

Studies of Ultra High Energy Cosmic Rays ($>10^{19}$ eV)

Features of the Highest Energy Cosmic Rays

Air Shower Detectors

Pierre Auger Project

Future Projects

Astrophysics at the High Energy Physics Laboratories

The Highest Energy Cosmic Rays

Over the last 30 years

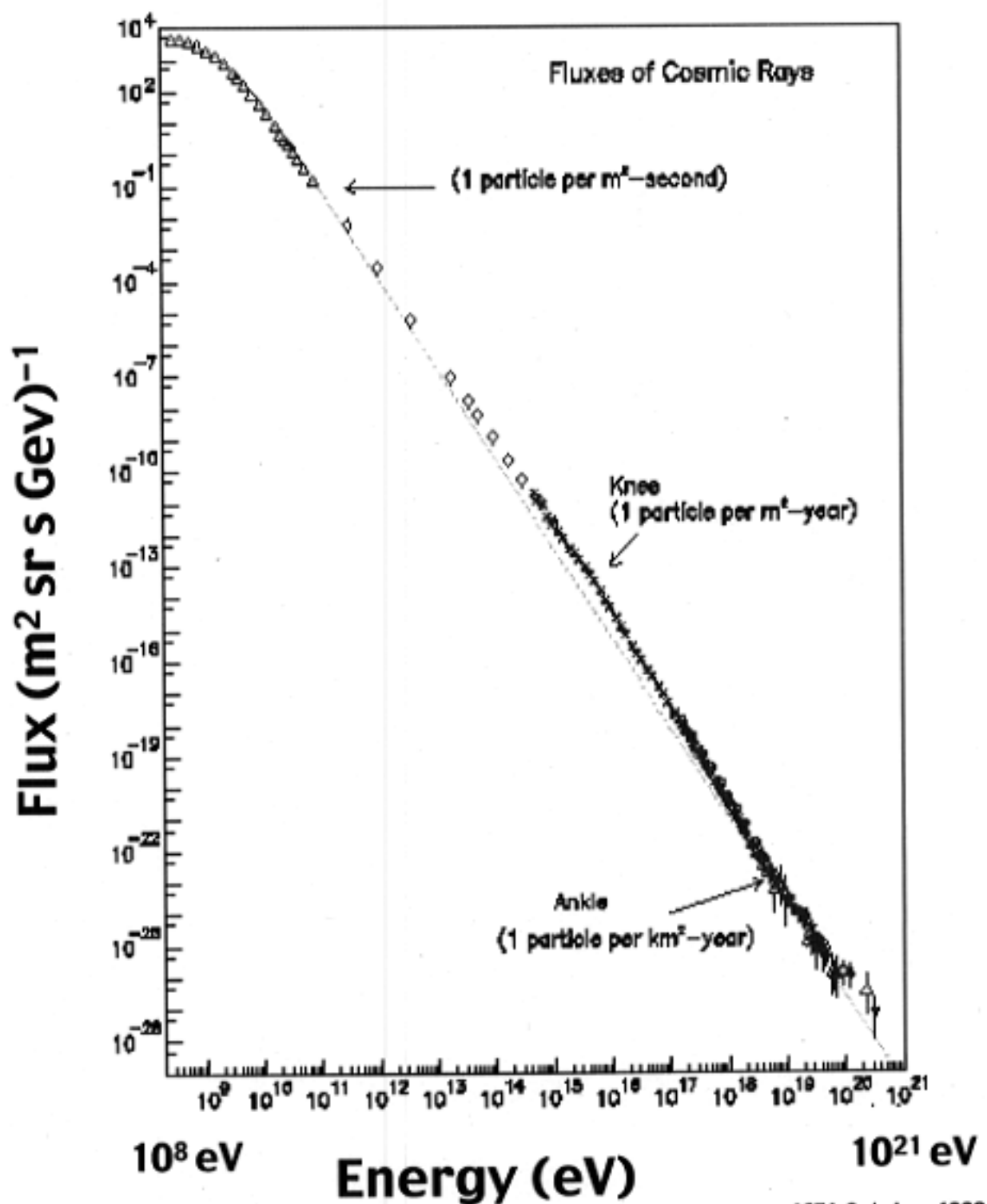
~ 20 events with $> 10^{20}$ eV

50 Joules!

1991 Fly's eye detector in Utah – 3.2×10^{20} eV

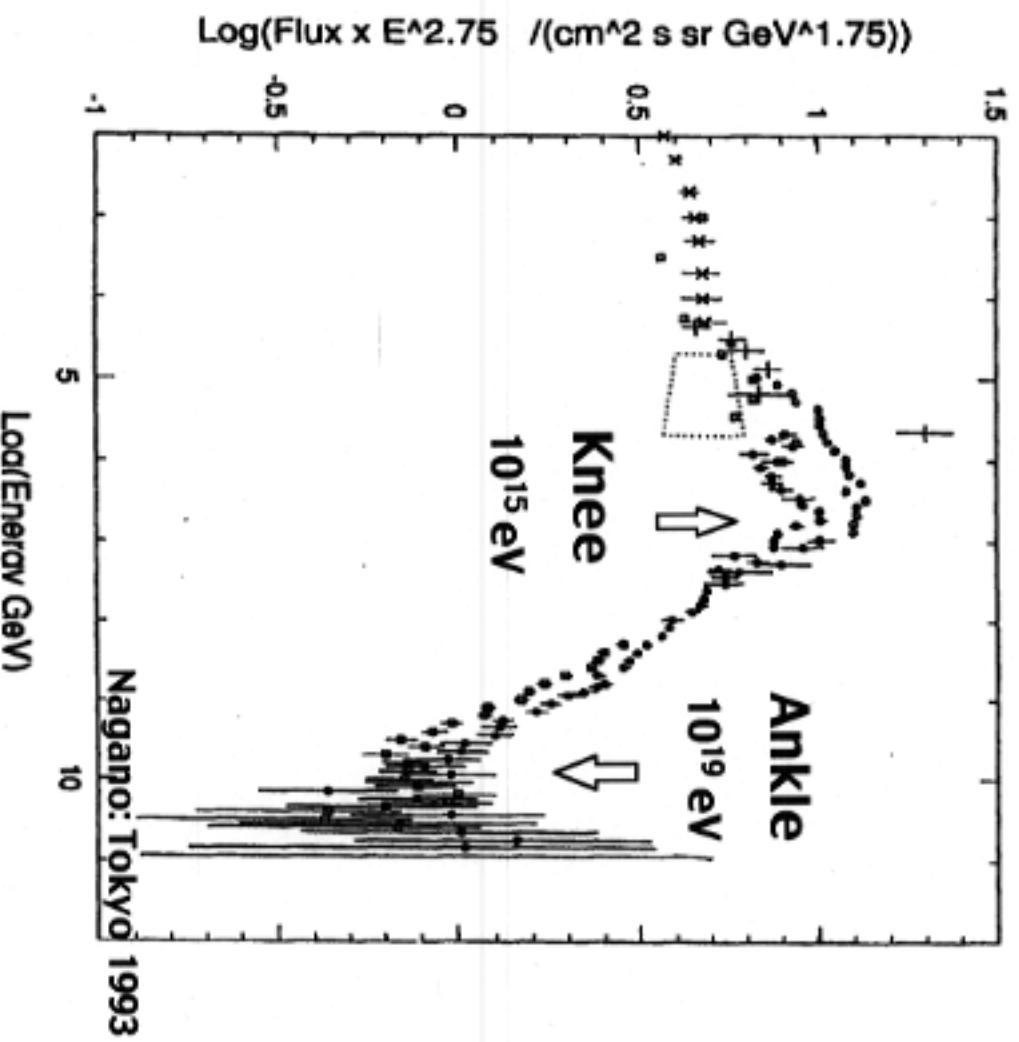
1993 AGASA detector in Akeno, Japan – 2×10^{20} eV

Ultra High Energy Cosmic Rays



Ultra High Energy Cosmic Rays

Details of the cosmic ray spectrum



Propagation of high energy cosmic rays

$$p + \gamma_{2.7K} \rightarrow p + \pi^0$$

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

For energy $> 5 * 10^{19}$

Greisen-Zatsepin-Kuzmin Cut Off

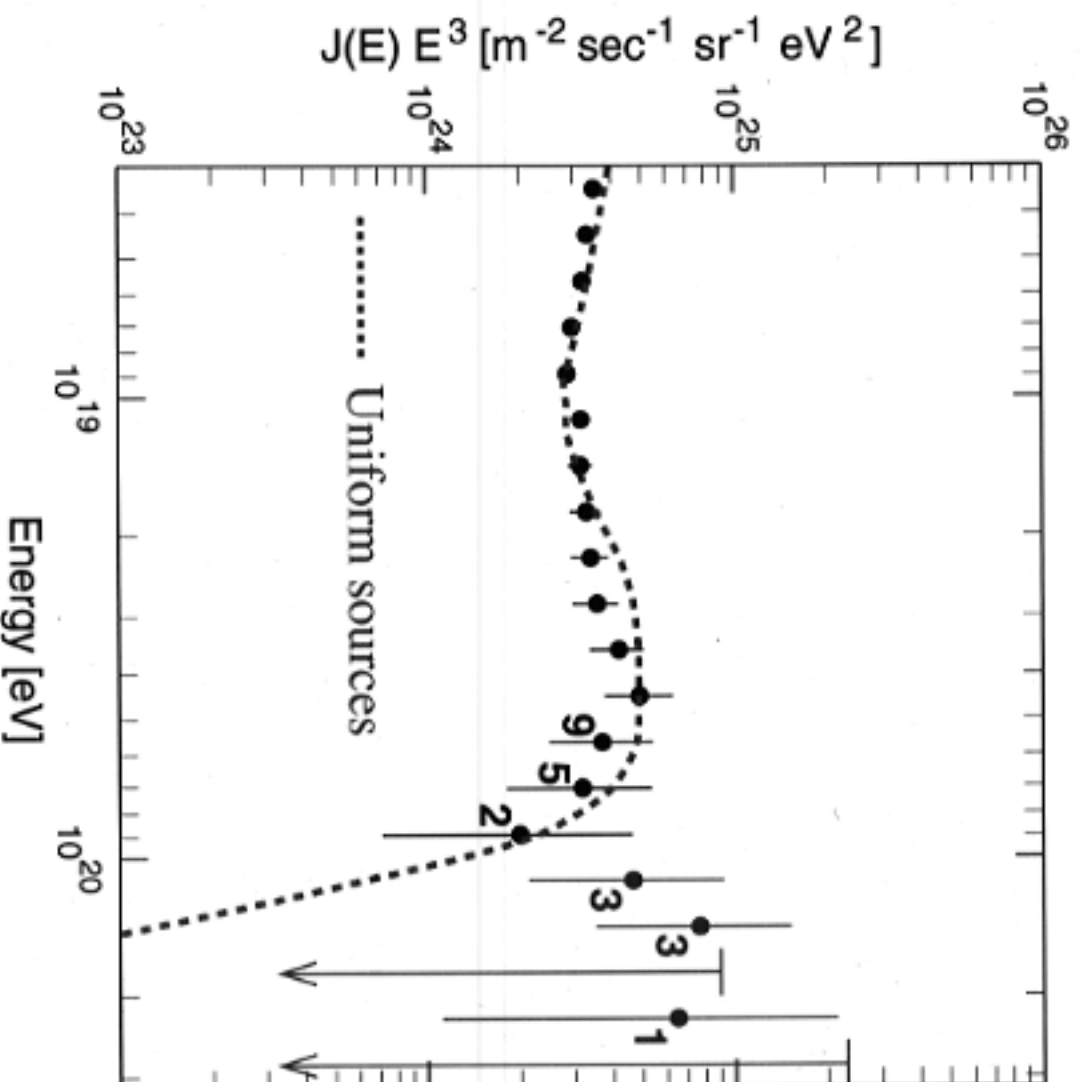
Particles $> 5 * 10^{19}$ eV

must be $< \sim 50$ Mpc away

Ultra High Energy Cosmic Rays

The latest Data From AGASA

M. Teshima
August 1999



Possible Sources

Powerful radio sources?

Active Galactic Nuclei (AGN)?

Supernova
 $\sim 10^{15}$ eV

Associated with gamma ray bursts?

Annihilation of topological defects?

New astrophysics?

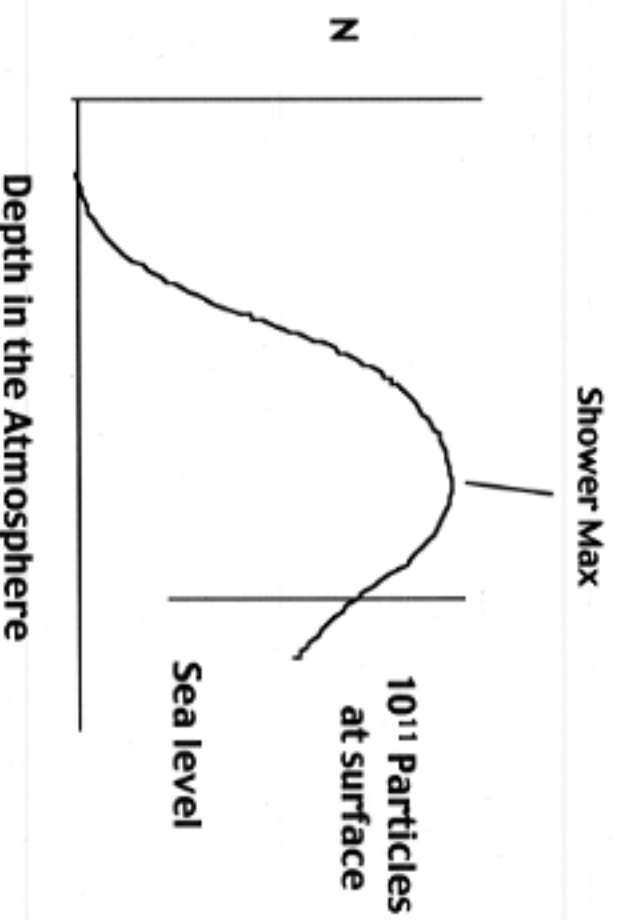
New physics?

Cosmic Mysteries

- ➡ **Difficult to explain acceleration process
for particles $> 10^{20}$ eV**
- ➡ **Source must be < 50 Mpc because of the CMB**
- ➡ **The highest cosmic rays do not point back to
possible sources**

Development of Air Showers

The Earth is an excellent calorimeter!



Away from the core

$\gamma \sim 89\%$
 $e^{\pm} \sim 10\%$ } 10 MeV

$\mu \sim 1\%$ 1 GeV

Air Shower Detector Techniques

- **Particle Detector Arrays**
- **Atmospheric Fluorescence Detectors**

Air Shower Detectors - Surface Detector Array

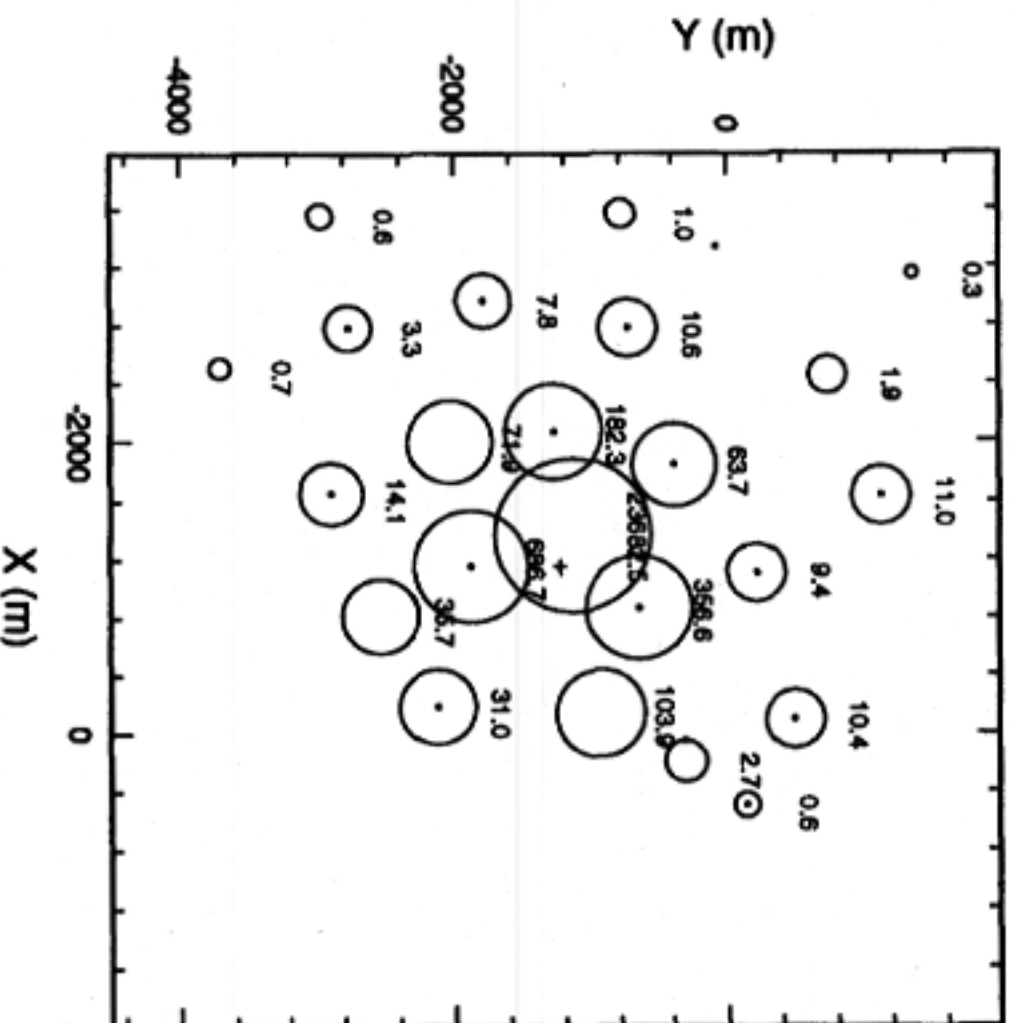
Shower timing  shower direction

Particle density  shower energy

Muon number  Measure of
Pulse rise time primary mass

AGASA Airshower event

Energy:
 $1.7-2.6 \times 10^{20}$ eV
Zenith angle:
 22.9°



Air Shower Detectors – *Fluorescence Detectors*

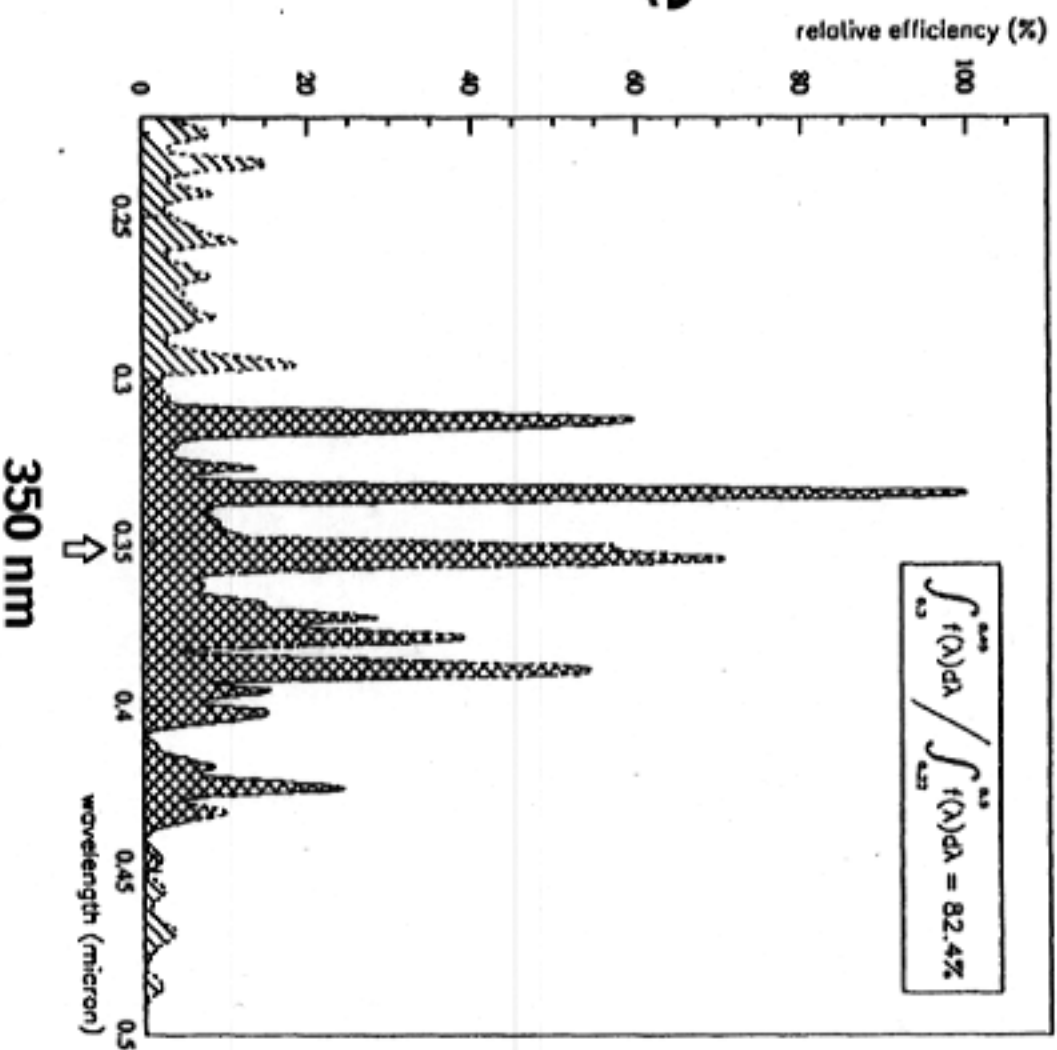
Shower ~ 90% electromagnetic

Ionization of nitrogen measured directly



**Calorimetric energy measurement
Measure of shower development**

Air fluorescence spectrum



High Resolution Fly's Eye

Five Mile Hill	22 mirror units	} <i>12.5 Km apart</i>
Camel's Back Mt.	42 mirror units	

Each mirror unit:

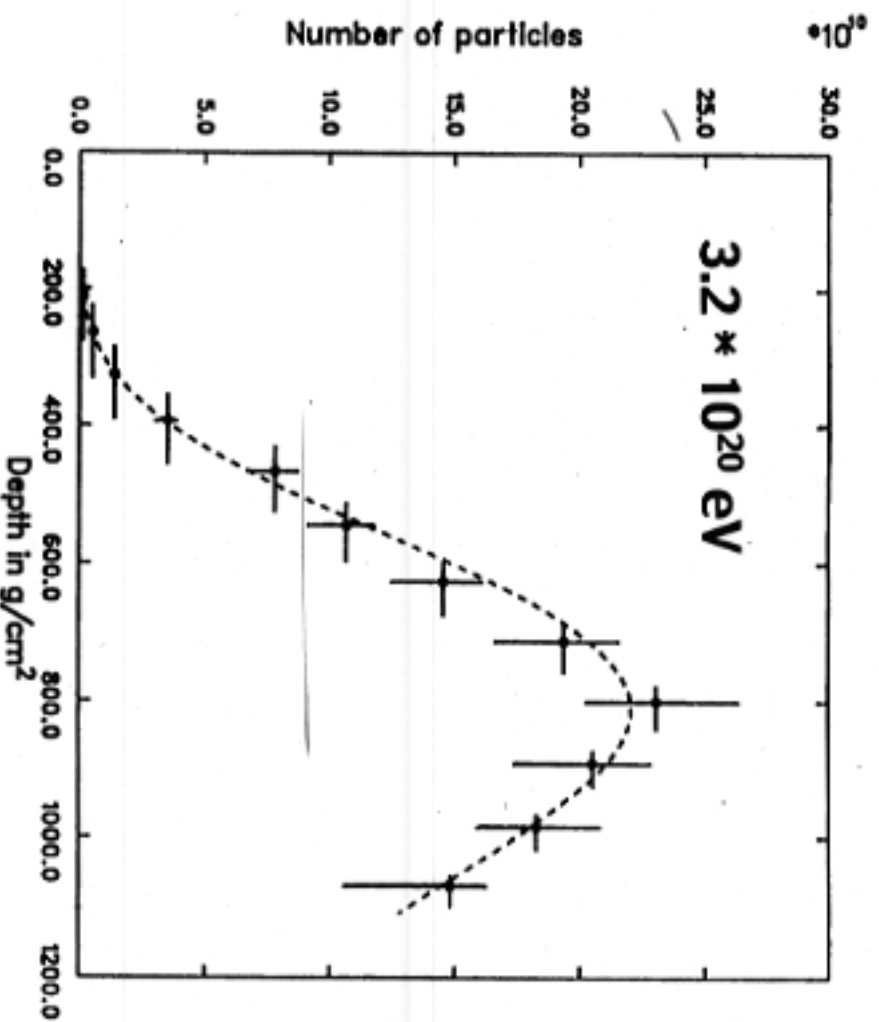
- 2 meter segmented mirror
- 256 PMT camera

Time averaged aperture: 1000 Km² str @ 10²⁰ eV

Five Mile Hill – 2 years data (monocular)

Ultra High Energy Cosmic Rays

The Big Fly's Eye Event



Depth of shower max ~ measure of primary mass

Features of the Detector Techniques

Surface Array

- 100% duty cycle
- Uniform sky coverage
- Simple robust detectors
- Mass determination using rise time, muon/em

Fluorescence Detector

- Calorimetric energy measurement
- Direct view of shower development
- Good angular resolution ($< 1^\circ$)

The Pierre Auger Project

A Study of Cosmic Rays

$10^{19} - 10^{21}$ eV

Energy Spectrum – Direction – Composition

Large Hybrid Air Shower Detectors

In Northern and Southern Hemispheres

Mendoza Province, Argentina

Utah, USA

Auger Observatory

Combines strengths of

**Surface Detector Array
and**

Fluorescence Detectors

- **Independent measurement techniques allow control of systematics**
- **More reliable energy and angle measurement**
- **Primary mass measured in complementary ways**

The Auger Collaboration

Argentina

Italy

Armenia

Japan

Australia

Mexico

Bolivia

Poland

Brazil

Russia

Czech Republic

Slovenia

Peoples Republic of China

United Kingdom

France

USA

Germany

Vietnam

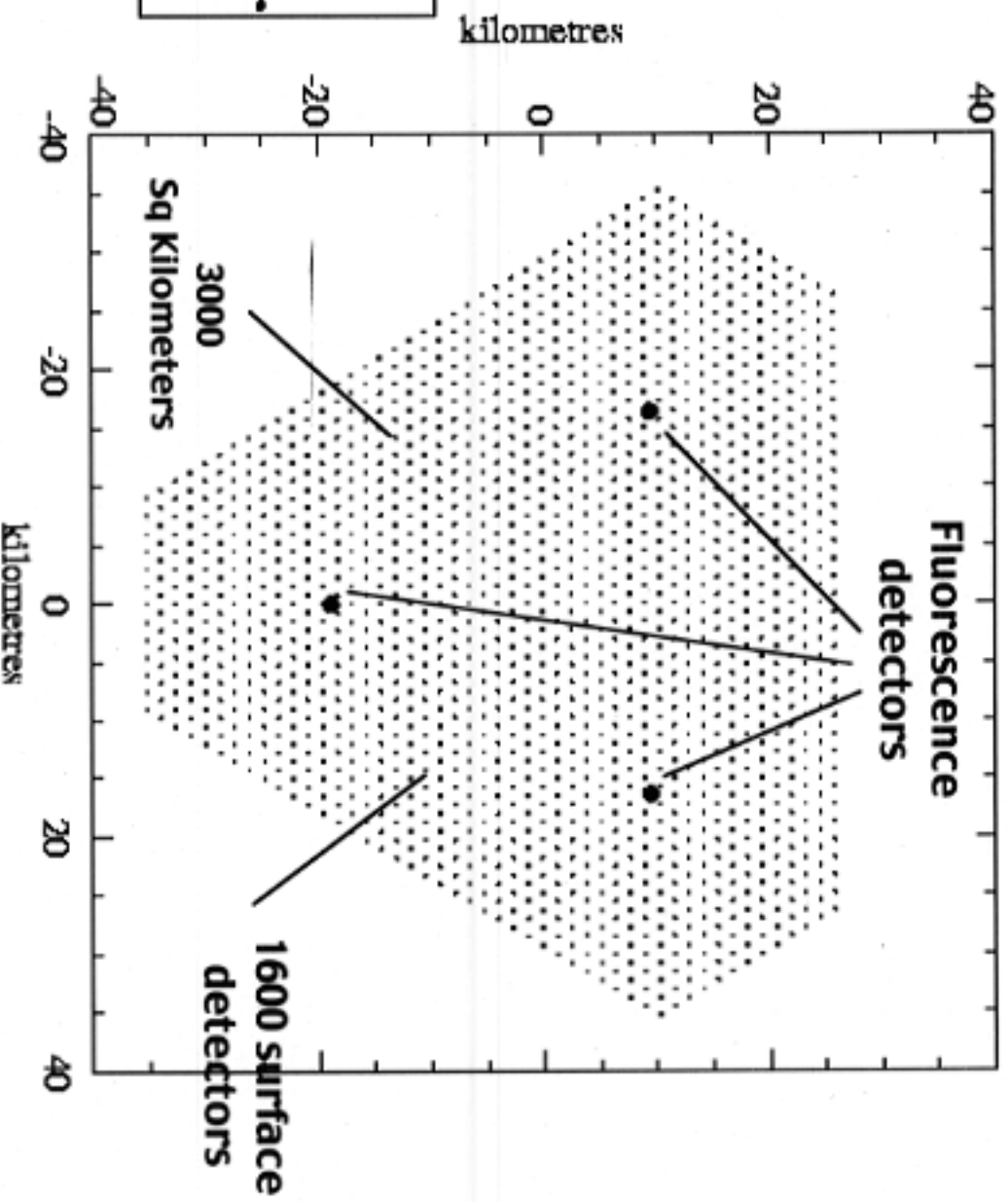
Greece

50 Institutions, >250 Scientists

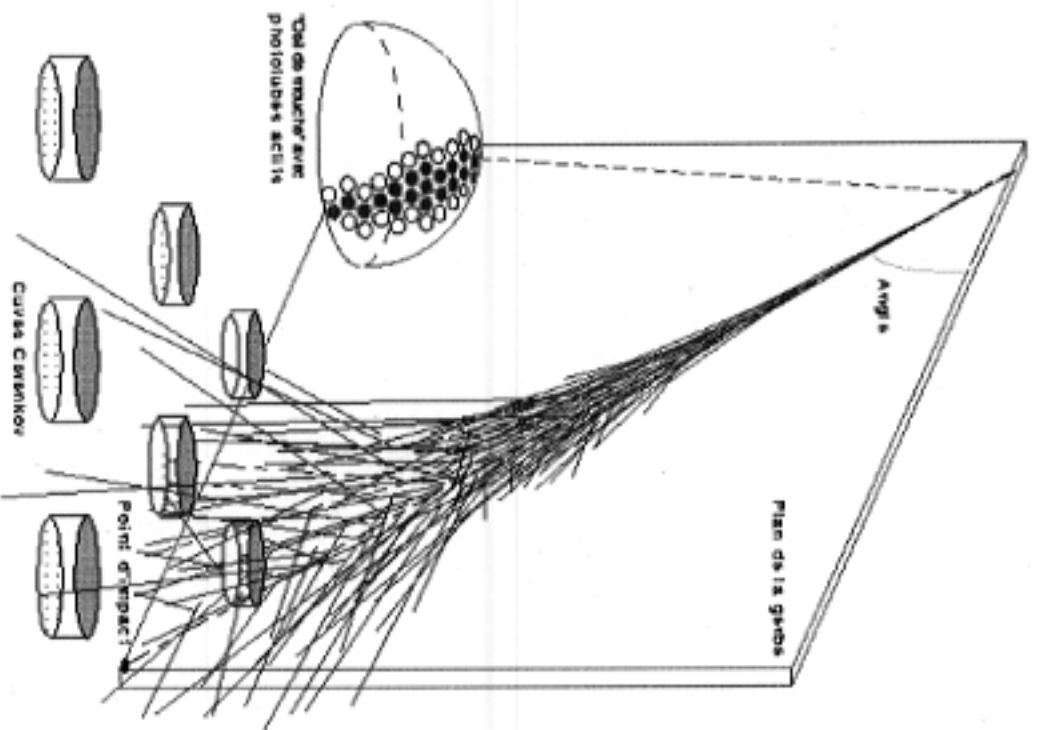
Ultra High Energy Cosmic Rays

Auger Detector Array

Each Site
7000 km² str
~40 events/yr
> 10²⁰ eV



Ultra High Energy Cosmic Rays



The Japanese Telescope Array

A proposal for an all fluorescence detector

Ten 360° Fluorescence Stations

Mirror: 3 meters in diameter

Camera: 256 PMTs

40 mirror units per station

Total Acceptance (time averaged):

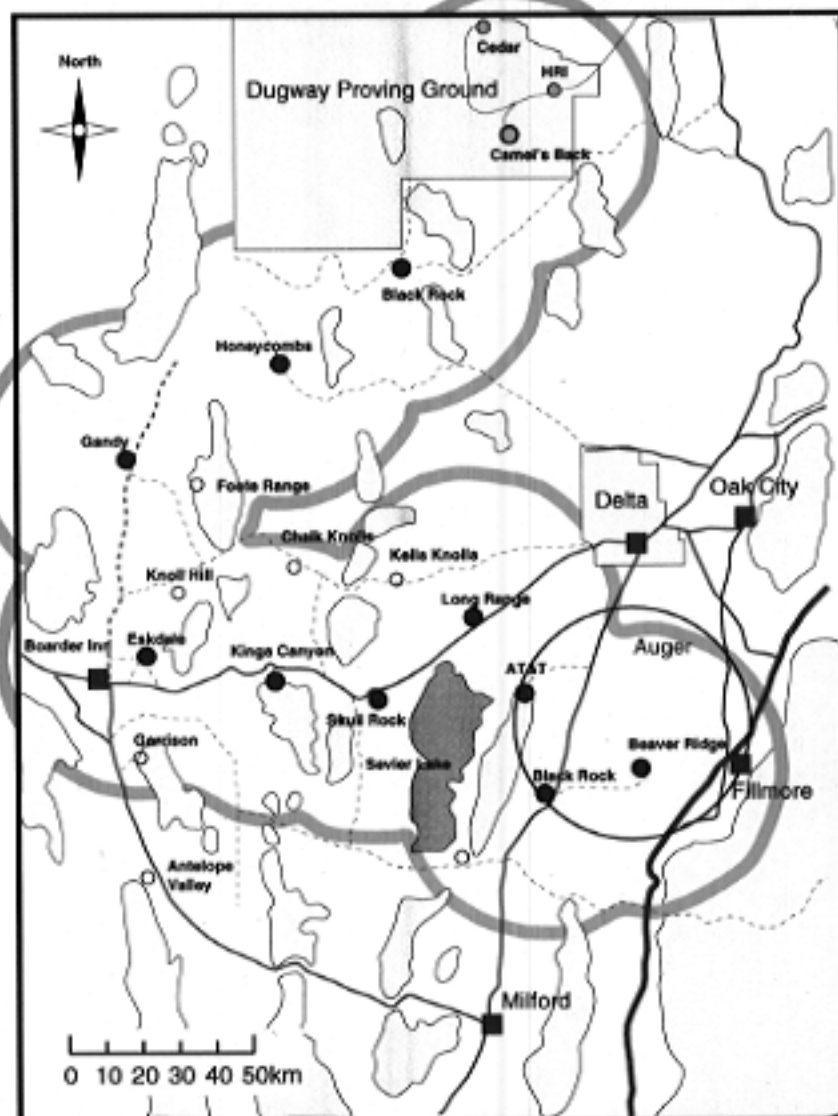
6000 Km² sr @ 10²⁰ eV

To be build in Utah, USA

Ultra High Energy Cosmic Rays

Japanese Telescope Array

Telescope Array Station arrangement, Utah USA



AGASA Scale

Utah State

ICFA October 1999

Owl/Airwatch

One (or more) down looking satellites

Large arrays of imaging devices (10^6 pixels)

Large aperture camera

2-4 m objective, 60° field of view

Expect ~ 1000 events/year above 10^{20} eV

Astrophysics at the High Energy Physics Laboratories

*Laboratories bring important resources to
large Astrophysics Experiments*

- **Experience in managing large projects**
- **High capacity computing facilities**
- **Design and Engineering skills**

Summary

- Study of the highest energy cosmic rays promises some very exciting science.
- The Auger project is a high statistics, full sky study of cosmic rays above 10^{19} eV.
- Future projects are being planned to extend these studies.
- The High Energy Physics Laboratories can play a important role in these experiments.