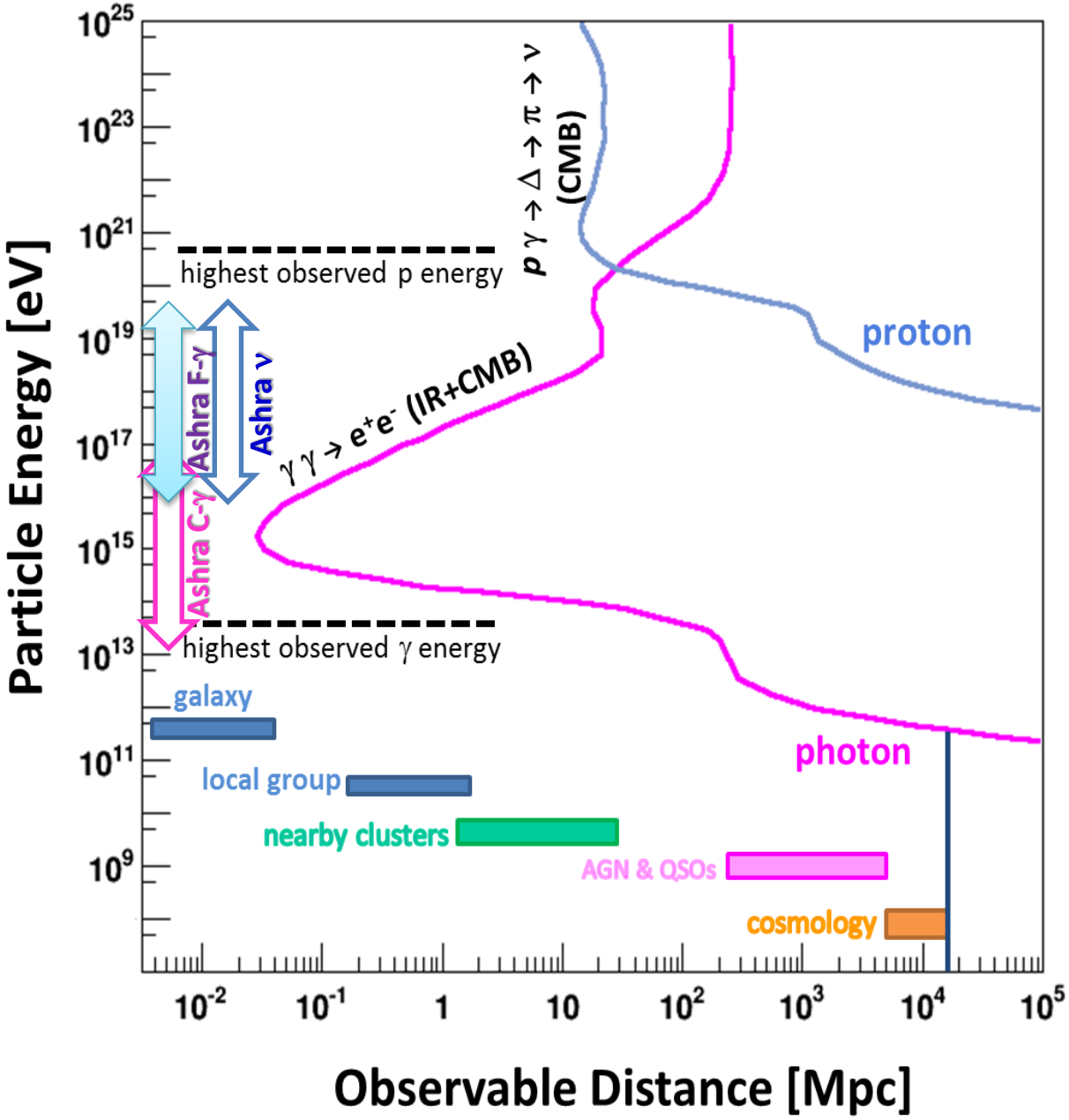
Ashra-1 Obs04 γ Exposure





Thank to T. Kifune.

LA. Anchordoqui et al./Journal of High Energy Astrophysics 1-2 (2014) 1-30.



PeV-EeV Universe

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

Ashra/NTA => PeV-EeV Universe Explorer