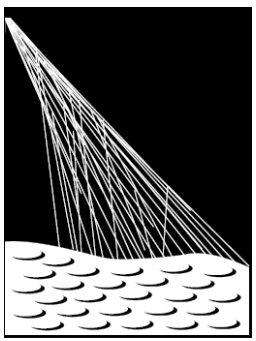
Giving a golf ball the energy of a high-energy cosmic ray: South Pole, Jan. 1988

‘History of the Telescope’ Lecture Series

University of Oxford : 24 March 2009

The Development of the Pierre Auger Observatory

- and the Birth of Cosmic Ray Astronomy



PIERRE AUGER OBSERVATORY

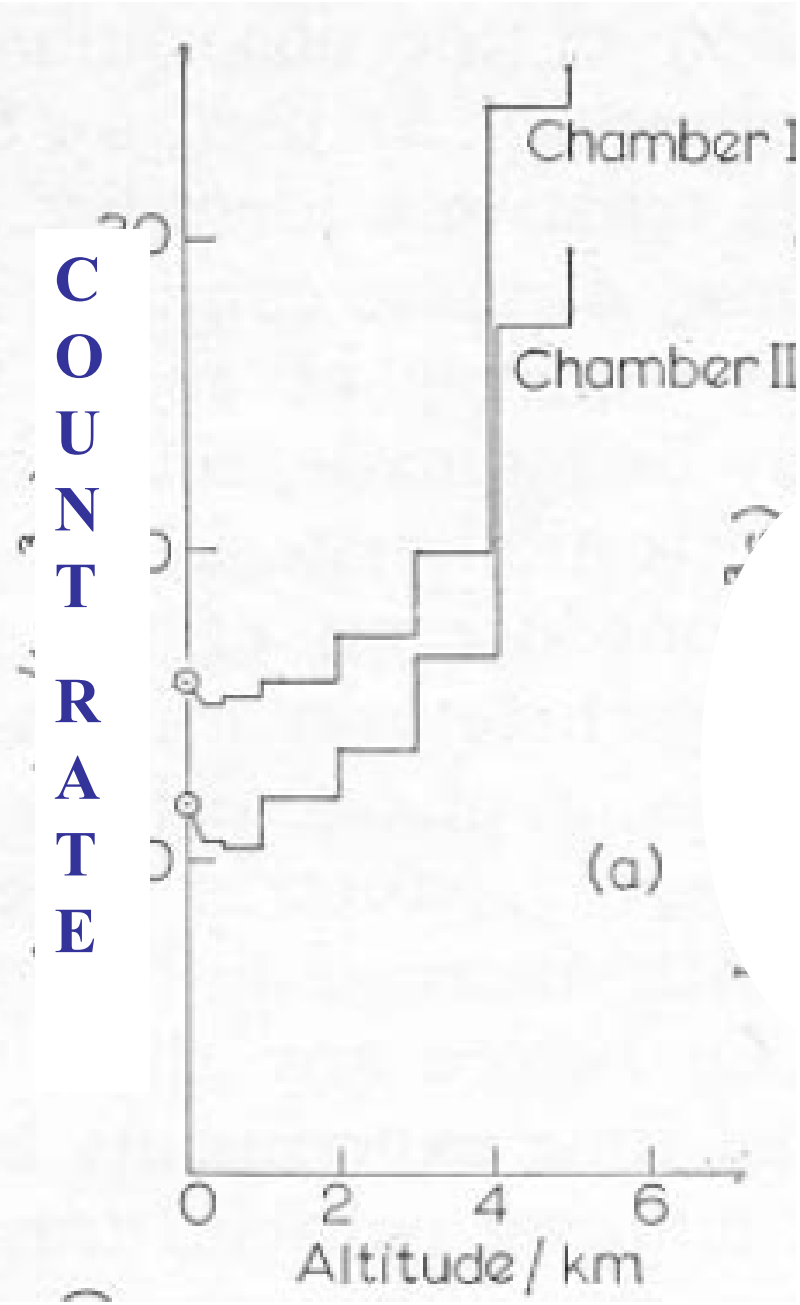
Alan Watson
School of Physics and Astronomy
University of Leeds

a.a.watson@leeds.ac.uk

Overview:

- **What cosmic rays are and why they are interesting**
- **Early work leading to the construction of the Pierre Auger Observatory**
  - **forming the collaboration**
  - **some of the difficulties**
  - **1991 – 1999 and the start of construction**
- **Building the Observatory: 2000 - 2008**
- **The Birth of Cosmic Ray Astronomy**

Measurements by Victor Hess (1912)



Hess bei Ballonlandung (1912).

Principal Results from early studies

- Ubiquitous
- **From outer space**
- **Charged particles** – mainly protons - and so difficult to track back to their source(s)
- Energy density comparable to starlight
- **Most energetic particles in Nature** and, as such, source for the discovery of first elementary particles (positron, muon, pions…….)>> 7 x 10^{12} eV of the LHC

Low energy cosmic rays can be studied from balloons (à la Hess) or by putting equipment on satellites, but for the highest-energy cosmic rays

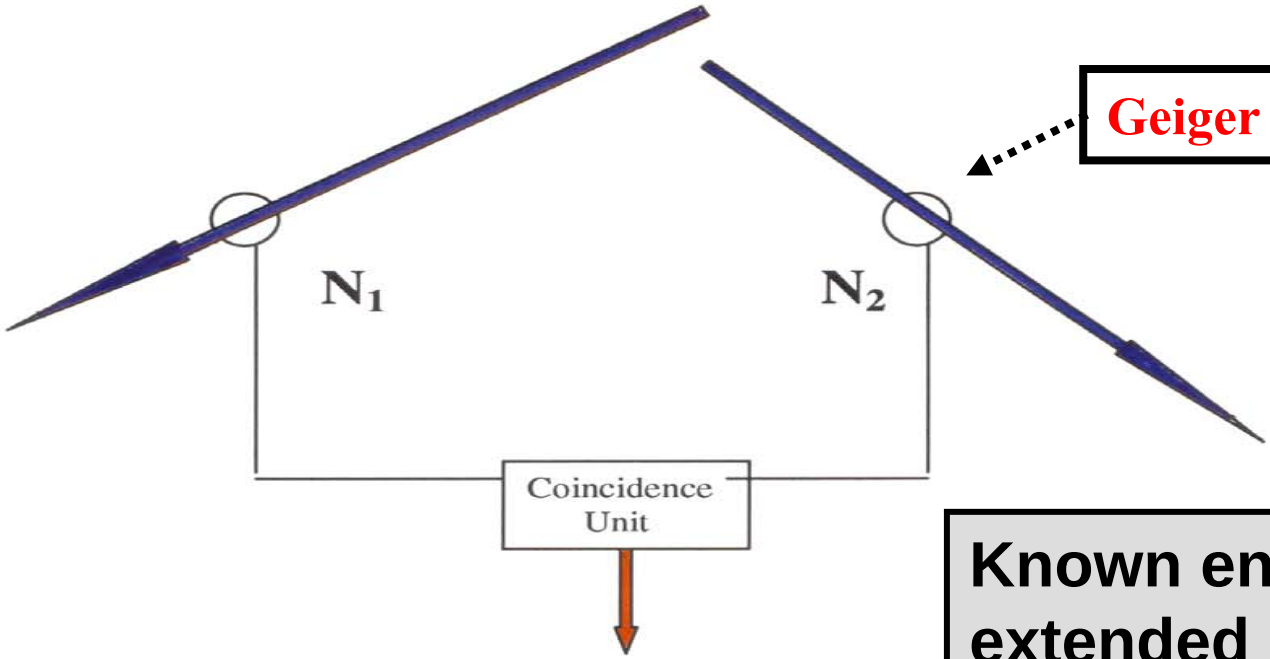
- which are very rare –

we make use of a phenomenon called

‘Extensive Air Showers’

discovered by chance by Pierre Auger (1938)

Discovery of Extensive Air Showers: Pierre Auger (1938)



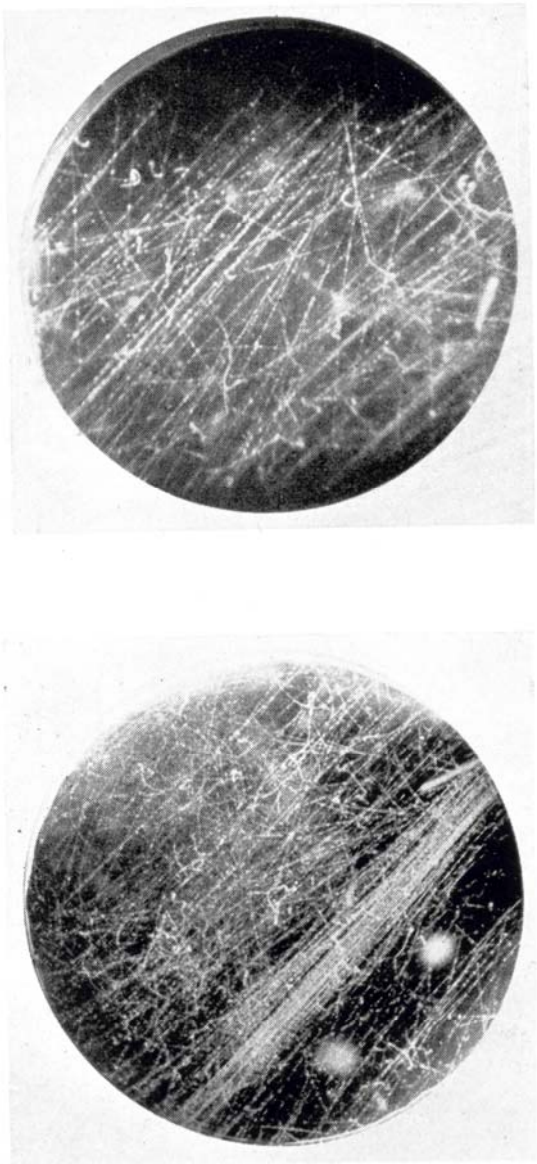
Known energy scale extended by ~10^6

Chance Rate $= 2N_1N_2\,\tau,$

Resolving time = 10 millionth of a second (10^{-5} s)

Observed Rate was found to be much higher than the Calculated Chance Rate – even when the counters were as far as 300 m apart

Pierre Auger, Paris 1981



h. Extensive air shower
(Wilson and Lovell)

Two small cloud chambers a few metres apart in Manchester

J G Wilson and C B A Lovell

Nature 1938

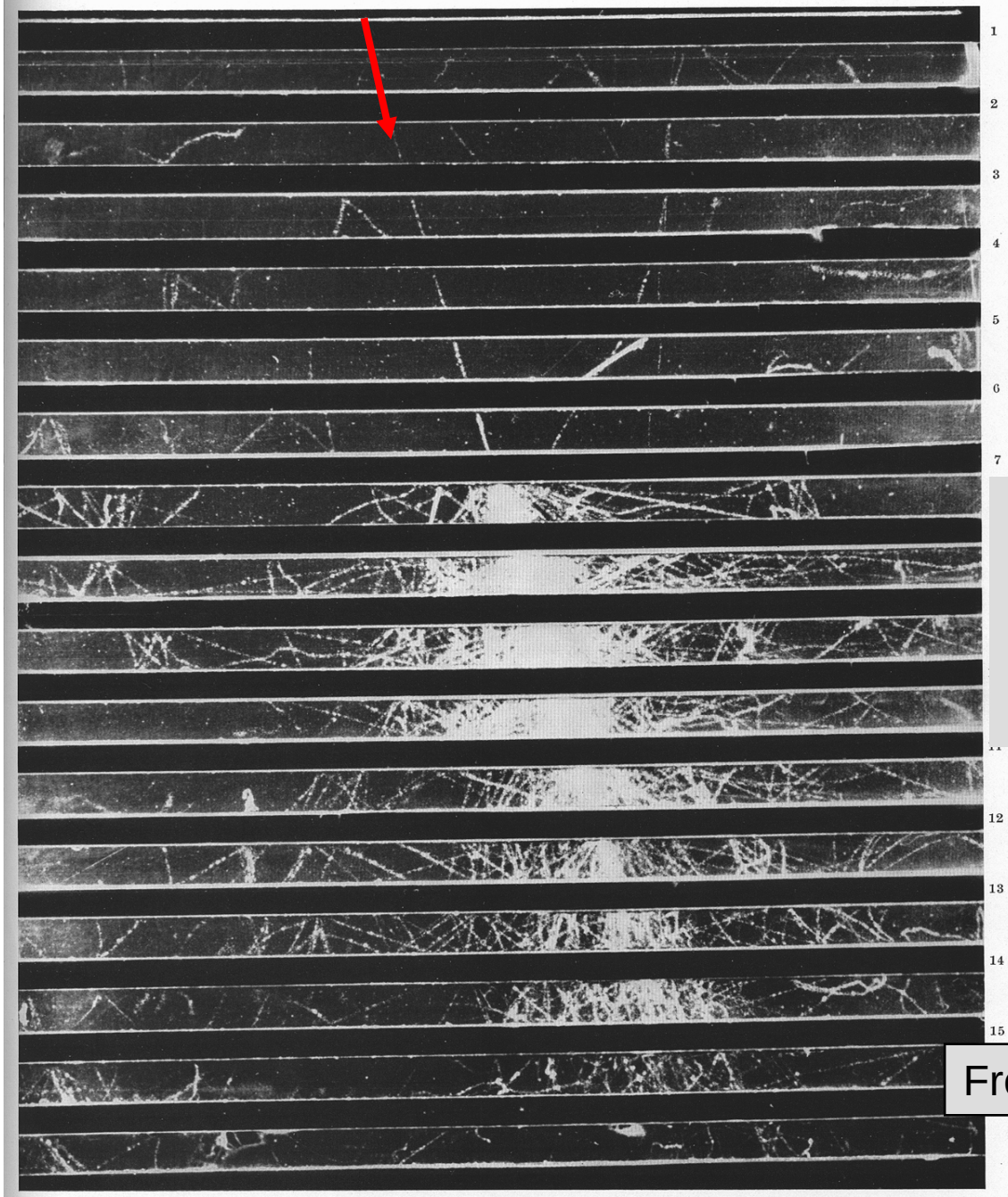


Plate 92

1.3 cm Pb

Shower initiated by proton in lead plates of cloud chamber

Detectors yield particle number and arrival times

Fretter: Echo Lake, 1949

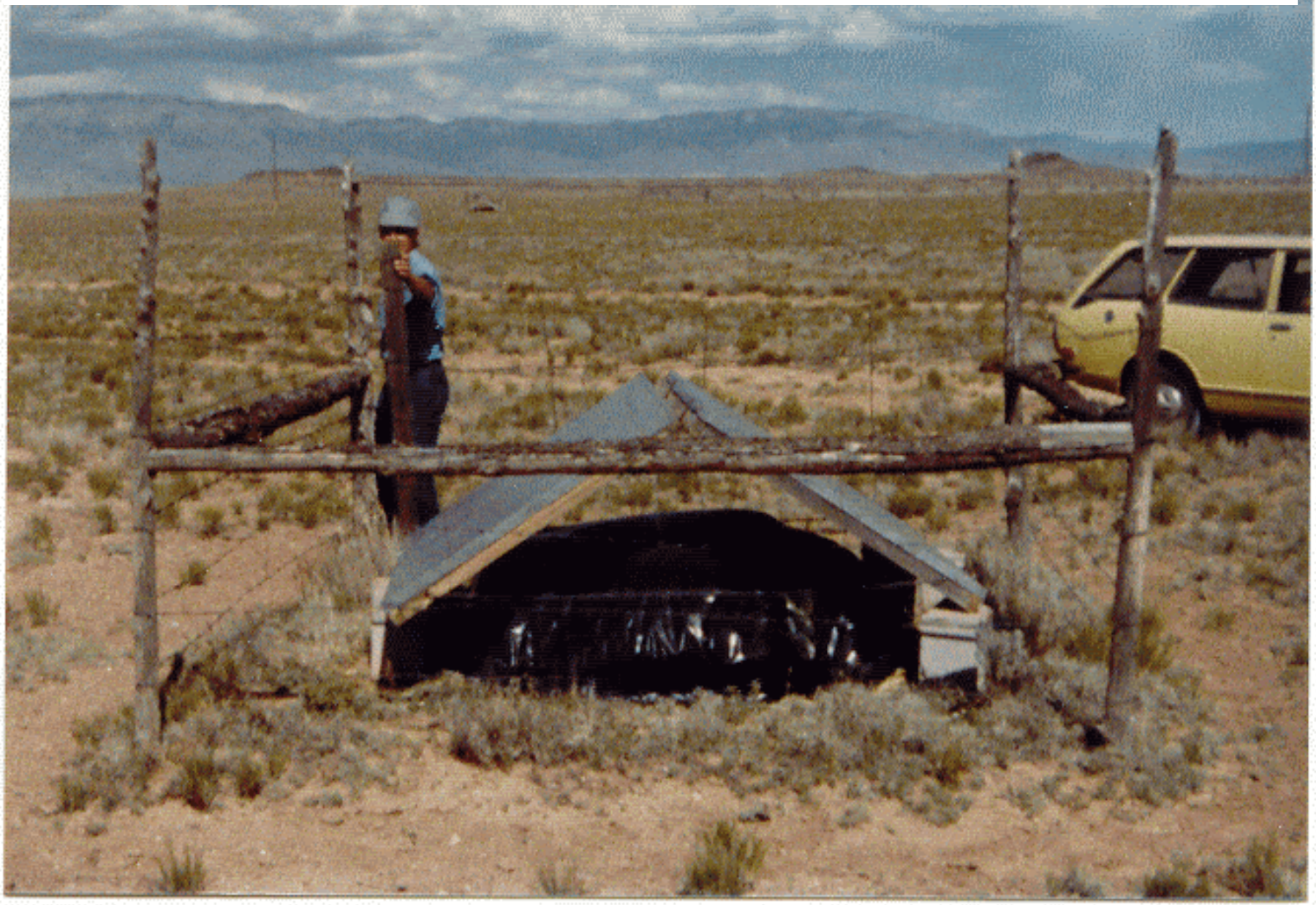
One of the early motivations for studying extensive air showers was the expectation that anisotropies would be discovered if one got to high enough energies

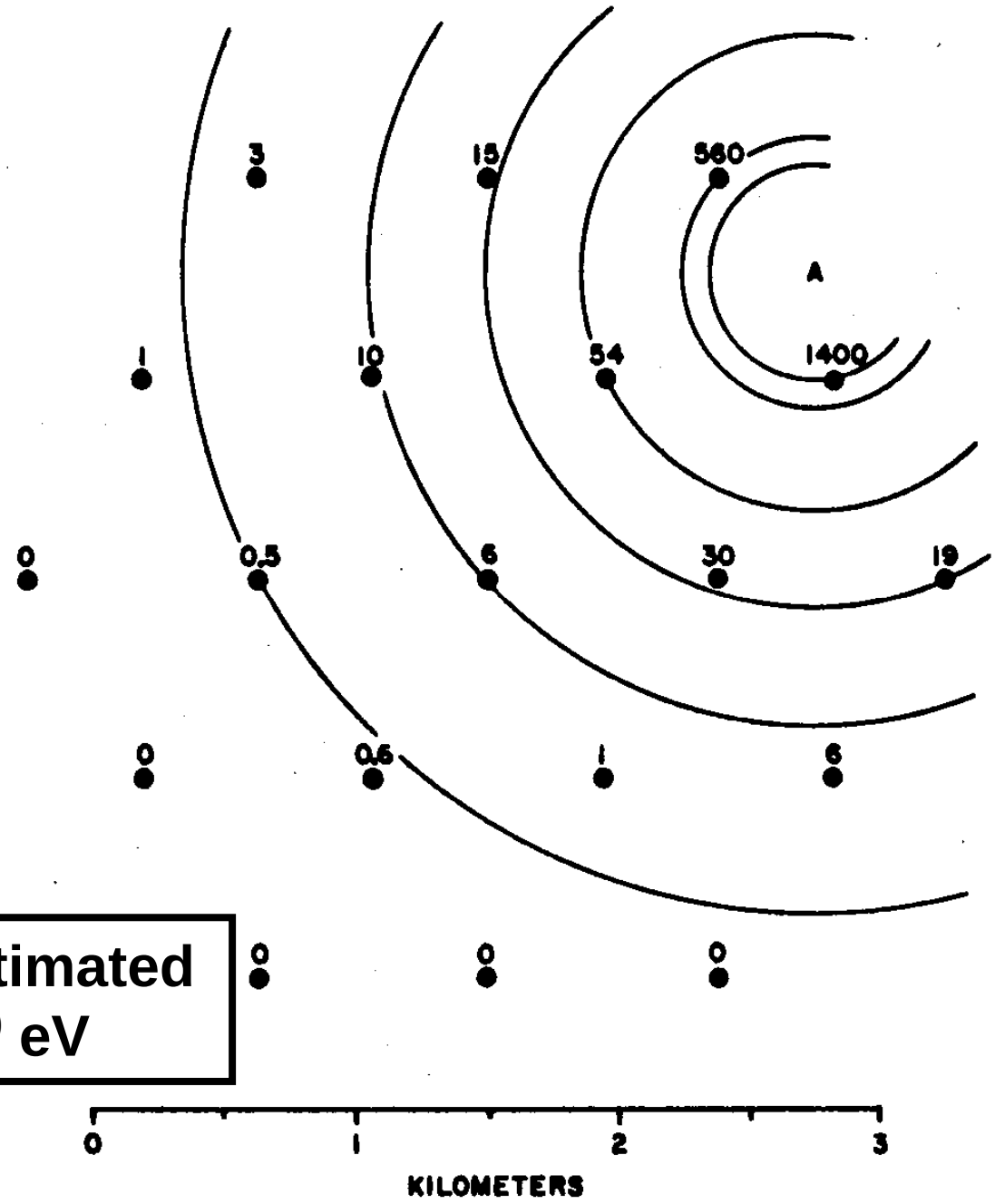
This led to the construction of larger and larger arrays of particle detectors to study the showers - 'large' meant a few square kilometres

Volcano Ranch (US) - 1963
Haverah Park (UK) - 1967
SUGAR (Australia) - 1970
Yakutsk (Siberia) - 1972

A small but select group!

John Linsley at Volcano Ranch, New Mexico:
The Pioneer of Giant Arrays for the study of Ultra High Energy Cosmic Rays





Event with estimated energy of 10^{20} eV

FIG. 1. Plan of the Volcano Ranch array in February

Unlike starlight or radio waves, the highest energy cosmic rays MUST come from nearby – less than 100 Mpc or 300 Million light years

Number of events is expected to drop off very rapidly with energy above 5 x 10^{19} eV and we will only 'see' nearby sources

Greisen-Zatsepin-Kuz'min – GZK-effect (1966)

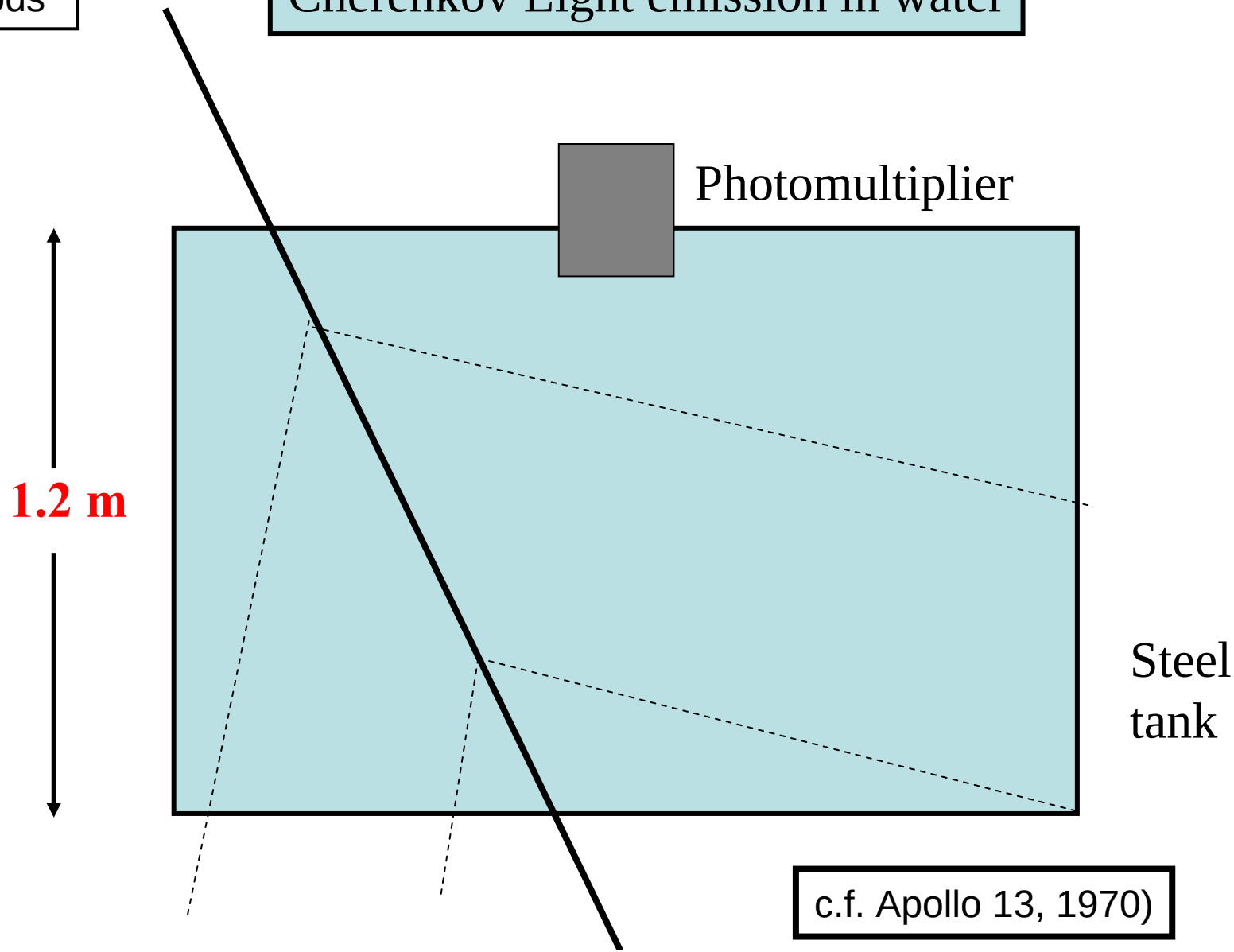
$$\gamma_{2.7\,K} + p \rightarrow \Delta^{+} \rightarrow n + \pi^{+} \text{ or } p + \pi^{o}$$

Events of ~ 10^{20} eV are very rare:

only ~1 per km^2 per century

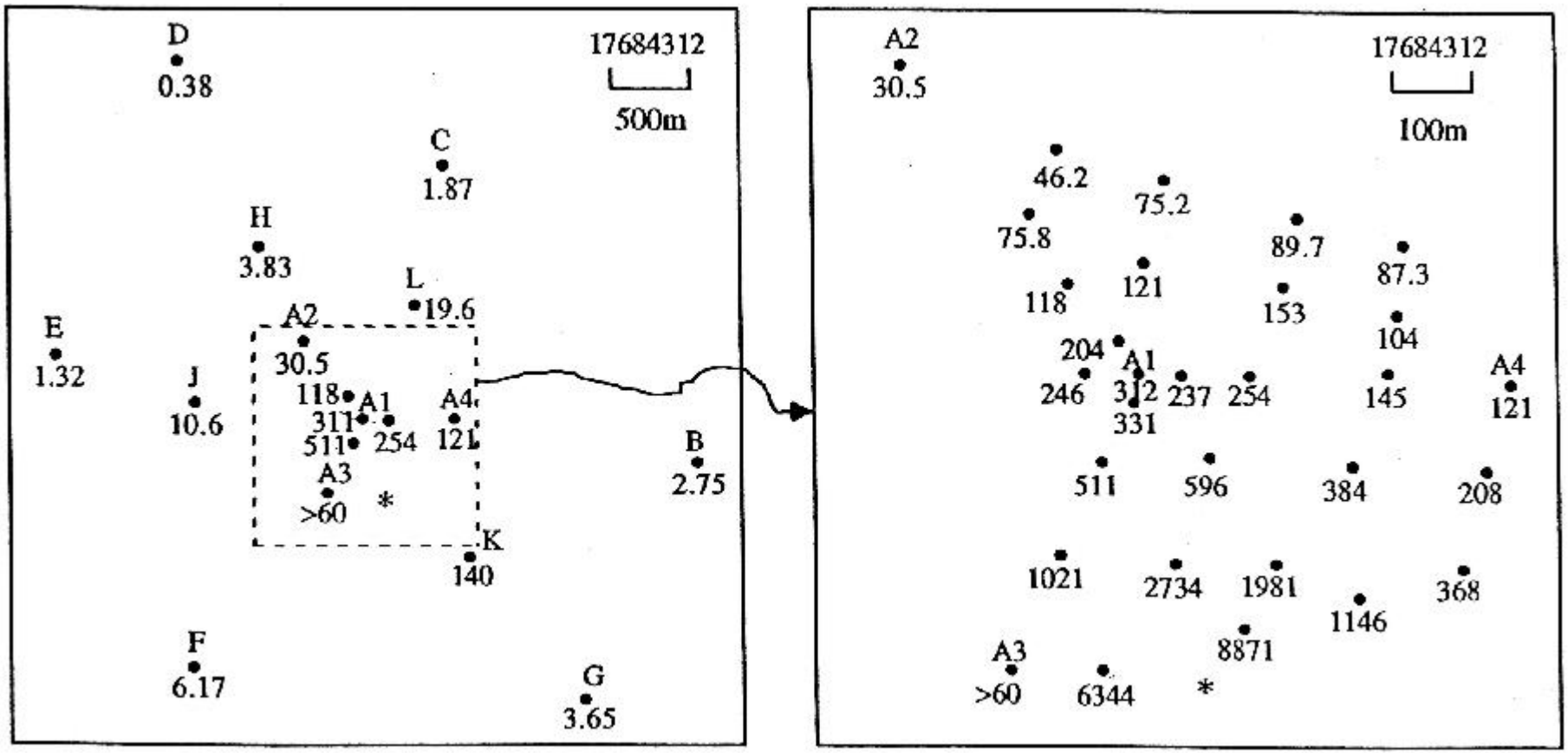
Detection Methods

Cherenkov Light emission in water

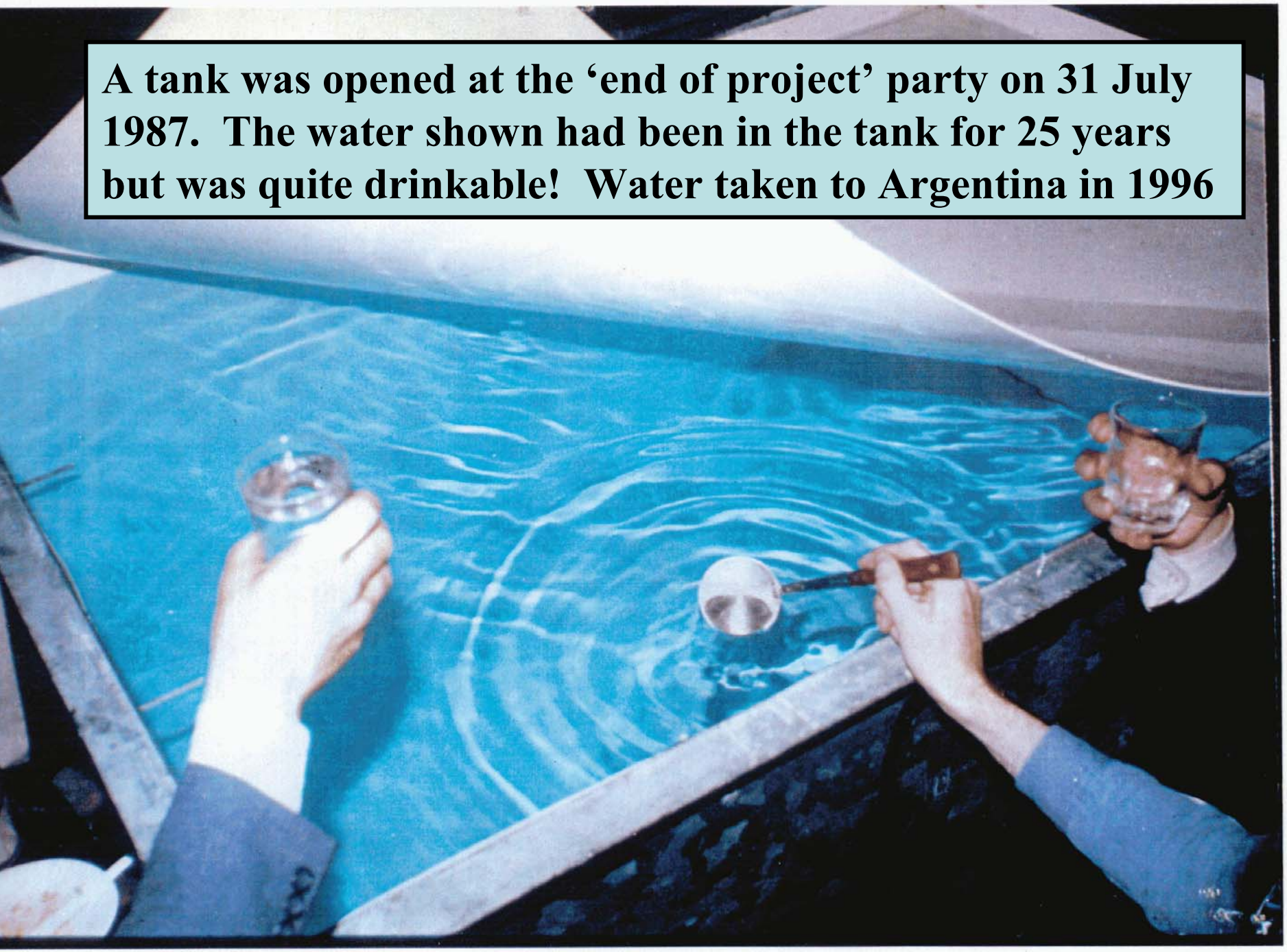


At Haverah Park: ~ 200 tanks each with ~ 2.7 tonnes of water

Event with energy of ~ 8 x 10^{19} eV, well above GZK cut-off

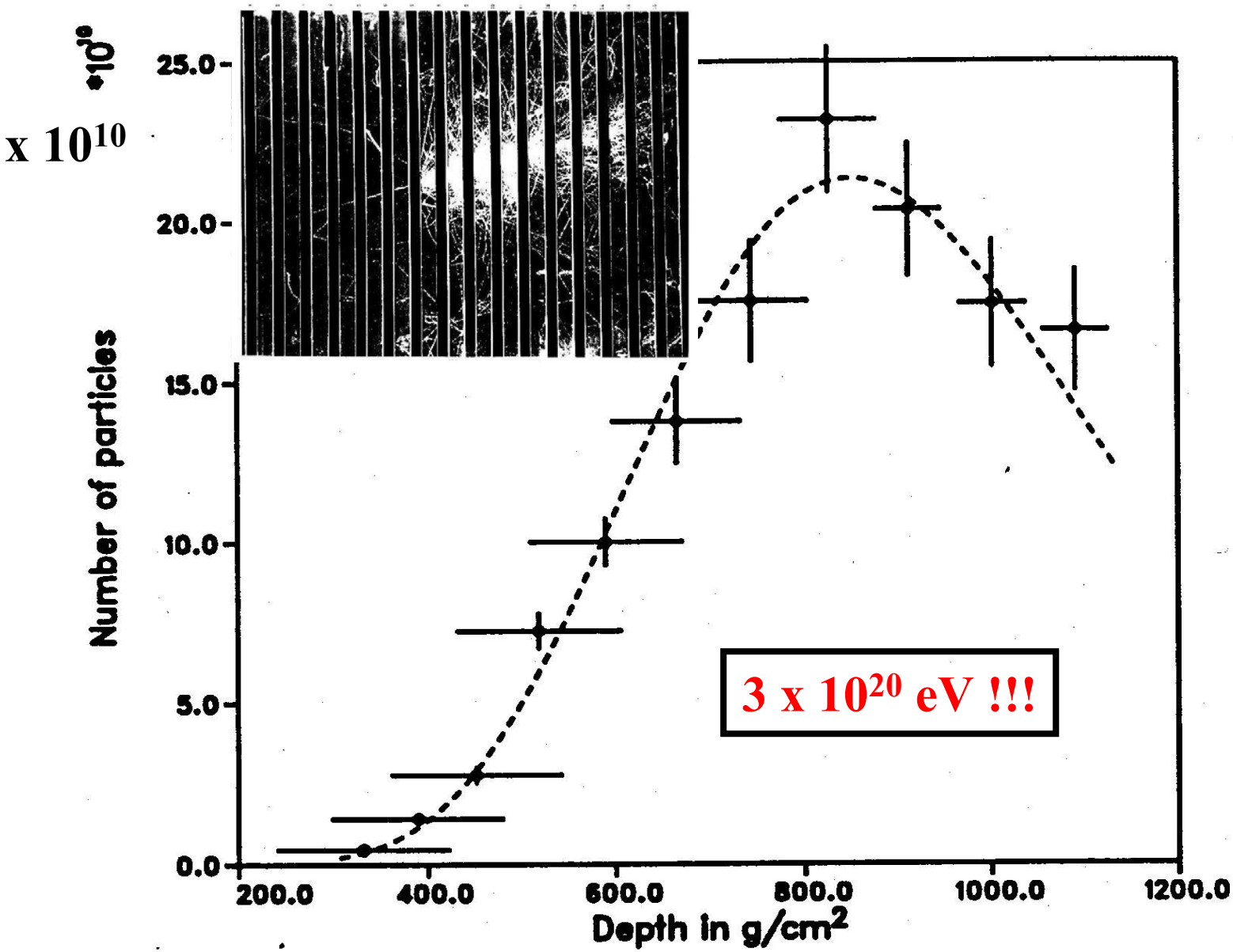


Haverah Park, near Leeds: Site of UK National Effort: 1960 - 1987


A tank was opened at the ‘end of project’ party on 31 July 1987. The water shown had been in the tank for 25 years but was quite drinkable! Water taken to Argentina in 1996

5 W blue light bulb moving at velocity of light at 15 km is equivalent to 3 x 10^{18} eV shower

A Fluorescence Detector of the Utah University Group


x 10^10
25.0
20.0
15.0
10.0
5.0
0.0
Number of particles
200.0
400.0
600.0
800.0
1000.0
1200.0
Depth in g/cm^2
3 x 10^20 eV !!!

The Pierre Auger Observatory stemmed from a review talk I gave in July 1990

"The problem is lack of exposure: while it has been clear for many years that 1000 km^2 of instrumented area is needed, progress towards getting this has been slow."

"The experimental problems are challenging and subtle but certainly soluble. All that is need is dedication, money and patience."

Enter a Nobel Prize Winner: James W Cronin (1980)

Conference in Dublin in August 1991

"You're not nearly ambitious enough:

we should build 5000 km^2"

This was the starting point of the what has become the Pierre Auger Observatory

Early name – P5000

Jim had sabbatical leave in Leeds for 4 months in late 1991.

His idea had been to work on data from his own cosmic ray project (1 km^2) in the US – which had just been struck by lightning!

Most of the time was spent on early planning for what became the Auger Observatory. Some test measurements were made at Haverah Park and contacts were developed with our Electronic Engineers (led to GPS and comms studies)

Nuclear Physics B (Proc. Suppl.) 28B (1992) NOVEMBER 1992

Major Meeting in Paris in April 1992 organised by Murat Boratav

COSMIC RAYS ABOVE 10^{19} eV - 1992

Proceedings of the International Workshop on Techniques to Study Cosmic Rays with Energies Greater than 10^{19} eV

Paris, France
22–24 April 1992

Edited by

Murat BORATAV
University of Paris 6
Paris, France

James W. CRONIN
University of Chicago
Chicago, IL, USA

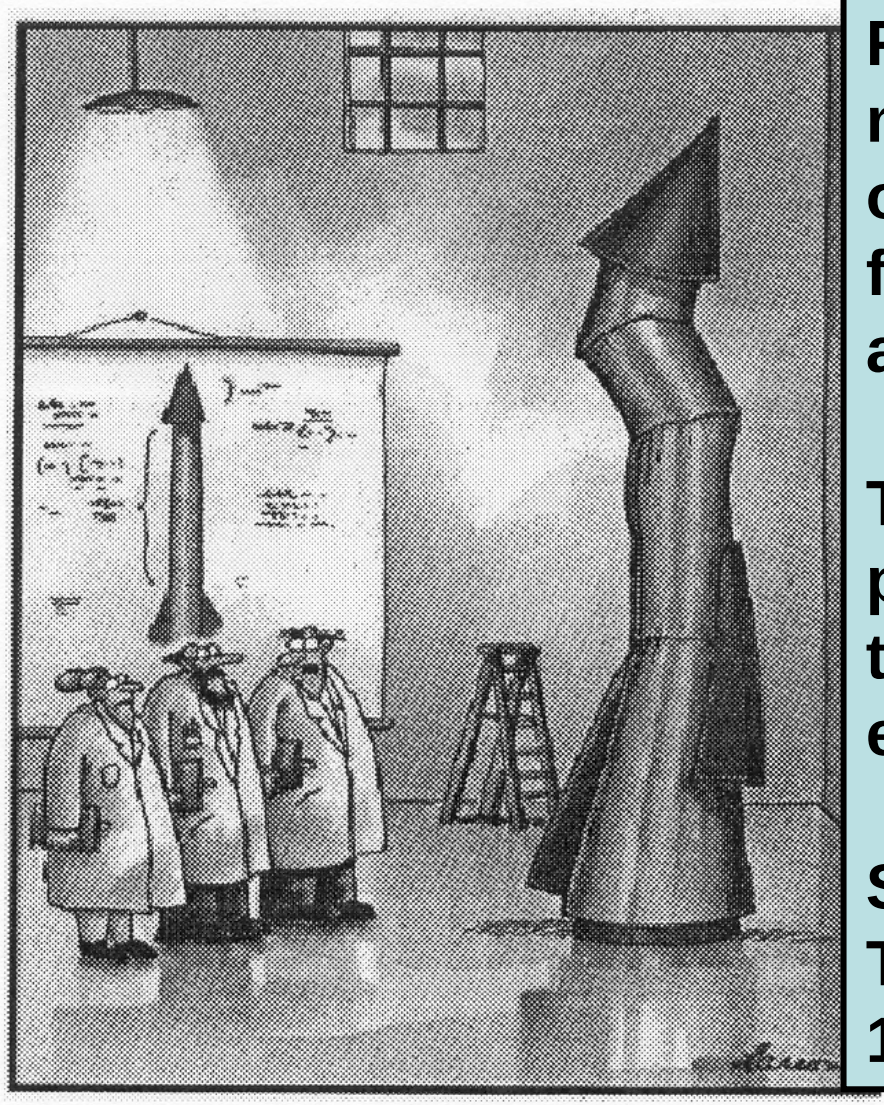
Alan A. WATSON
University of Leeds
Leeds, United Kingdom

Followed by workshops in Adelaide (January 1993) and Tokyo (September, 1993)

Some reflections post-Paris

- **Really the French were not very keen**
- **German situation was very complicated**
- **Italian groups (mainly Palermo and Naples) were rather reluctant to get involved under Jim's leadership as John Linsley had different ideas as to how things should be done – and really they didn't get on**
- **Competition between the two techniques**

How did it all start?



"It's time we face reality my friends: we should keep to ground detectors."

For the first eighteen months
or so, Jim and I were in favour of using only an array of particle detectors.

This was probably our worst piece of misjudgement throughout the whole enterprise.

Situation changed after Tokyo Workshop in Sept 1993.

MAJOR PROBLEMS TO BE OVERCOME

- **LACK OF MONEY TO DO ANYTHING**
- **Fight for recognition that the project was worthy of attention**
- **Site surveys needed – area like that inside the M25**
- **Develop a collaboration of critical mass and competence and with money to build a capital project of ~$100M**
- **How was the worth of the project to be assessed?**
- **A VULNERABILITY: that there are no hard theoretical numbers demanding the construction of an instrument of a certain size**

From CERN Charter

Drawn to our attention by Don Perkins

Article II

Purposes

1. The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available.

2. The Organization shall, in the collaboration referred to in paragraph 1 above, confine its activities to the following:

(a) the construction and operation of one or more international laboratories (hereinafter referred to as "the Laboratories") for research on high-energy particles, including work in the field of cosmic rays; each Laboratory shall include:

(i) one or more particle accelerators;

(ii) the necessary ancillary apparatus for use in the research programmes carried out by means of the machines referred to in *(i)* above;

(iii) the necessary buildings to contain the equipment referred to in *(i)* and *(ii)* above and for the administration of the Organization and the fulfilment of its other functions;

(b) the organization and sponsoring of international co-operation in nuclear research, including co-operation outside the Laboratories; this co-operation may include in particular:

(i) work in the field of theoretical nuclear physics;

(ii) the promotion of contacts between, and the interchange of, scientists, the dissemination of information, and the provision of advanced training for research workers;

(iii) collaborating with and advising other research institutions;

(iv) work in the field of cosmic rays.

Coping with the lack of Money

Small amounts of money for travel and limited R&D from budgets of interested Laboratories (e.g. Leeds: sale of lead previously used for muon shielding and Aluminium lids)

UNESCO: Jim, with Murat Boratav, persuaded Director General to give significant support for three years (travel, visits by scientists from developing countries to design studies)

Private donors whom Jim knew:

Robert Galvin, Motorola – son of the founder
David Grainger, benefactor of University of Chicago

Jim could get through doors that I could never even have knocked on!

3 weeks during August – September 1994

Visit to Far East with Jim

Japan
South Korea
Hong Kong
*** China –** involved for a few years
*** Vietnam –** Vice-President of the Communist Party
*** Australia**

Naming of the project:

A Unique **G**iant **E**AS **R**ecorder → **A.U.G.E.R.**

→ Auger

Design Study:

Role of Fermilab Director, John Peoples

Recollections of Paul Mantsch, Auger Project Manager

"I do not remember a time when there was any doubt that we would participate in this project. John said at the time that had recently read a book that was about or touched on the question of the source of cosmic rays.

John Peoples was convinced that this was important work.

He agreed to support the workshop, provided space and people to help me organize it. There was a cost to John in all of this as there was a lot of hostility at Fermilab toward resources diverted from anything other than maintaining the machine and the big collider detectors. This hostility was running particularly high because of the perceived number of people in the Computing Division working the Sloan Digital Sky Survey".

The Design Study: January to July 1995

pvc

Studies of various surface detector designs:

RPCs, water-Cherenkov, scintillators, radio….
"Let a thousand flowers bloom…."

Hybrid approach: ground array and fluorescence detectors
- chose water for the surface detectors

Very extensive Monte Carlo calculations

Two sites to give all sky coverage

Each site ~3000 km^2 : site survey was contemporaneous
Approximate cost ~$100M

Design Study document completed in October 1995

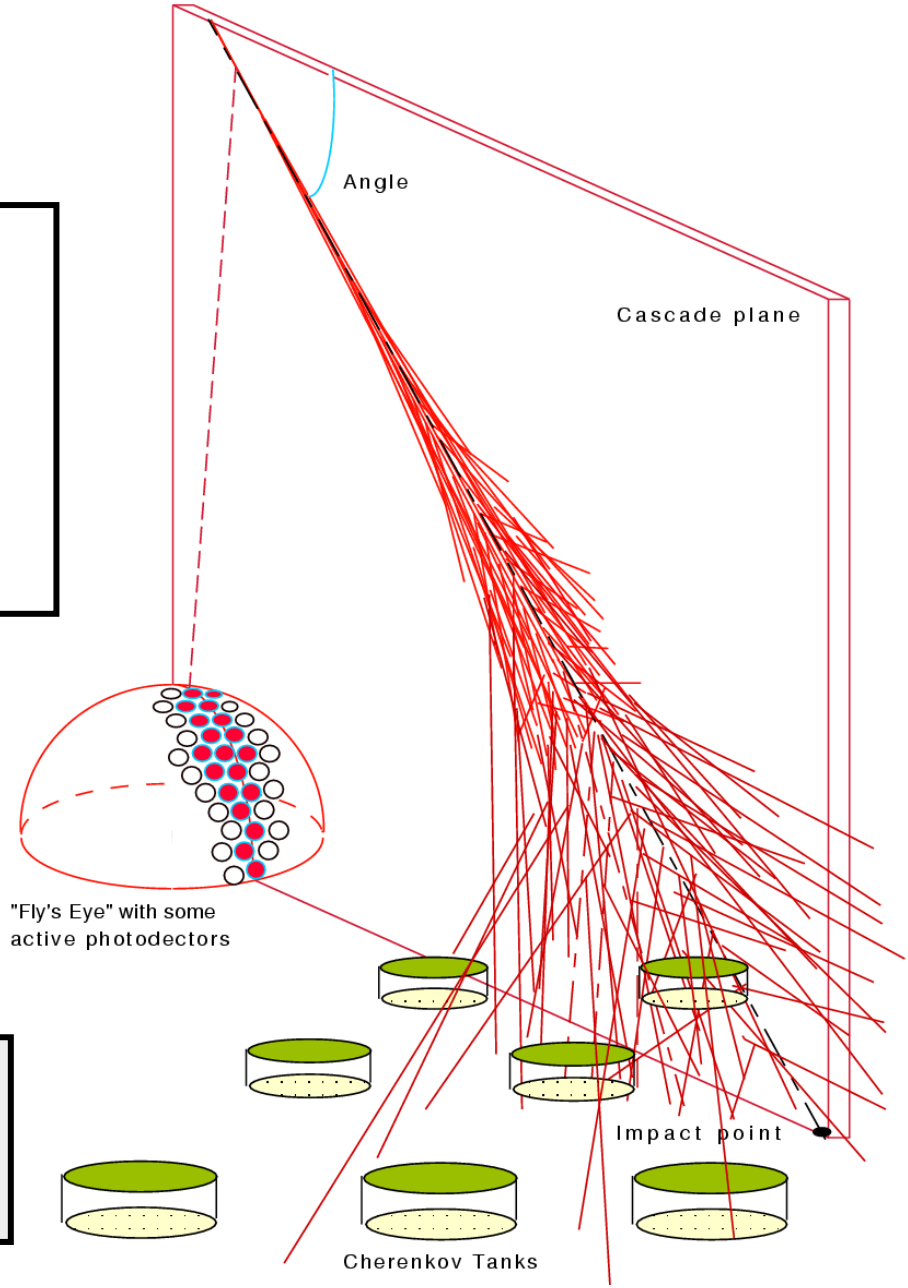
The design of the Pierre Auger Observatory marries the two well-established techniques

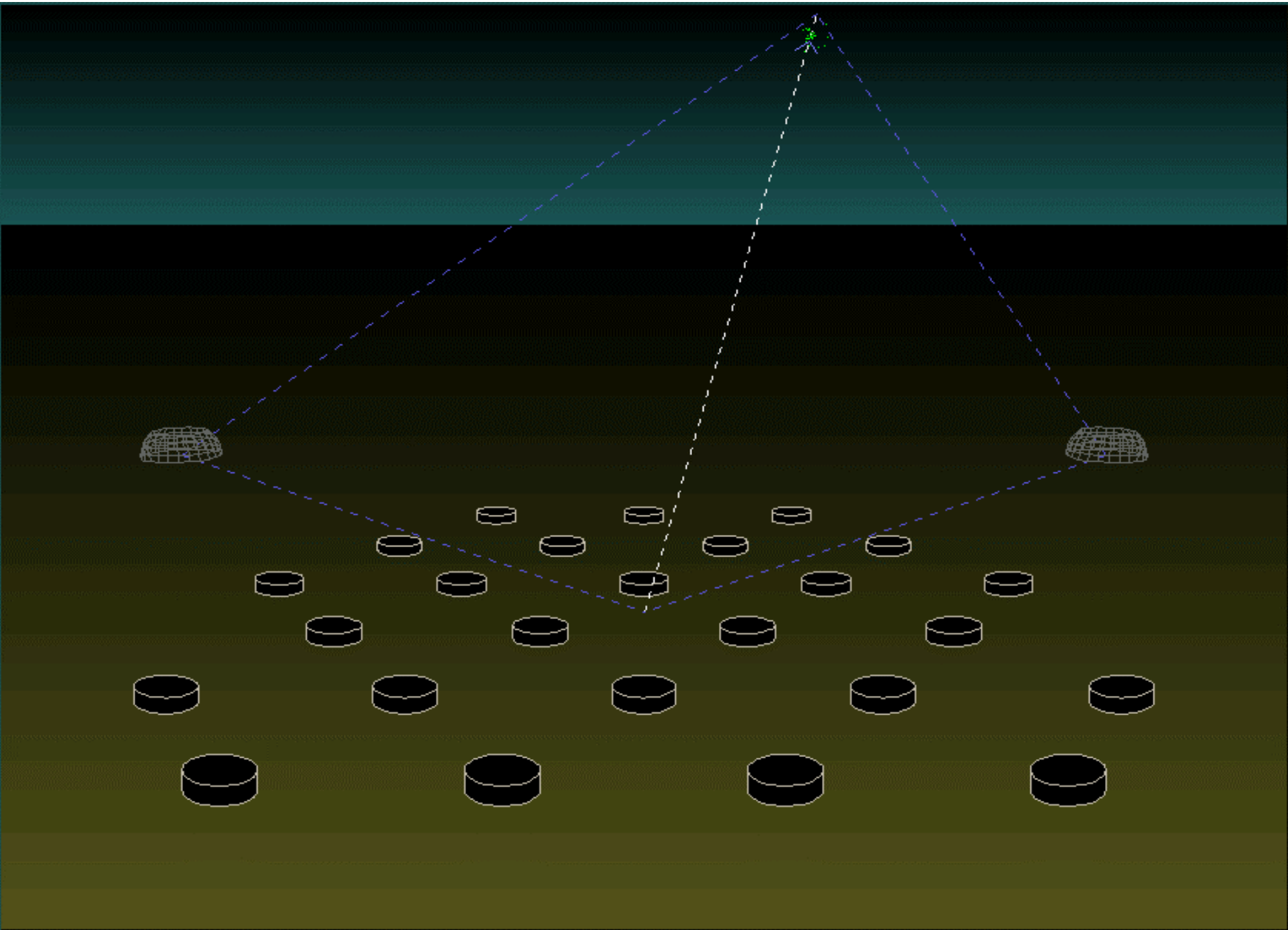
→ **the 'HYBRID' technique**

Fluorescence →

AND

Arrays of water-Cherenkov detectors →





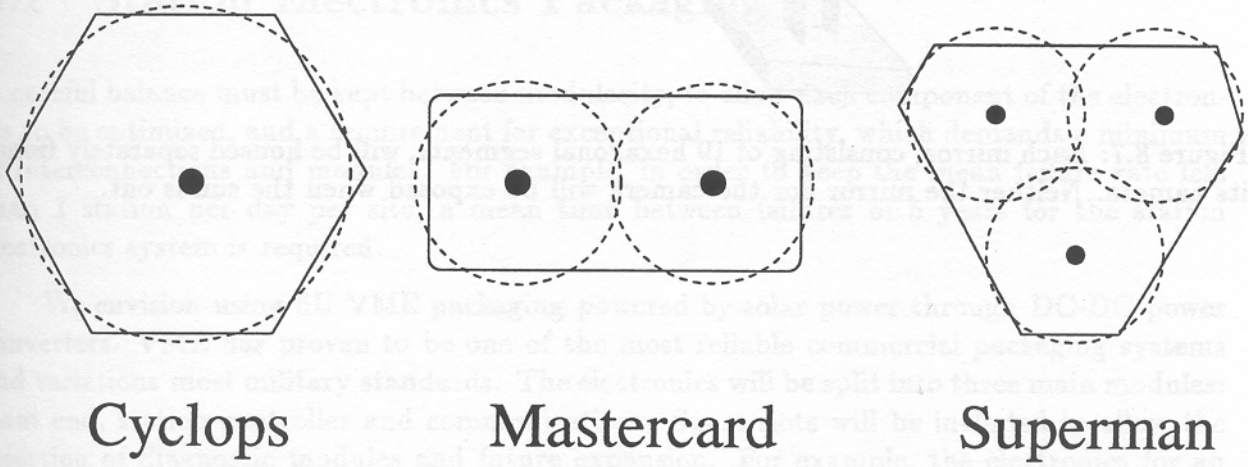
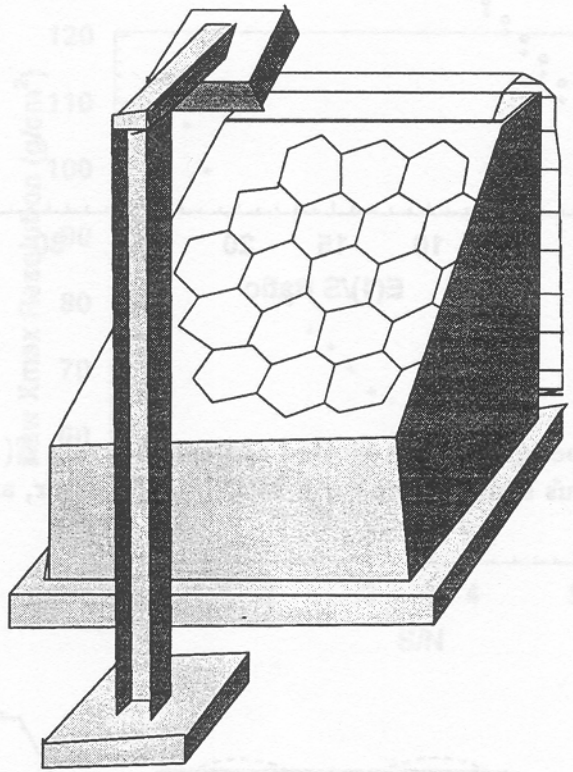
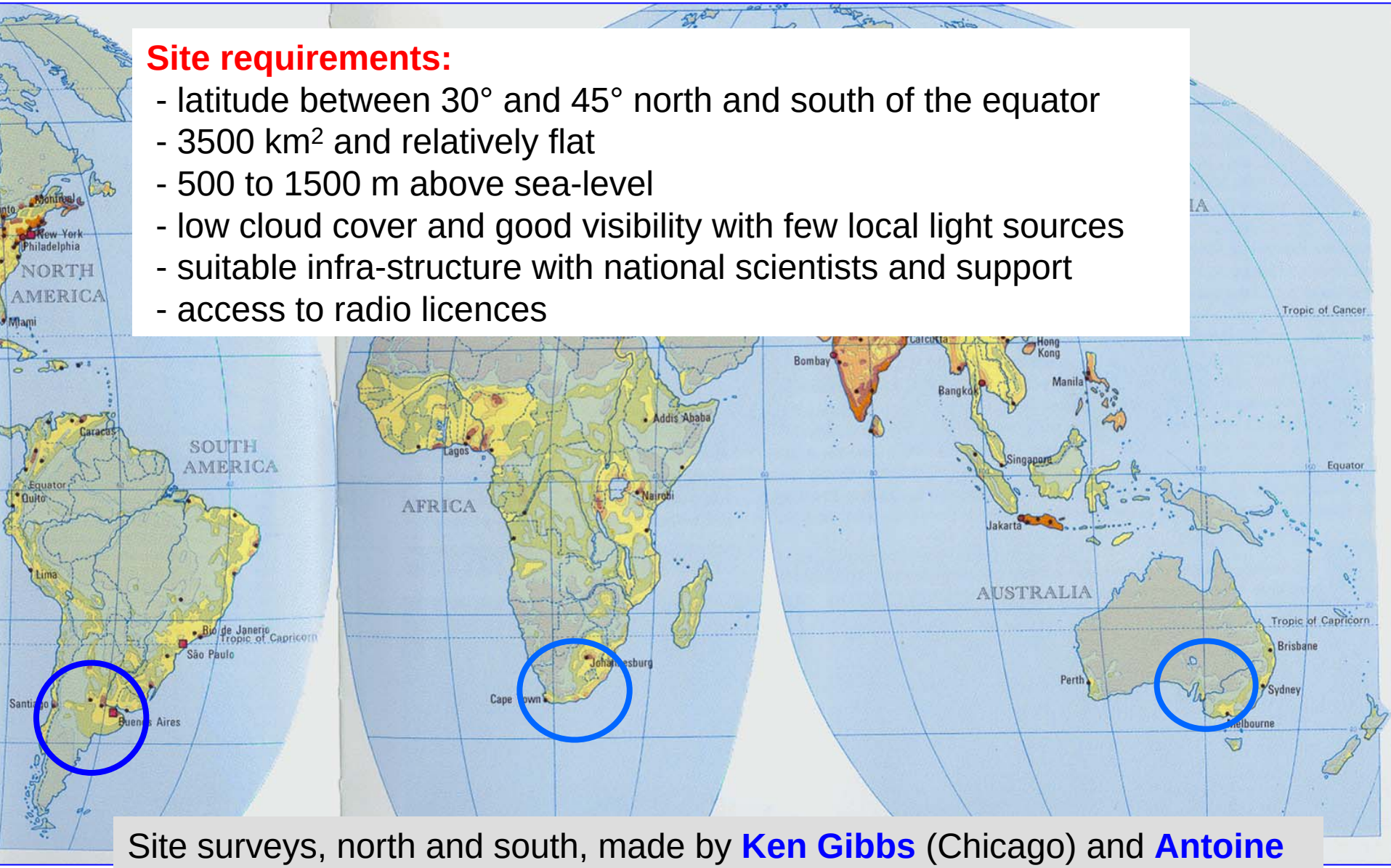


Figure 8.6: Possible array layouts for 1, 2 or 3 eyes. The
and the dotted circles the limits of their apertures for 1(

The concept of the layout following the design study (October 1995)

-But Nature does not provide hills so strategically placed!





Site requirements:

- latitude between 30° and 45° north and south of the equator
- 3500 km^2 and relatively flat
- 500 to 1500 m above sea-level
- low cloud cover and good visibility with few local light sources
- suitable infra-structure with national scientists and support
- access to radio licences

Site surveys, north and south, made by **Ken Gibbs** (Chicago) and **Antoine Letessier-Selvon** (Paris) during 1994 and 1995.

Argentina selected for South during meeting at UNESCO in November 1995

Site selection: November 1995

January 1995: Interest from Argentina – arose by chance Alberto Etchegoyen and President Carlos Menem

South Africa:

Australia:

Countries with quite long tradition in cosmic ray physics

UNESCO
November 1995

President *Republic of South Africa*

Dear Sir

Scientific and engineering achievements are the cornerstones upon which the future generations in Southern Africa will attain their goals for the successful development and upliftment of our peoples. There is consequently an urgent need for South Africa to be at the leading edge of expertise in the world of technological endeavour.

Recently I have been informed of the Giant Air Shower Array project which is truly an international project destined to become one of the scientific highlights of this and the next decade and that South Africa has one of the favoured sites in the southern hemisphere.

I am placing my full weight behind the sitting of the project in South Africa as it is clear to me that it will provide an exciting new focus for our young potential scientists and enhance our Reconstruction and Development Program. Just as important however is that our own expertise could significantly contribute to the international community in the spheres of science, training and facilities.

As a developing country with a good foundation in the sciences and related technologies, South Africa will be in a favourable position to extend our knowledge base into the Southern African subcontinent to the mutual benefit for all should we be successful in being awarded the project.

I wish to reassure you of our total commitment should you consider South Africa as the site for this prestigious undertaking.

With best wishes to you and your colleagues.

Yours sincerely

NRMandela

N R MANDELA

Dr M Boratav

Assessment of the Project (November 1995)

No host institution

(unlike new project at CERN, ESA, ESO, FNAL)

Formed our own Review Committee

W I Axford (MPI: Director, Katlenburg-Lindau): Chair
R Cowsik (Indian Institute for Astrophysics, Bangalore, India)
M Demassieux, ENST (France)
R Eckers (Autralian National Telescope, Australia)
M-T Koshiba (Japan)
J Steinberger (CERN, Switzerland)

'Entirely favourable' report used to help with agencies

"But of course it is a favourable report: you chose the committee"

- an agency that will remain anonymous

The Search for Funding in the USA

All countries watched what the US was doing

Significant promises of funding from Argentina, Brasil and Mexico

US assessment by SAGENAP committee:

DIFFICULT! Third time lucky (April 1998)

BUT:

BUILD ONLY ONE Observatory

- and GO SOUTH

Itacaruça, Brasil: May 1998

- **Should we follow what SAGENAP is saying?**

Jim was in a minority of 1!!

After US funding announced in 1998, funding from European Countries came relatively quickly (UK awarded me £2M over 5 years, with main task to deliver the communications system)

(Initial reactions from UK astronomers)

This allowed International Agreements to be signed

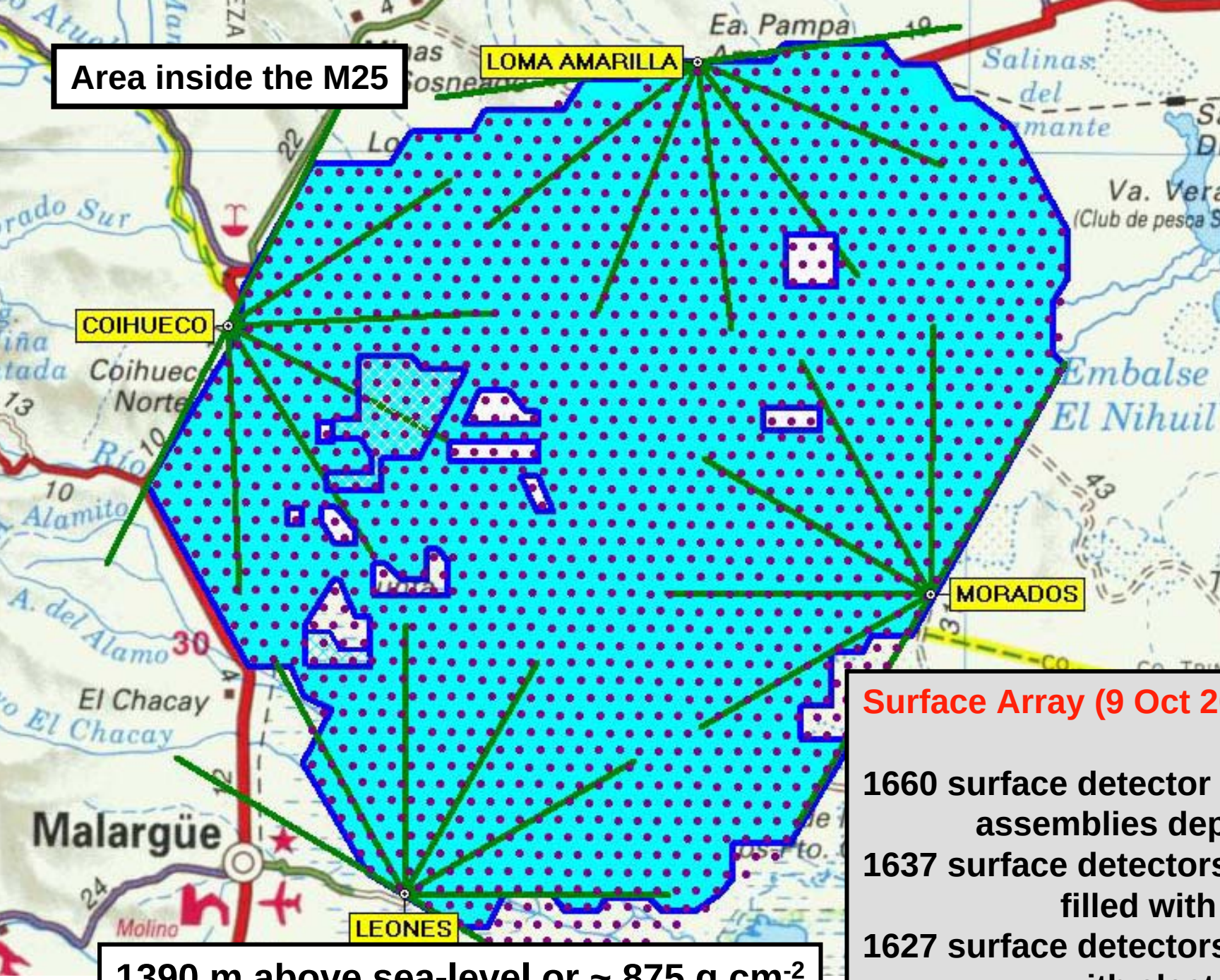
Ground breaking Ceremony on 17 March 1999

The Pierre Auger Collaboration

Czech Republic	**Argentina**
France	**Australia**
Germany	**Brasil**
Italy	**Bolivia***
%Netherlands	**Mexico**
Poland	**USA**
%Portugal	**Vietnam***
Slovenia	***Associate Countries**
%Spain	
United Kingdom	**~300 PhD scientists from ~70 Institutions and 17 countries**
% joined later on	

17 March 1999: Ground Breaking Ceremony

Ground Breaking Ceremony: 17 March 1999



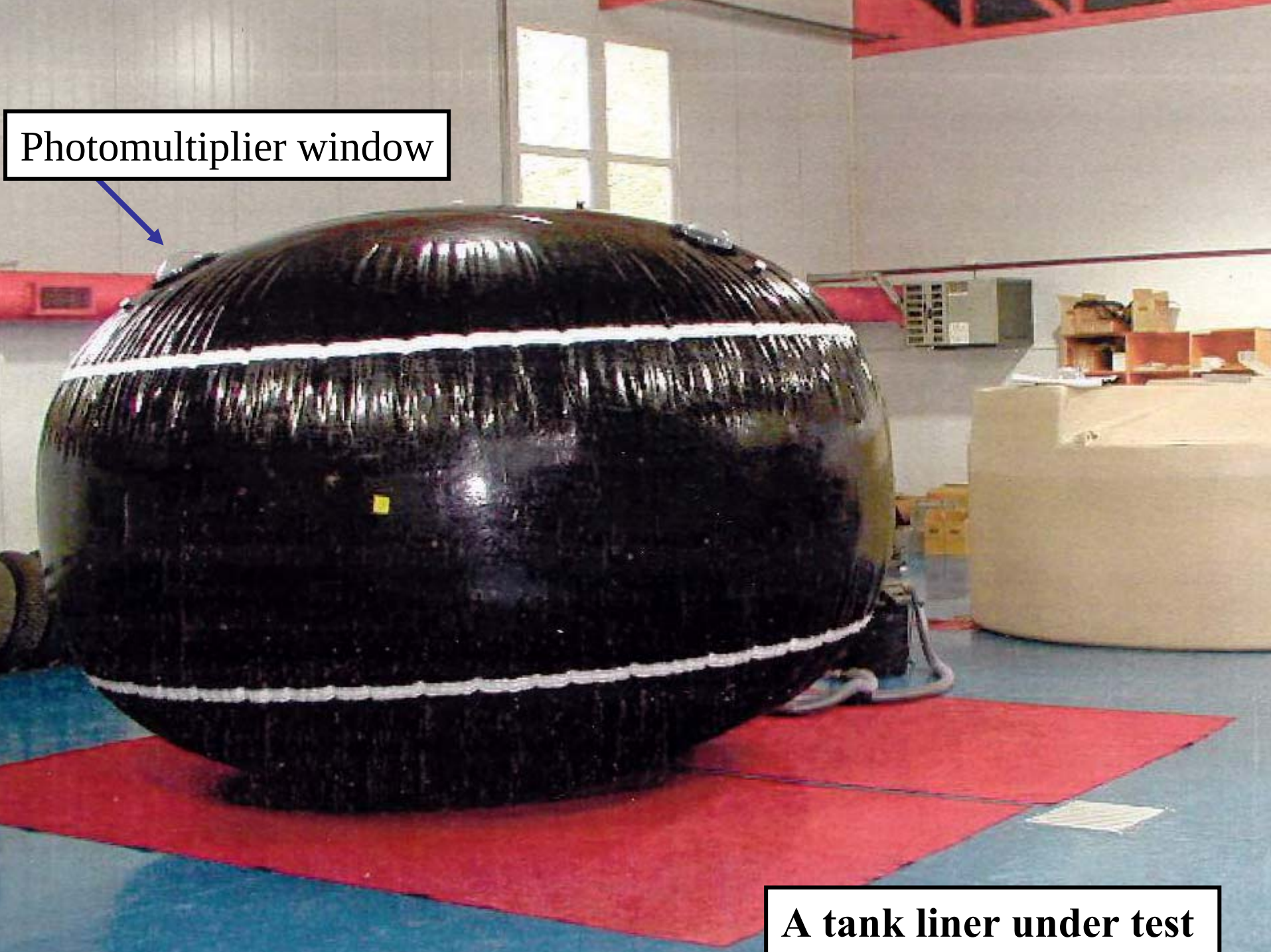
Surface Array (9 Oct 2008)

1660 surface detector assemblies deployed

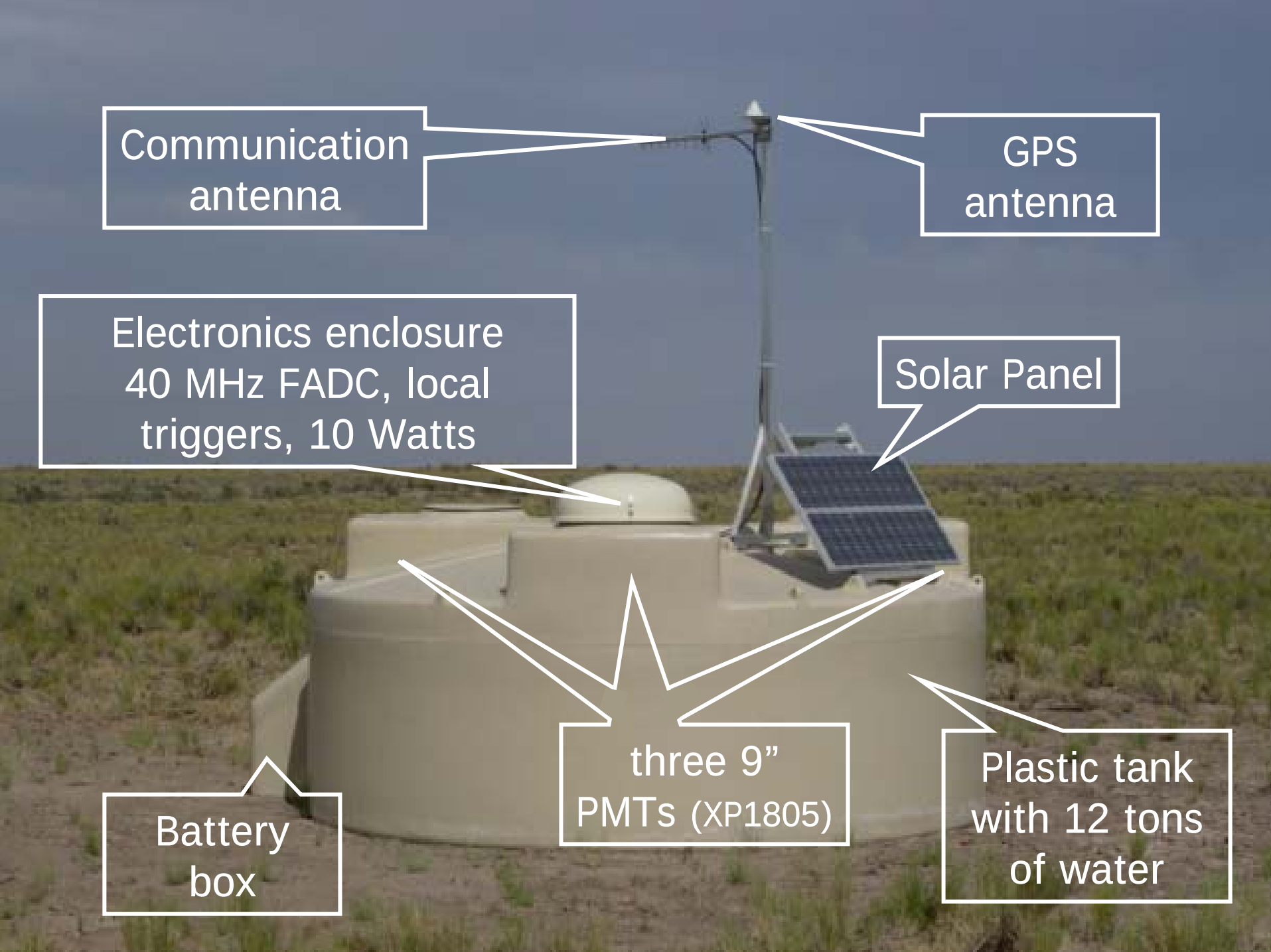
1637 surface detectors filled with water

1627 surface detectors with electronics

Campus of Auger Observatory in Argentina



A tank liner under test


Communication antenna
GPS antenna
Electronics enclosure 40 MHz FADC, local triggers, 10 Watts
Solar Panel
three 9” PMTs (XP1805)
Plastic tank with 12 tons of water
Battery box


A. WATSON
RANDON
CKJ 803

Water-filling at a distance

Last tank deployed: 13 June 2008

Set Backs

- **Lack of up-front money – ordered items in small quantities: this can lead to problems of obsolence – GPS receivers – and cost inflation.**

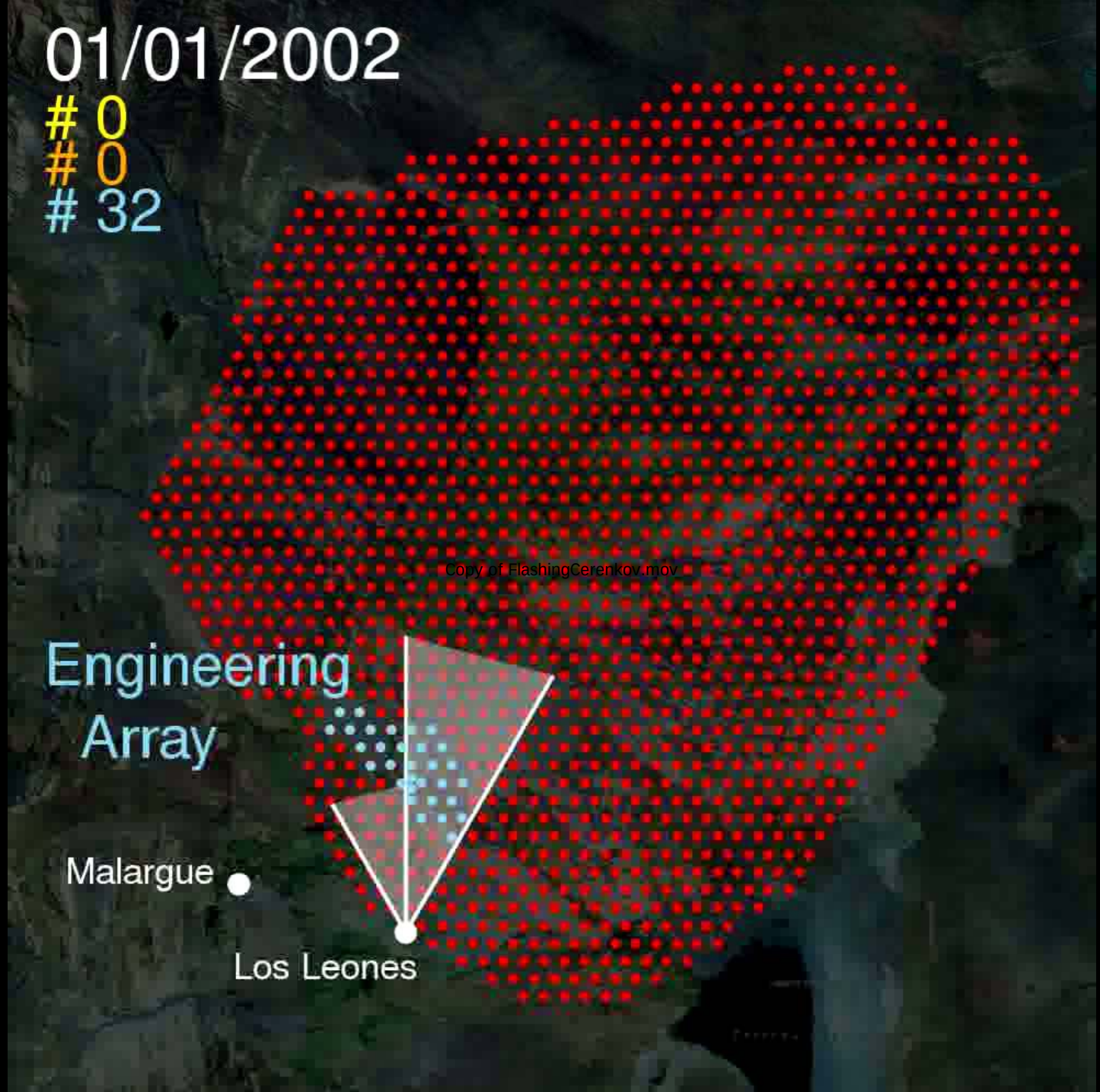
- **Argentinian financial crisis in early 2002**

  President Menem had sold all the family silver! Peso/dollar parity to 4:1

  Most countries put in some more

  and some new countries joined

  Major problems with new land-owners


01/01/2002
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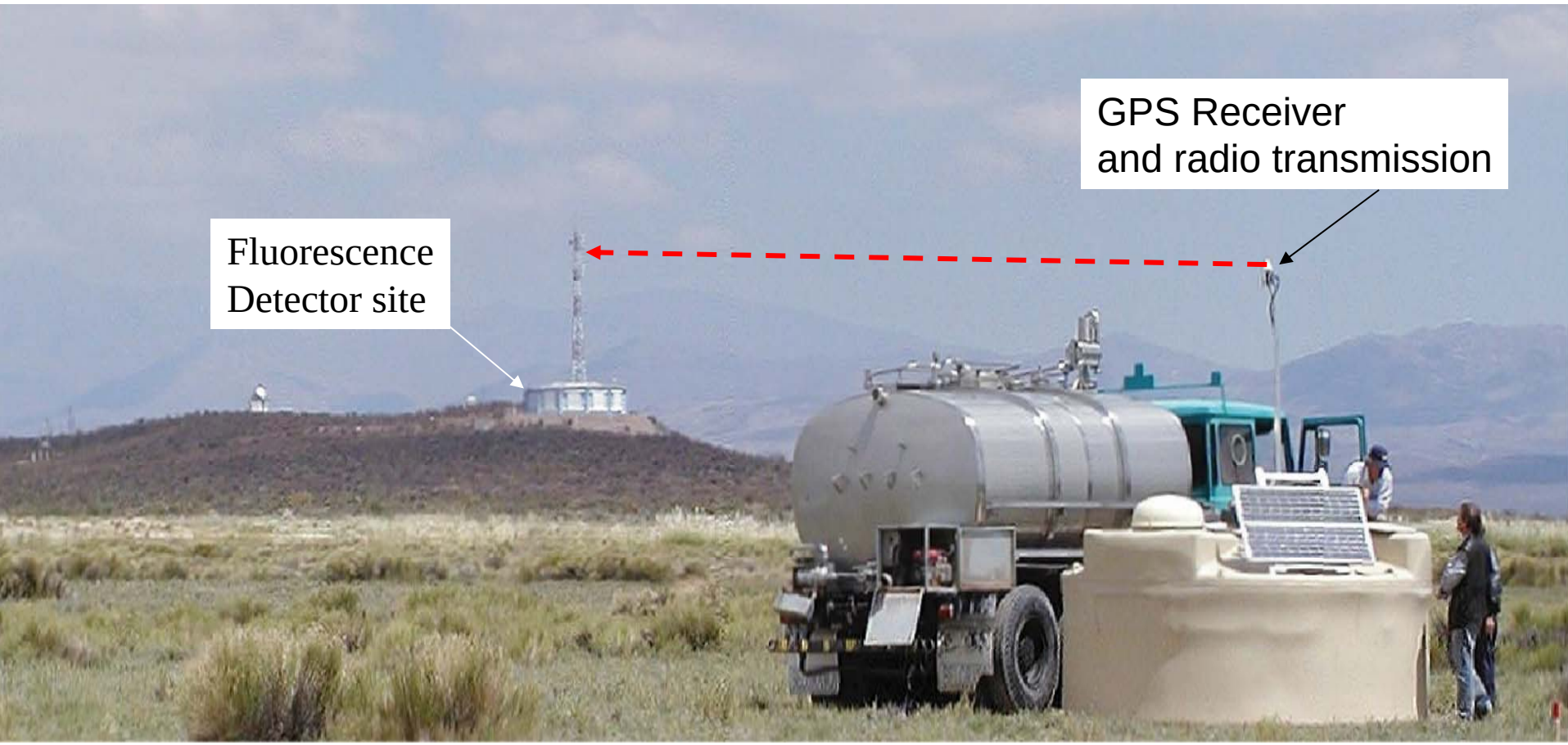
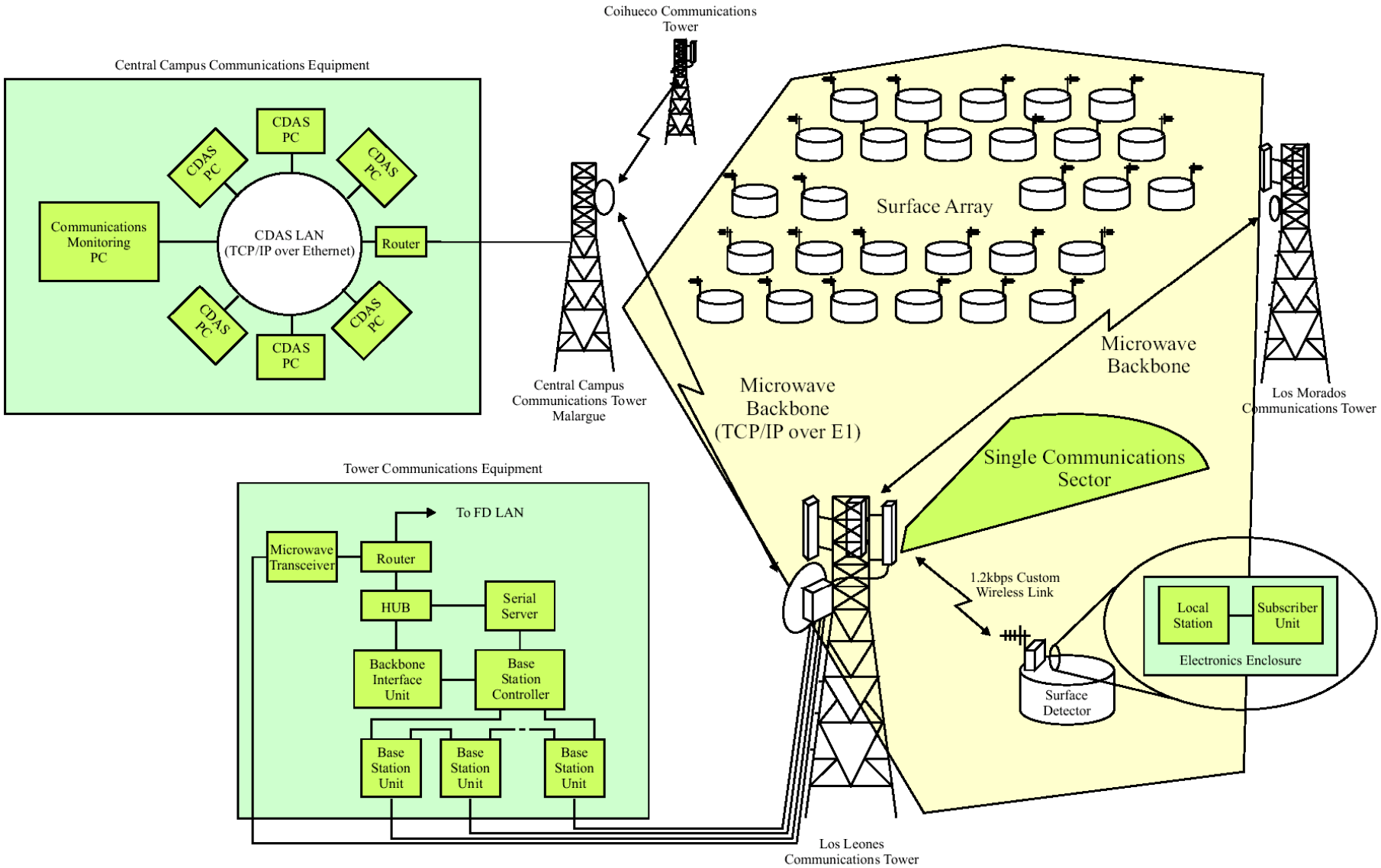
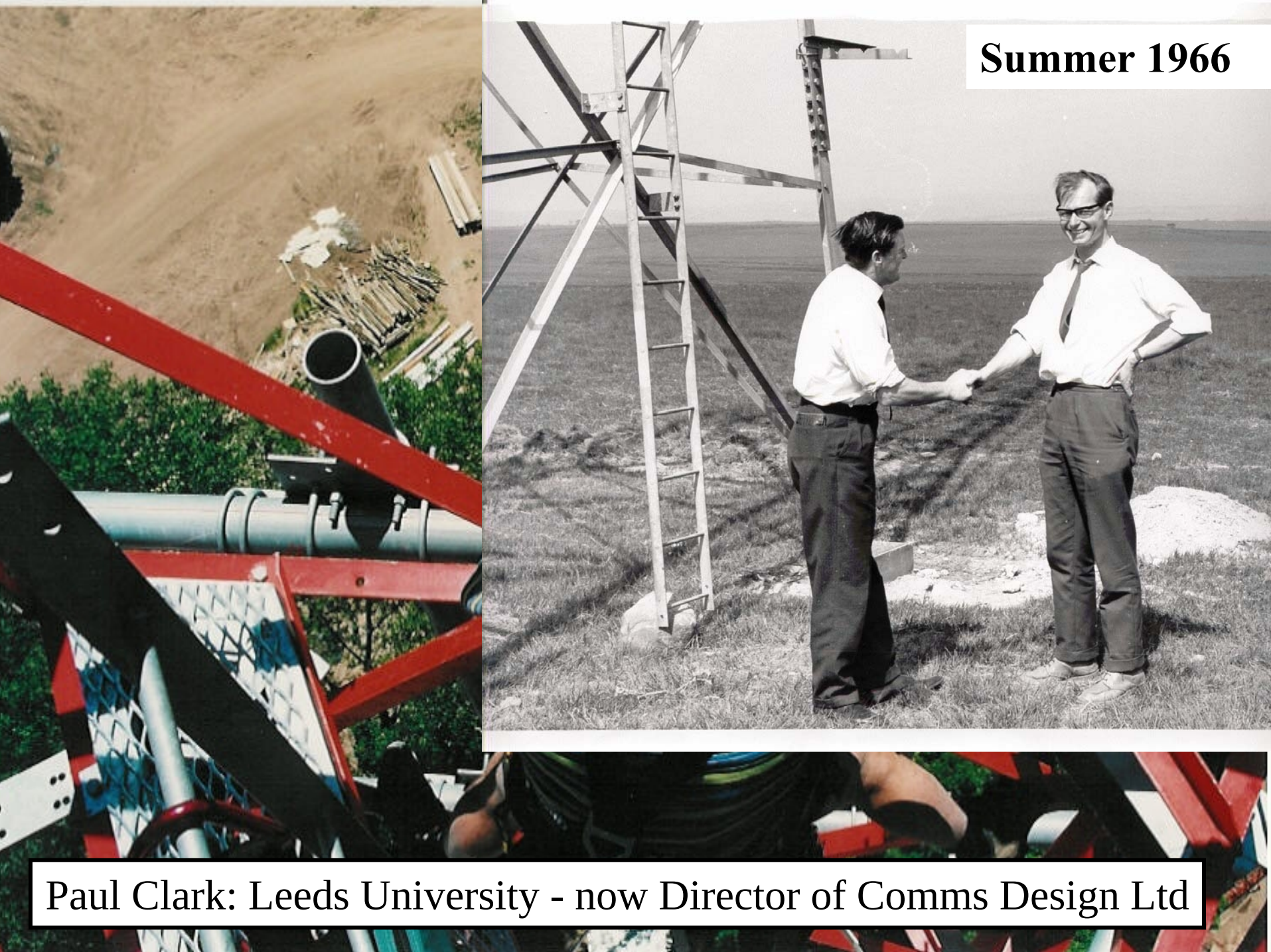
0
32
Copy of FlashingCerenkov.mov
Engineering
Array
Malargue
Los Leones

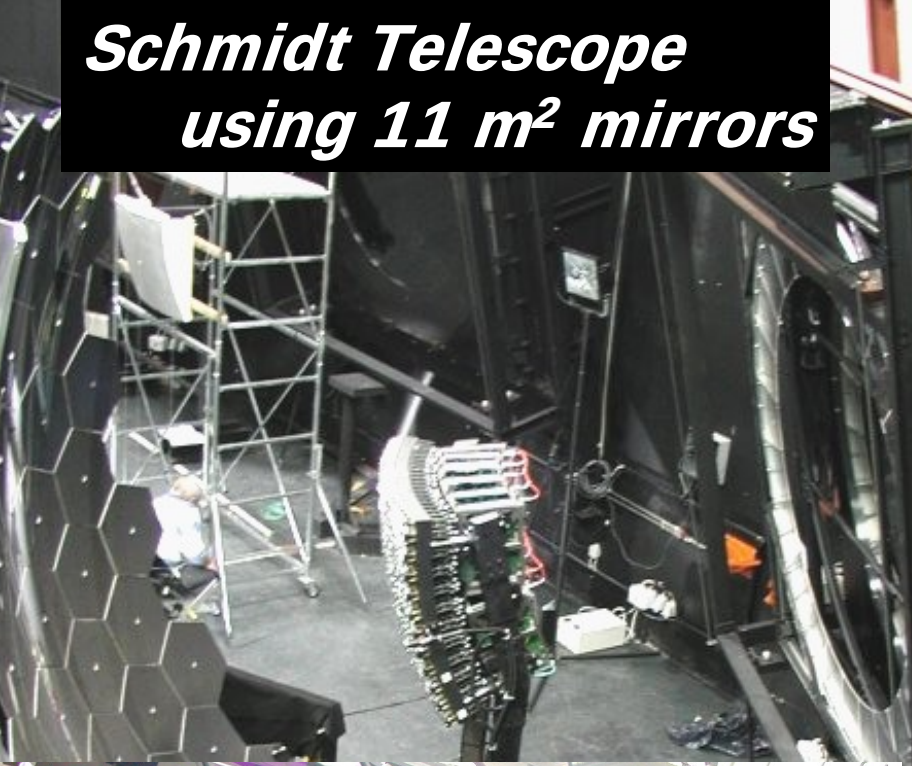

GPS Receiver
and radio transmission
Fluorescence
Detector site

Telecommunication system

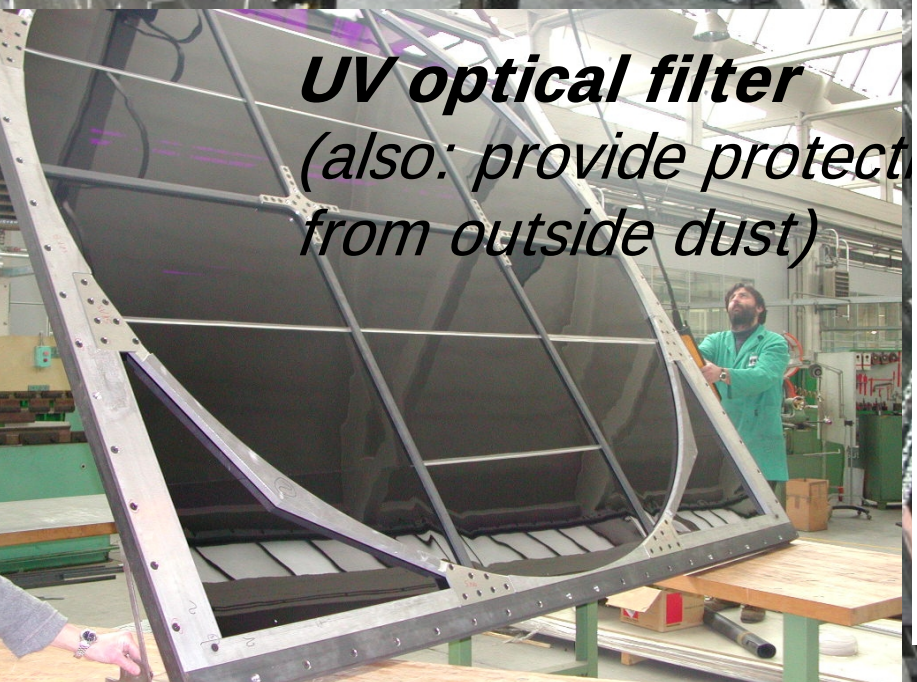




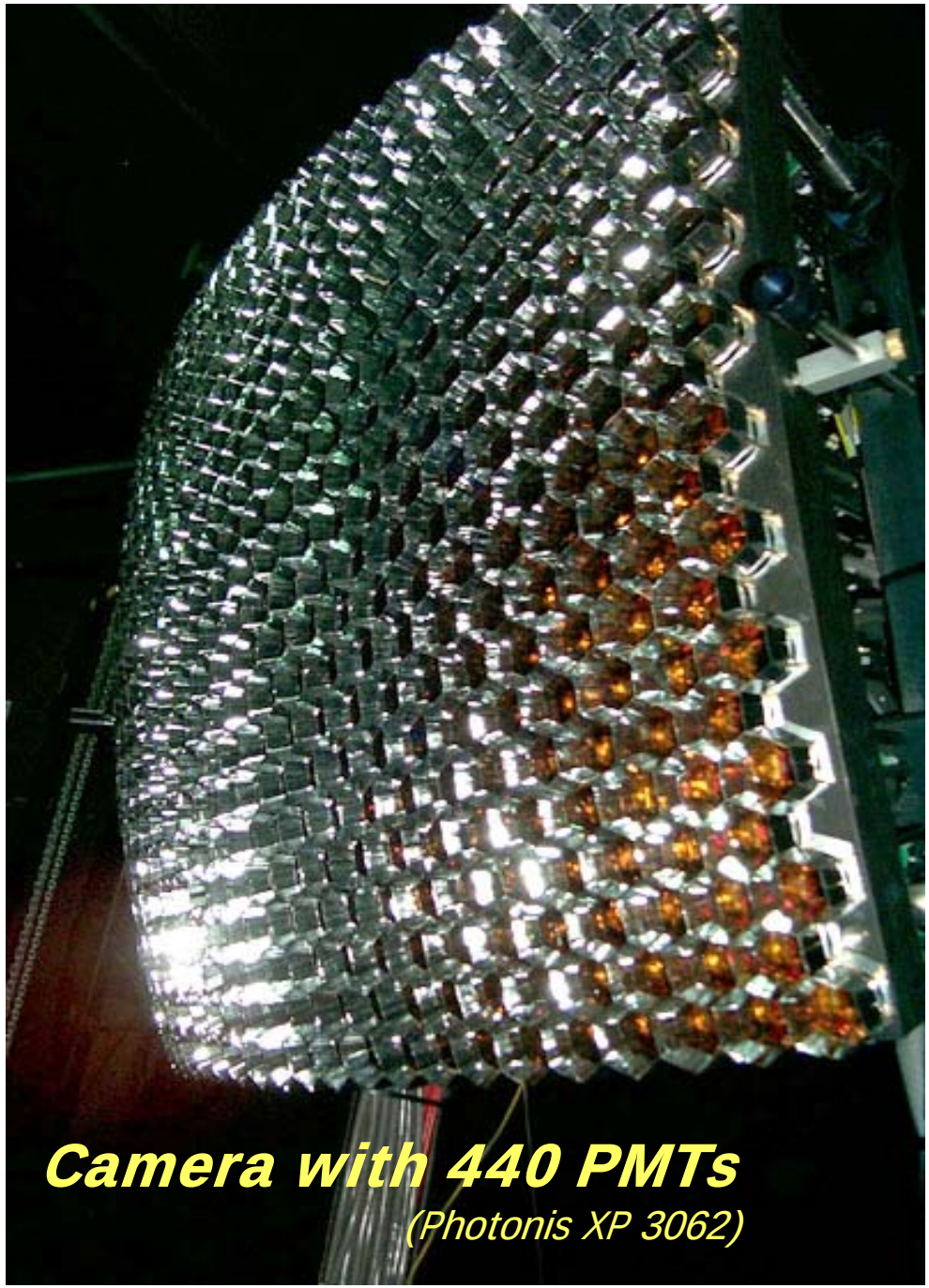
Paul Clark: Leeds University - now Director of Comms Design Ltd



Schmidt Telescope using 11 m² mirrors



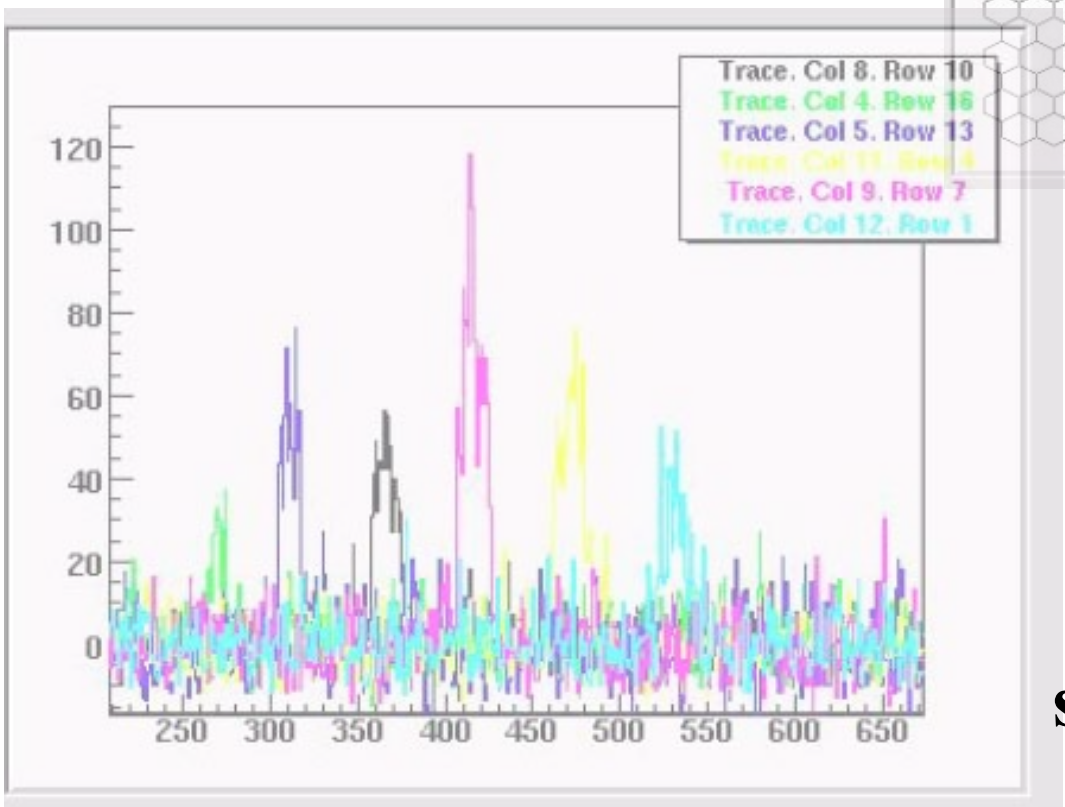
UV optical filter
(also: provide protect from outside dust)

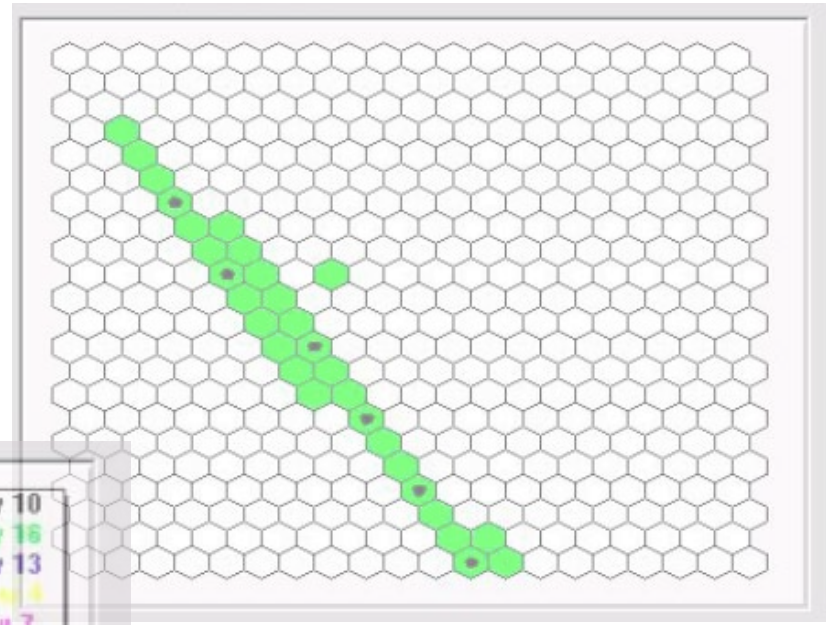


Camera with 440 PMTs
(Photonis XP 3062)

FD reconstruction

Signal and timing
Direction & energy

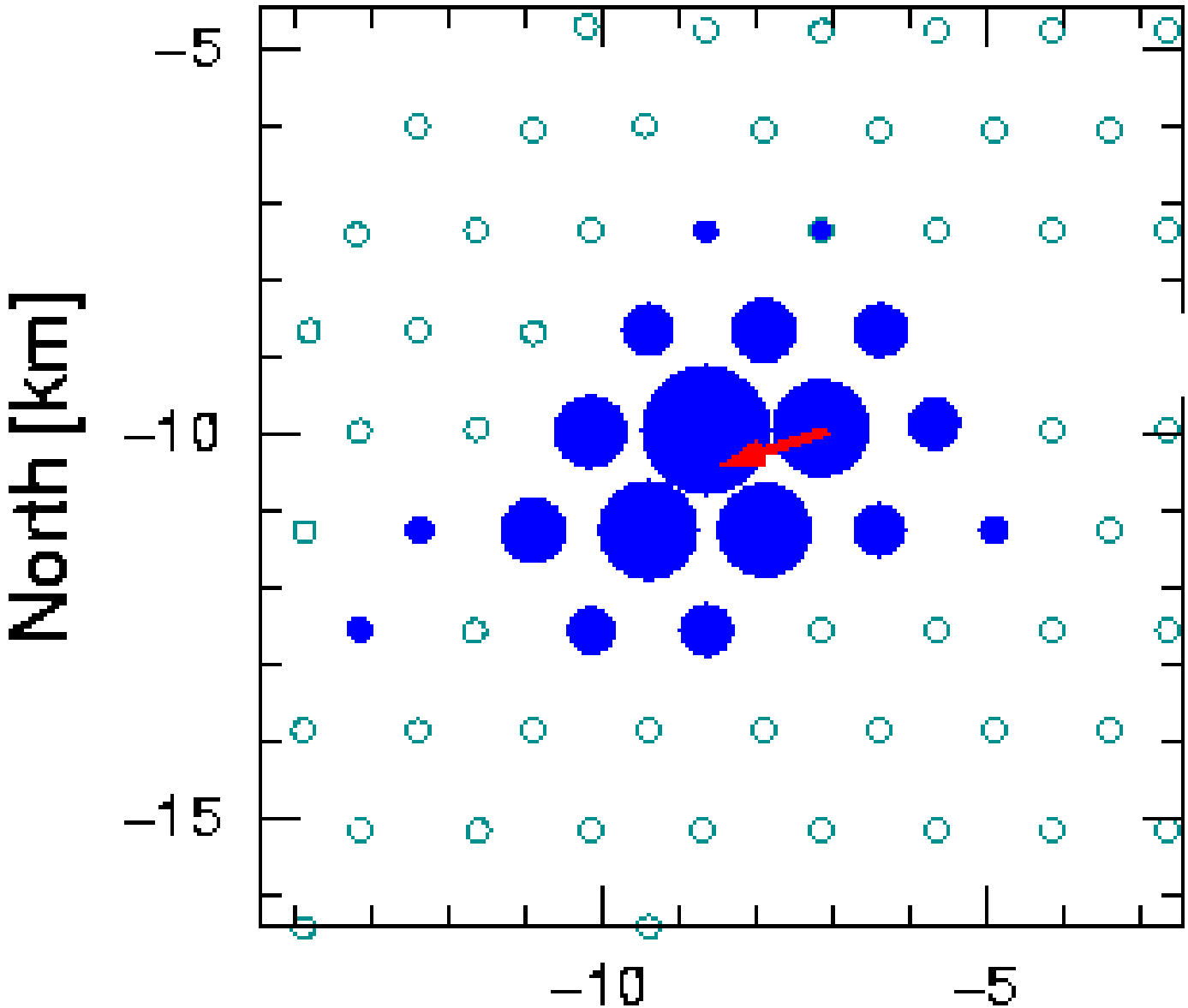


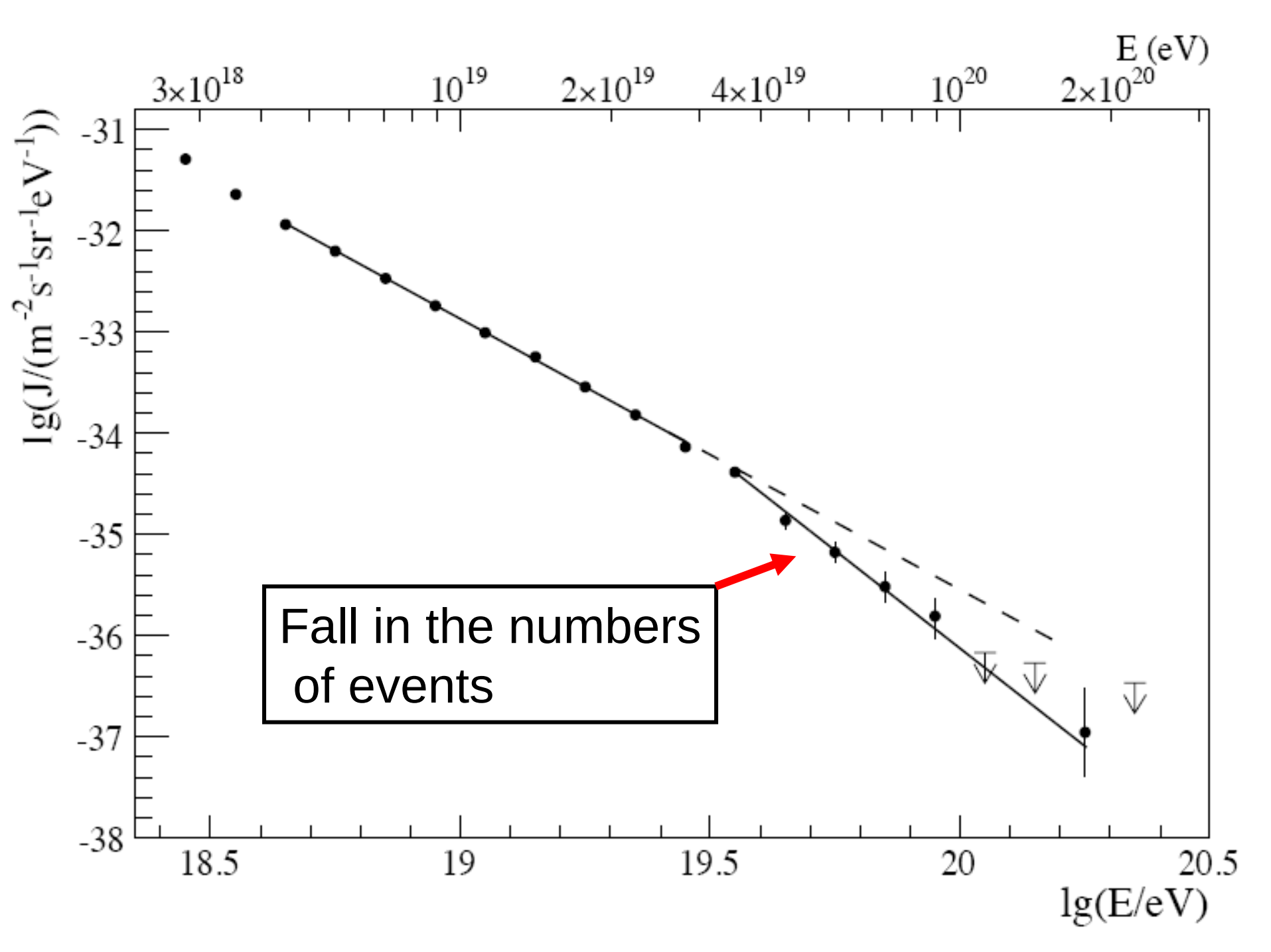


Pixel geometry
shower-detector plane

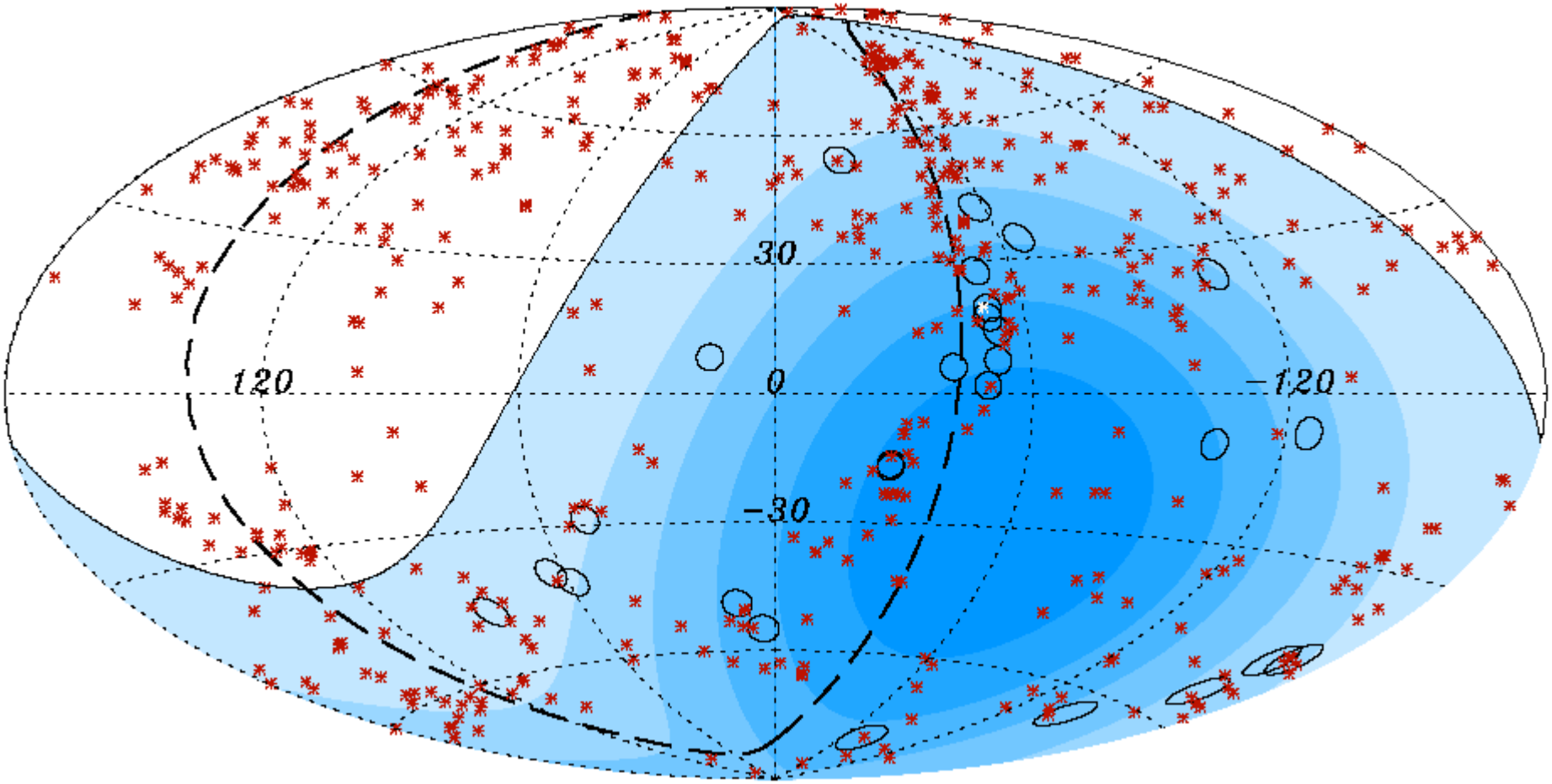
A large event: 7 x 10^{19} eV

Footprint ~ 25 km^2
18 detectors hit

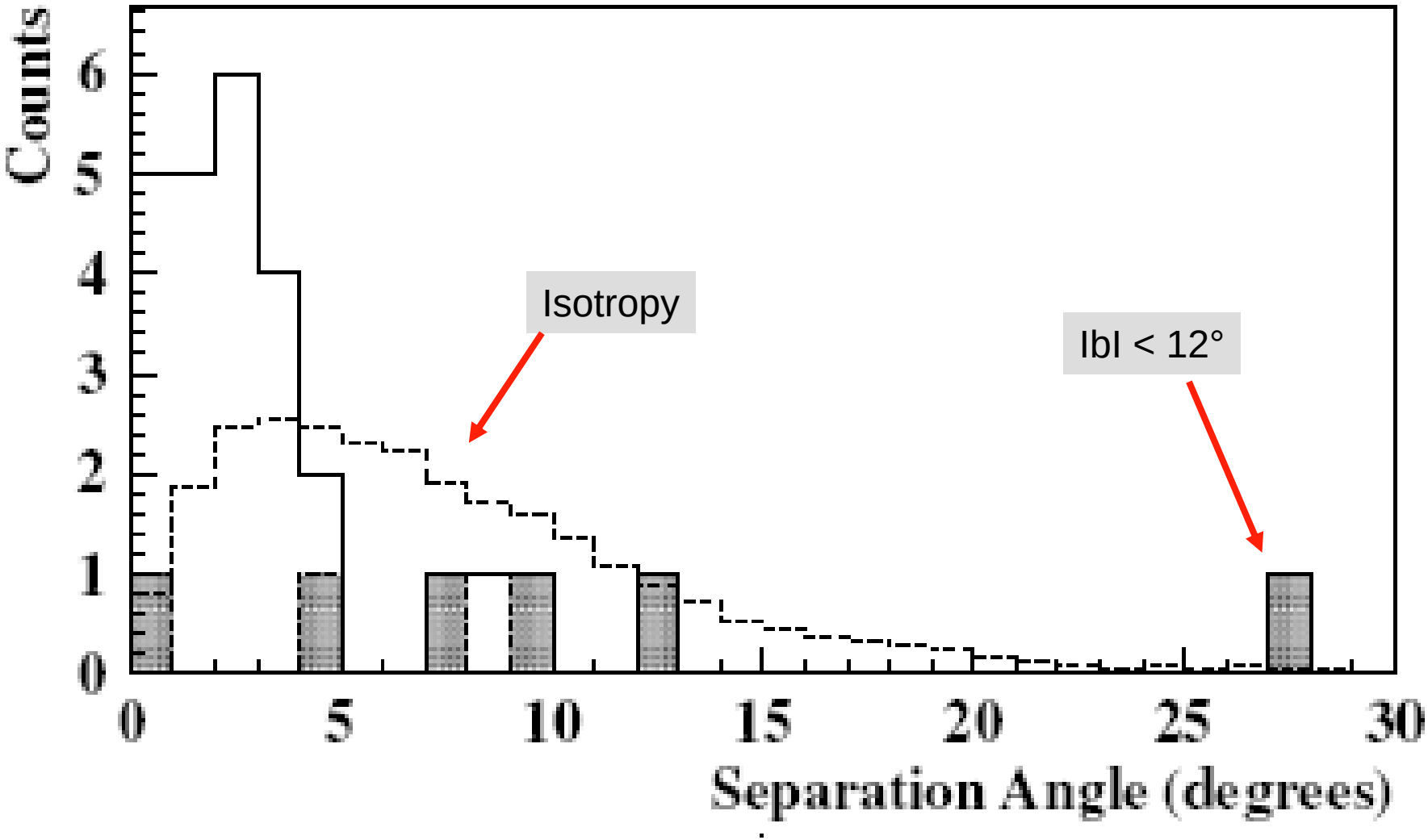



E (eV)
3×10^18
10^19
2×10^19
4×10^19
10^20
2×10^20
lg(J/(m^-2 s^-1 sr^-1 eV^-1))
-31
-32
-33
-34
-35
-36
-37
-38
18.5
19
19.5
20
20.5
lg(E/eV)
Fall in the numbers of events

Science: 9 November 2007



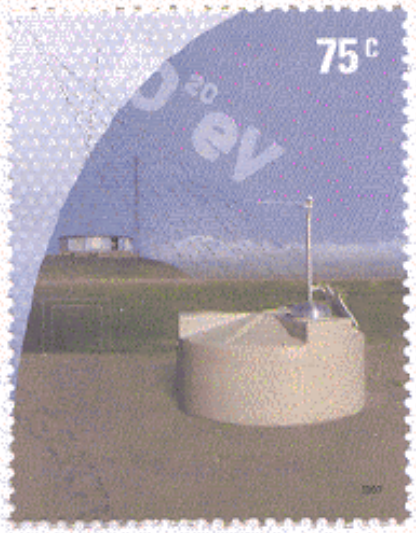
First scan gave ψ < 3.1°, z < 0.018 (75 Mpc) and E > 56 EeV



Distribution of angular separations to closest AGN within 71 Mpc

CORREO ARGENTINO

CORREO OFICIAL DE LA REPUBLICA ARGENTINA S.A.



COSMOS CIENCIA

OBSERVATORIO
PIERRE
AUGER
MALARGÜE MENDOZA

Sobre primer día oficial

Official First Day Stamp
- to mark birth of cosmic ray astronomy?

Sur la piste des rayons cosmiques dans la pampa argentine

Quelle est l'origine des **rayons cosmiques**? *C'est pour résoudre cette* **énigme** *que des chercheurs ont investi la pampa argentine. Là, ils ont installé* **le plus grand détecteur** *du monde qui, jour et nuit, traque les* **flux de particules** *venues du* **cosmos**. *Une* **quête** *dont les physiciens espèrent beaucoup.*

Par Claire Martin. Photos: Rodrigo Gomez Rovira/Vu

Carlo Crivelli (1430 – 1490): 'The Annuciation with St Edimus'

Raising the profile of the Idea

Seminars in many places:

USA – meeting at FNAL in March 1993, post demise of SSC
Argentina
Australia
Hong Kong
China
South Korea
Seoul
Vietnam
Europe: Italy, UK, France, Germany, CERN, Russia

Many, many talks – one was really a salesman!