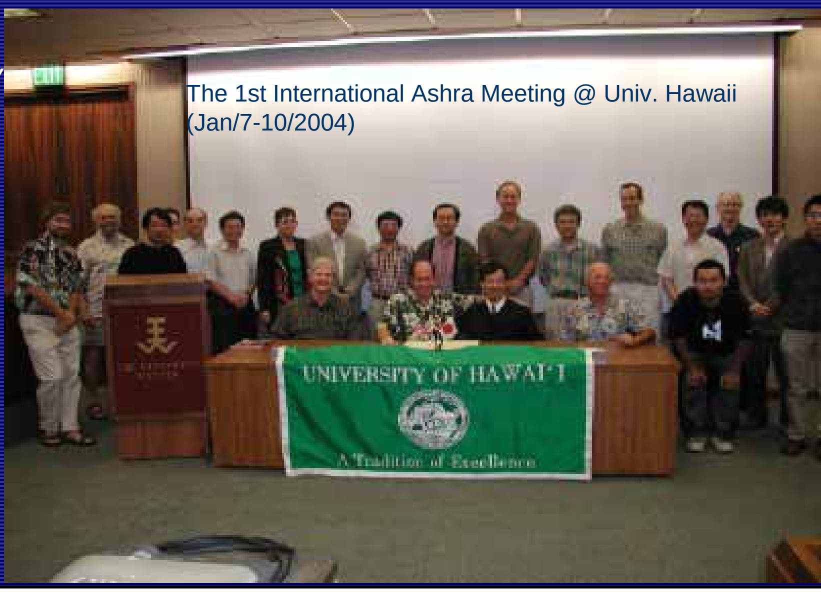
All-sky Survey High Resolution Air-shower detector

Ashra Update

On Behalf of the Ashra Collaboration
Makoto Sasaki
ICRR, Univ.Tokyo

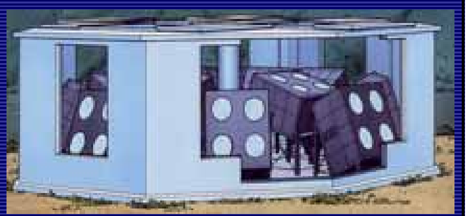
Ashra Collaboration



The 1st International Ashra Meeting @ Univ. Hawaii (Jan/7-10/2004)

Ashra Project

Neutrino Astronomy



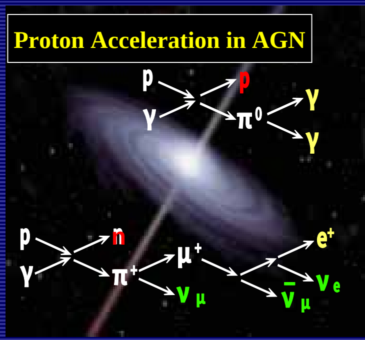
- *Low Energy ν*
  - **MeV**
  - Water Target (~1000t)
  - Crude Pointing (ν_e~10°)
  - Near SN (160K ly)
- *Very High Energy ν*
  - **PeV (10^{15}eV)~ZeV (10^{21}eV)**
  - Earth & Air Target (~10^{12} t)
  - Precise Pointing (~arcmin)
  - Ext.gal. Origin (~500M ly)

New Tide of VHE '*Deep Survey*' Particle Astronomy

Source Candidates of VHE Particles

Gamma Ray Burst

Active Galactic Nuclei



GZK Mechanism

Studying origin and propagation of VHE CRs

Photo-meson Interaction

Evidence of Ext.gal. p Acceleration

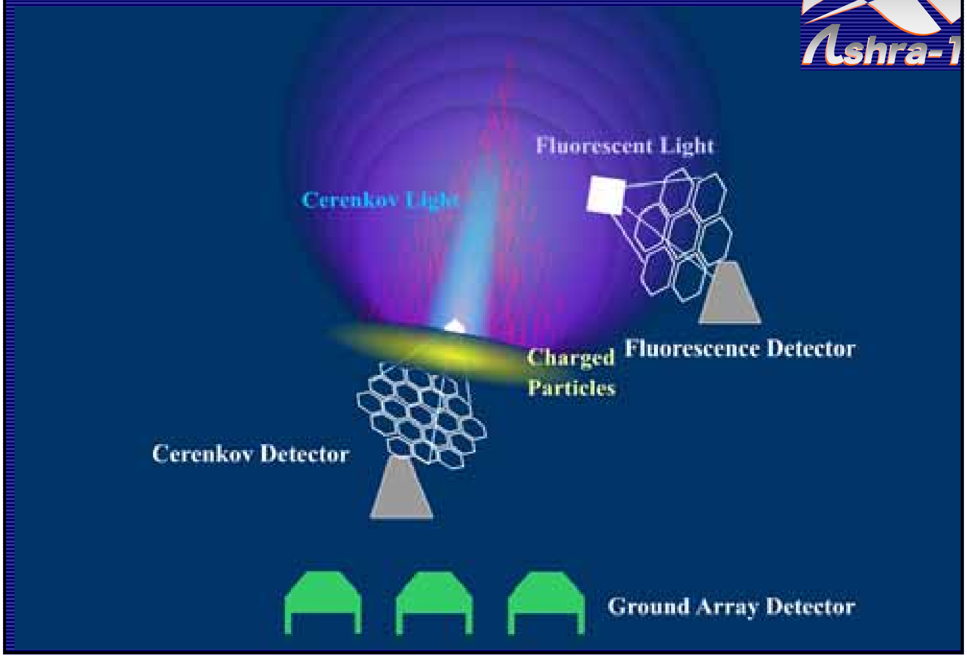
$$p\gamma \rightarrow \Delta \rightarrow n\pi^{+},\ p\pi^{0}$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu} \rightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu} + \nu_{\mu},\quad \pi^{0} \rightarrow \gamma\gamma$$

$$\varepsilon_{\gamma}\varepsilon_{p} \approx 0.2\Gamma^{2}\mathrm{GeV}^{2},\ \varepsilon_{\nu} \approx 0.05\varepsilon_{p}$$

1st Exam of VHE Particle Astronomy

VHE Particle Detection



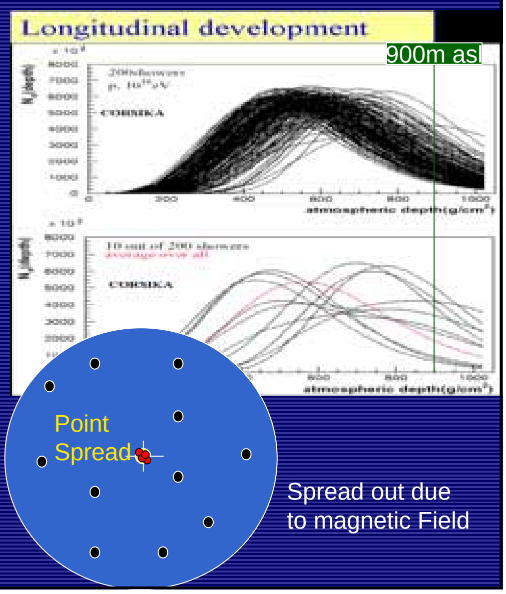
Advantage of Imaging Air-lights

- Can correct AS development fluctuation event by event

  =>Convincing E estimation

- Particle ID using mag. field
  - p: spread over 1deg.
  - ν、γ: only PSF

  =>High resolution required



Air-shower Detection by Ashra

Ashra Detector

New VHE Particle Detector System for Cerenkov & Fluorescence Air-lights

Distinctive Features:

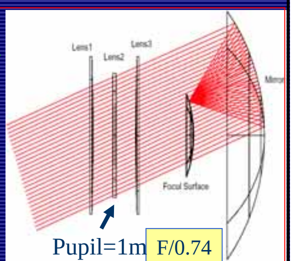
- All Sky Survey ⇒ ~2 π sr
- High Resolution ⇒ arcmin
- Simultaneous Observation
  - **TeV γ**
  - **EHE p/ γ**
  - **VHE ν**

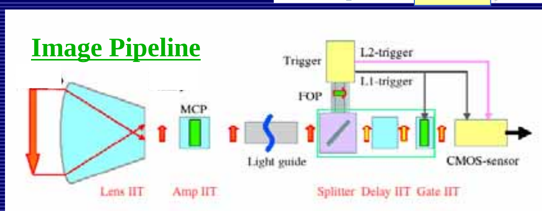
Ashra Station:

- **12 Detectors / Station**
- **0.5 sr F.O.V / Detector**
- **All Sky / 50M pixel**

Wide Angle Fine Optics

- Modified Baker-Nunn Optics
- Spherical Mirror (segmented)
- Spherical Focal Surface
- 3 Correcting Lenses





High Resolution, High S/N, Sefl-triggered

Details in *M.Sasaki et al, NIM A492 (2002) 49*

Ashra Project Plan

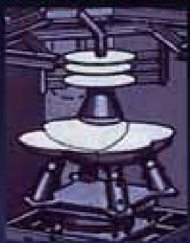
2002	2003	2004	2005	2006	2007

phase 0
R&D

phase 1
Pioneering

phase 2
High Statistics

sub-telescope

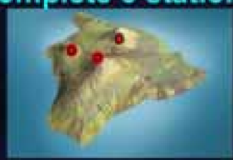


prototype in labo.

1 + 1/3 stations

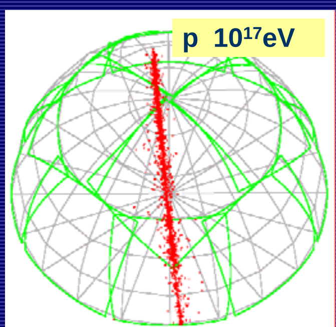
2 Mt.s on the Hawaii Is.

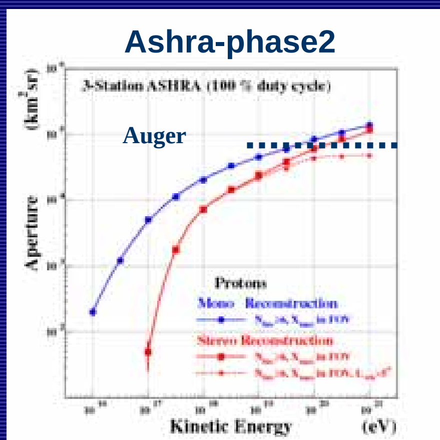
complete 3 stations



3 Mt.s on the Hawaii Is.

Ashra-2 Sensitivity for EHECR





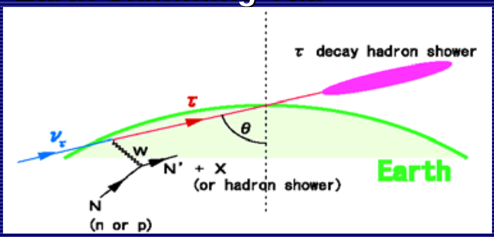
Stereo Event Rate (duty 10%)

E thres.	Events/year
10^{19}eV	1324
$10^{19.5}$eV	259

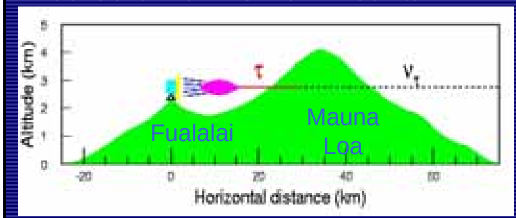
Tau Neutrino

Tau Neutrino Detection using Earth and Mountain

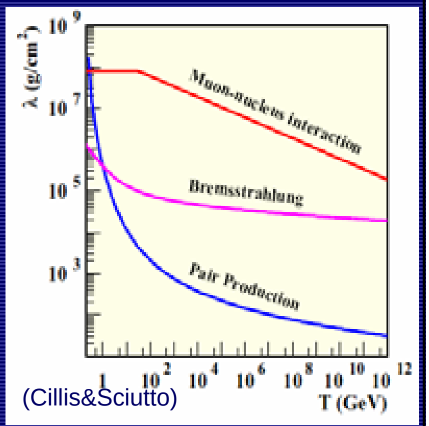
Earth Skimming Tau



Tau Cerenkov AS from Mountain



μ **λ～1m @ 10^{15}eV**

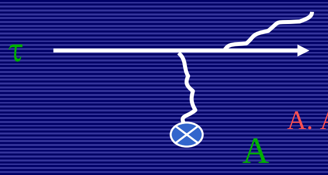


Tau dominates appeared leptons@VHE

The tau lepton loses its energy in the rock through 4 kinds of interactions:

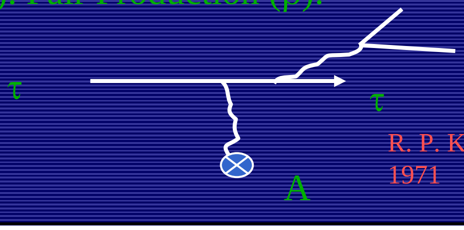
(1). Ionization (α): the tau lepton excites the atomic electrons. H. A. Bethe 1934

(2). Bremsstrahlung (β):



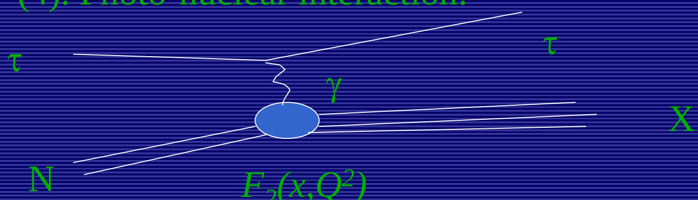
A. A. Petrukhin &V.V. Shestakov, 1968

(3). Pair Production (β):



R. P. Kokoulin & A. A. Petrukhin, 1971

(4). Photo-nuclear interaction:



$F_2(x,Q^2)$

Basic component

The nucleus shadowing effect is considered:

$$a(A,x,Q^2)=\frac{F_2^A(x,Q^2)}{AF_2^N(x,Q^2)}$$

Brodsky & Lu, 1990; Mueller & Qiu 1986;
E665 Collab. Adams *et al.*, 1992

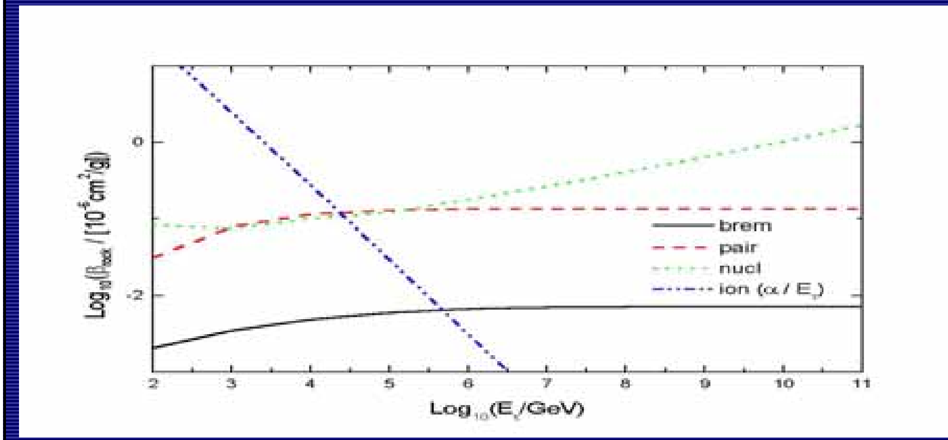
Summarizing all these:

The τ energy loss:

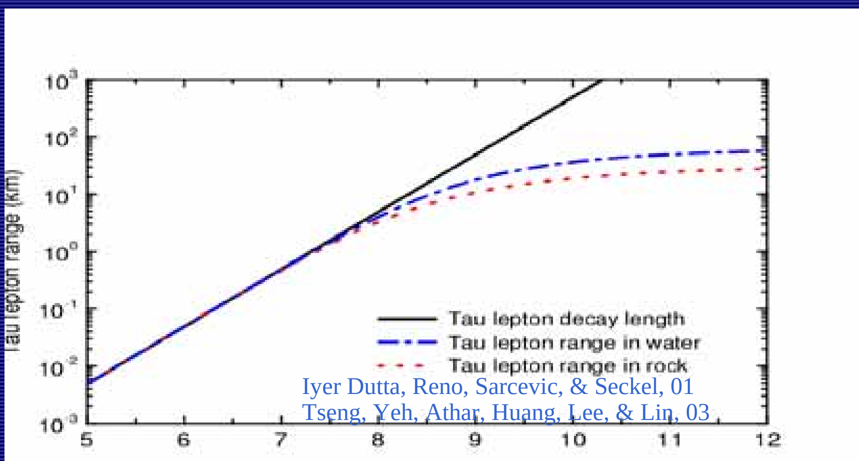
Iyer Dutta, Reno, Sarcevic, & Seckel, 01

$$-\frac{dE_\tau}{dX} = \alpha + \left(\sum_i \beta_i\right) E_\tau, X \text{ in units of g/cm}^2,$$

α and β_i's are plotted below.



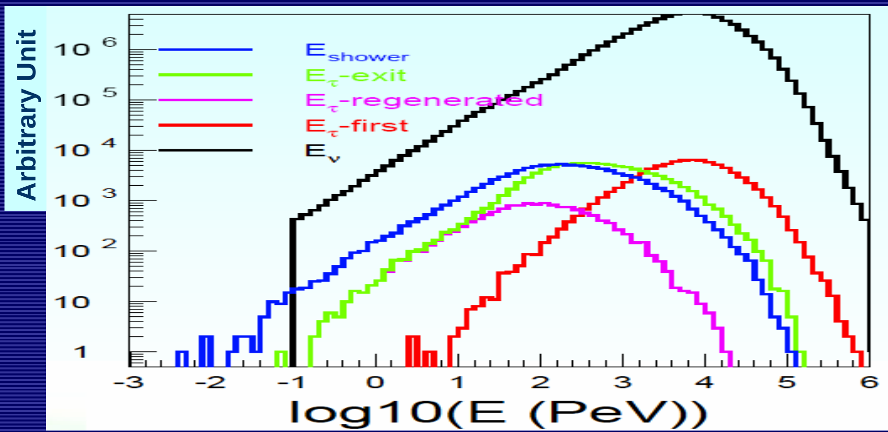
Tau Lepton Range



Log(E/GeV)

Tau lepton range approaches to 20 km in rock.
Mountain-penetrating is sufficient!

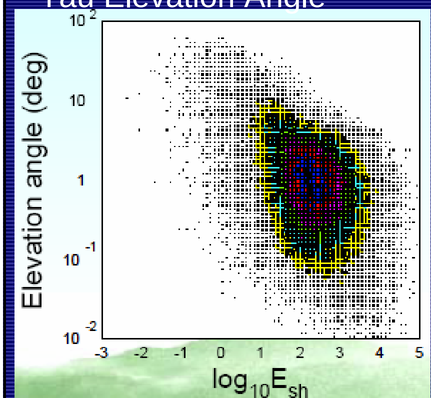
Energy of Tau from GZK ν



- Tau shower energy peak at E=100PeV (10^{17}eV)
- Significant contribution from regenerated tau at E<100PeV
- Importance of both Cerenkov and fluorescence detections

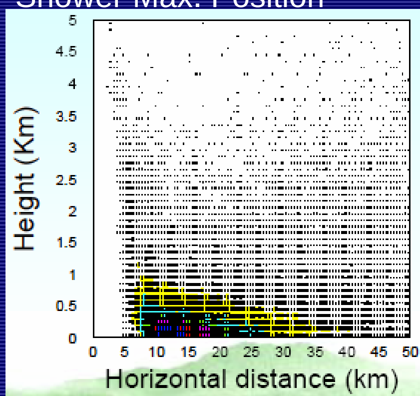
Shape of Appeared Tau from GZK ν

Tau Elevation Angle



- Mostly ε < 8°
- mean ε ~ 2° ,
  - re-generated τ could come out at larger angle

Shower Max. Position



- Mostly at H < 500 m and 8 Km < D < 25 Km

Clear evidence of AS originated from Earth

=> Directional precision

Integrated tau lepton flux

in units of km^{-2}yr^{-1}sr^{-1}

by G.-L.Lin

'Guaranteed' ν Source

Energy & flux	AGN	GRB	GZK
10^{15}-10^{16} eV	2.2	9.6×10^{-3}	7.4×10^{-5}
10^{16}-10^{17} eV	4.9	7.1×10^{-3}	1.1×10^{-2}
10^{17}-10^{18} eV	0.2	5.4×10^{-4}	8.2×10^{-2}
10^{18}-10^{19} eV		1.1×10^{-5}	3.3×10^{-2}

W resonance (AGN) 0.08

Effective aperture $(A\Omega)_{eff}$

required for 1 event/yr, assuming a 10% duty cycle.

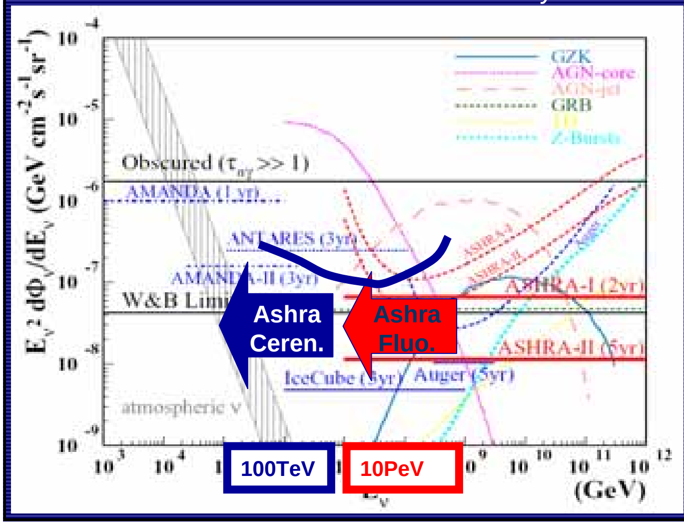
'Guaranteed' ν Source

Energy & Aperture (km^2 sr)	AGN	GRB	GZK
10^{15}-10^{16} eV	4.5	1000	
10^{16}-10^{17} eV	2.0	1400	910
10^{17}-10^{18} eV	50	19000	120
10^{18}-10^{19} eV			290

GZK- ν_τ => Highly Plausible Detection by Ashra

Neutrino Sensitivity

- 1 event/year/decade of energy (curve)
- 90% upper limit assuming E^{-2} flux (straight line)
- Interaction in mountain has not been taken yet.



Ashra

Cerenkov + Fluo.

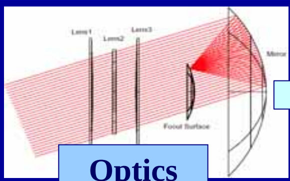
Ashra can keep good sensitivity in whole range E>100TeV

Great Chance of the first clear detection VHE Neutrino showers

Test Observation

Test Plan

Design → Prototyping → Test Obs. in Hawaii



Optics

2/3 Scale Prototype

GRB Optical Flash Search

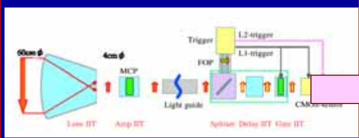
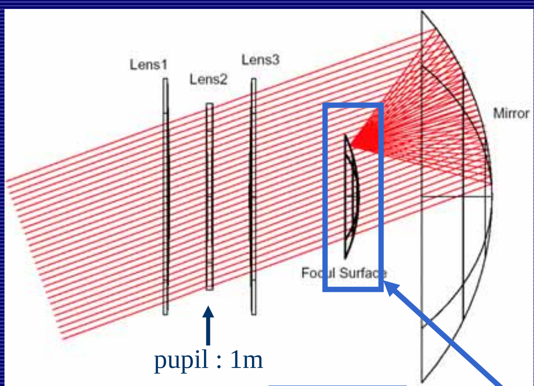


Image Pipeline

TeV γ Source Tracking

w/ alt-azimuth

Ashra Optics



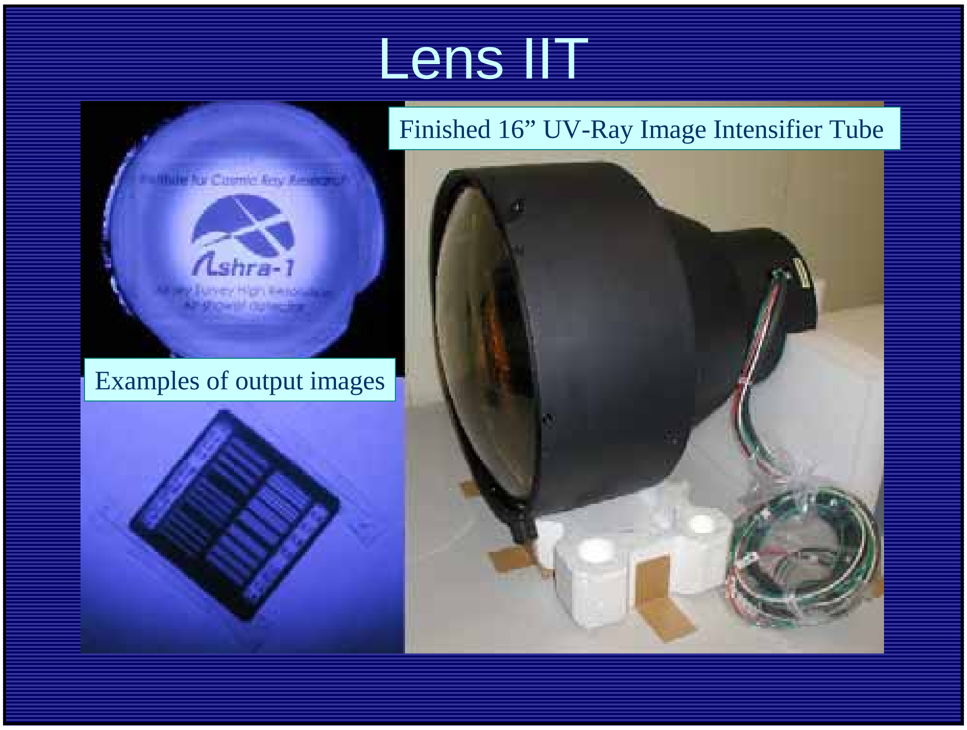
F/0.74

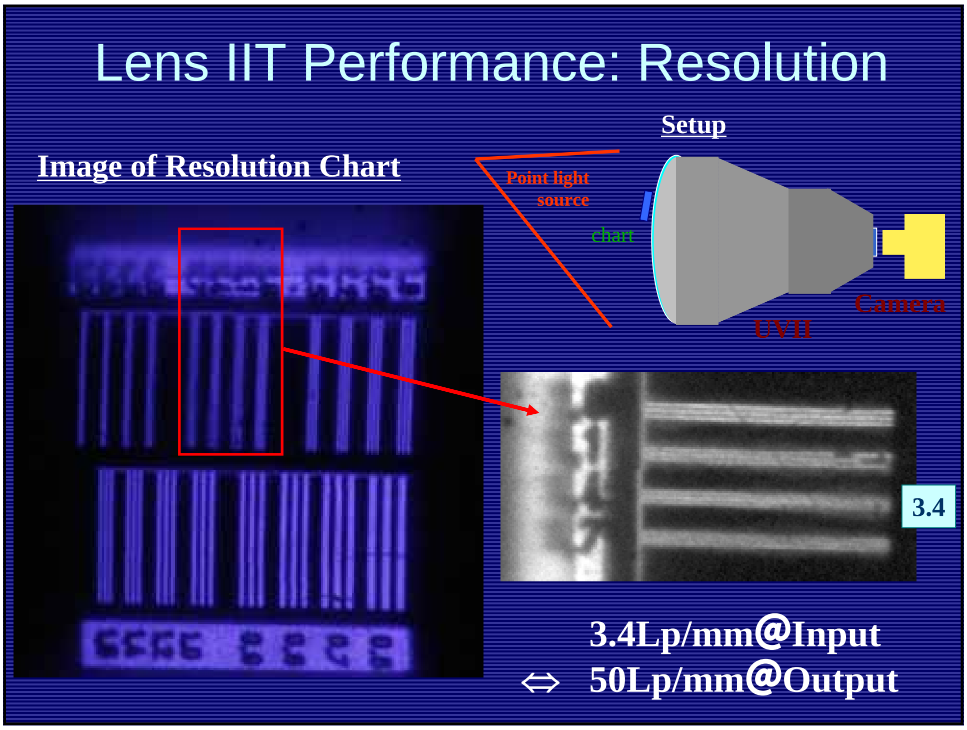
Photocathode of Lens IIT

Modified Baker-Nunn

- Schmidt-type optics
- Spherical segment mirror
- Spherical focal surface
- 3-element corrector lens

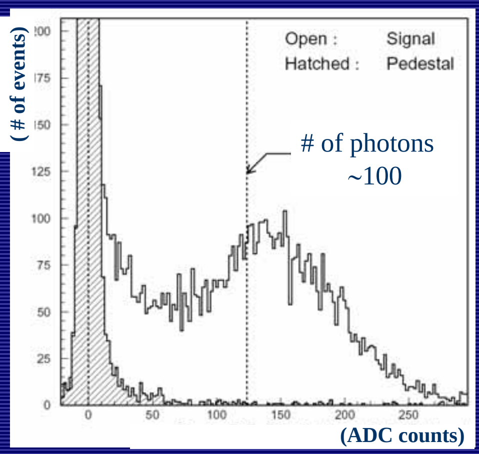
Details can be found in
M.Sasaki et al, NIM A492 (2002) 49


Lens IIT
Finished 16” UV-Ray Image Intensifier Tube
Examples of output images


Lens IIT Performance: Resolution
Setup
Image of Resolution Chart
Point light source
chart
UVII
Camera
3.4
3.4Lp/mm@Input
⇔ 50Lp/mm@Output

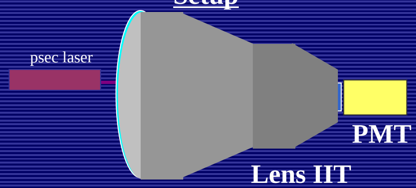
Lens IIT Performance: Gain Distribution

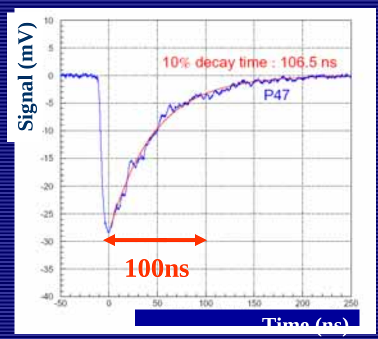
Single photoelectron response
measured w/ 415nm pulse laser



Gain distribution

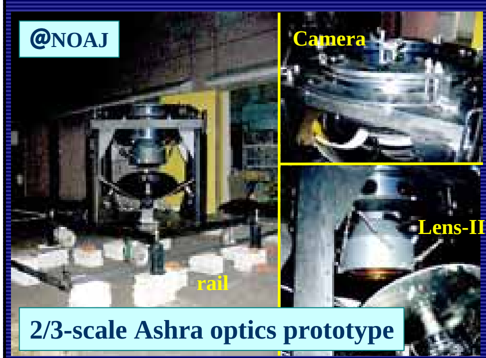
Setup

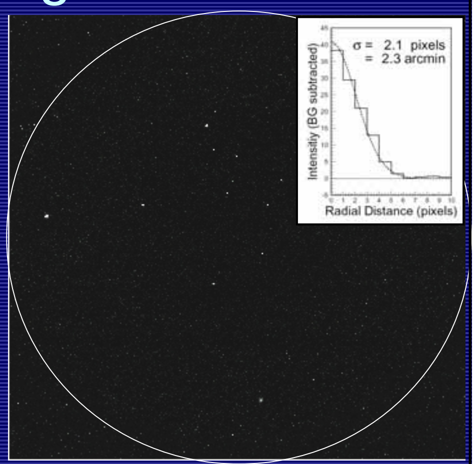




Decay curve

First Light





- Spot size of star image: ~2 arcmin.
- Concept of wide angle fine optics has been realized.

Test Observation (1) with Ashra Prototype Optics

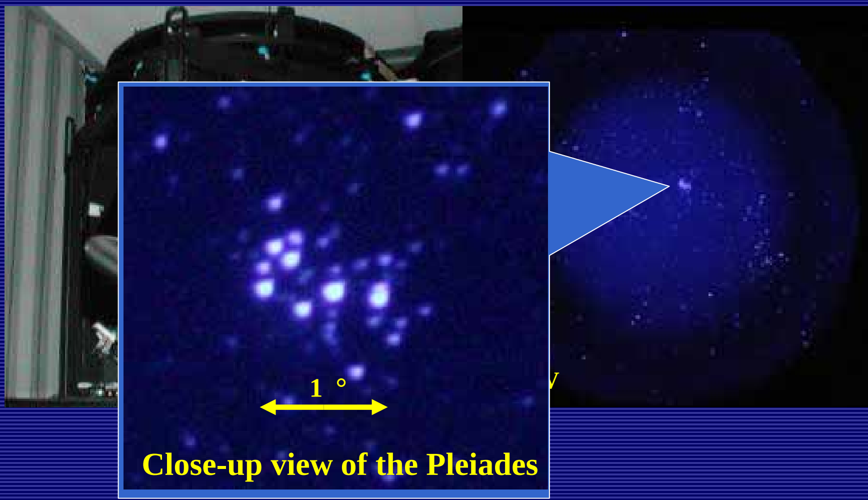
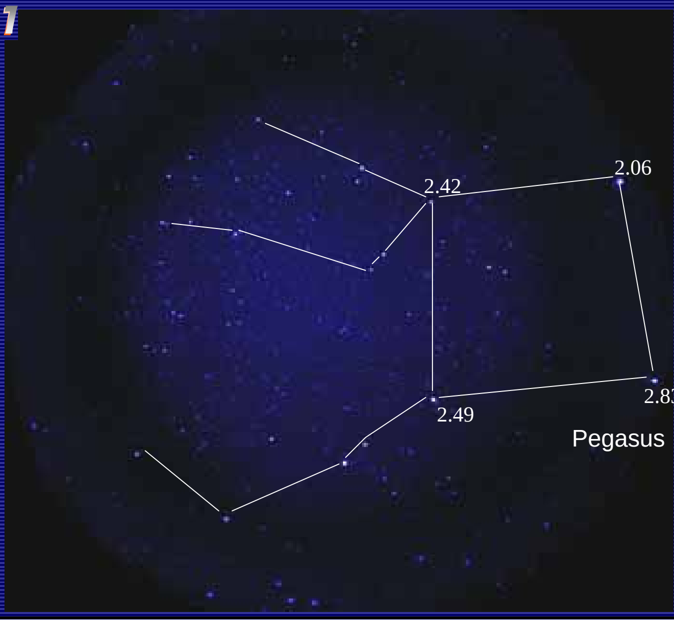
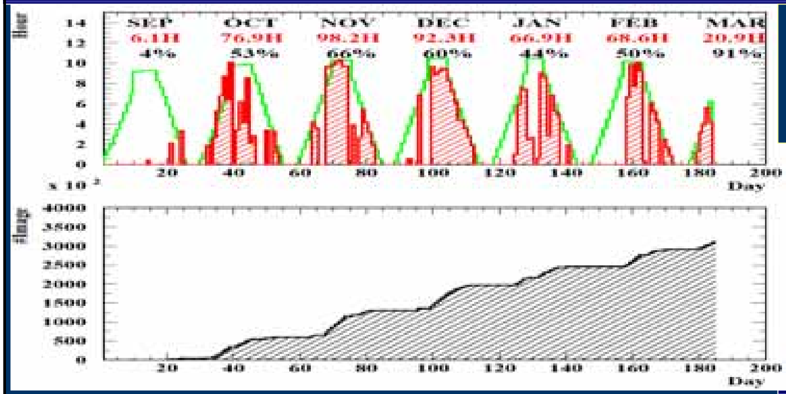


Image Taken at Haleakala

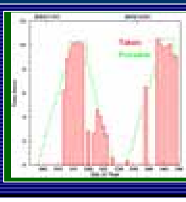


Live Time



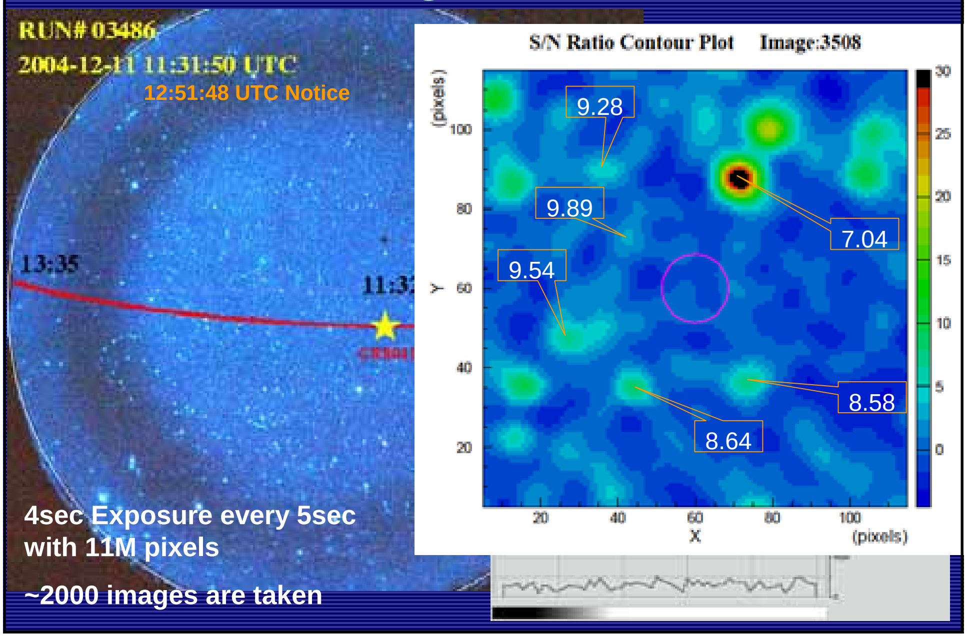
Ashra Proto for Opt. Flash

Possible Live time：
astronomical twilight end to astronomical twilight begin
&Moon bright area rate<10%
astronomical twilight =>Elevation of Sun between -20° and -18°



Ashra Proto for Gamma

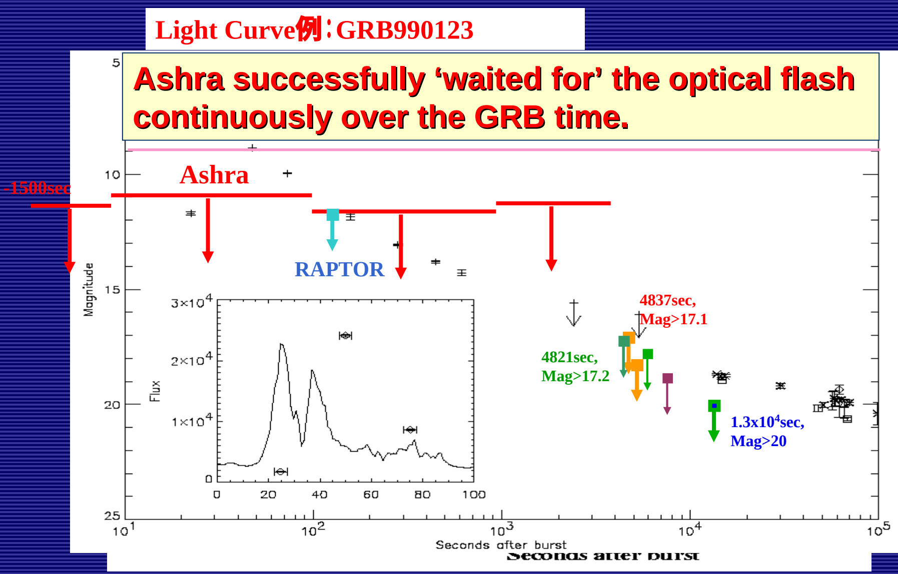
Catching GRB041211



4sec Exposure every 5sec with 11M pixels

~2000 images are taken

GRB041211 Obs. Results (GCN)



Sari & Piran (99)

Comparison of GRB Optical Observation

	RAPTOR -A,B (wide)	Ashra -P2/3
FOV (sr)	0.36	0.48
Sensitive area (cm²)	57	990
Resolution (arcmin)	0.57	2.0
Wavelength band	R	~B
Limit mag. / exp.time	12 / 30sec	14 / 4sec
Start	2002.10	2004.9

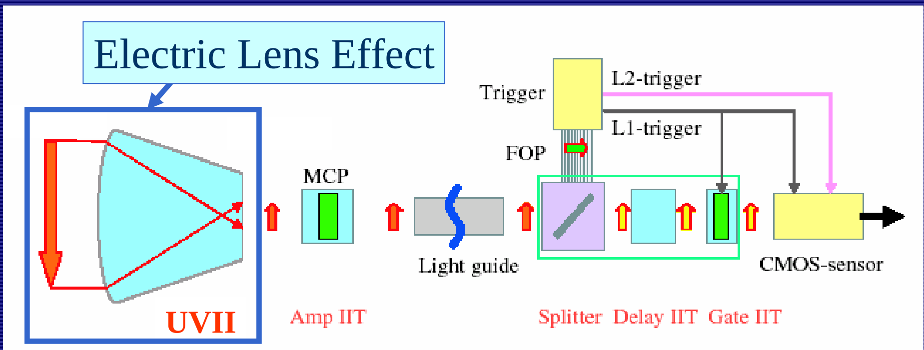
Even Ashra Prototype Test Observation

=> Fairly Competitive

Ashra Image Pipeline

To reduce image size into a solid state imager

⇒ Big reduction in pixel cost



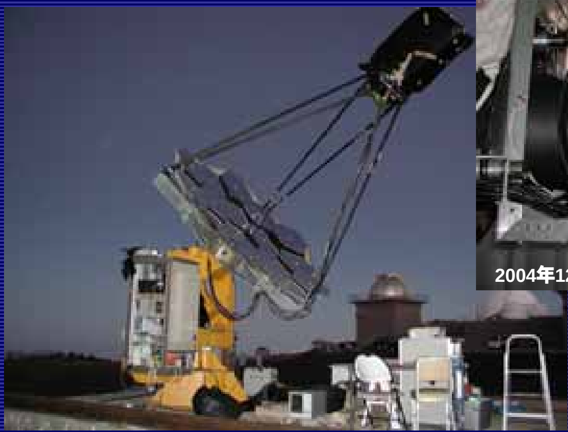
1. Amplification of image intensity w/ pipelined IITs.
2. Self triggering using light splitting
3. Fine imaging w/ CMOS sensor

Details can be found in *M.Sasaki et al, NIM A501 (2003) 359*

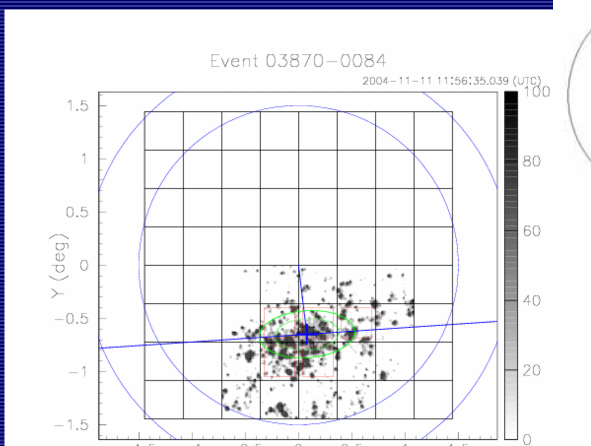
New Prototype of Image Pipeline

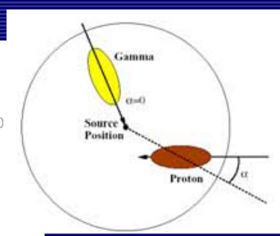
Test Observation (2) with Ashra Prototype Image Pipeline

TeV gamma ray observation using an alt-azimuth mounting telescope



AS Cerenkov Images





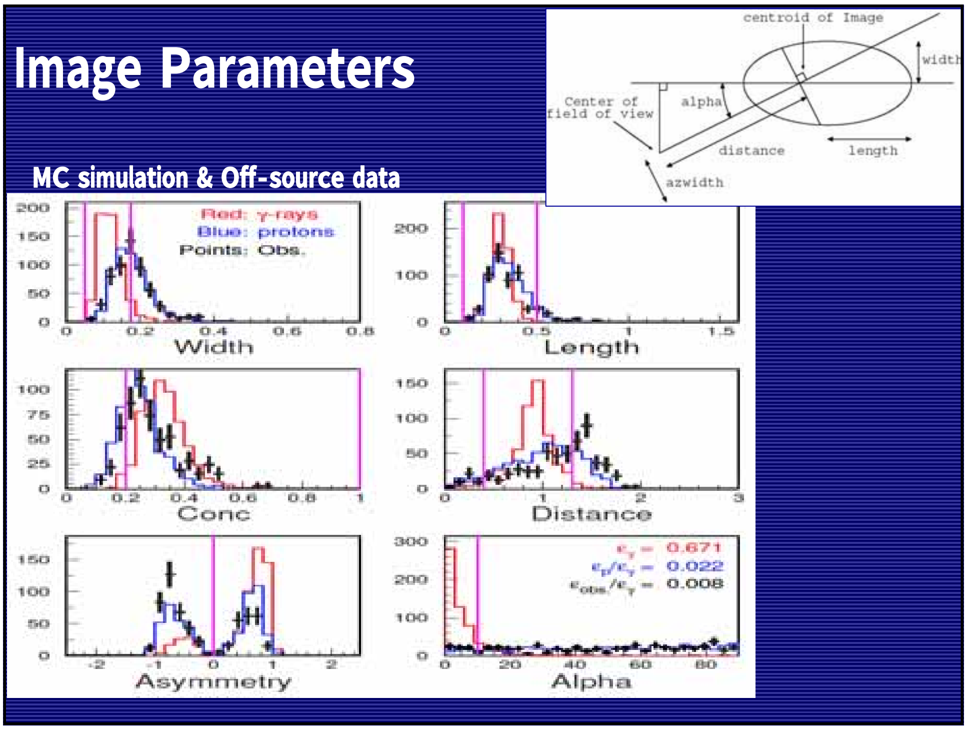
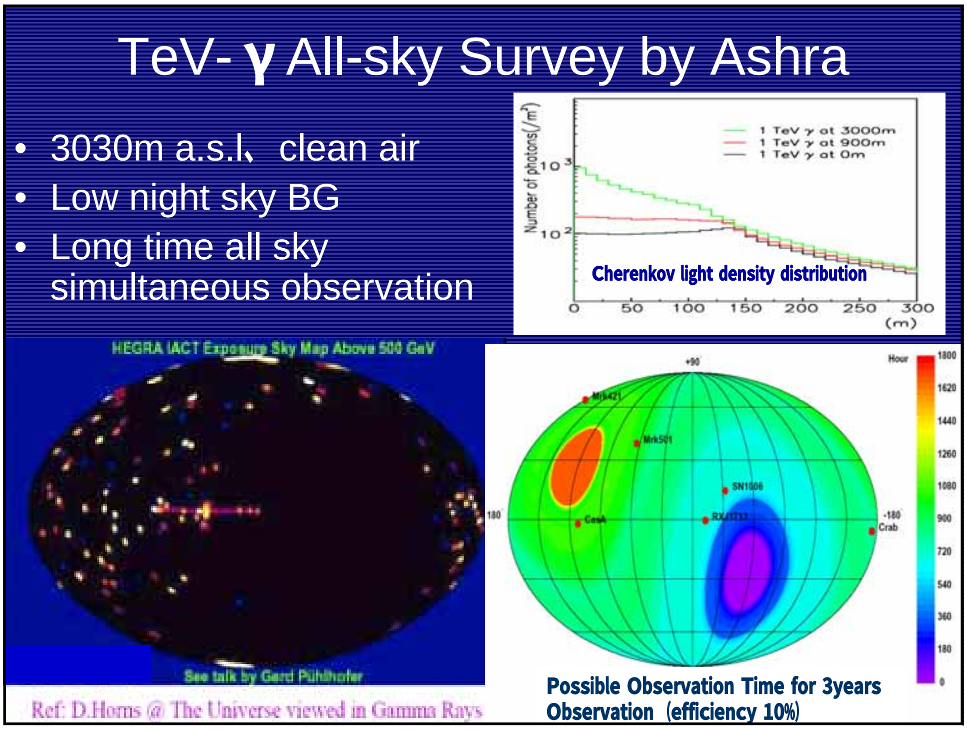


Image Parameters
MC simulation & Off-source data
centroid of Image
width
Center of field of view
alpha
distance
length
azwidth
Red: γ-rays
Blue: protons
Points: Obs.
Width
Length
Conc
Distance
Asymmetry
Alpha
ϵ_γ = 0.671
$\epsilon_p/\epsilon_\gamma$ = 0.022
$\epsilon_{obs}/\epsilon_\gamma$ = 0.008


TeV-γ All-sky Survey by Ashra
• 3030m a.s.l、clean air
• Low night sky BG
• Long time all sky simultaneous observation
Number of photons(/m²)
1 TeV γ at 3000m
1 TeV γ at 900m
1 TeV γ at 0m
Cherenkov light density distribution
(m)
HEGRA IACT Exposure Sky Map Above 500 GeV
See talk by Gerd Pühlhofer
Ref: D.Horns @ The Universe viewed in Gamma Rays
Mrk421
Mrk501
SN1006
CasA
Crab
Hour
Possible Observation Time for 3years Observation (efficiency 10%)

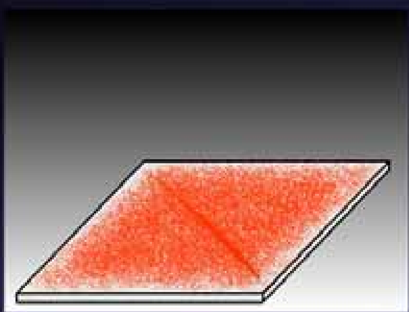
Elements

Under Development

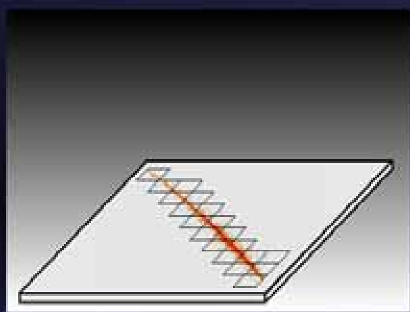
Local Exposure Control (Expectation)

Improvement of Image on CMOS sensor

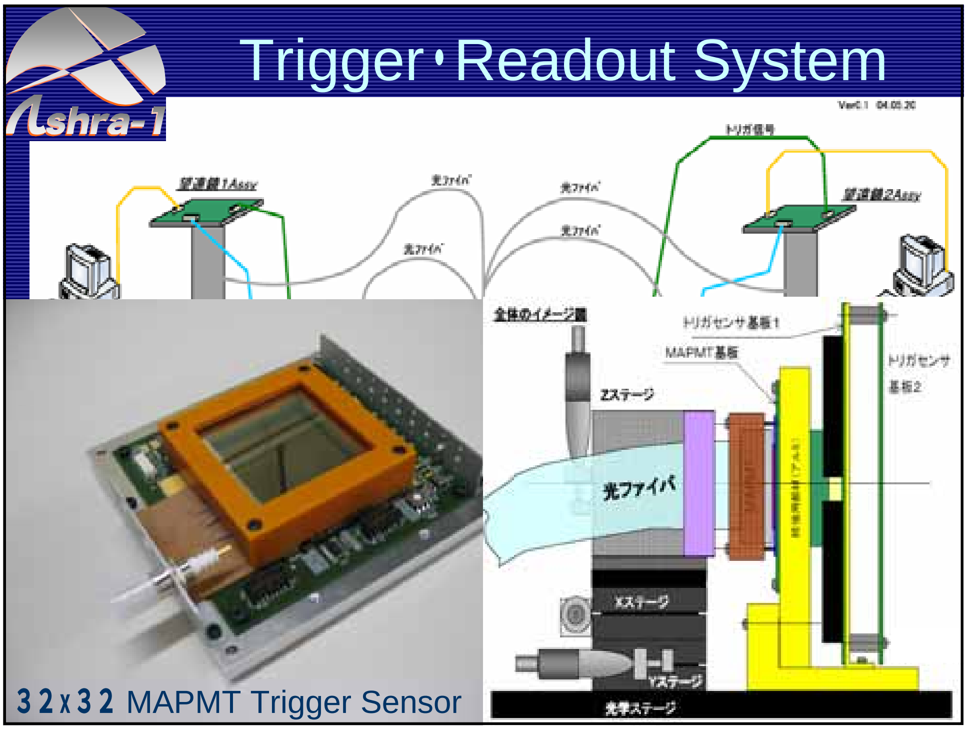
Global Exposure Control

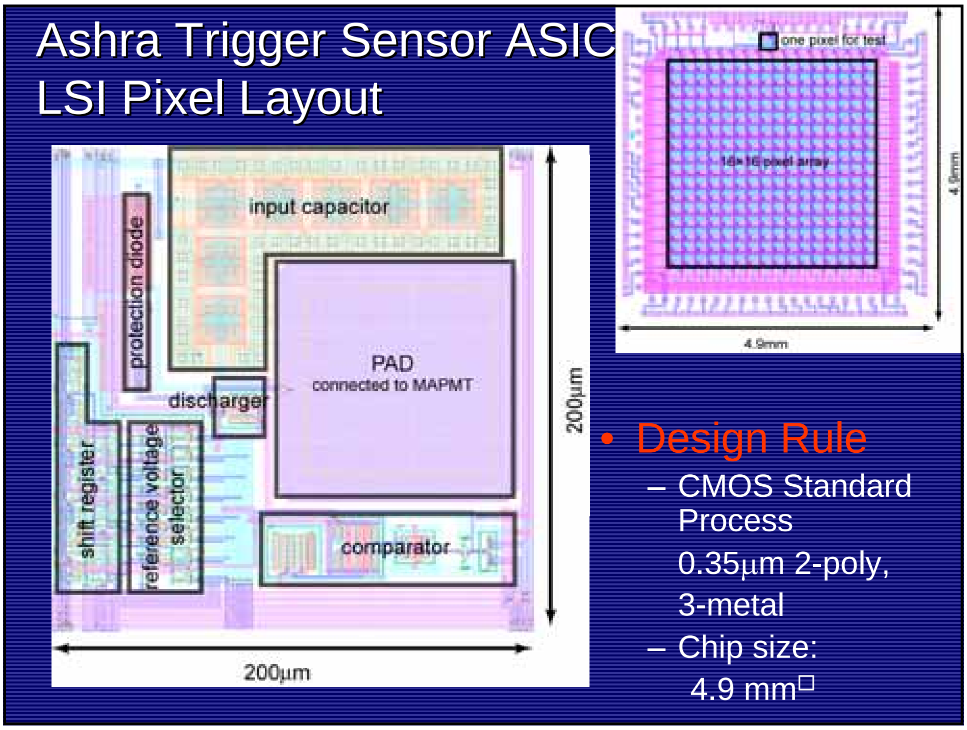


Local Exposure Control



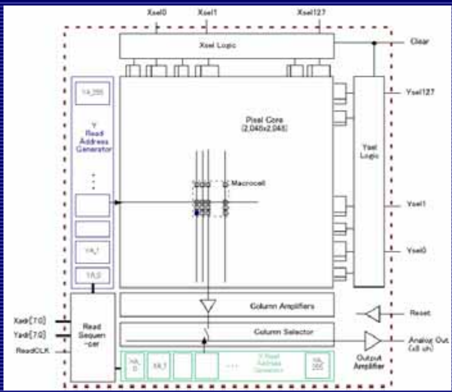
Excellent reduction of BG noise

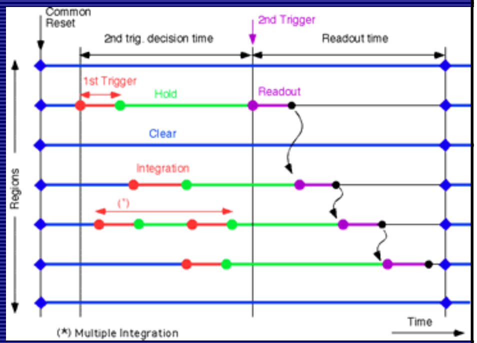

Trigger・Readout System
Ashra-1
トリガ信号
望遠鏡1Assy
望遠鏡2Assy
光ファイバ
全体のイメージ図
トリガセンサ基板1
MAPMT基板
トリガセンサ基板2
Zステージ
光ファイバ
Xステージ
Yステージ
光学ステージ
32x32 MAPMT Trigger Sensor


Ashra Trigger Sensor ASIC
LSI Pixel Layout
input capacitor
protection diode
PAD
connected to MAPMT
discharger
shift register
reference voltage selector
comparator
200μm
200μm
one pixel for test
16×16 pixel array
4.9mm
4.9mm
• Design Rule
– CMOS Standard Process
0.35μm 2-poly, 3-metal
– Chip size:
4.9 mm□

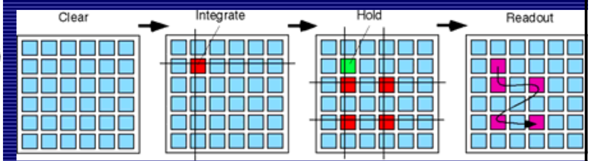
Ashra Fine Sensor ASIC

2-Dim Exposure&Readout
By Outer Control Signals

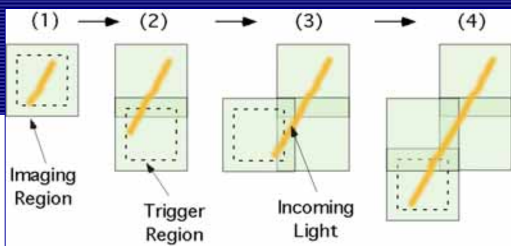


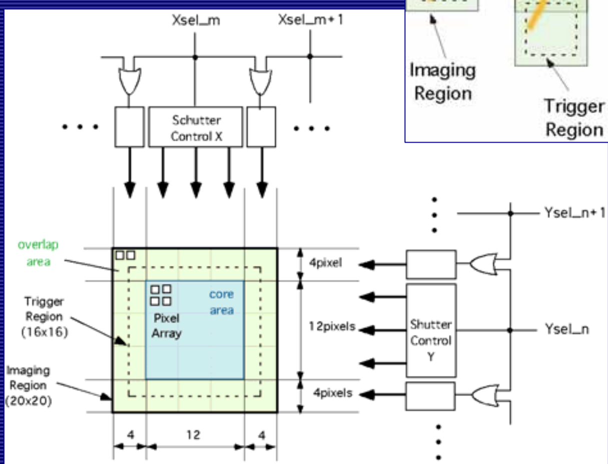


信号説明	
ReadClk	・・・・読み出しCLK
Reset	・・・・システムリセット
Clear	・・・・全画素クリアー（Discharge）
Xadr	・・・・読み出しX軸アドレス
Yadr	・・・・読み出しY軸アドレス
Xsel	・・・・蓄積用X軸アドレス
Ysel	・・・・蓄積用Y軸アドレス
Analog Out	・・・・アナログ画素出力



Ashra Fine Sensor Overlap Process





Summary

- Advanced capabilities of Ashra:
  – Wide Angle Fine Image Optical System
  – Self-trigger of Cerenkov Images with the Pipeline System

  have been demonstrated at Haleakala.

- Installation at Mauna Loa starts spring:
  – Adjustment of the optical system with star images
  => Search for optical transients simultaneously.
  – Cerenkov and fluorescence triggers will be implemented step by step.
  => Start all-sky survey of TeV γ sources in FY2005.

Mauna Loa Site