Ashra-1

Optics and Lens Image Intensifier

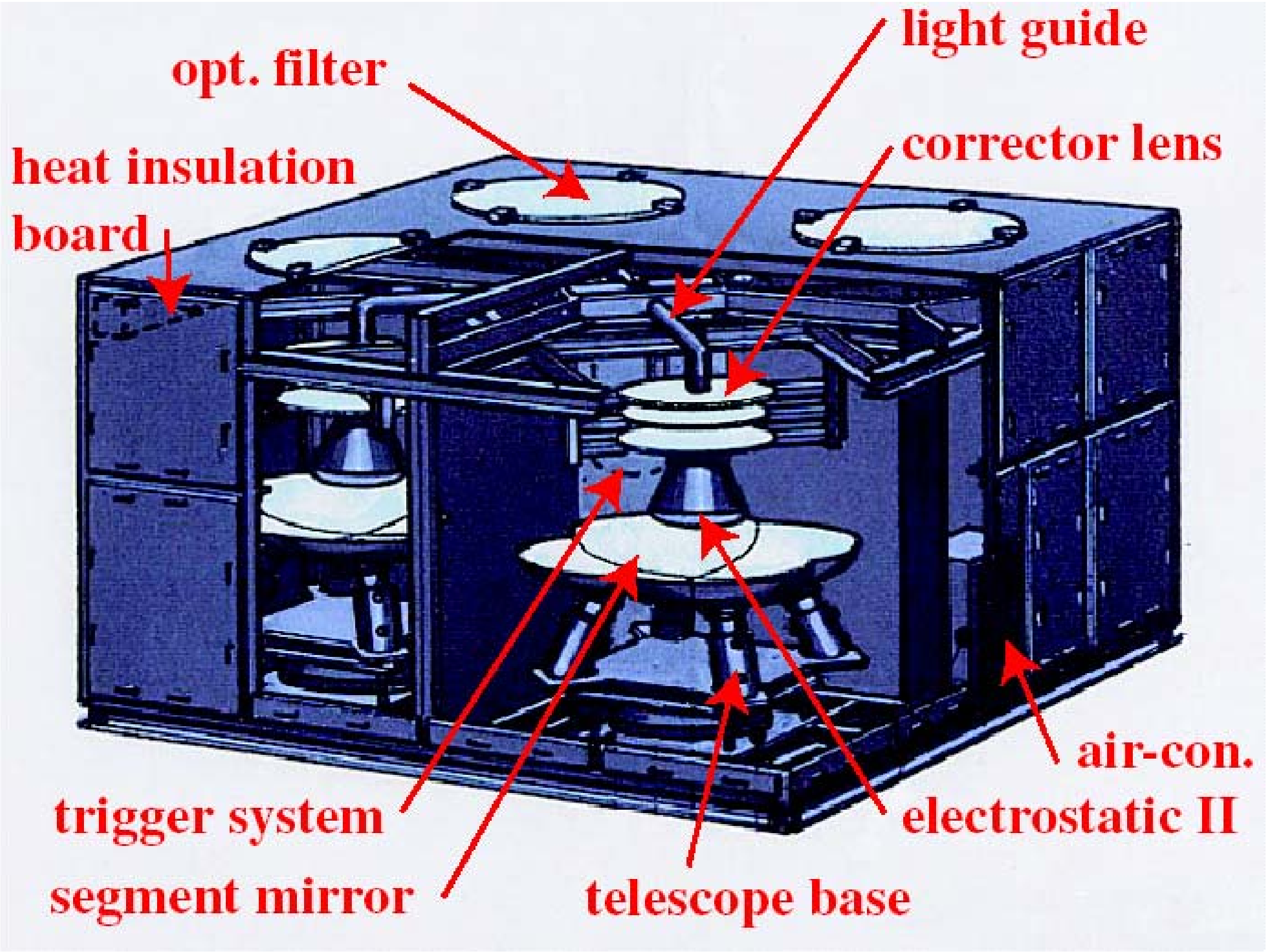
2004.1.9 Ashra Meeting @ UH

Ashra-1 Collaboration

Y.Asaoka, @ ICRR

Contents

Ashra Detector : Telescope



A detector consists of

i) 4 sub-telescopes and

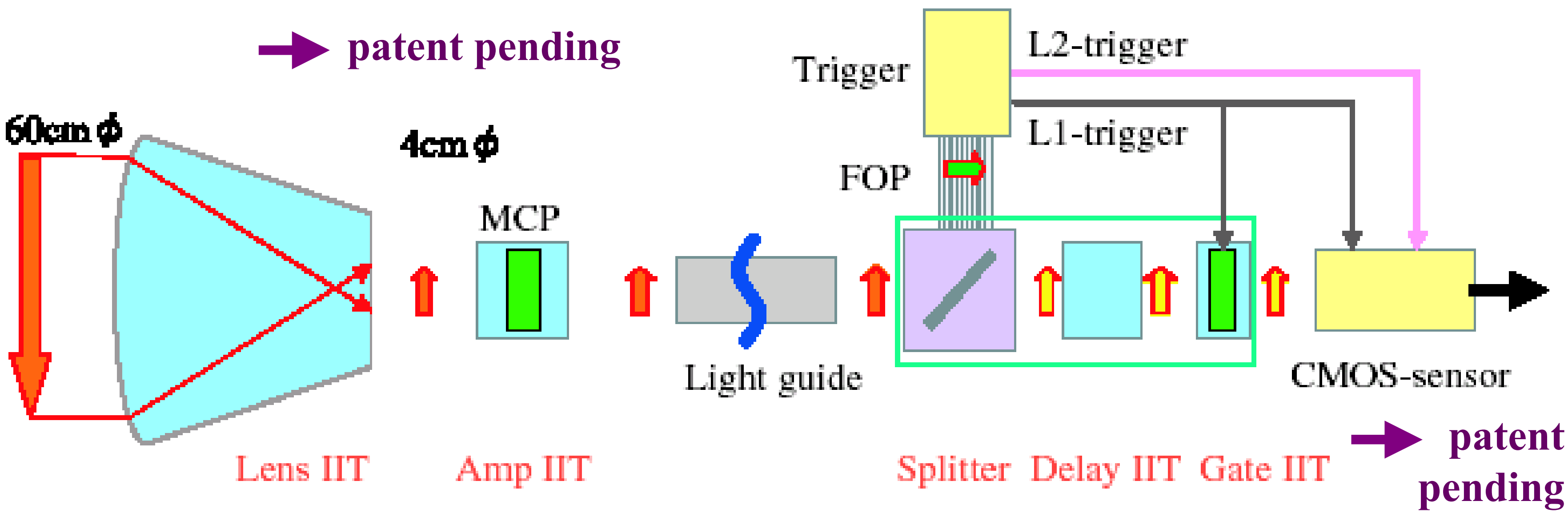
ii) 1 photoelectric image pipeline.

4 sub-telescopes view the same direction to have better aperture in a cost-effective way.

Ashra Detector : Image Pipeline

Sasaki-san's Talk

Photoelectric Image Pipeline



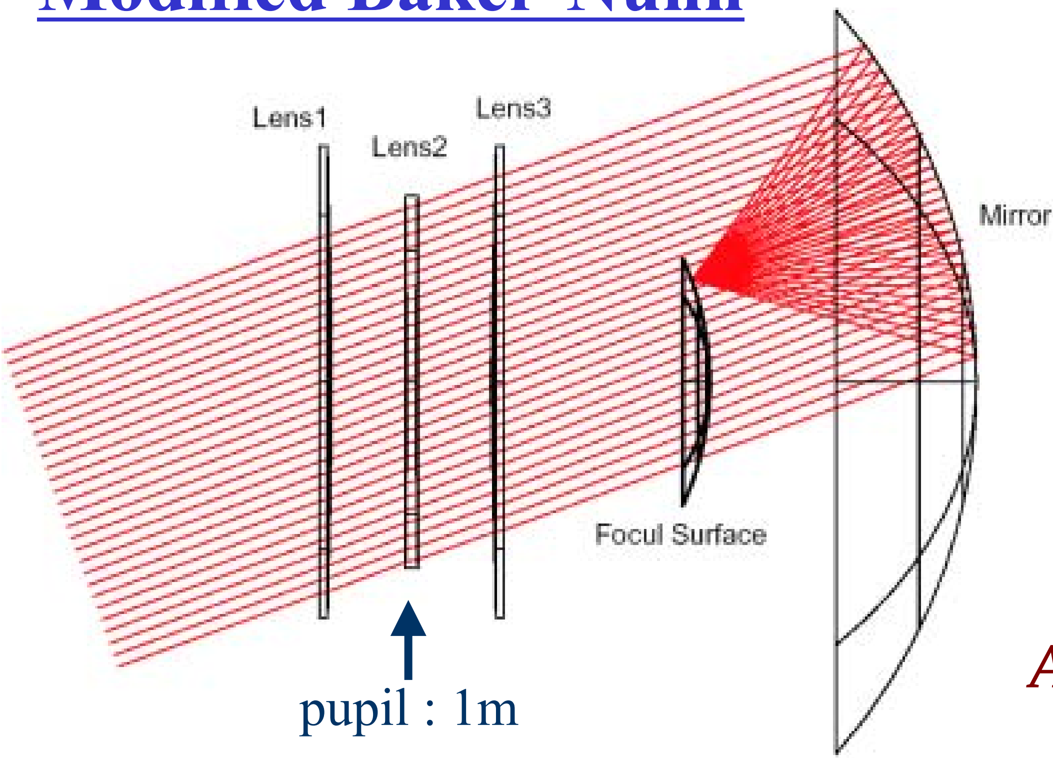
Functions:

1. Amplification w/ pipelined I.I.'s
2. Self triggering w/ light splitting & phosphor delay
   - Signal time scale : ns~μs
   - Shuttering is important to have higher S/N ratio
3. Fine imaging w/ CMOS sensor

Distinctive features:
High precision, high S/N ratio, and self triggering capability

Ashra Optics : Design

Modified Baker-Nunn



F/0.74

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

Advantage: a large degree of freedom for optimization of lens surface shape to cancel

1. spherical aberration
2. chromatic aberration.

Details can be found in

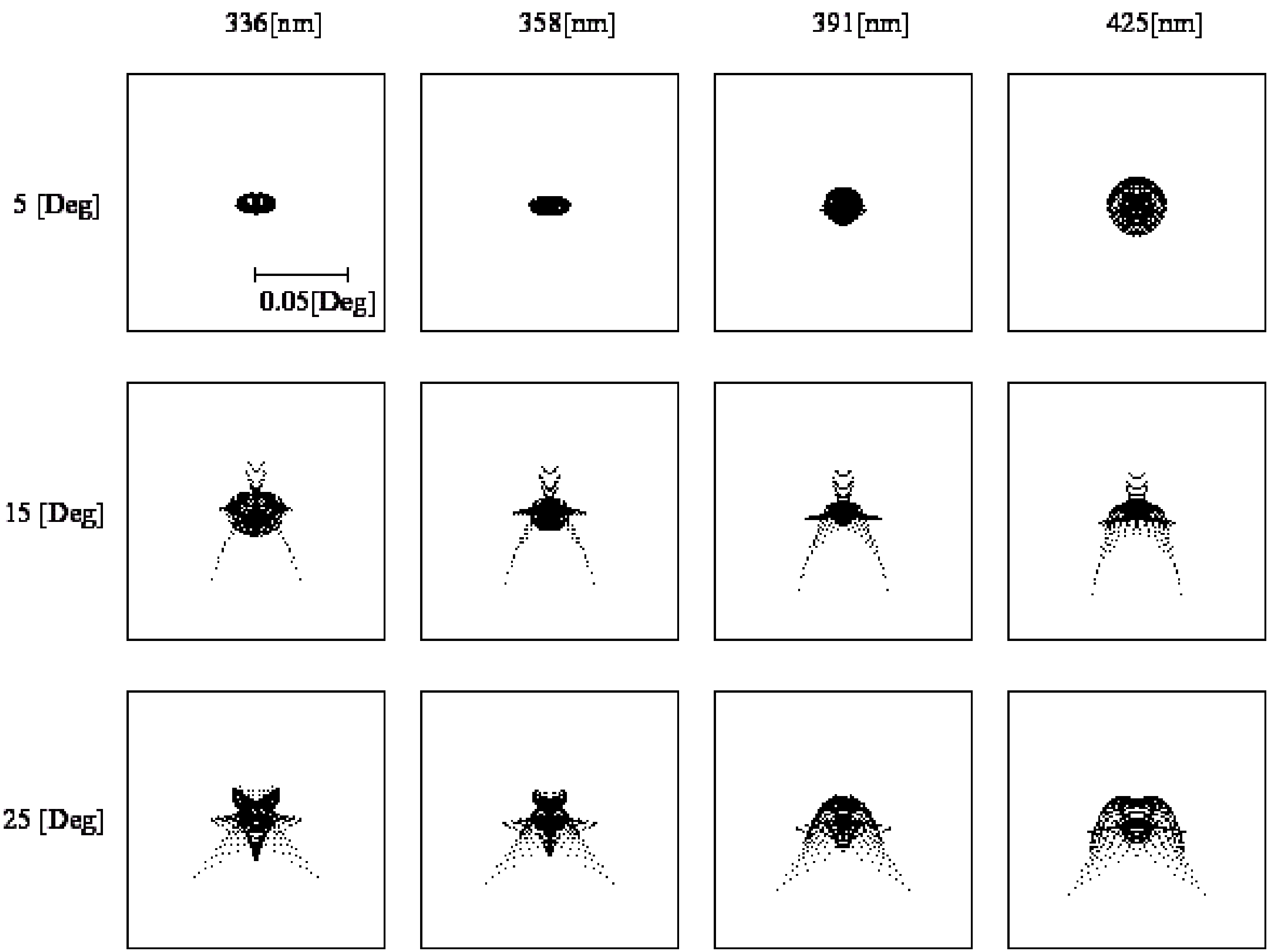
M.Sasaki et al, NIM A492 (2002) 49

Ashra Optics : Performance (1)

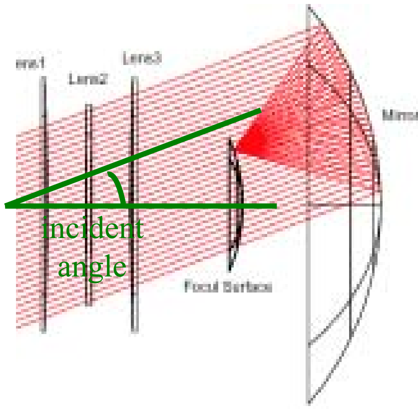
Spot diagram after optimization

wavelength

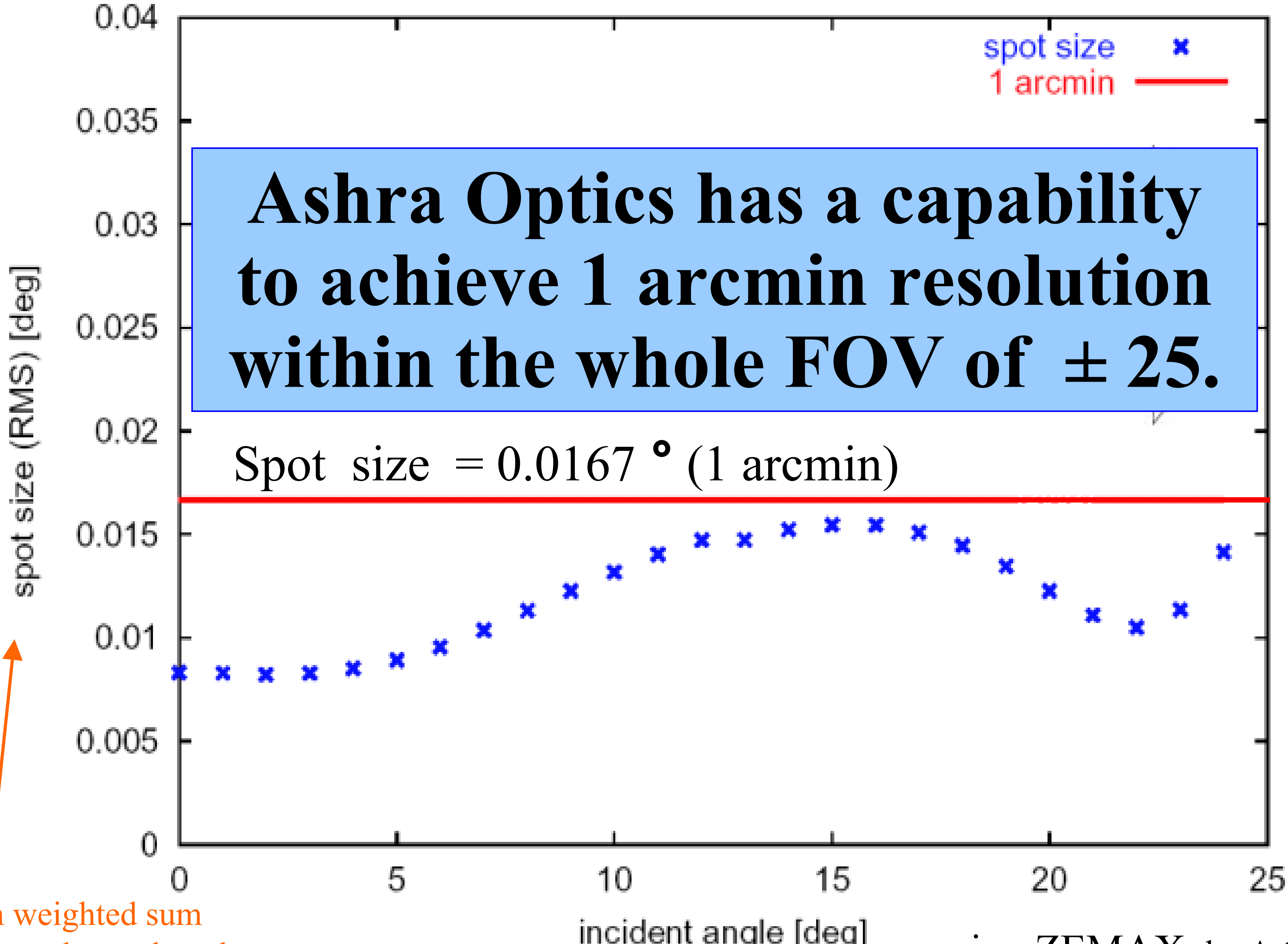
incident angle



4 largest filtered fluorescence peak after propagation in the air



Ashra Optics : Performance (2)



Ashra Optics has a capability to achieve 1 arcmin resolution within the whole FOV of ±25.

Spot size = 0.0167° (1 arcmin)

from weighted sum of several wavelength

using ZEMAX by A.Okumura

Optical Components

Components	Material and Method	Requirements
Mirror	• Tempax glass • segmented • mold + polish	• surface roughness < 20nm • spot size < 0.1mm • curvature radius ± 0.1%
Corrector Lens	• UV-transparent acrylic resin • normal lens • direct cutting w/ or w/o polishing	• surface roughness < 20nm • slope accuracy < 1 arcmin small sag because of corrector lens (no focusing)
Lens I.I. (I.I.= Image Intensifier)	• modification from commercial X-ray II	• spot size < 0.16mm

R&D status of each component

R&D Status : Mirror

<u>Prototype Segment Mirror</u>

Target performance:

- Surface roughness < 5nm
- Spot size < 0.16mm
- Curvature radius ±0.1%

Mirror: Surface Roughness

Surface Roughness was measured with interferometer

$Rs = R_0 \cdot \exp[-(4\pi\sigma/\lambda)^2]$

Ex.) σ=5nm, λ=350nm
Rs = R0 ・ 0.97 ⇒ 3% loss

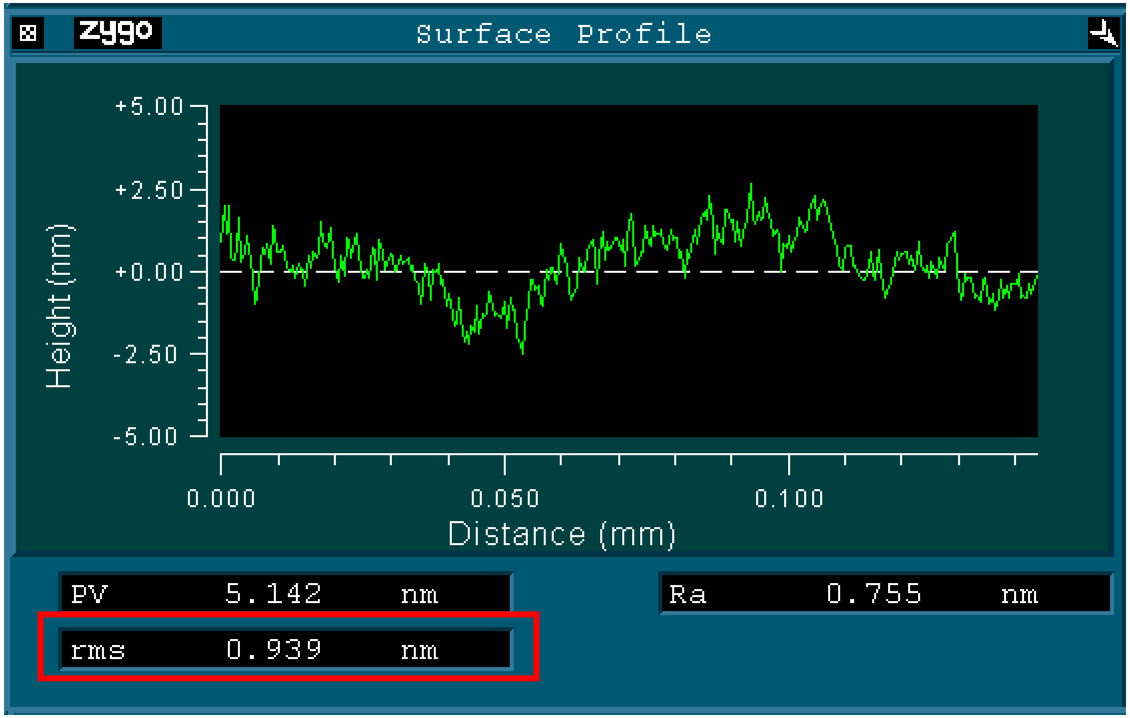
σ :surface roughness (rms)

λ :wavelength

⇒ Very important to keep high reflectivity

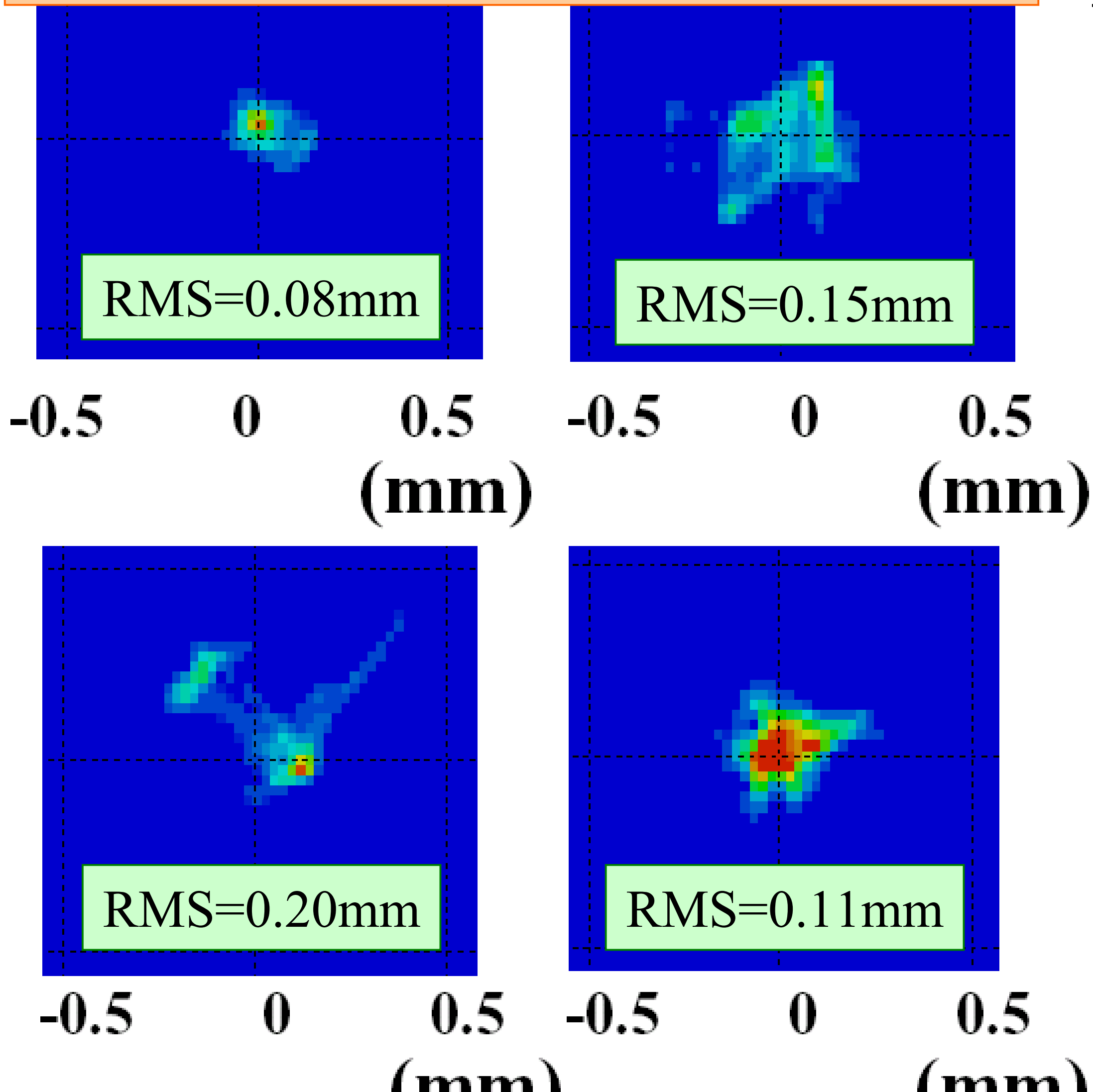
σ=1nm, λ=350nm
⇒ 0.1% loss

Results: σ~1nm < 5nm ⇒ OK

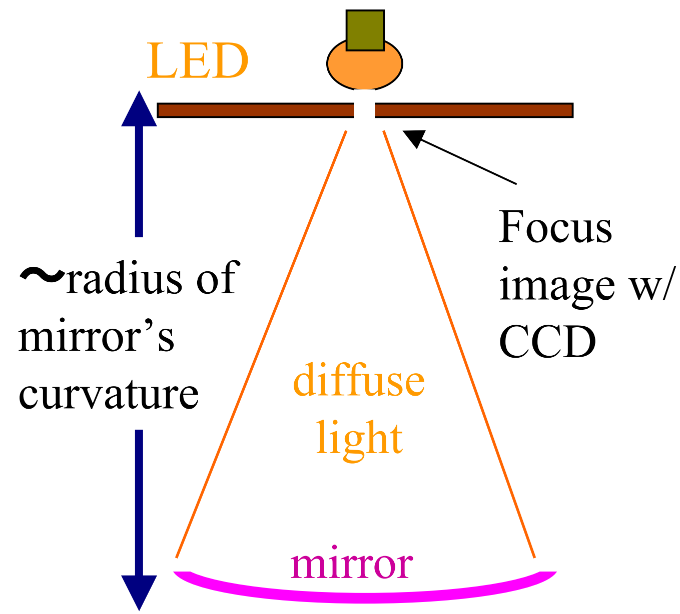


Mirror: Spot Size

Spot images of 4 prototype segment mirrors



Setup of spot size measurements



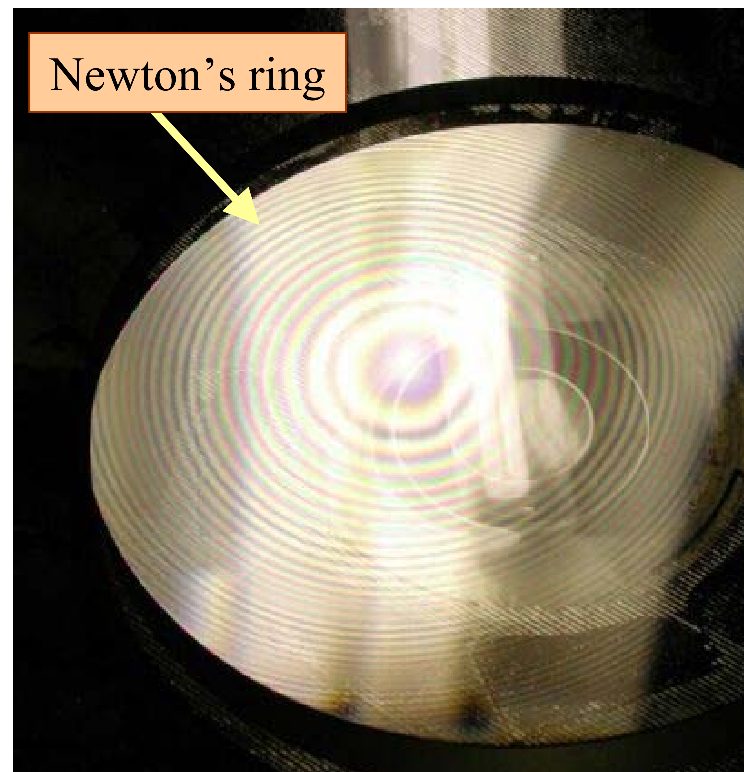
3 of 4 mirrors meats the spot size requirement, and the cause of bad spot size has already been fixed.

Mirror: Curvature Radius

<u>Curvature radius was measured with Newton standard.</u>

R discrepancies between segment mirrors should smaller than 0.1%

R discrepancies ≦ 0.7% ⇒ OK



R&D Status : Mirror

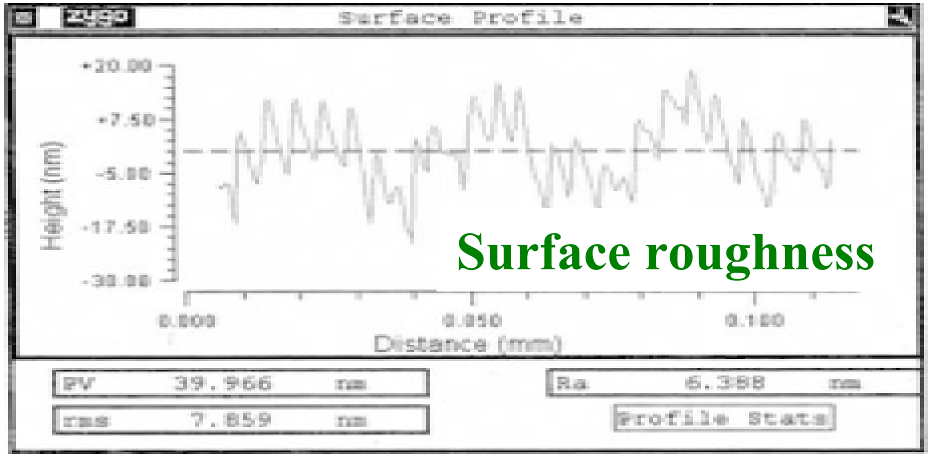
<u>Prototype Segment Mirror</u>

Target performance:

- Surface roughness < 5nm
- Spot size < 0.18mm
- Curvature radius ±0.1%

Prototype mirrors showed excellent performance.
Thus production method for segment mirrors has been fixed.

R&D Status : Acrylic Corrector Lens

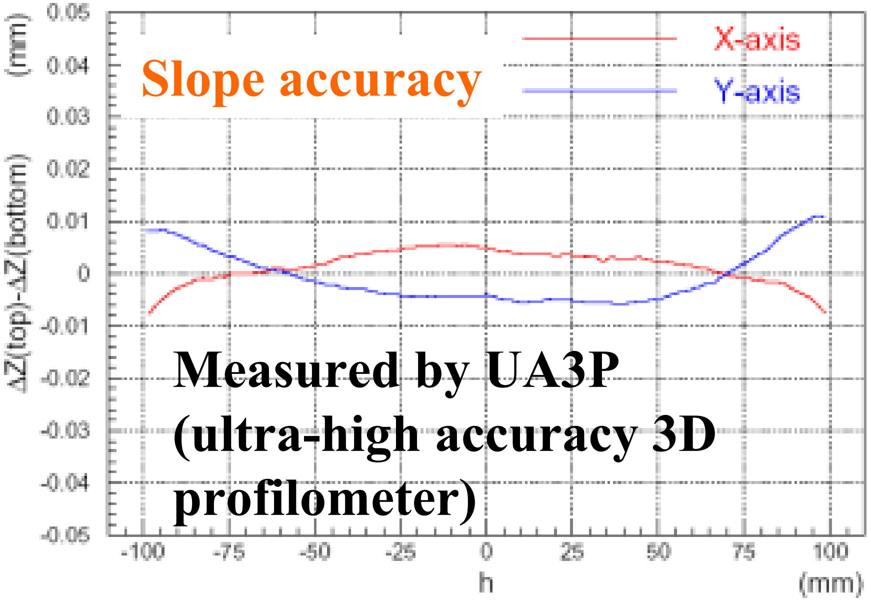


Direct measurements of lens surface show:

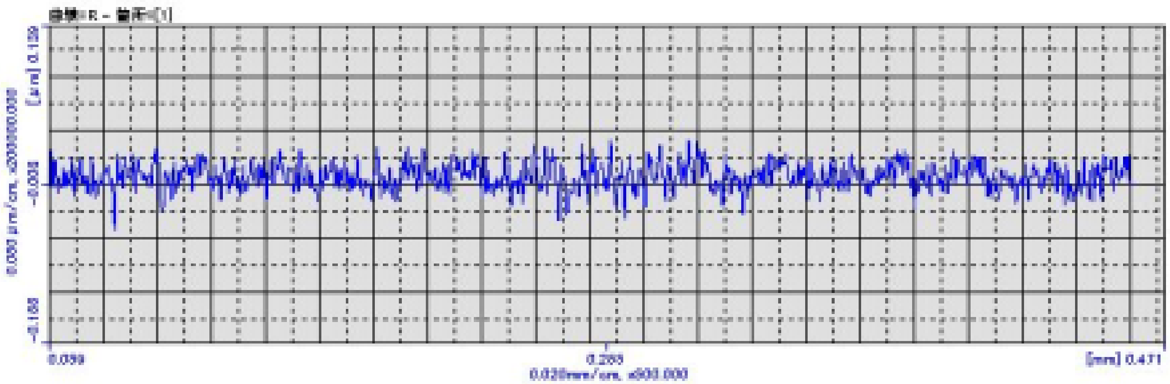
- **surface roughness < 10nm**
- **slope accuracy < 1 arcmin**

Small prototype is OK!

Next Step:
much larger lens sampling



Lens: Φ630mm Prototype



パラメータ集計表

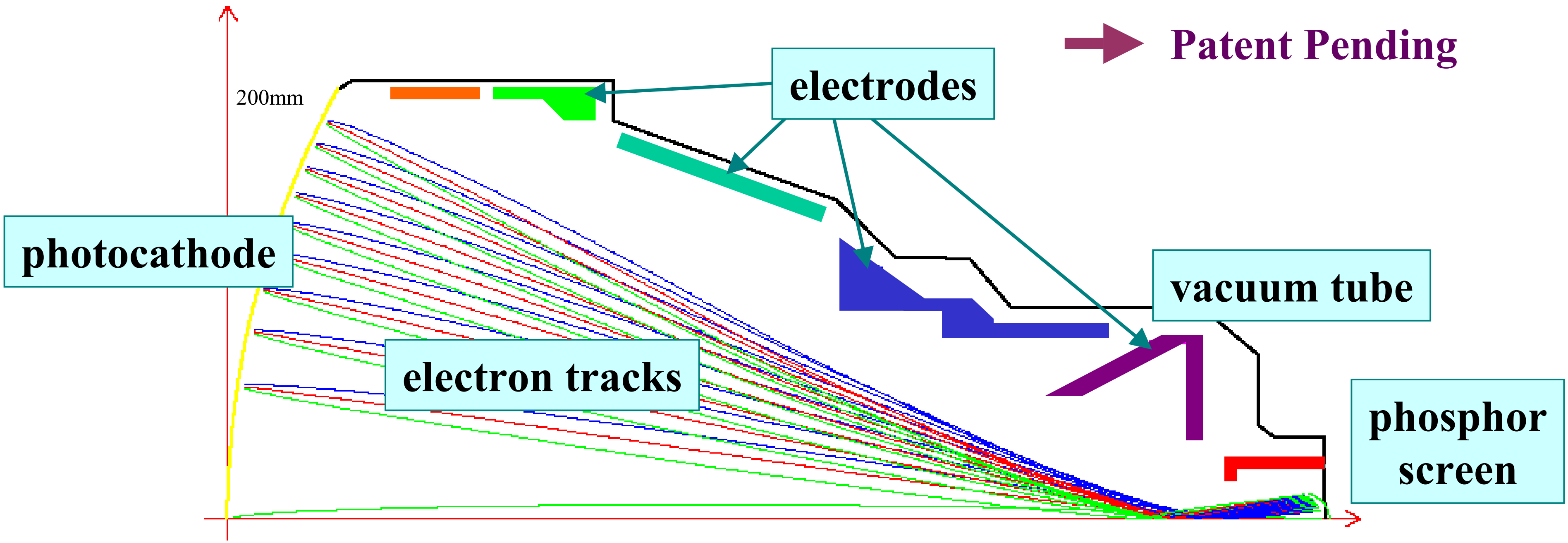
	曲線=R - 箇所=[1]	平均値
Ra (μm)	0.010	0.010
Ry (μm)	0.062	0.062
Rz (μm)	0.052	0.052

Φ630mm lens
Surface roughness:
Ra=10nm

Prototype lens

R&D Status : Lens I.I.

Modification from Commercial X-ray I.I.



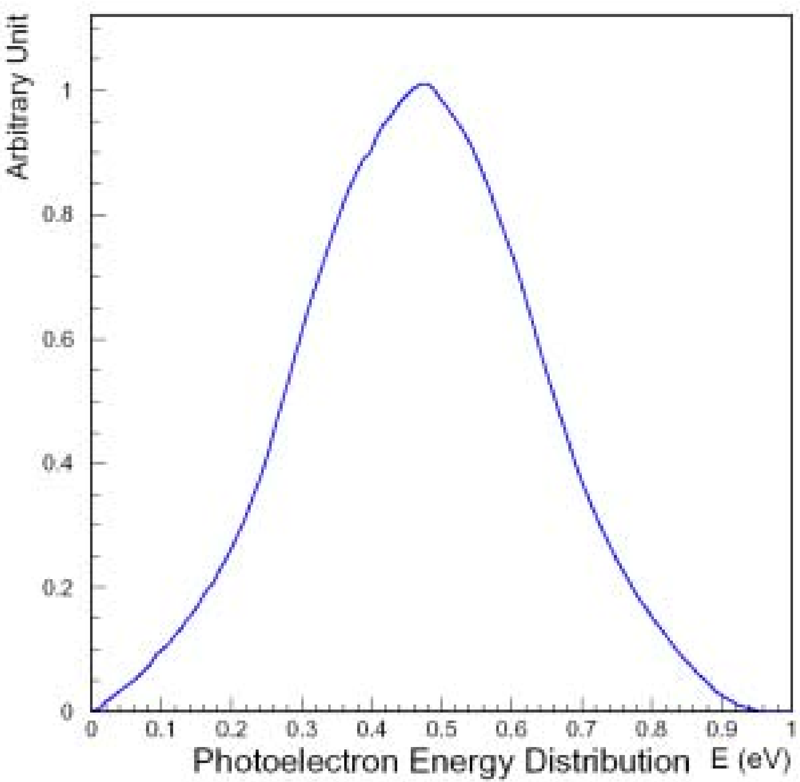
φ400mm **Focal sphere ⇨ CMOS sensor** **φ25mm**

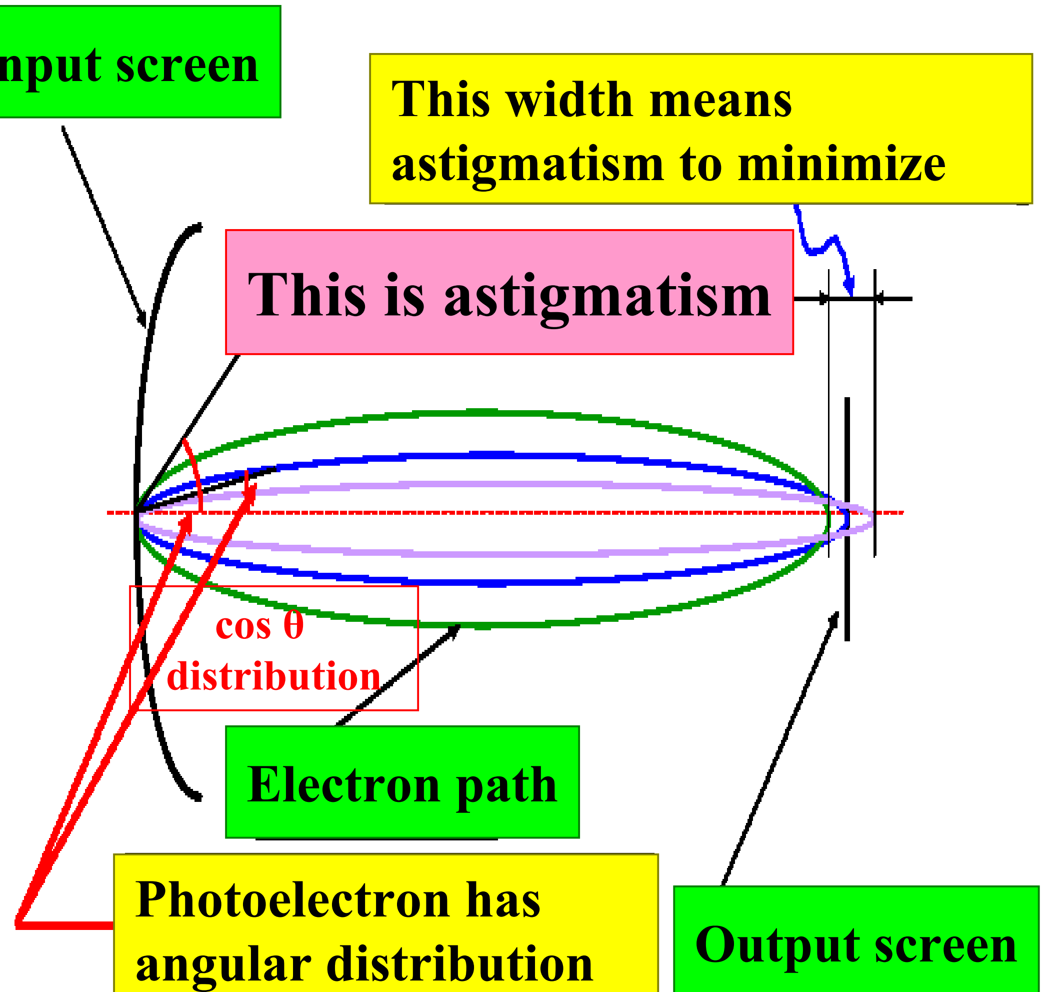
The lens I.I. works as the focal sphere detector which reduces the image size into solid state imaging devices.

Astigmatism in Electric Lens

Source: energy and angular distribution of photoelectron

Peak at ∼0.5 eV

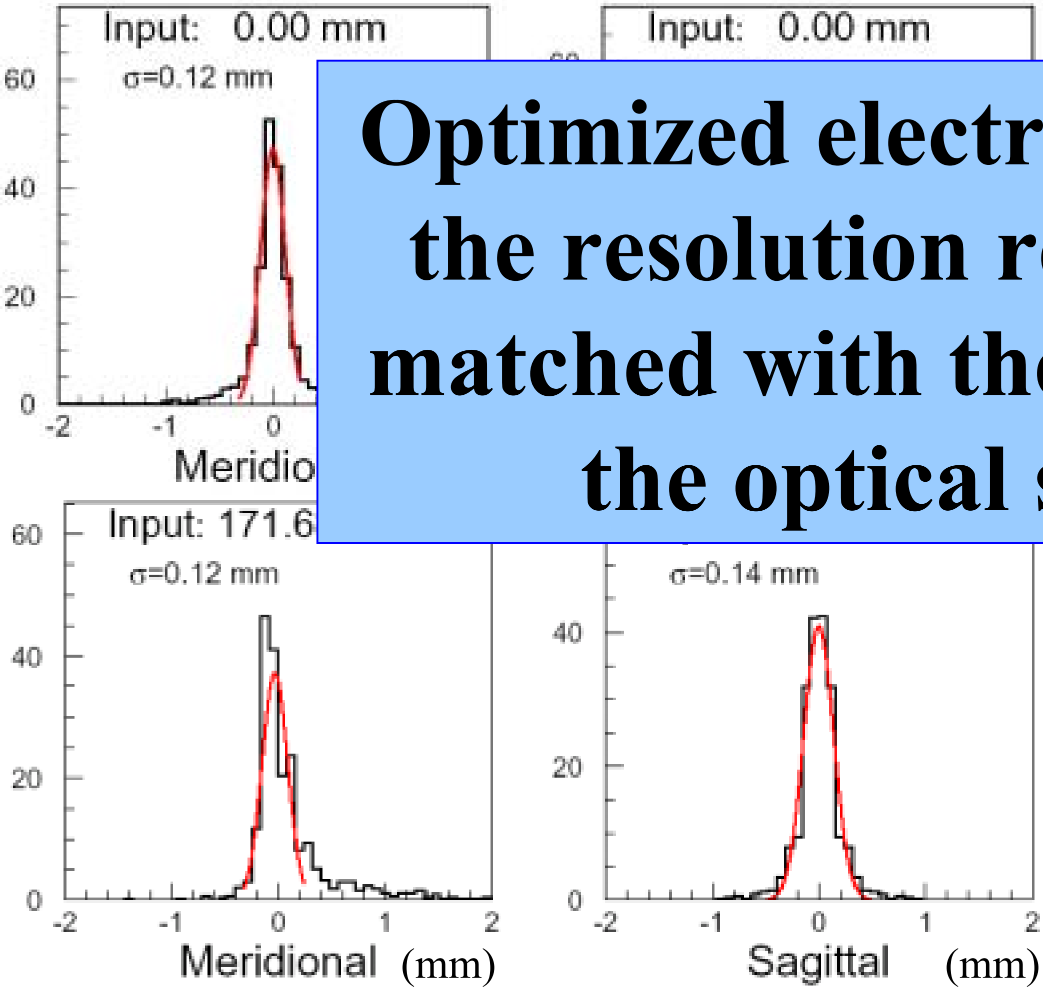




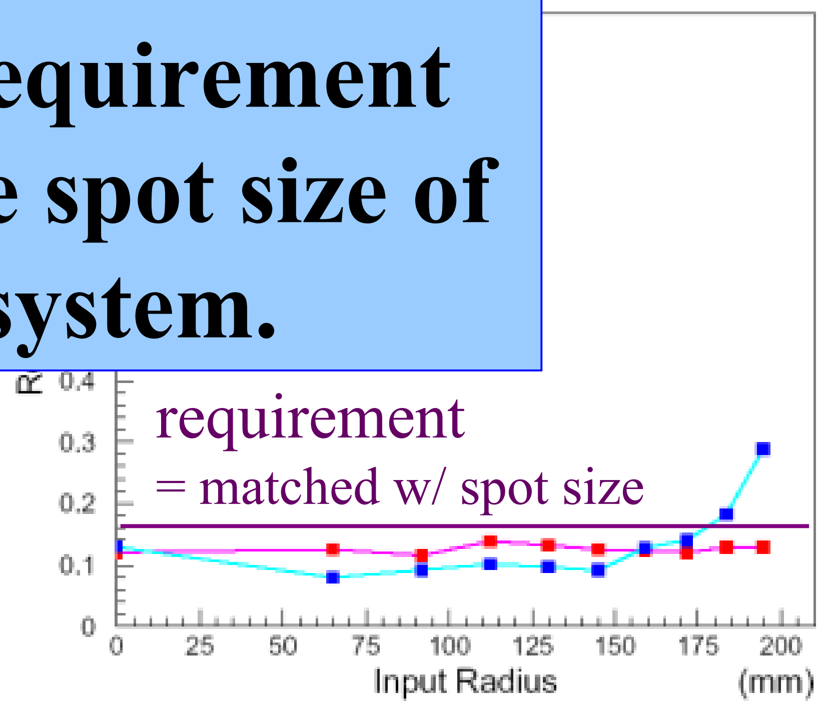
Lens I.I. : Resolution of Electrostatic Lens

Using electron-ray trace simulation

Position and supplied voltage of electrodes have been optimized, ... s estimated.



Optimized electric lens meets the resolution requirement matched with the spot size of the optical system.



0 °

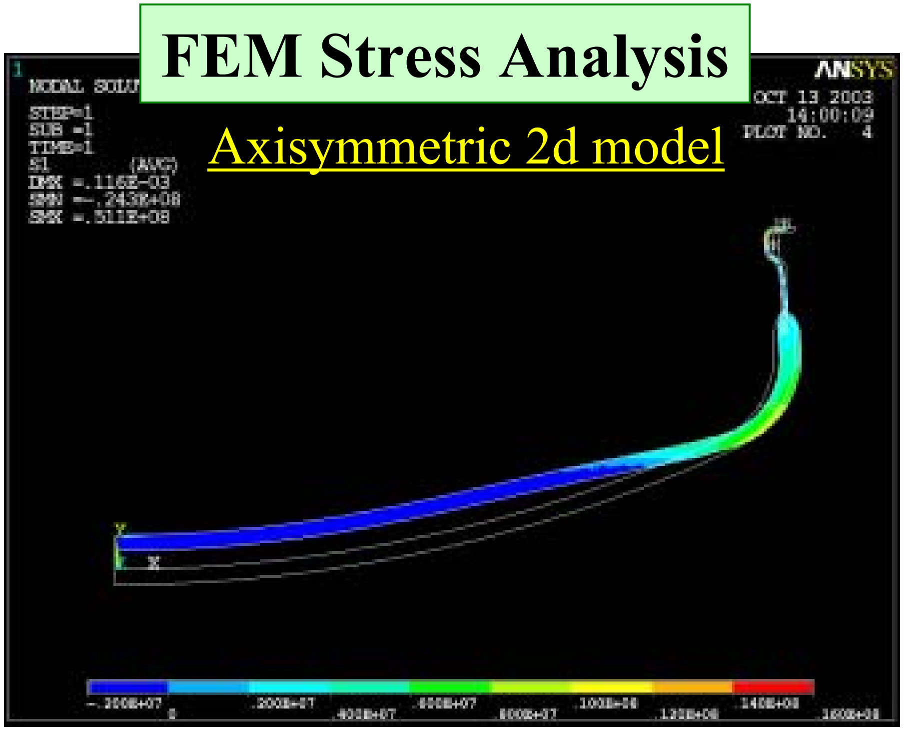
25 °

Lens I.I. : Designing the Input Window

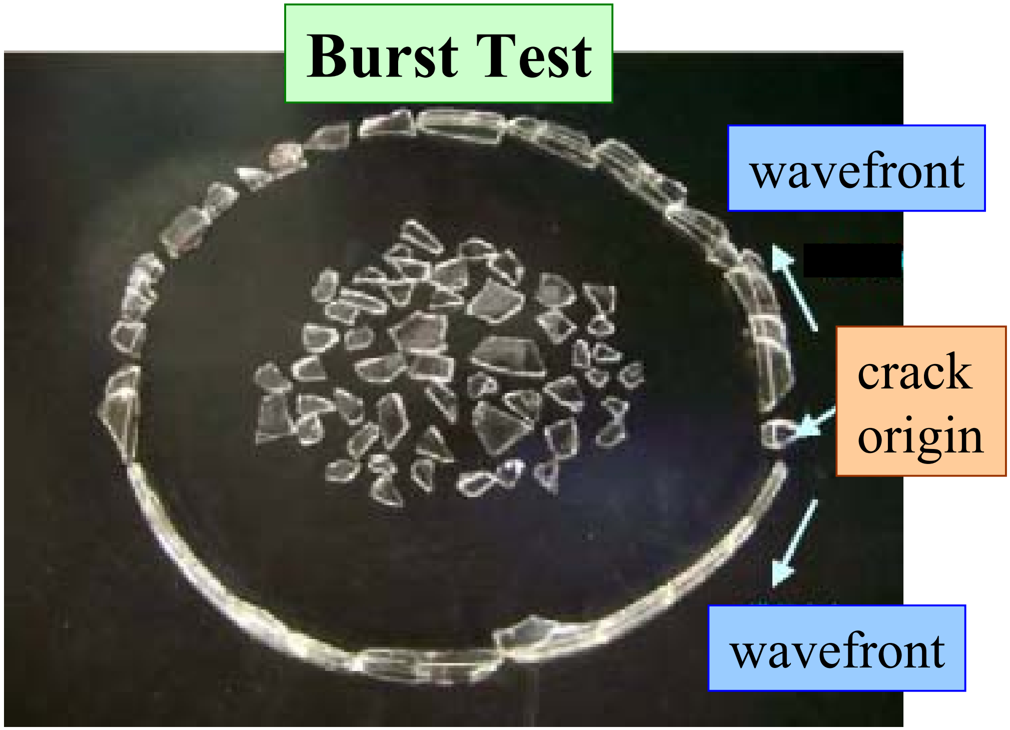
Modification from X-ray II

- **Material:** **Al+CsI phosphor → UV-transparent glass**
- **Shape:** **Partial sphere to match focal surface of the telescope**

Pressure endurance: one of the most critical issue of the input glass



To keep tensile stress below 10MPa



crack origin = the weakest point

➡ Design of input window was fixed.

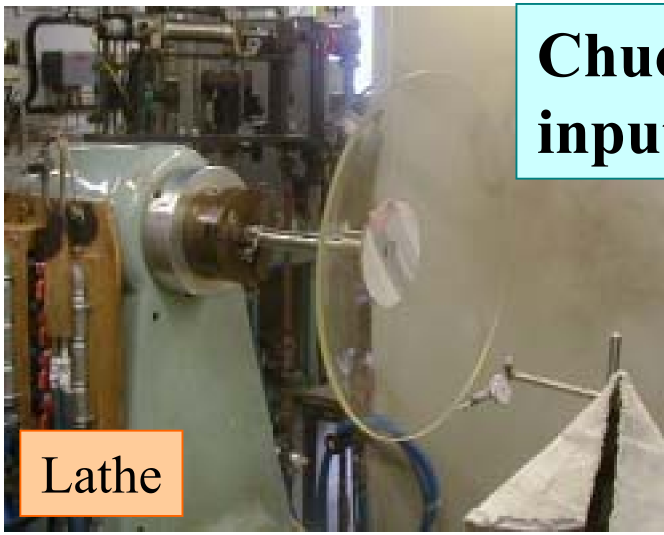
Lens I.I.: How to Make Input Window (1)

"Seed" of input glass

A "seed" is blowed into a mold, and then took out from the mold.

Only his part will be used as a "input window".

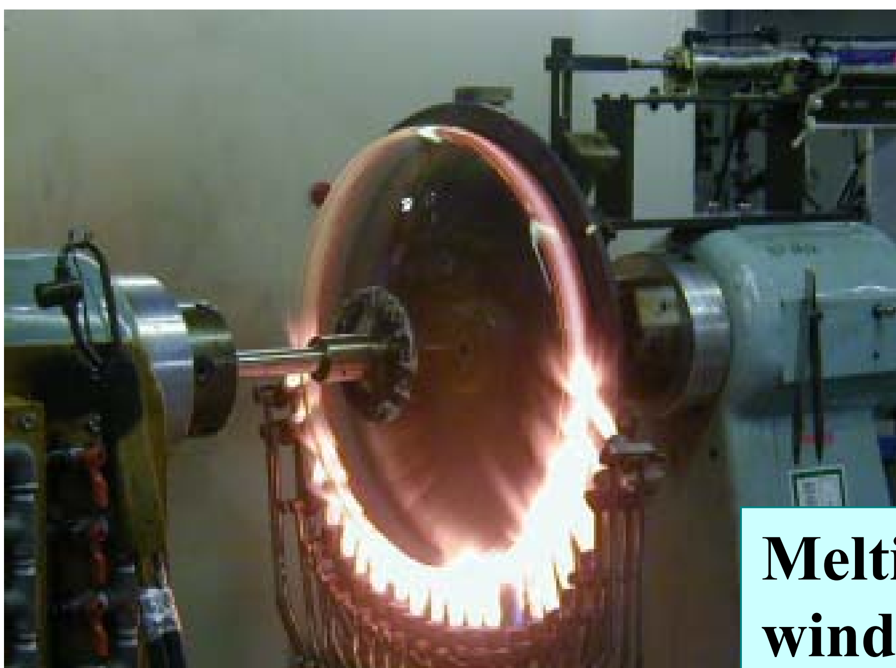
Lens I.I.: How to Make Input Window (2)



Chucking of a input window

Kovar ring welded to I.I. tube.

Final fire polishing



Melting and bonding the input glass window and the Kovar-ring part.

Lens I.I.: Current Status of Input Window

Finished Sample (Polished)

Setup of the pressure endurance test:
Pressurizing after pumping the inside.

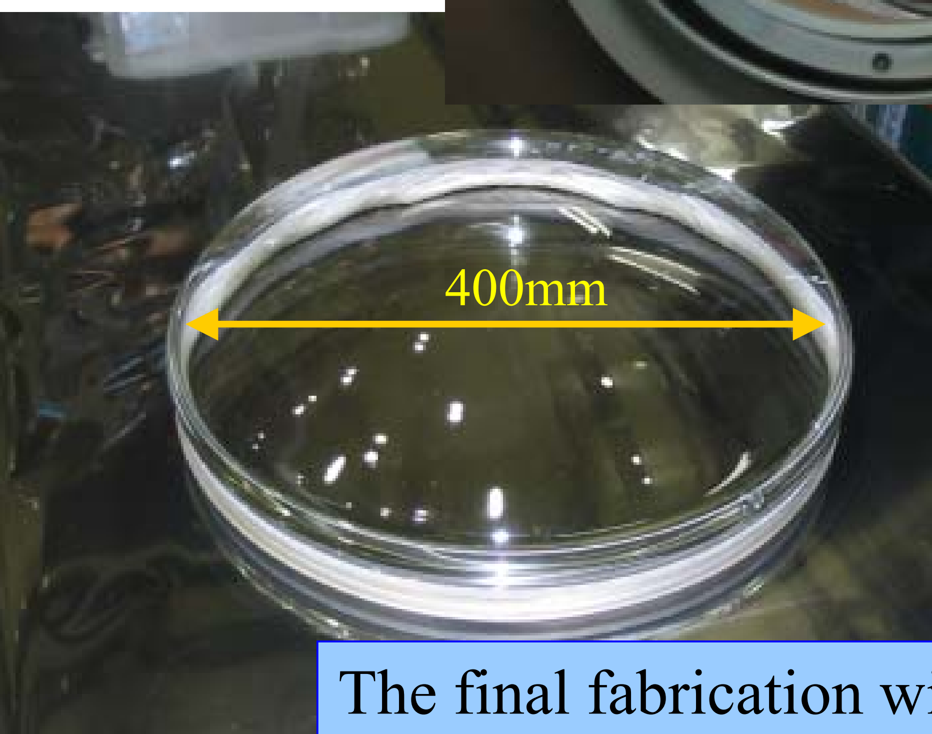
<u>**Evaluation of pressure endurance**</u>:

Maintain 5 minutes under the pressure of 3 atm.

⇒ ～50-years endurance

Sufficient Pressure Endurance

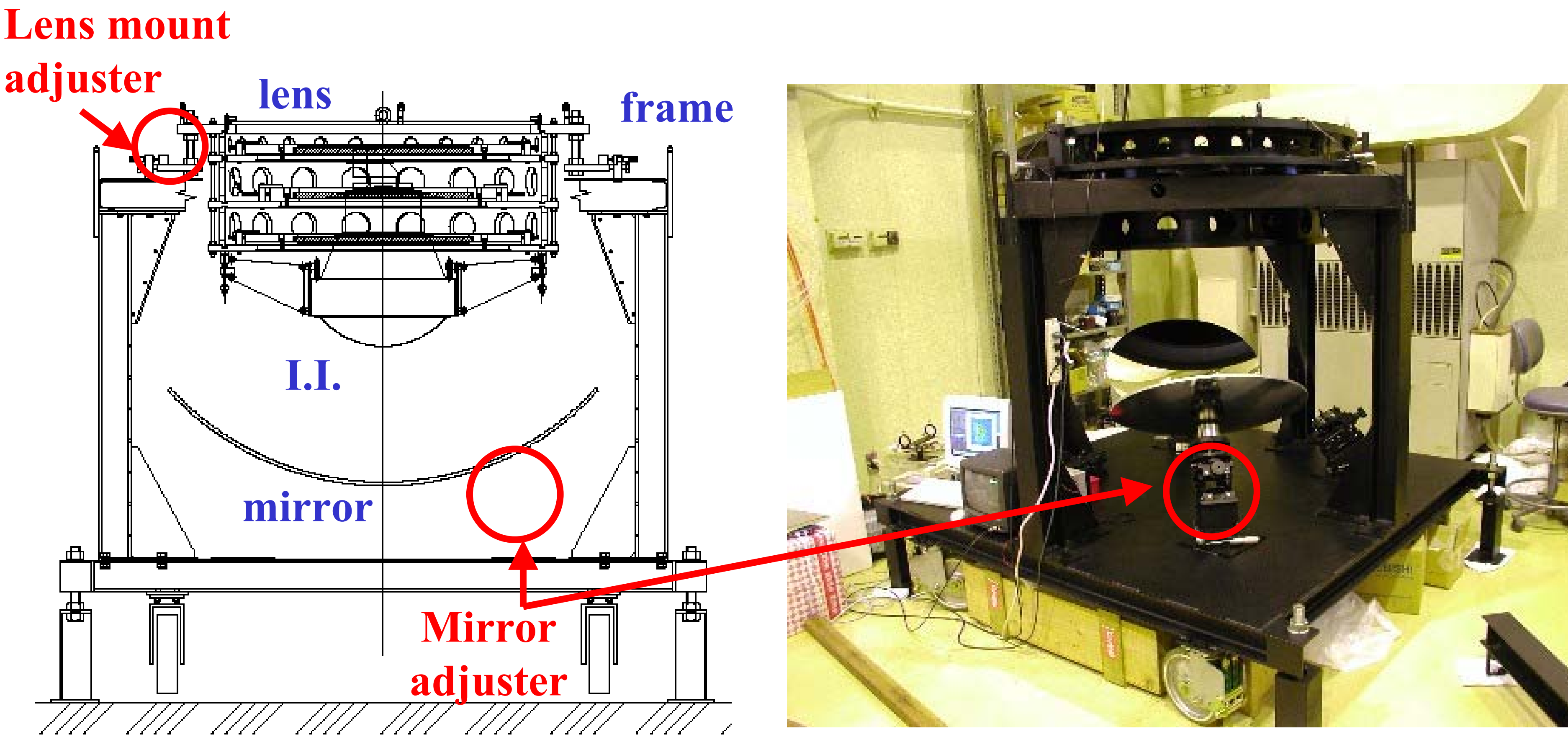
R&D Status : Construction of Lens II



The final fabrication will be carried out soon.

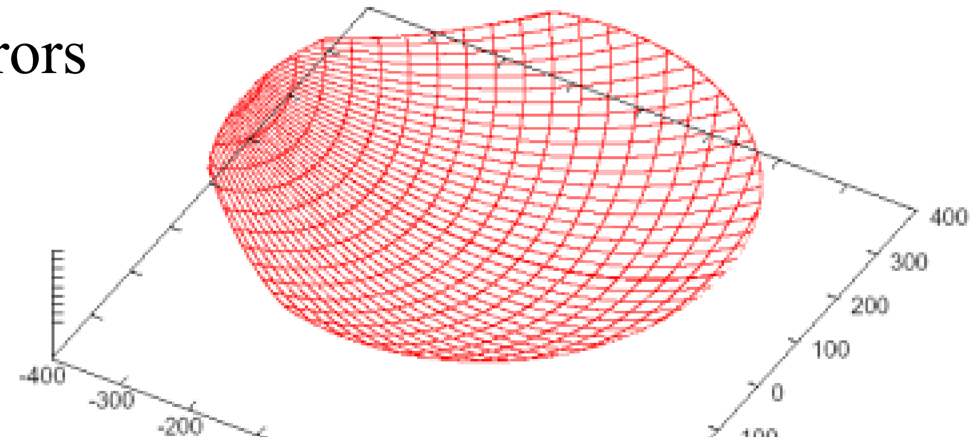
R&D Status : Sub-Telescope

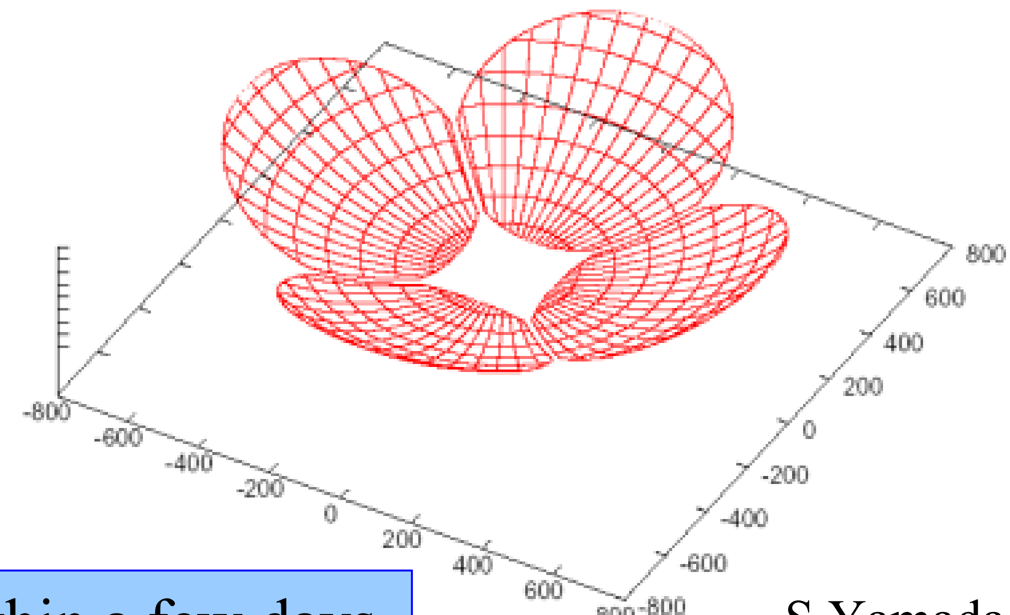
<u>Integration test of optical system</u>
- **Achieve 1 arcmin resolution**
- **Develop fabrication processes**



Sub-Telescope: Mirror Arrangement

1. Cut to mount 4 segment mirrors
2. No deterioration after cut



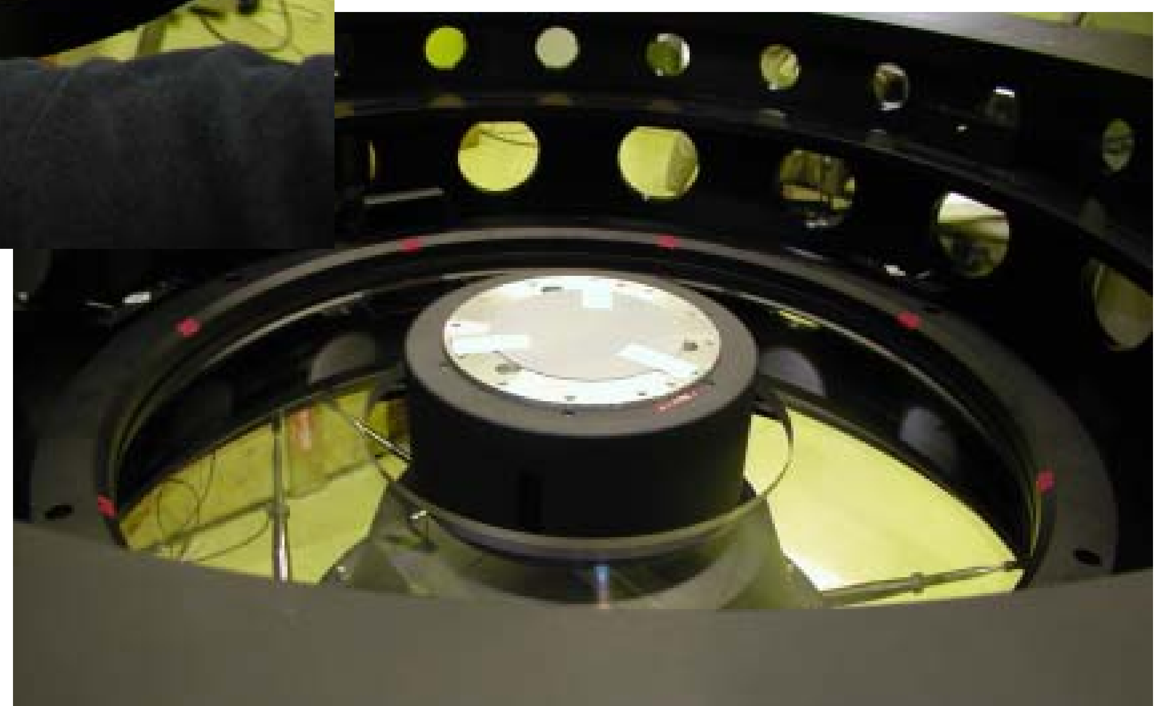


All mirrors will be mounted within a few days.

S.Yamada

Sub-Telescope: Φ630mm Lens Mount

Lens holding



Lens mounting

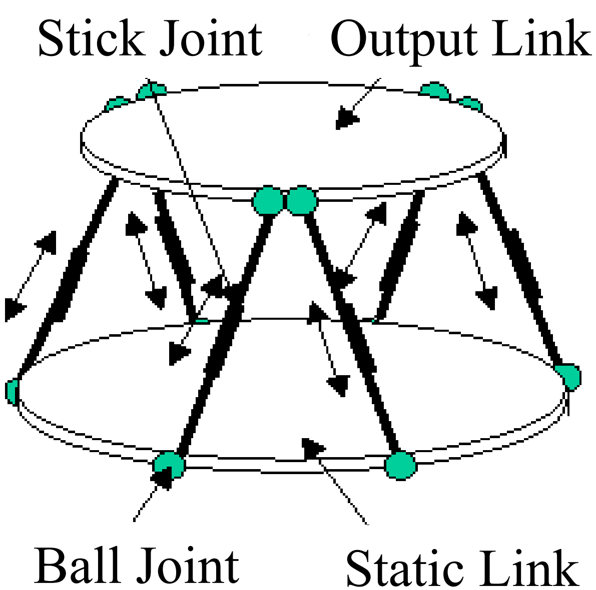
Sub-Telescope: Lens I.I. Mount (1)

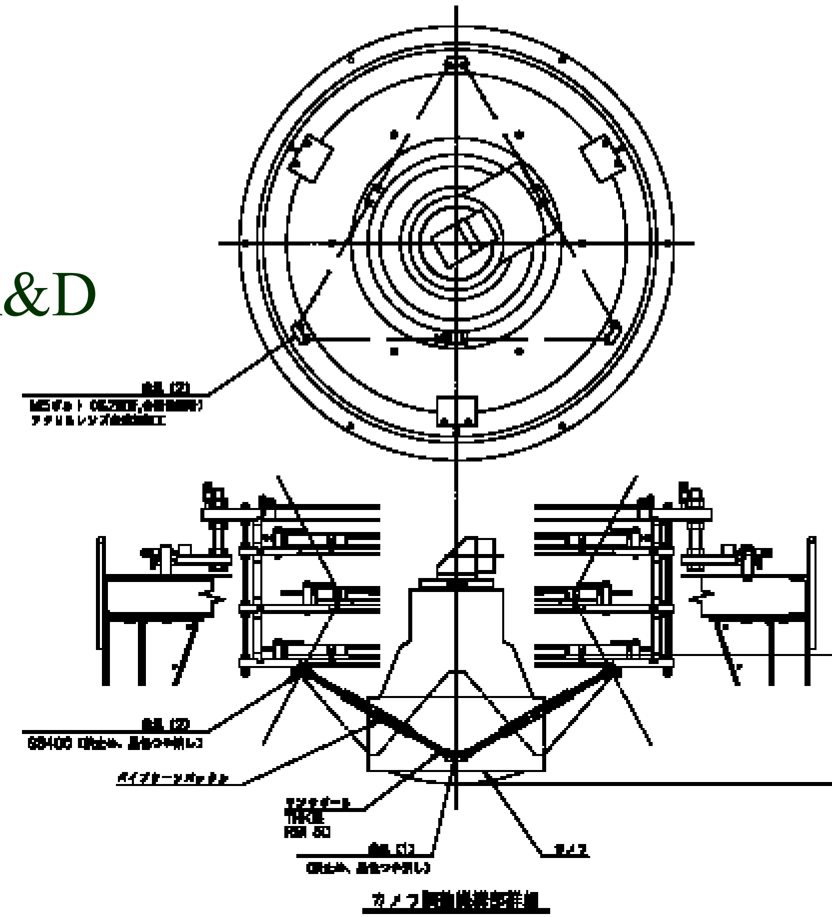
Requirements:

- Low obscureness
- Wide tuning range

⇒ Trying **Schwart Platform** as a R&D

Adopted in "Subaru" Telescope





Focal surface $(x, y, z, \theta, \phi, \rho)$ ⇔
Stick length (L1,L2,L3,L4,L5,L6)

Sub-Telescope: Lens I.I. Mount (2)

Utilizes commercial parts:
Ball and stick joints

Lens I.I. mounting test:
Schwart Platform works well.

Summary

Optical System

We have adopted the modified Baker-Nunn optics which has the capability to achieve 1 arcmin resolution within the whole FOV of 50^{o} x 50^{o}.

R&D Status

- Mirror : prototyping OK. Mass production preparation
- Corrector lens : small prototype is OK. Φ630 mm lens has been produced.
- Lens II : components design is fixed, and the fabrication will be carried out soon.
- Sub-telescope : integration test and final estimate of resolution of Ashra optics.

Ashra Collaboration

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Ashra Project Plan

Ashra-1 PI
M.Sasaki

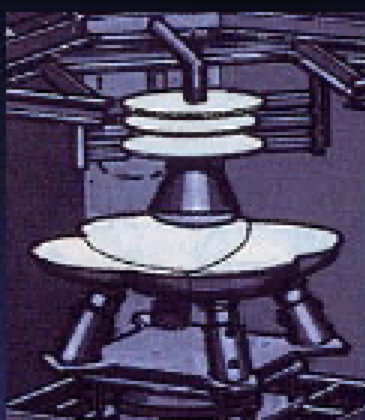
2002	2003	2004	2005	2006	2007

phase 0
R&D

phase 1
Pioneering

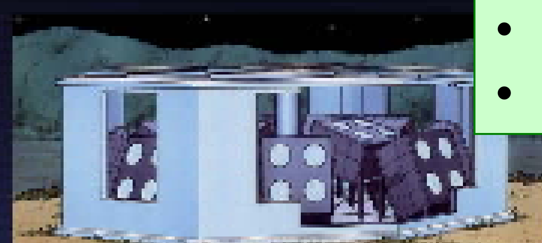
phase 2
High Statistics

sub-telescope



prototype in labo.

1 + 1/3 stations



2 Mt.s on the Hawaii Is.

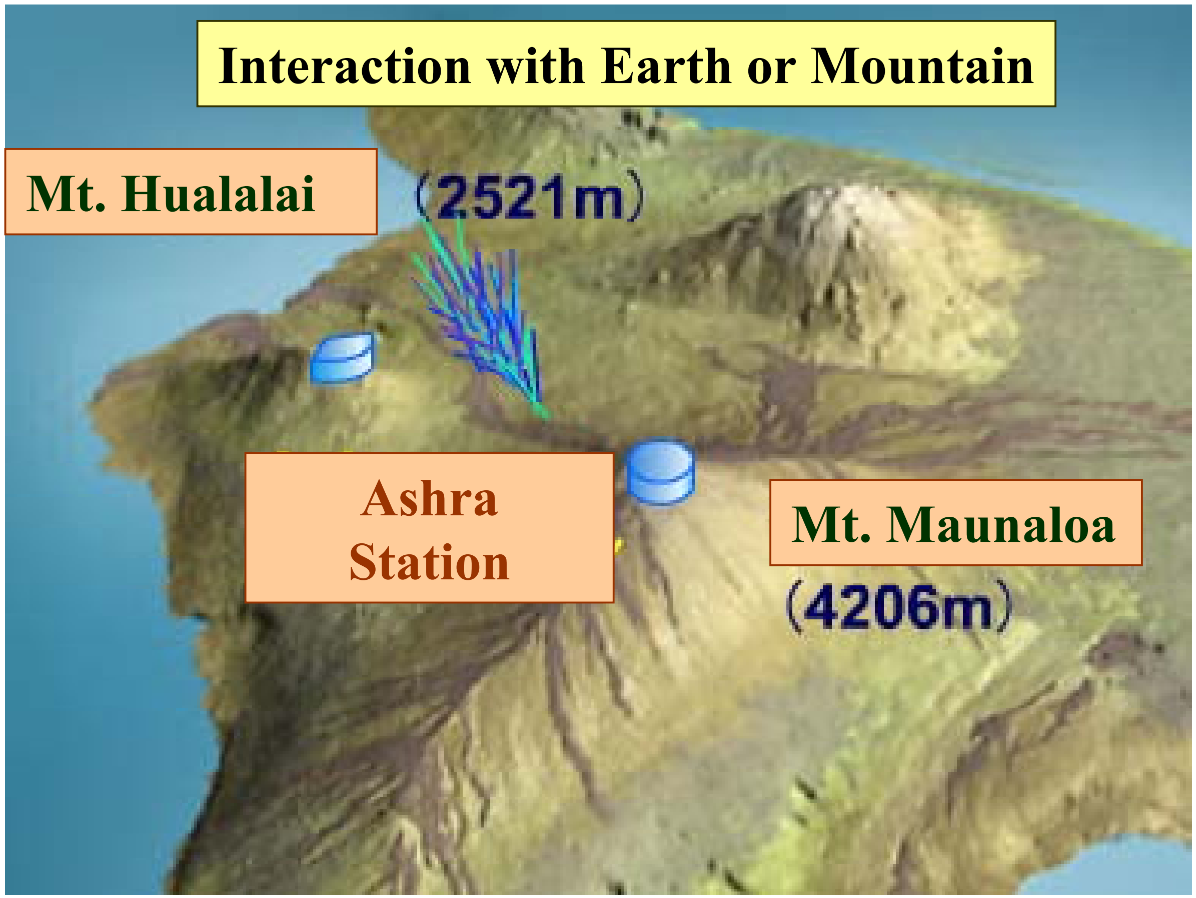
Expected Event Rate for VHEν

- GRB : 2 /yr
- AGN : 26 /yr
- GZK : 2 /yr

3 Mt.s on the Hawaii Is.

Ashra-1

Earth and Mountain Skimming ν_τ



Ultra Long Baseline Neutrino Oscillation

- $\nu_e : \nu_\mu : \nu_\tau = 1:1:1$
- search for $\delta m^2 > 10^{-17} eV^2$
- pseudo-Dirac-ν? (Beacom et al.)

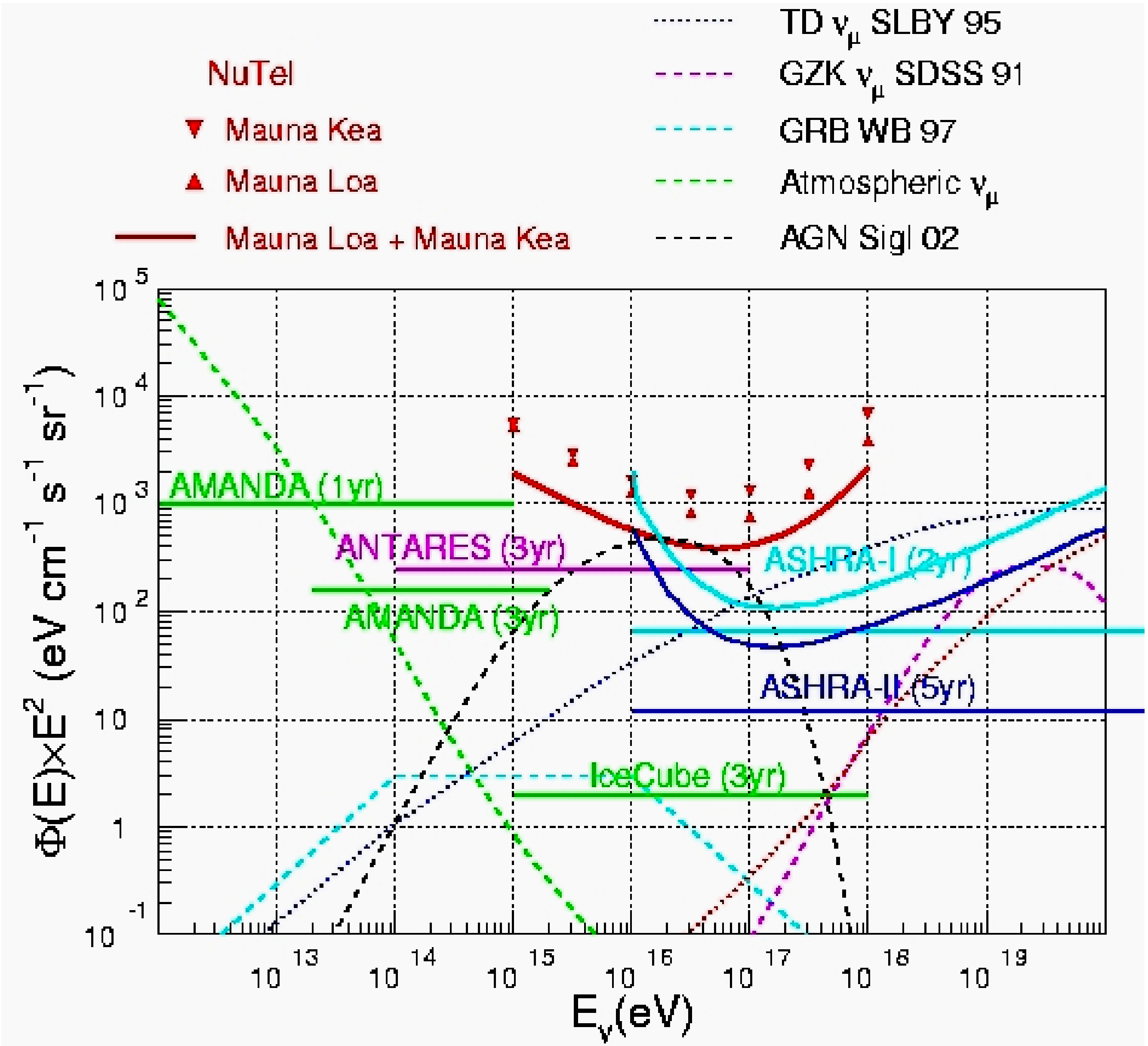
Tau Dominant

- **Tau range ~10km**
- **Muon range ~1km**
- **1200$\nu_\tau \Rightarrow$ 1τ** ($>1/10 E_\nu$)
- Maunaloa Mass $>1000 Km^3$weq

Arrival Direction Conservation

- **High Lorentz boost**
- **Accuracy <1arcmin** (E_ν **>10PeV**)

Ashra EHEν Sensitivity



<u>curve:</u>
differential flux corresponding 1event/yr/energy decade

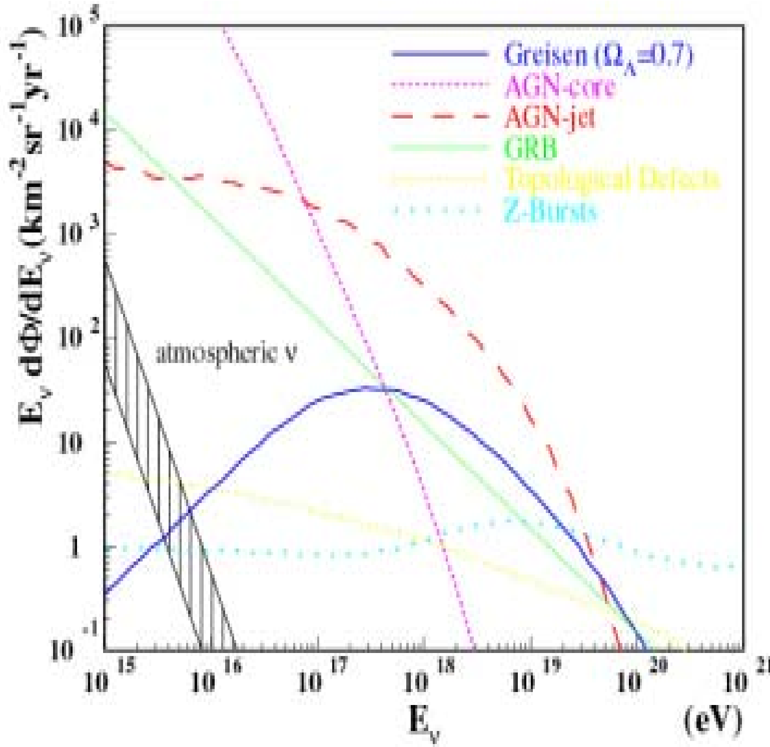
<u>line:</u>
90% CL for E^{-2} flux

Comparison

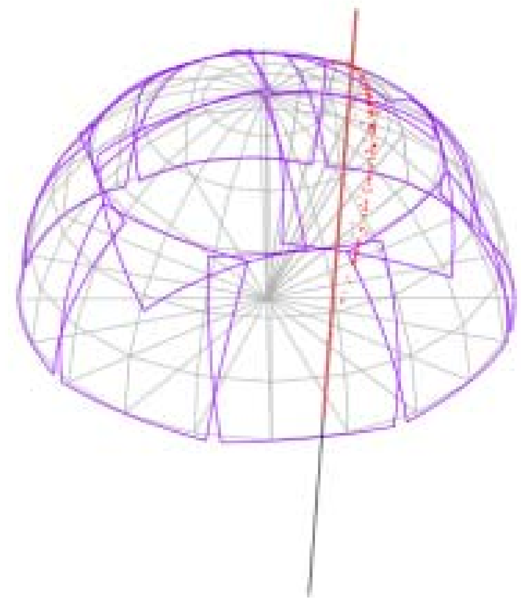
Detector	AGASA	HiRes	ASHRA-1	Auger	ASHRA-2	IceCube
Obs. Start	1990	1998	2005 ?	2005 ?	2007 ?	2010 ?
Method [Readout Device]	Gnd [PMT]	Fluo. [PMT]	Fluo. + Cerenkov [II+CMOS]	Gnd + Fluo. [PMT]	Fluo. + Cerenkov [II+CMOS]	Water Cerenkov [PMT]
Dir. Accuracy(°)	2~3	0.5~0.8	0.01~0.02	1.0~2.0	0.01~0.02	0.4
Protons / yr ($>10^{20}$eV)	1	6	15	41	34	--
ν s / yr AGN($>10^{16}$ eV) GZK($>10^{19}$ eV)	 -- --	 <1 --	 11 1	 27 --	 26 2	 16 --
Cost ($)	2M	6M	5M	50M	12M	260M

Excellent cost-performance and originality

MC performance for EHE ν

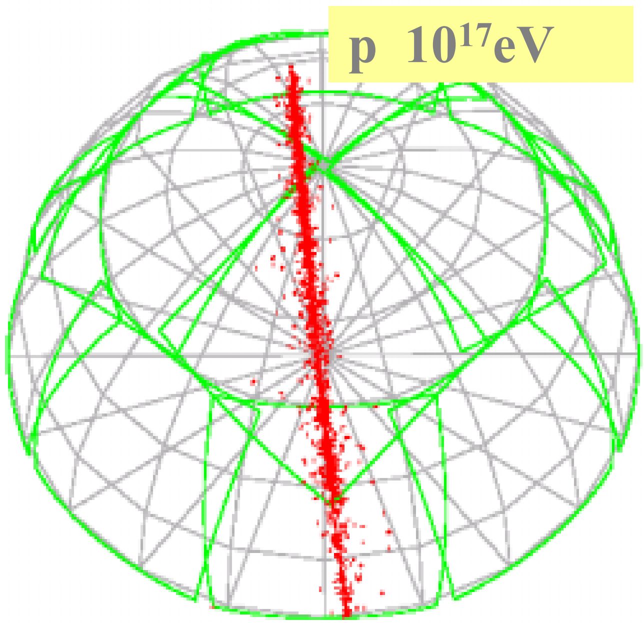


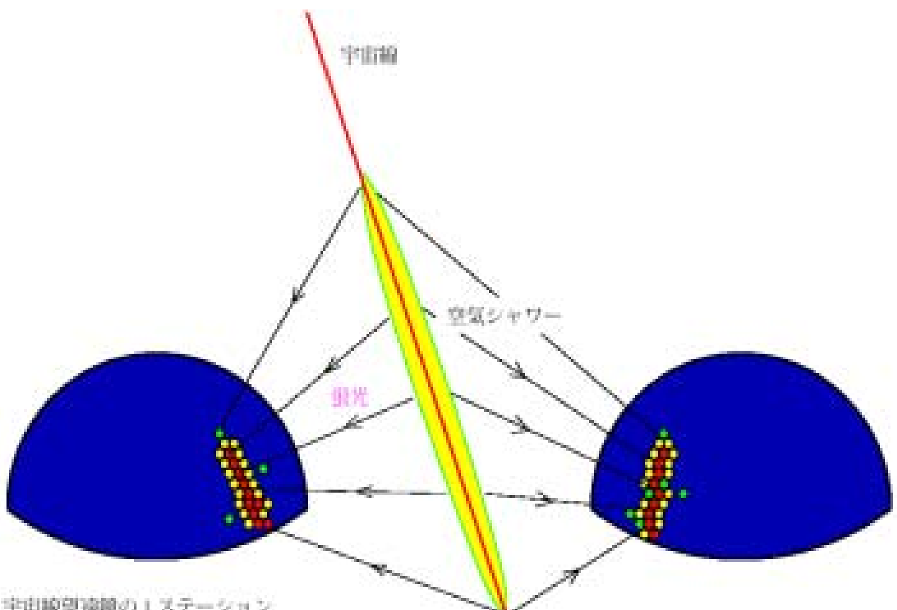
Earth-skimming tau ν

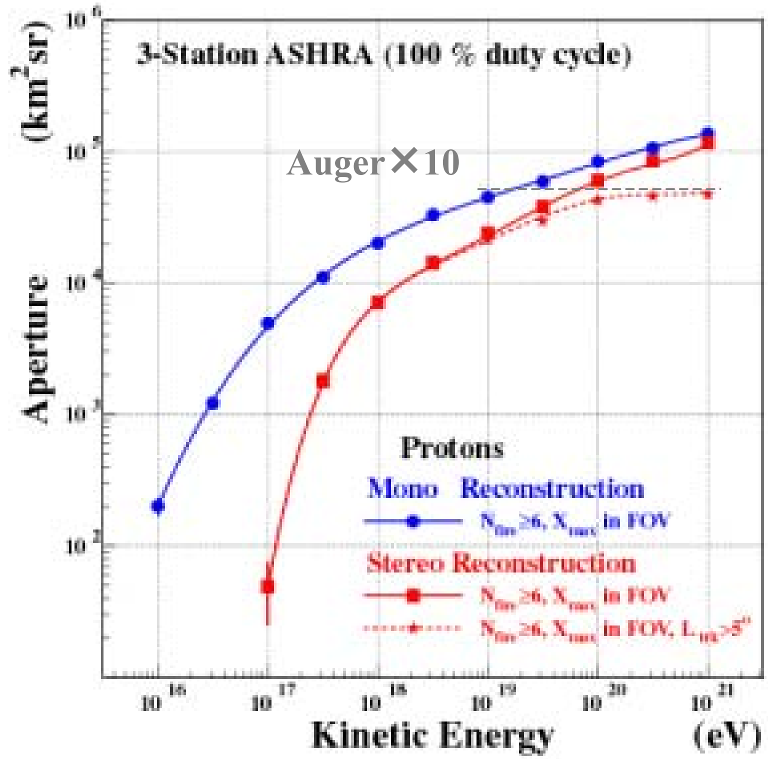


Model	Events/yr
GZK ν	1.9
AGN-jet	25.9
AGN-core	5.4
GRB	1.6
TD	0.3
Z-burst	1.3

MC performance: EHECR



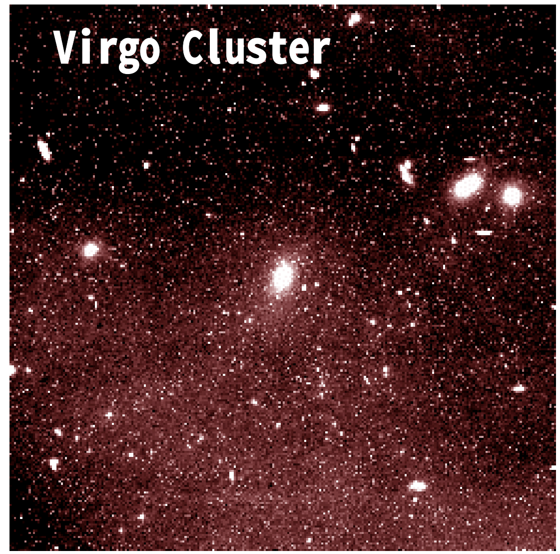




Stereo Event Rate (duty10%)

Threshold	Events/yr
10^{19}eV	1324
$10^{19.5}$eV	259
10^{20}eV	34

Advantages of Fine Imaging



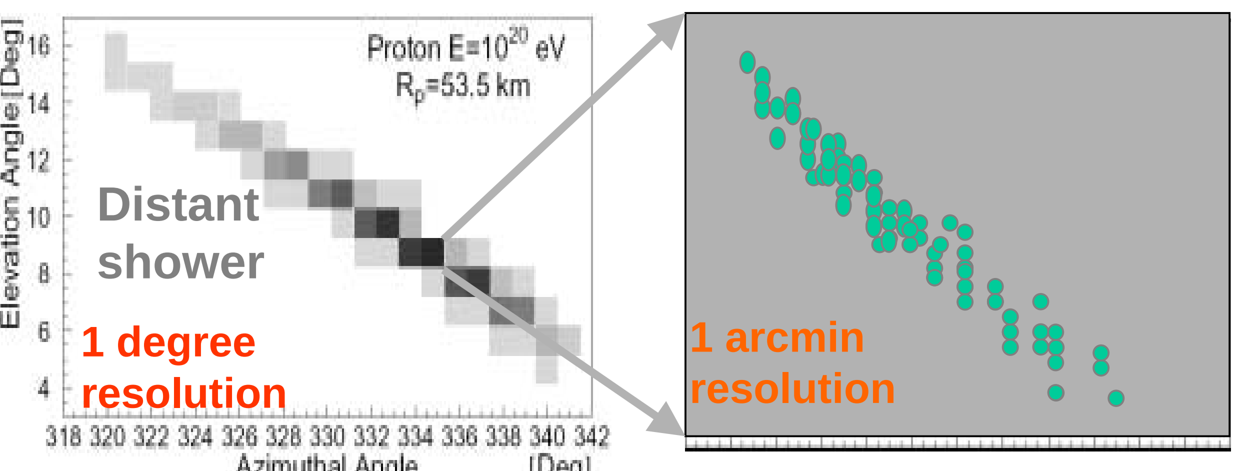
1 arcmin resolution

Equivalent to human "eye" resolution

Observation of GRB optical flash (Ioka's suggestion)

Accurate estimation of arrival direction

Identification of appearance from earth or mountain



Sensitivity up!

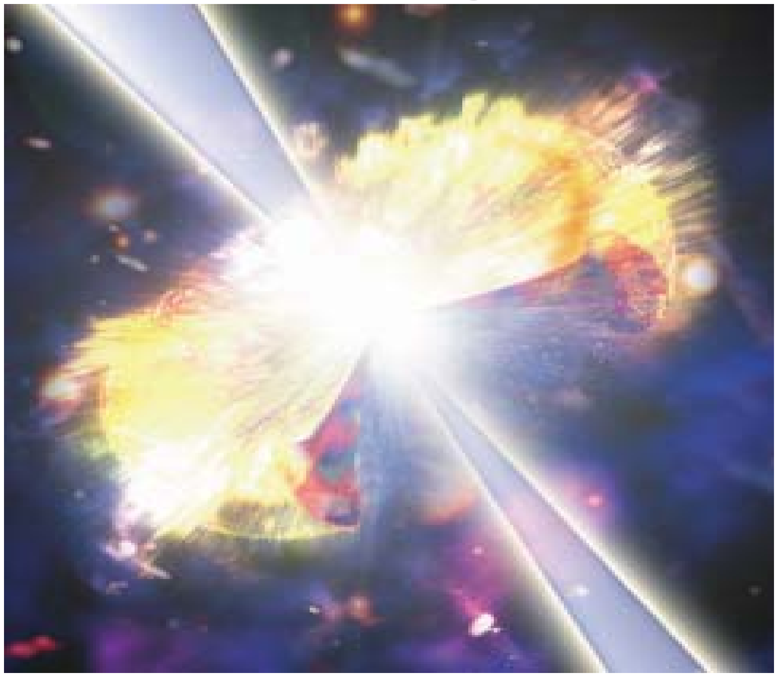
trigger S/N

imaging of distant shower

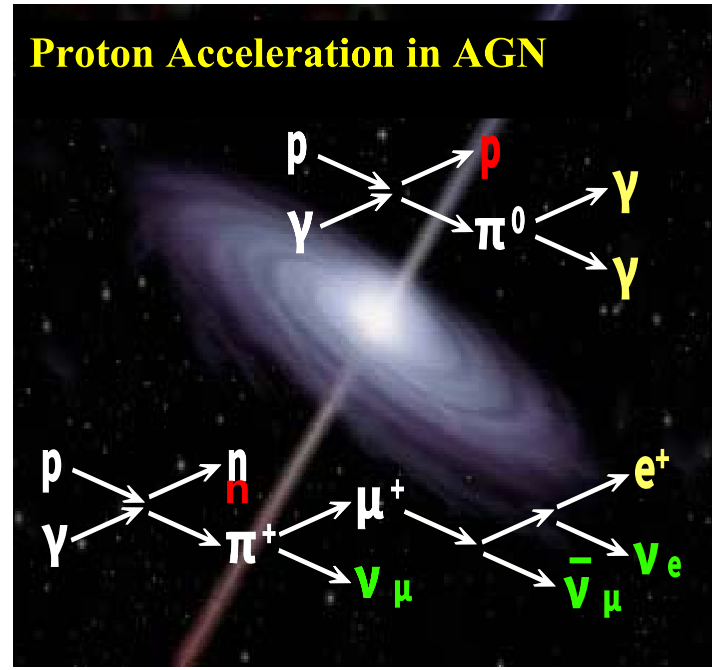
Ashra-1 PI
M.Sasaki

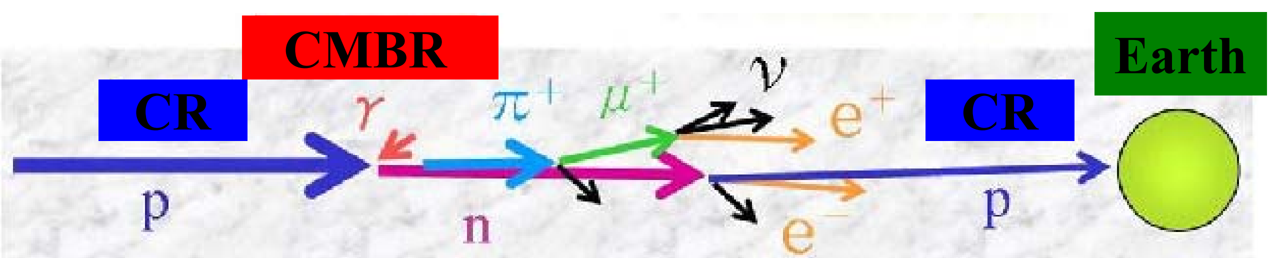
Very High Energy Neutrinos
(VHE ν's)

Gamma Ray Burst



Active Galactic Nuclei





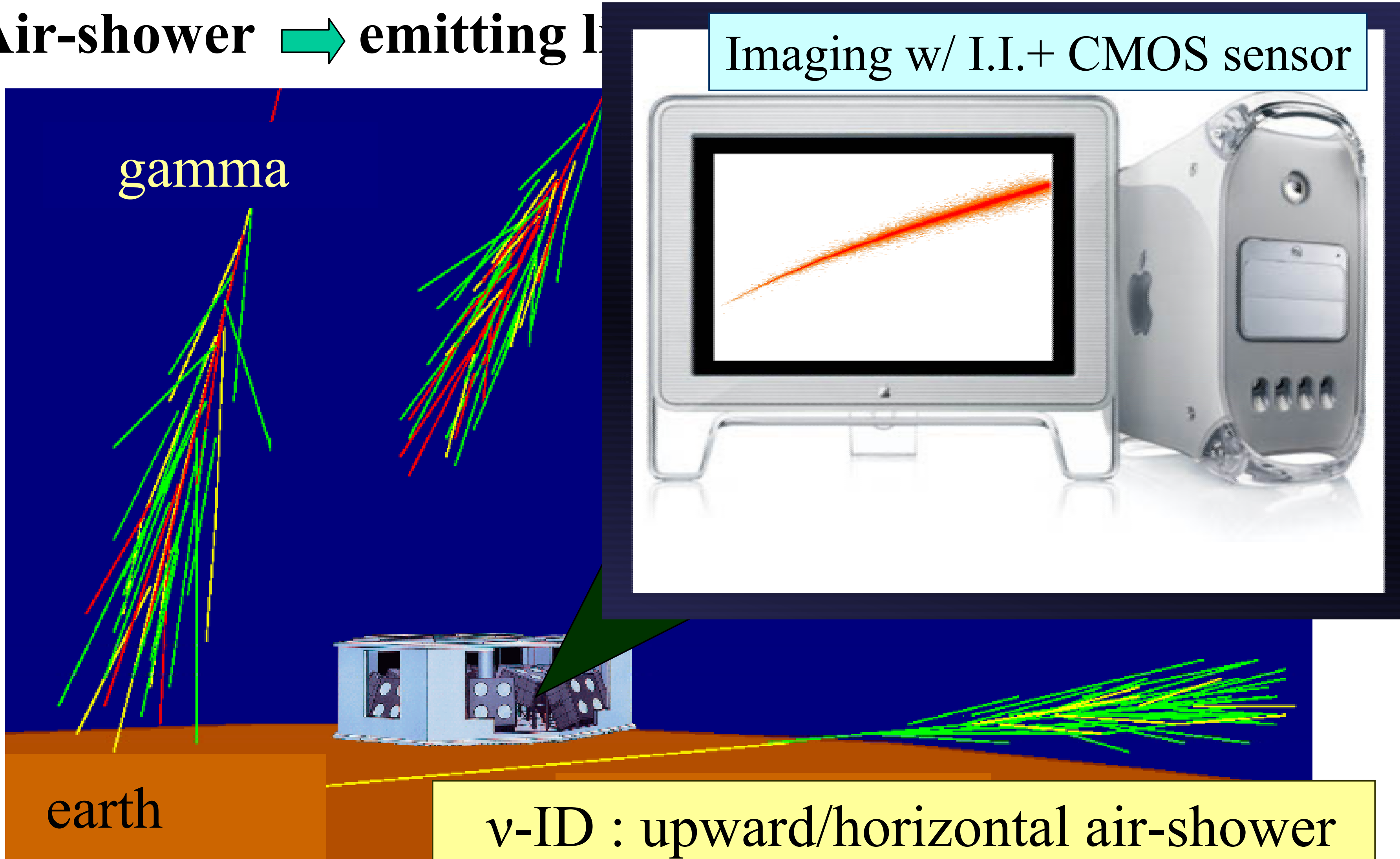
GZK Mechanism

Studying origin and propagation of VHE cosmic rays

Detection of VHE ν's

Ashra-1 PI
M.Sasaki

Air-shower ➡ emitting l



New Eye for Particle Universe

Ashra-1 PI
M.Sasaki

Key Technology:

9M-pixel CMOS sensor
covering 50deg FOV

Leading Features:

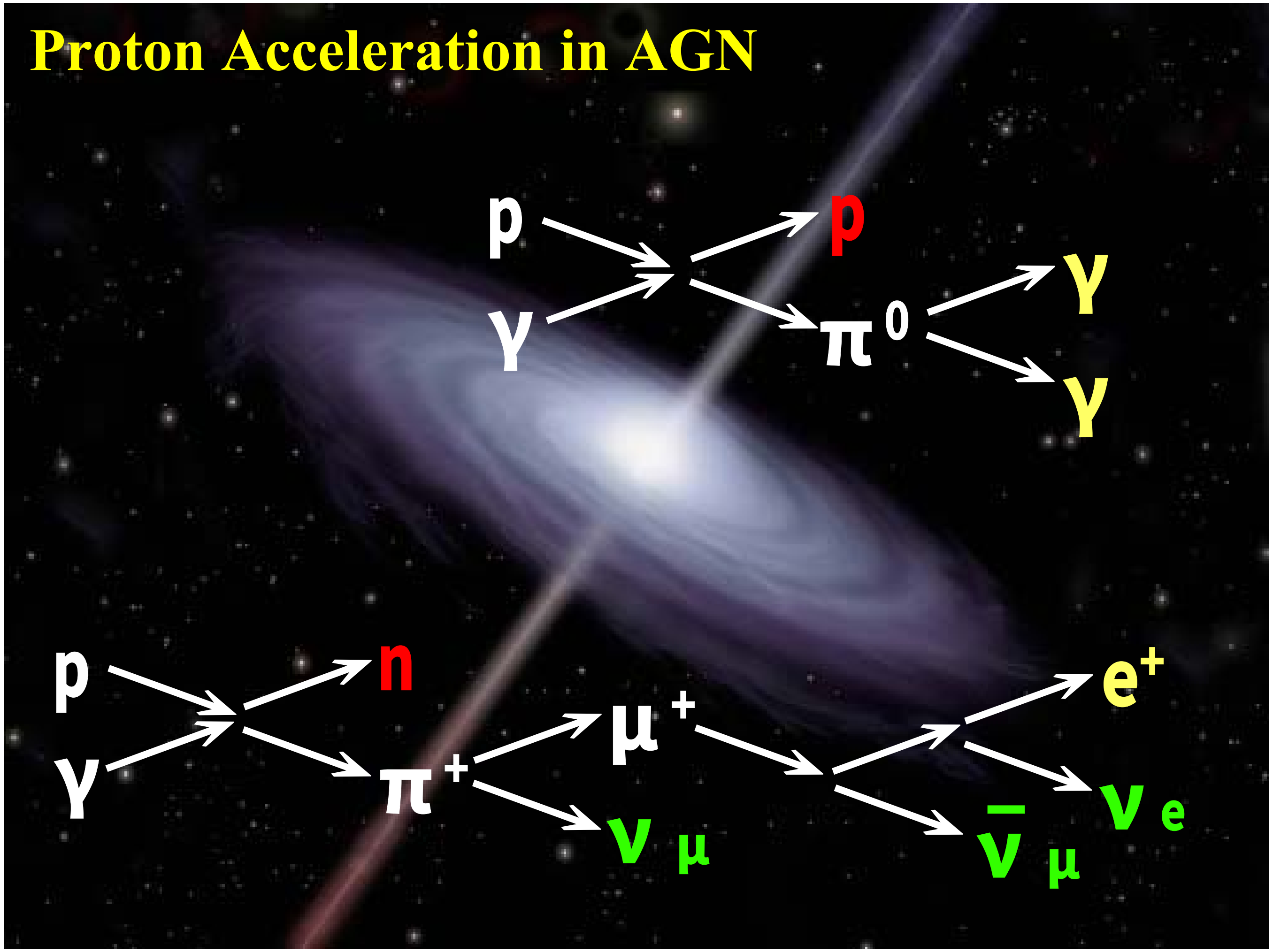
All-sky Survey
=> Discovery Potential

1arcmin directional accuracy
=> Source ID

Simultaneous Detection for
Cerenkov & Fluorescence
=> Physics ID

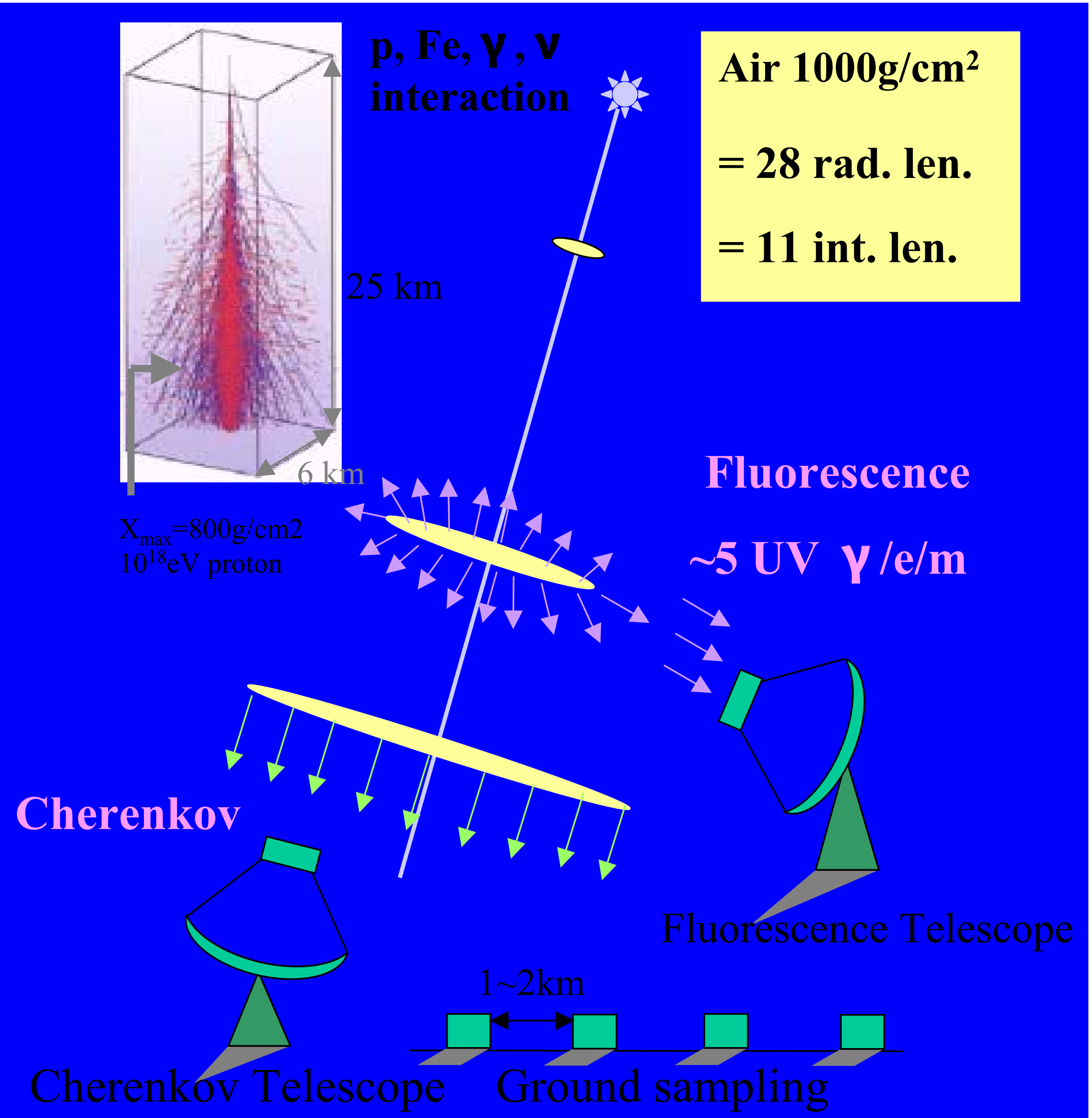
Pioneer Experiment for VHE Particle Astronomy: Ashra-1

Direct Detection of VHE ν



To identify proton acceleration, detection of VHE neutrinos plays the key role.

Detection Technique of EHECR



EHECRs

⇒ interacting at the upper atmosphere

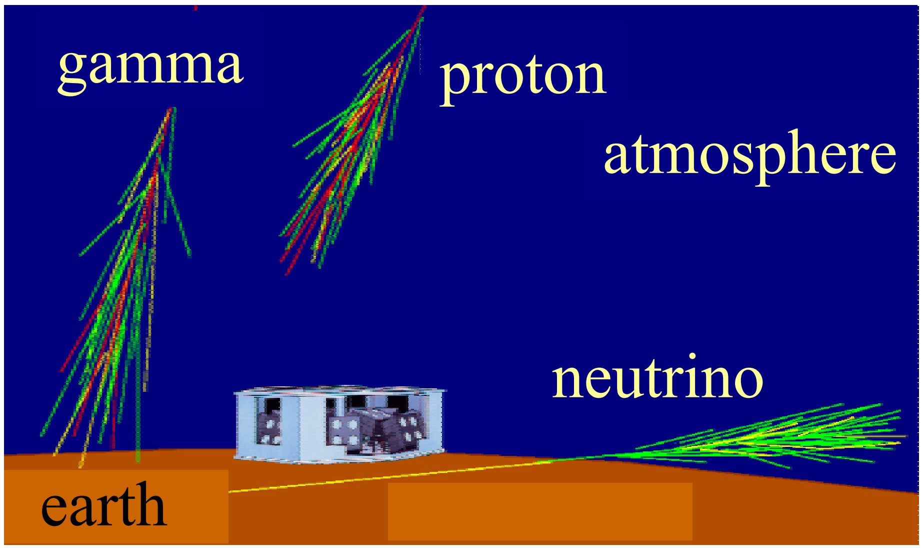
⇒ Air shower

⇒ emitting fluorescence and Cherenkov photons

⇒ gathering lights w/ telescope

Advantages of Fluorescence Technique

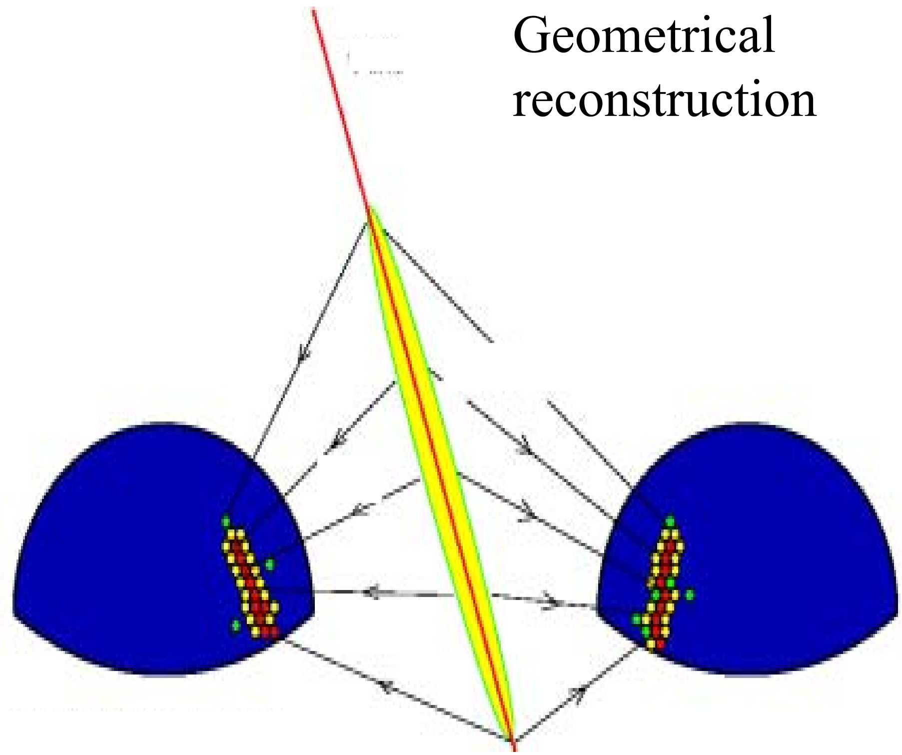
1. Measuring AS longitudinal development



Clear identification of VHE **ν**

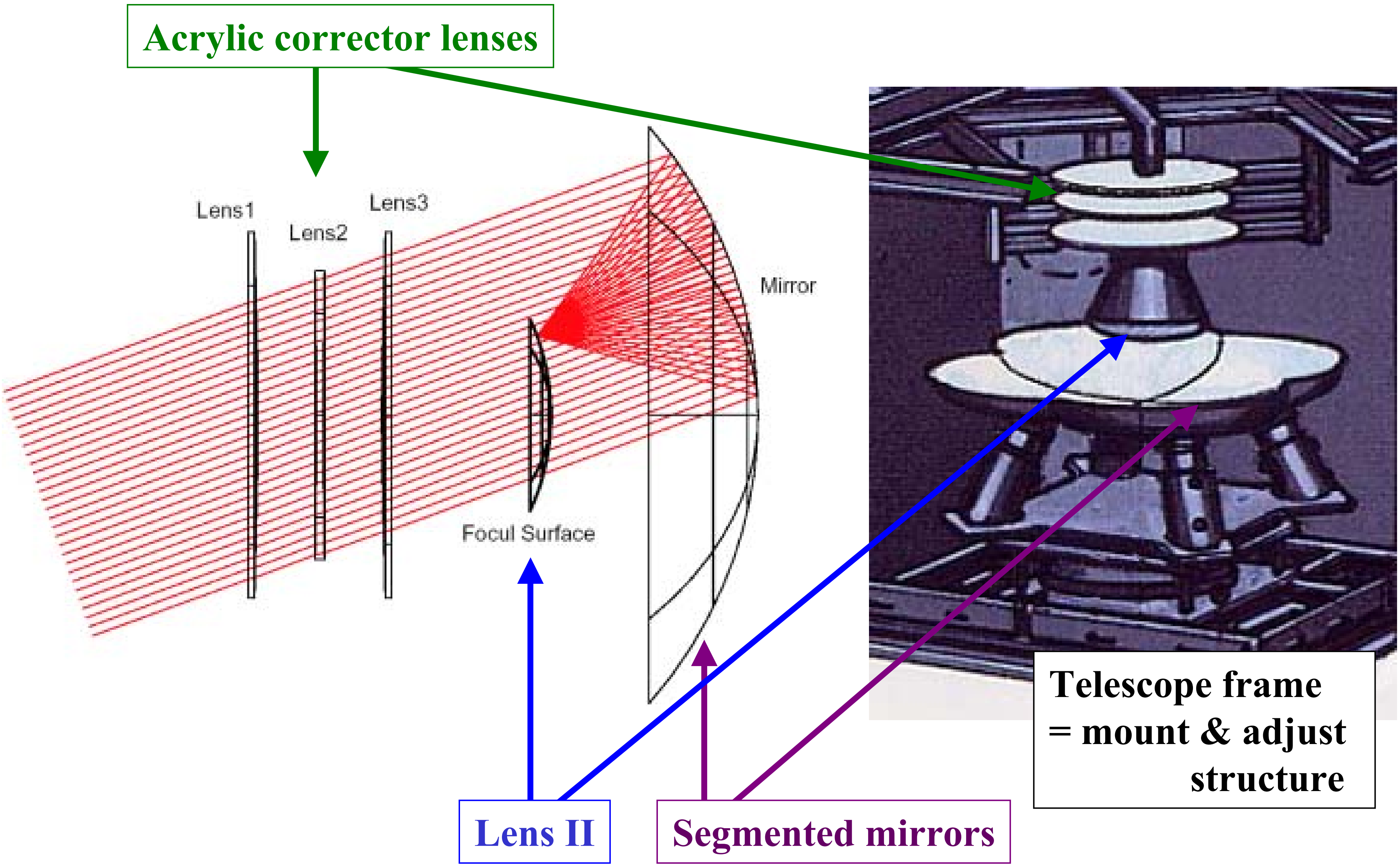
⇒ 1st Observation of VHE- ν

2. Stereo Observation



⇒High-resolution Telescope

Ashra Optics : Components



Ashra Optics : Optimization Method

Optimization parameters: surface shape of corrector lens

Surface Shape:

$$Z = \frac{h^2/R}{1+\sqrt{1-h^2/R^2}} + Ah^4 + Bh^6 + Ch^8$$

Evaluation function:

$$F = \sum_{\theta} \left(\sum_{\lambda} s(\theta, \lambda)^2 \right)^2$$

wavelength

consider fluorescence peak

incident angle

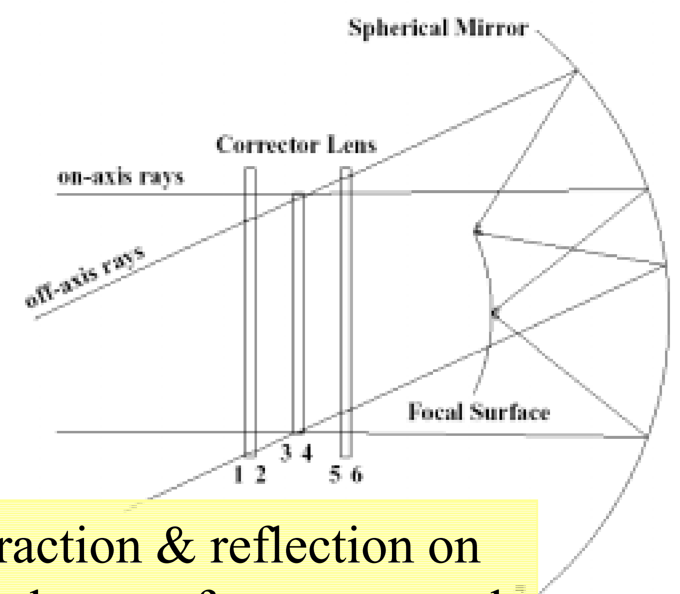
Z: Surface sag

h: radial height

R: curvature

A,B,C: correction term

s(): spot size (RMS)



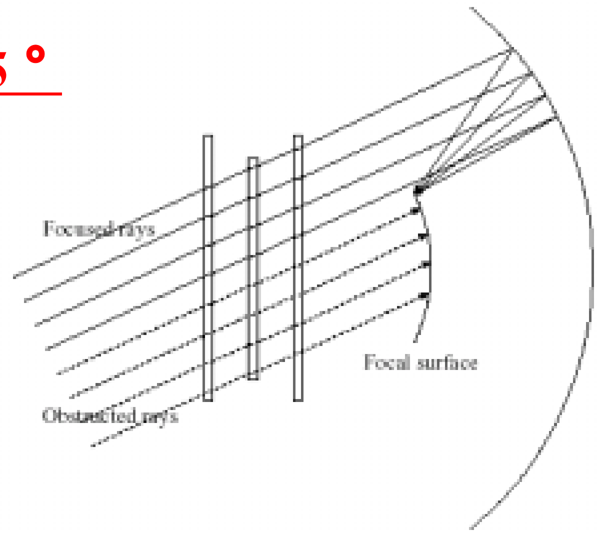
Modified Powell's method

To reduce the # of free parameters, thickness and position of corrector lens are fixed.

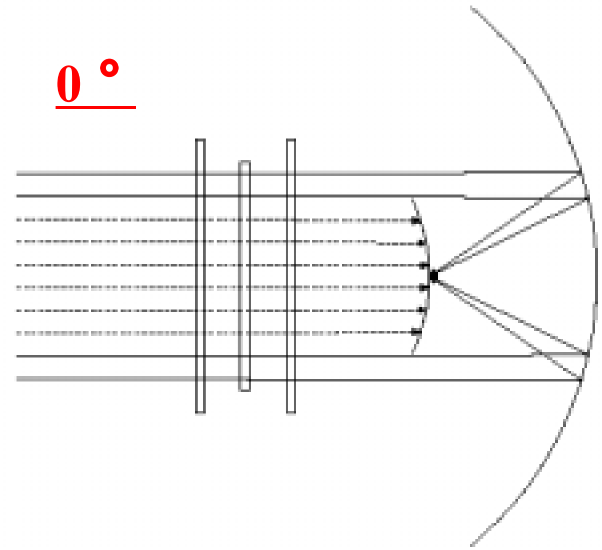
Refraction & reflection on each lens surface are traced.

Region obscured by the focal surface

25 °

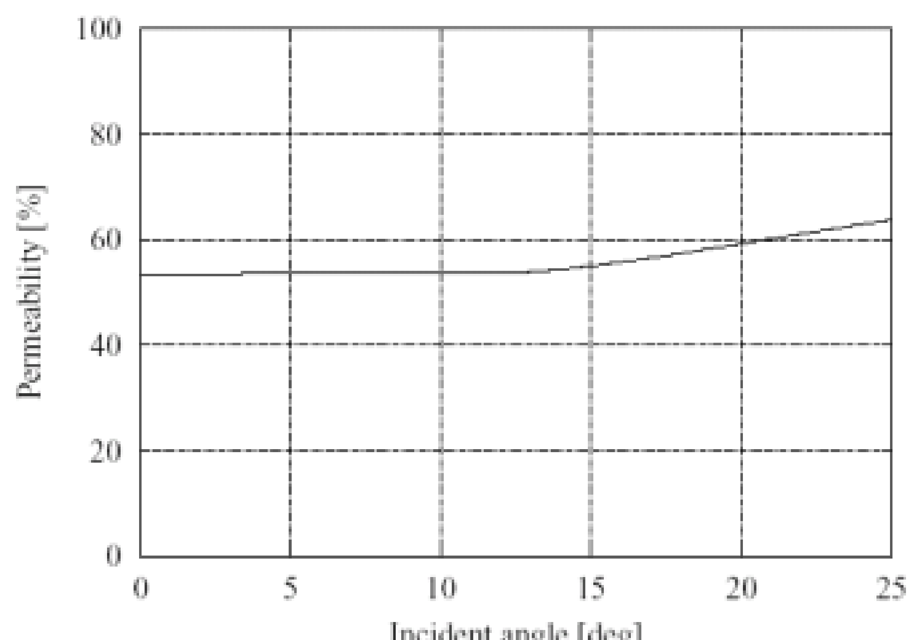


0 °



Permeability:
Region not obscured
by the focal surface

> 50%

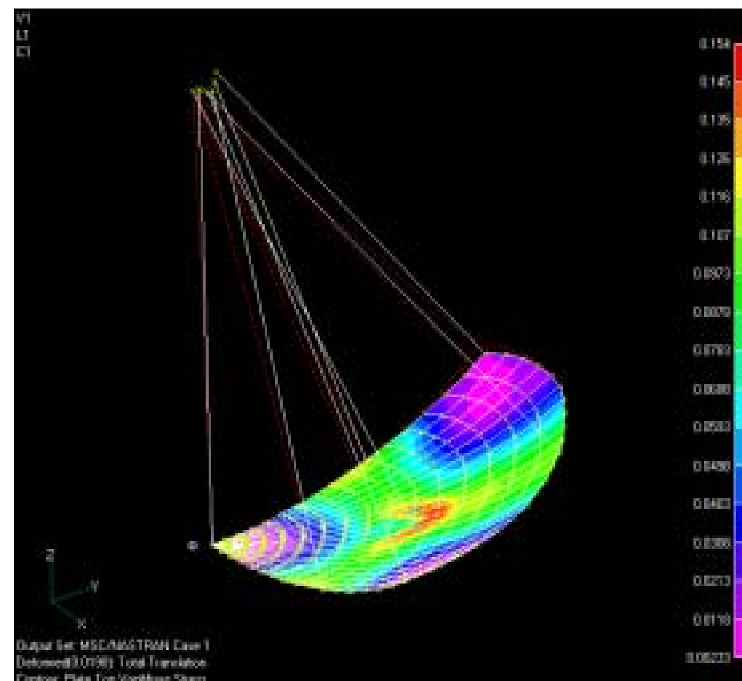


R&D Status : Mirror

Material： Tempax glass (Schott corp.)
Shape： segmented spherical mirror
Process： heating a planar glass on a ceramic mold plate

<u>**Structure Analysis:**</u>
Estimate surface sag caused by self weight using finite element method ⇒
design mounting system and determine thickness of the mirror

Sampling of segmented mirror



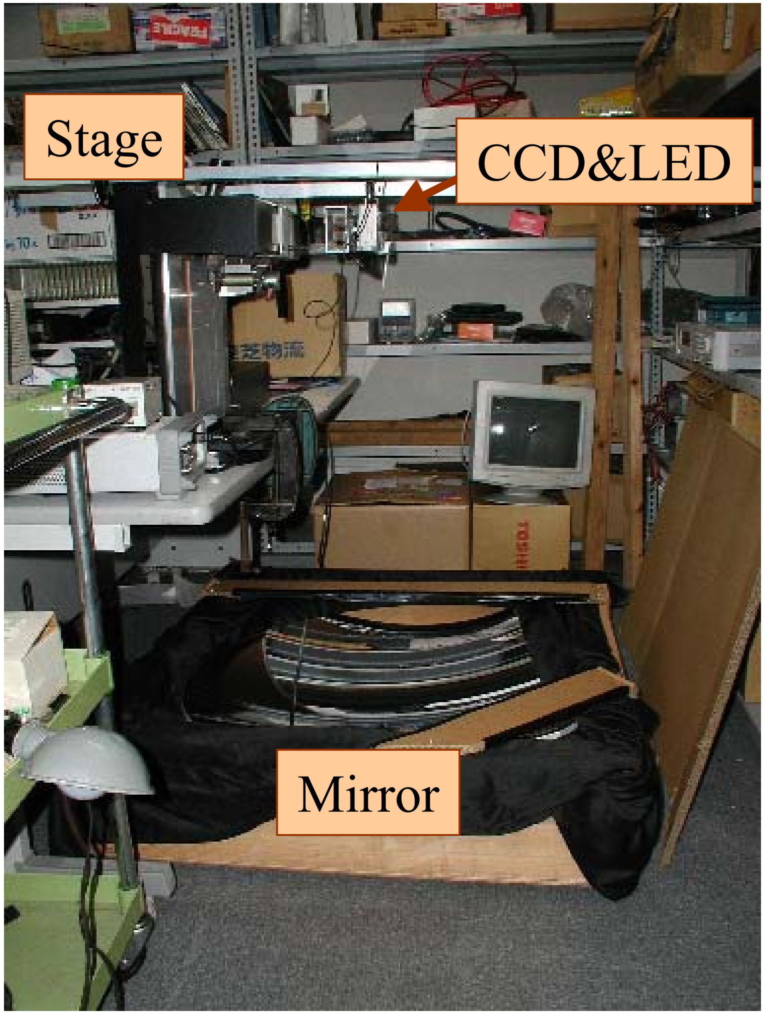
Prototype of Segment Mirror

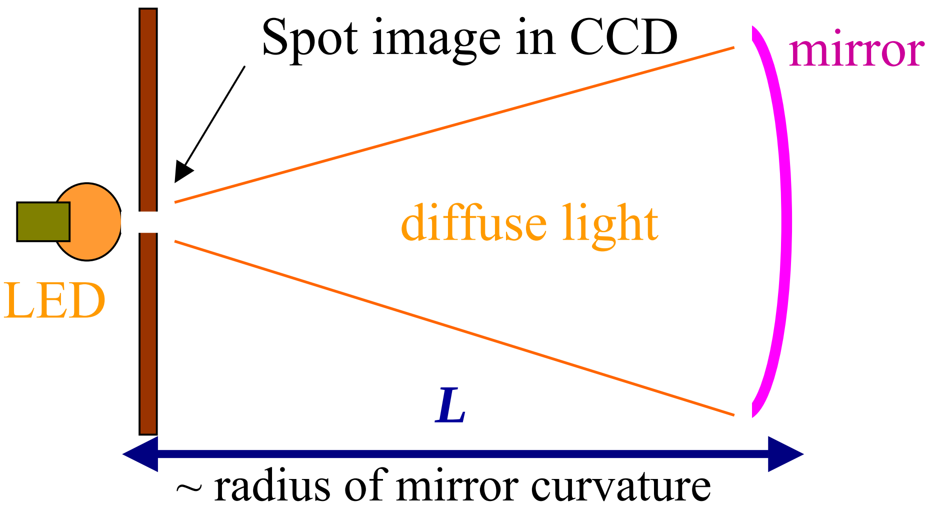
The segment mirror is shaped by heating a planar glass on a ceramic mold plate in the temperature controlled electric oven.

To improve spot size:

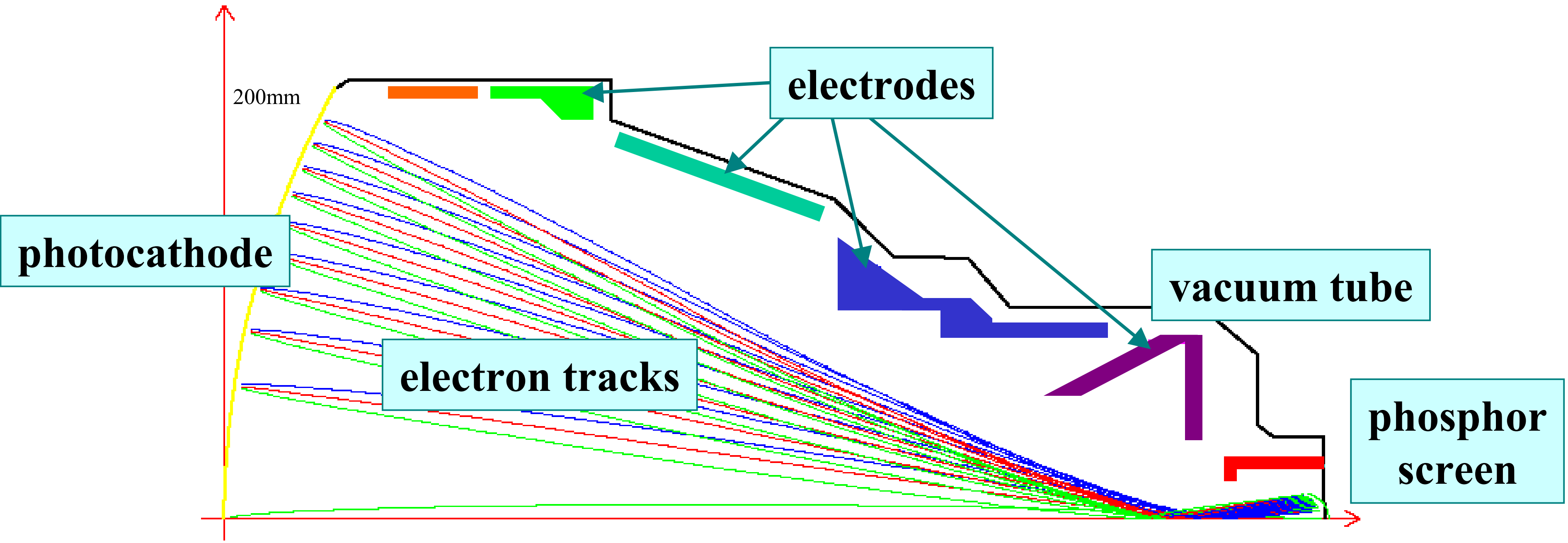
- A support disk is glued before polishing
- Support disk itself is made of glass
- Polishing time: 16 hr

Prototype Mirror : Spot Size Measurements





R&D Status : Lens II



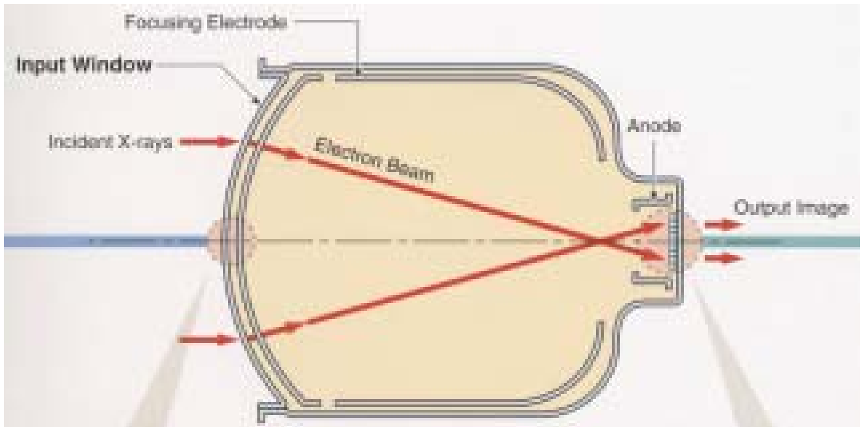
Φ400mm **Focal sphere ⇒ CMOS sensor** **Φ25mm**

Modification from Commercial X-ray II

1. **Input window:** **Al+CsI phosphor ⇒UV-transparent glass**
2. **Electric lens:** **Design new field configuration**
3. **Output window:** **Plane glass ⇒ Spherical FOP** **⇒Patent Pending**

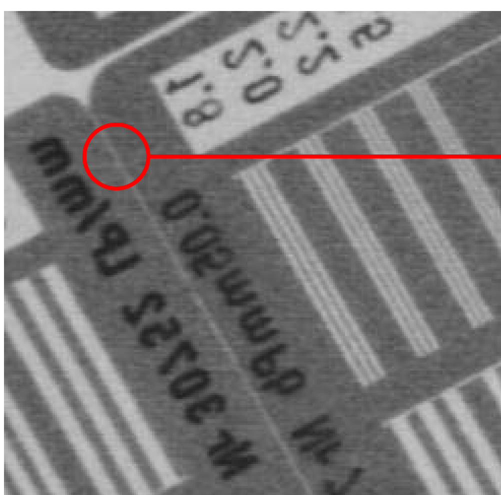
Resolution Matching

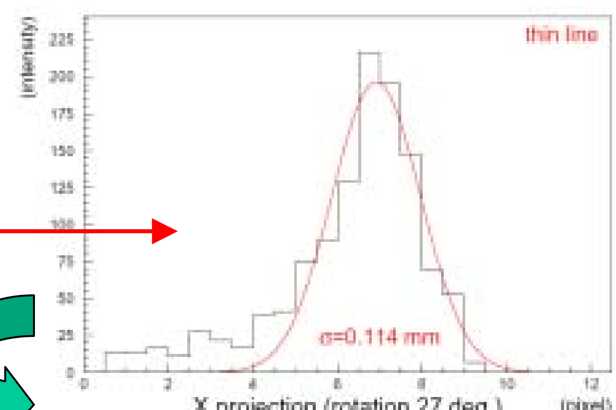
1 arcmin resolution ⇒ σ=0.16 mm @focal surface=I.I. input surface



<u>16 inch X-ray I.I. (commercial)</u>:
4.6Lp/mm @ input surface
(magnification factor~10)

<u>Line pair (Lp) ⇔ σ</u>





2.8 Lp/mm ⇒
σ= 0.12 mm
(along one axis)

Requirement: 3 Lp/mm @ I.I. Input surface

UA3P

Ultra-high Accuracy 3D Profilometer

UA3P uses a nondestructive laser and atomic force probe to measure aspherical surfaces with an accuracy from 0.01 to 0.05 μm.
It features the finest stylus, with a tip radius of curvature measuring just 2 micron. The stylus, which is diamond, is key to obtaining the high precision accuracy of 10nm.

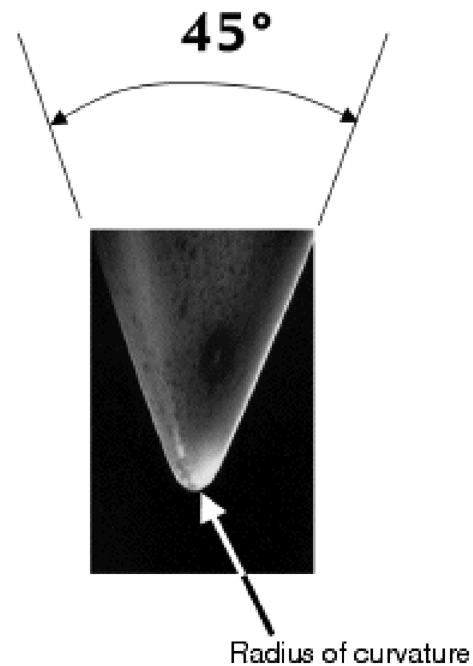


Fig 2 Diamond Stylus Tip

Adjustment Precision

Components		1^{st} Adjustment Precision	Required Mounting Precision
Mirror	XY	0.02 [mm]	0.05 [mm]
	Z	0.02 [mm]	0.05 [mm]
	θ	0.03 [arcmin]	0.1[arcmin]
Lens	XY	0.6[mm]	0.1[mm]
	Z	0.2 [mm]	0.1[mm]
	θ	0.2[arcmin]	0.2[arcmin]
I.I.	XY	0.7 [mm]	0.1[mm]
	Z	0.3 [mm]	0.05[mm]
	θ	1[arcmin]	0.8[arcmin]

Ashra Detector

Ashra is a new air Cherenkov & fluorescence detector.

Distinctive Features:

- All-sky Survey ⇒ 2π sr
- Higher resolution ⇒ 1 arcmin
- Simultaneous observation
  - **TeV γ,**
  - **EHE p/γ,**
  - **VHE ν**

  ⇒ Sugiyama-san's and Kohri-san's talks (OG2.5-14 Aug.5, HE3.4-5 Aug.6)

Ashra station:

- **12 telescopes / station**
- **All-sky (2π sr) / 80M pixels**