UHECR2018

Paris: 8 October 2018

The Highest Energy Particles in Nature: the past, the present and the future

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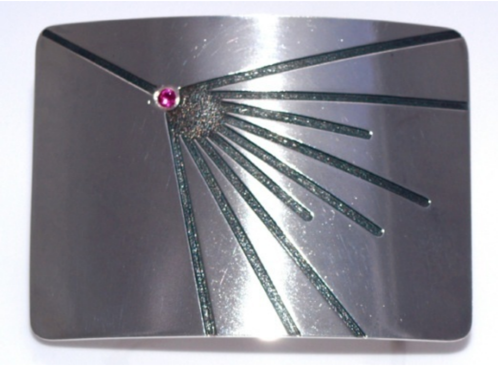
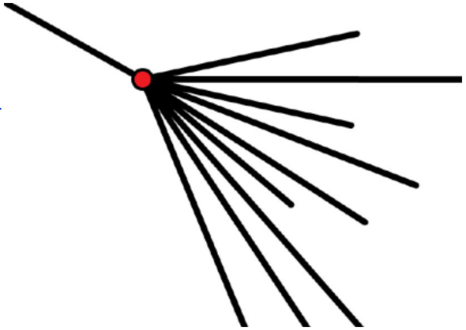




The Brief:

Quoting (freely) Malcolm Longair: many of the ideas and experimental procedures that our speakers will present have a long and distinguished history which reflects the insight and ingenuity of the great scientists of the past. These are our legacy and the foundation of our current scientific practice, including our Auger Observatory. So, what we would love to hear from you in those 40 minutes is a historical introduction to ultra-high energy cosmic rays, to remind to all of us that if we are now seeing a bit further, it is by standing on the shoulders of giants.

Draws upon article by K-H Kampert and myself, EPJ-History 2012

The Text for much of today's Sermon:

"Elementary Particle Physics"

Val Fitch

Rev Mod Phys 71 S25 1999

"Those who became interested in cosmic rays tended to be rugged individualist, to be iconoclastic and to march to the drummer in their own heads rather than some distant one"

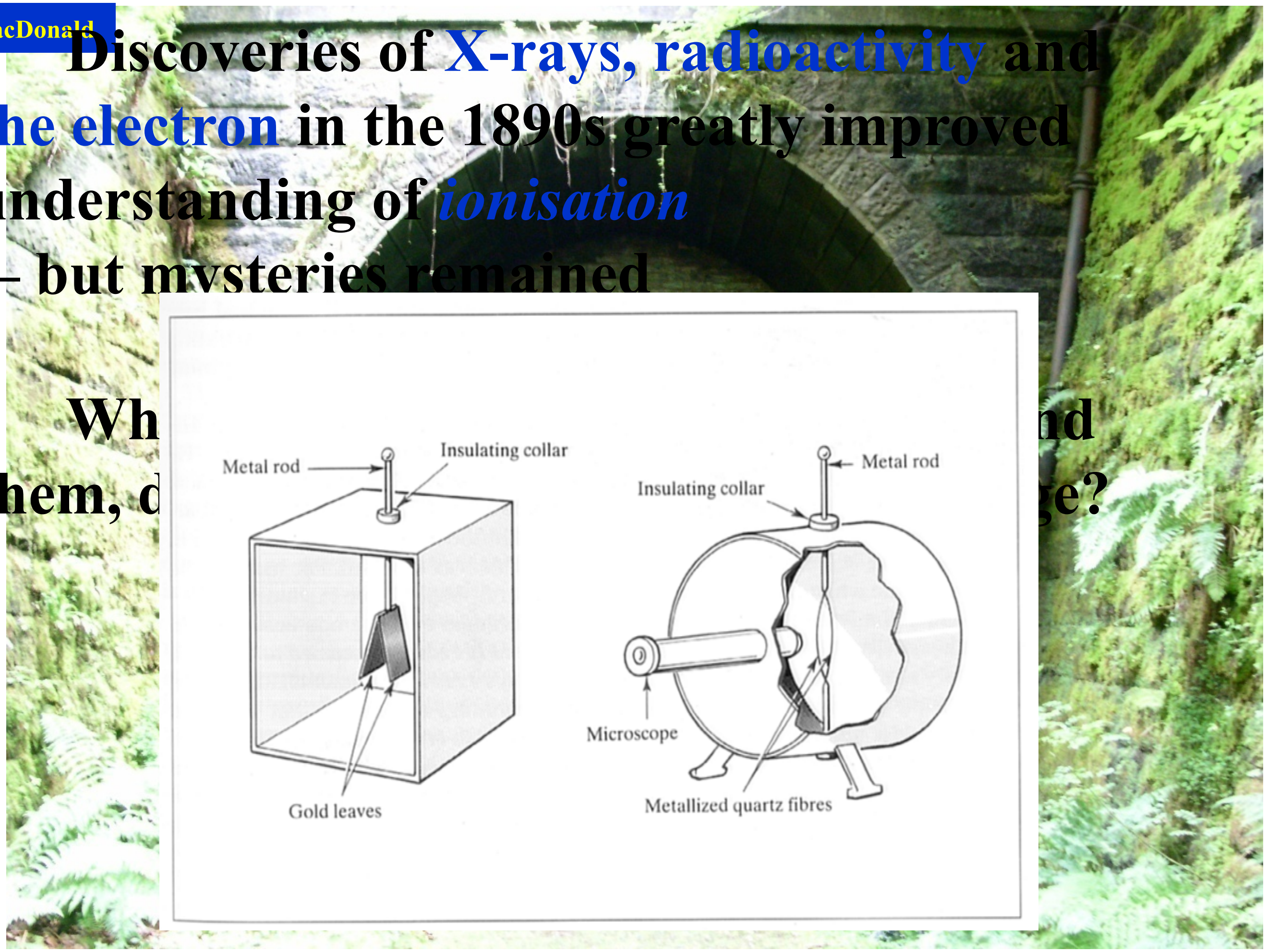
- **New techniques tend to drive the trajectory of science**
- **Is UHECR an exception? No new technique for over 40 years**
- **Despite this the field is extremely lively: more money**
  Cygnus X-3 (1983) fall-out?
- **Ideas of the ancient iconoclasts can at last be exploited**

Plus: High-performance computing:
transformed data analysis
Monte Carlo simulations
Data from accelerators

Major developments in electronics: no thermionic valves!

How did it begin?

Credit Alex MacDonald



- Discoveries of X-rays, radioactivity and the electron in the 1890s greatly improved understanding of *ionisation*
 – but mysteries remained

- Wh … nd
them, d … e?

C T R Wilson, Proc Roy Soc A 68 151 1901

"the continuous production of ions in dust-free air could be explained as being due to radiation from sources outside our atmosphere, possibly radiation like Röntgen rays or cathode rays, but of enormously greater penetrating power"

Flight to 5 km without oxygen

Diplomarbeit Georg Fede
Institut für Radiumforschung und Kernphysik
Wien, 2003

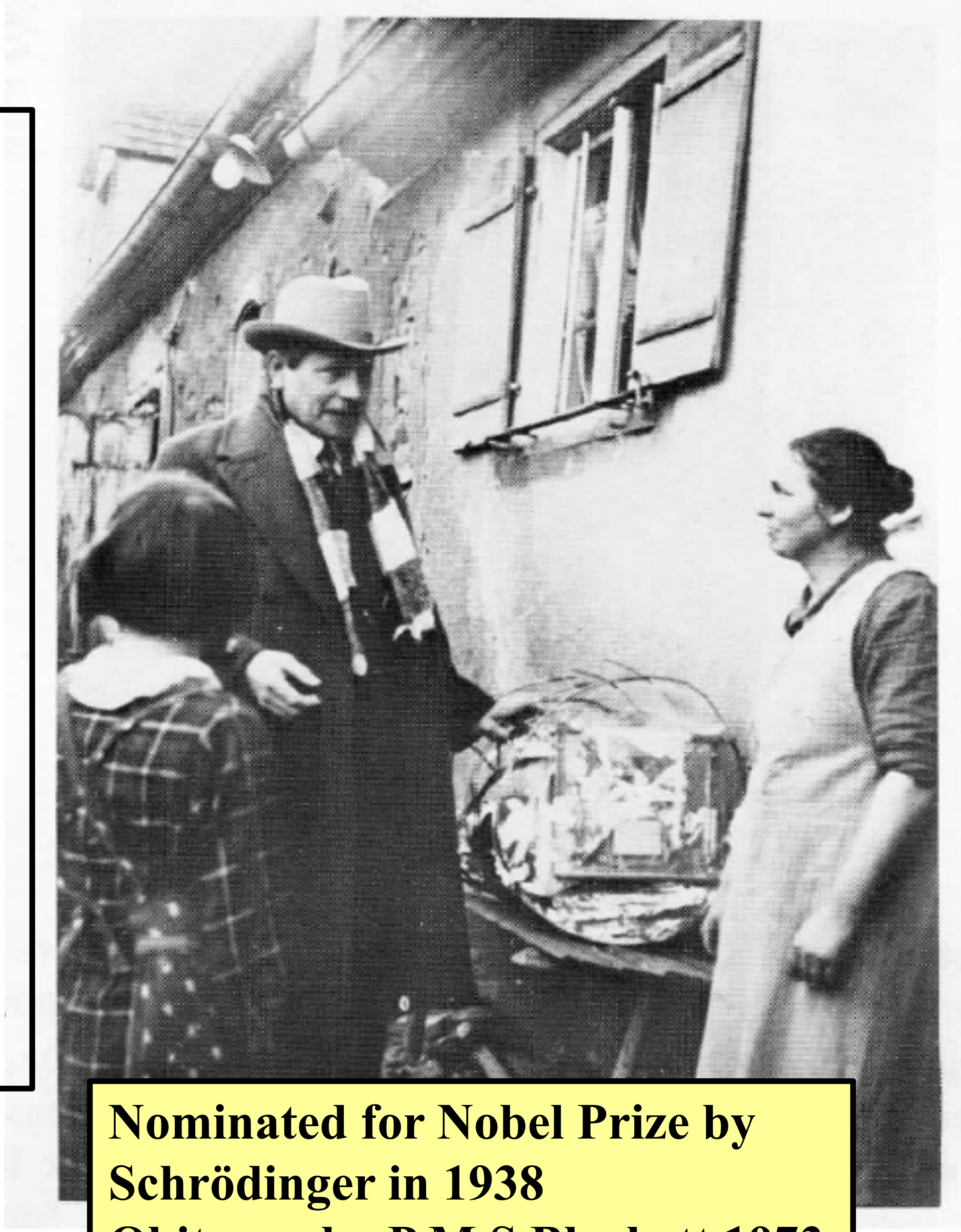
Surely a 'rugged individualist and an iconoclastic'

Victor Hess at the balloon-landing (1912)

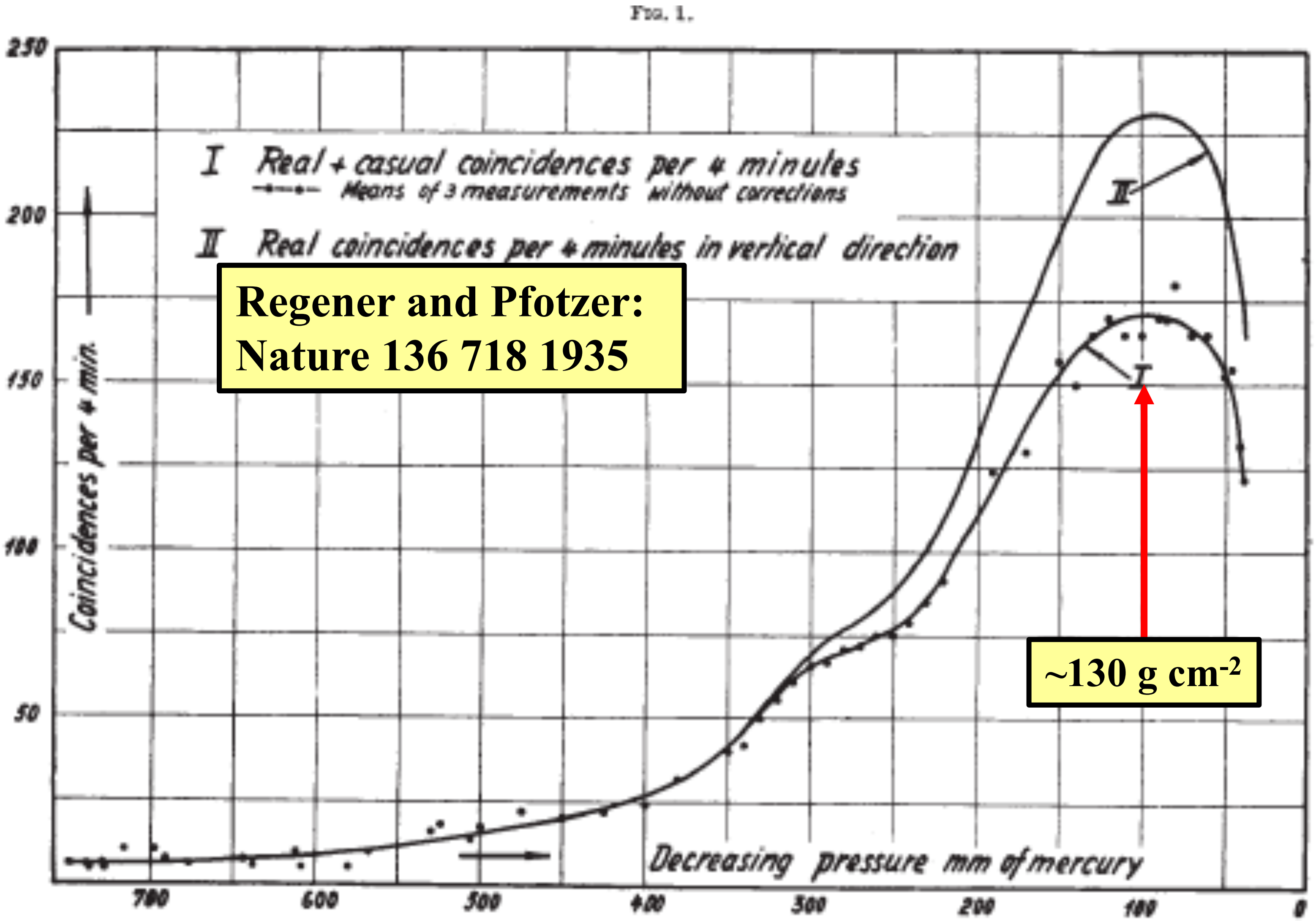
During the 1930s, Erich Regener greatly extended the observations of Hess, Kolhörster, Millikan and others

– his work indirectly led to searches for air-showers

Important development of encasing equipment in cellophane – like a greenhouse



Nominated for Nobel Prize by Schrödinger in 1938
Obituary by P M S Blackett 1973



3 G-M tubes in coincidence, 20^0 about Zenith, 22 km (~40 g cm^{-2})

- typically Regener published short article in Nature before longer article in German journal

Bruno Rossi: 1905 – 1993: truly major figure

improved Geiger counter, invented electronic coincidence circuits, East-West effect, started MIT work on showers etc.

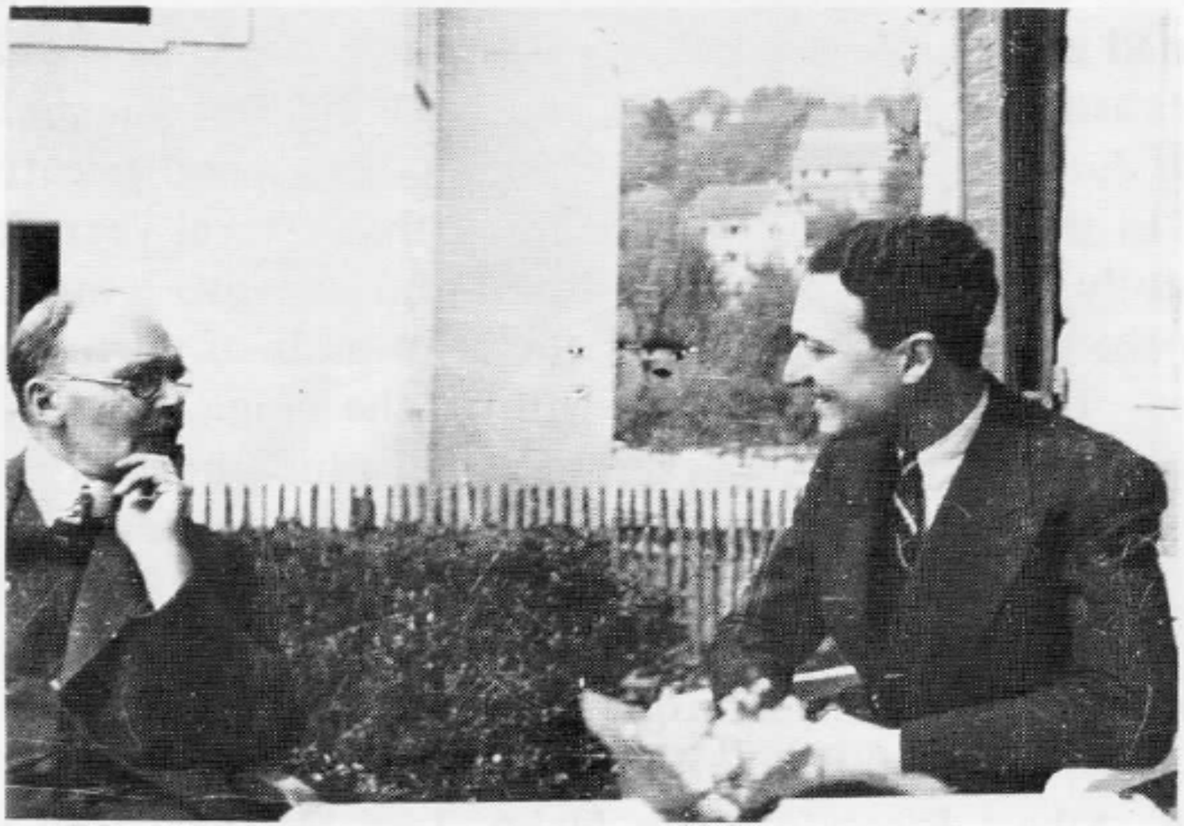
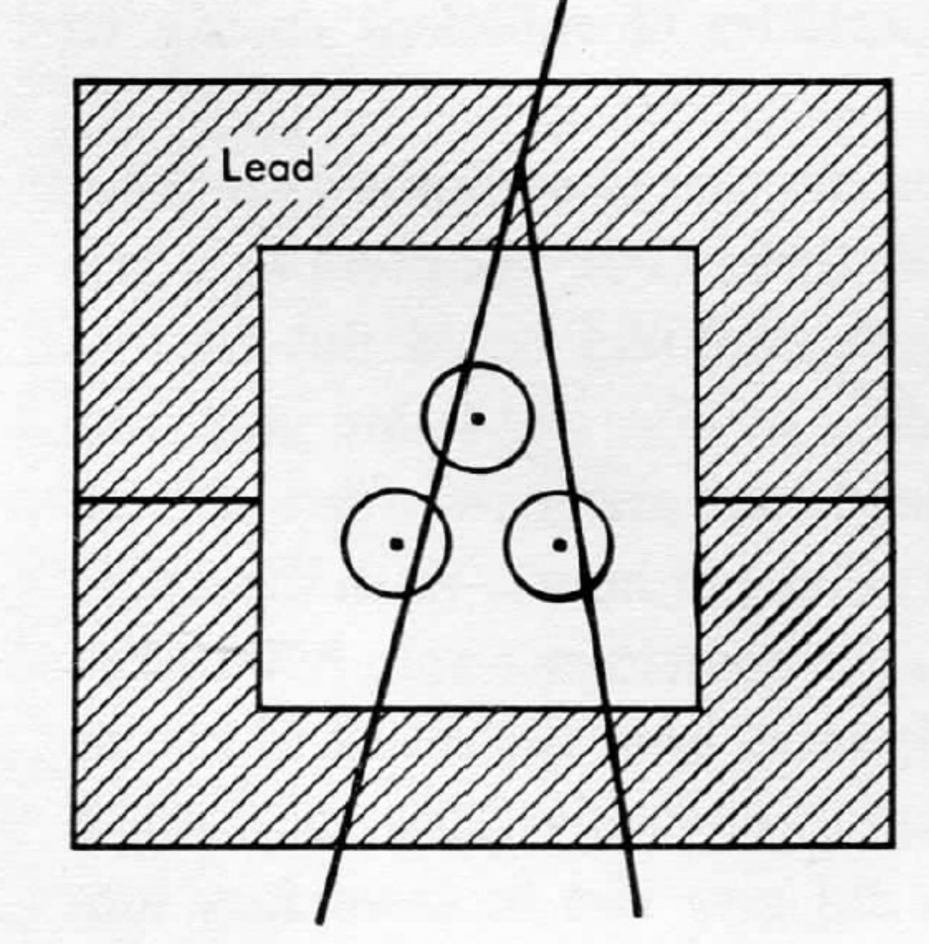


Fig. 12. With Professor Hans Geiger in Tübingen. 1930

Rossi Transition Curves



Rossi 1933: **Coincidence rate much higher with top lead blocks (~ 10 cm thick) in place**

Rejected by Naturwissenschaften

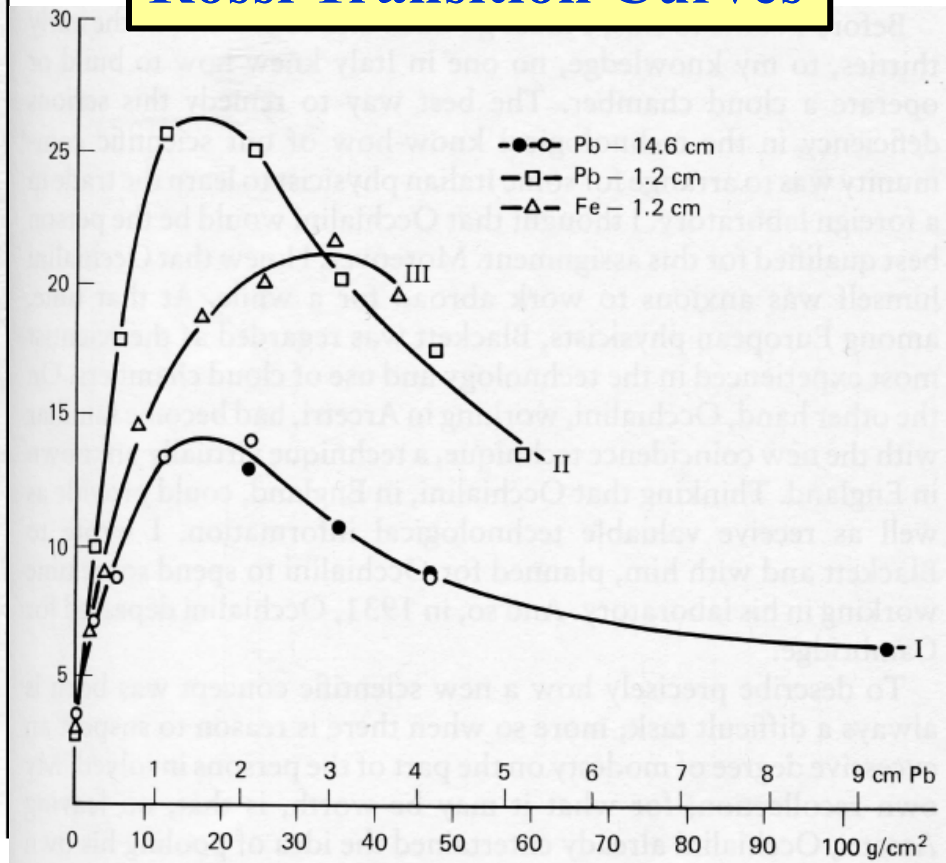


Fig. 1.6. The rate of coincidences between three counters in a triangular array (see Fig. 1.5) as a function of the thickness of a screen of lead or iron placed above the counters. Curves I and II

Rossi 1933: Zeitschrift für Physik

But with support of Heisenberg, published in Physikalische Zeitschrift

Key work by, independently by Bothe and Kolhöster (1938):

- **predicted and demonstrated existence of air-showers** ***'luftschauer'***

Dr. Werner Kolhörster im Jahre 1912.

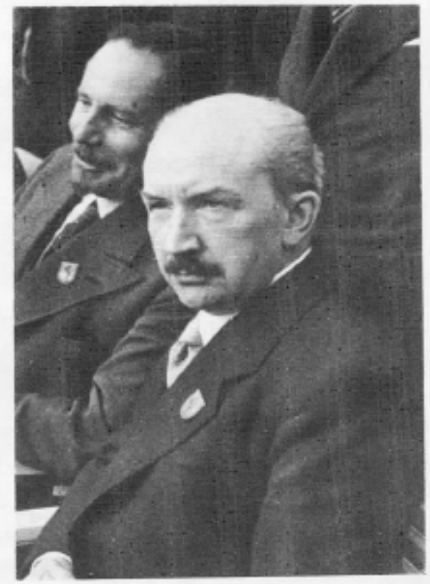
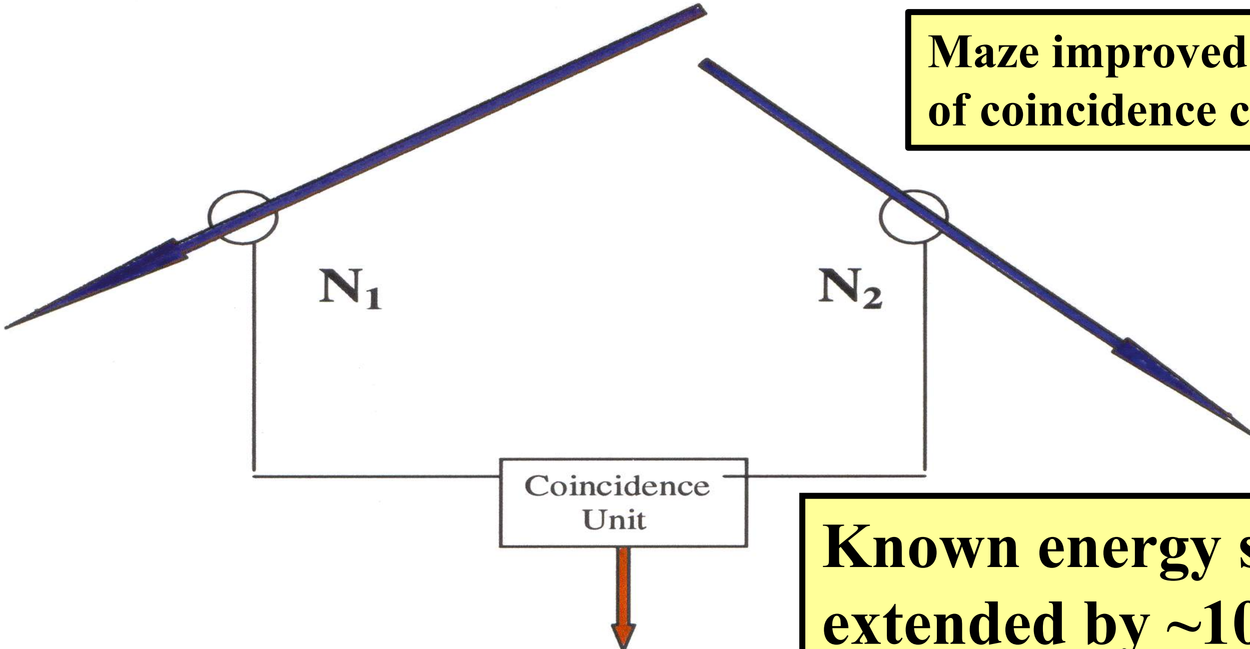


Fig. 2. Professor Walter Bothe (1891–1957) (right), Nobel prize winner 1954, (coincidence method and discovery of artificial nuclear gamma radiation) and Professor Erich Regener (1881–1955) at a meeting in 1937. (Courtesy of Max-Planck-Institut für Kernphysik, Heidelberg).

Work motivated by Rossi's transition curves, theory of cascades by Bhabha and Heitler – but probably not by Regener's maximum (though clearly the same phenomenon) – and discussed by Bhabha and Heitler

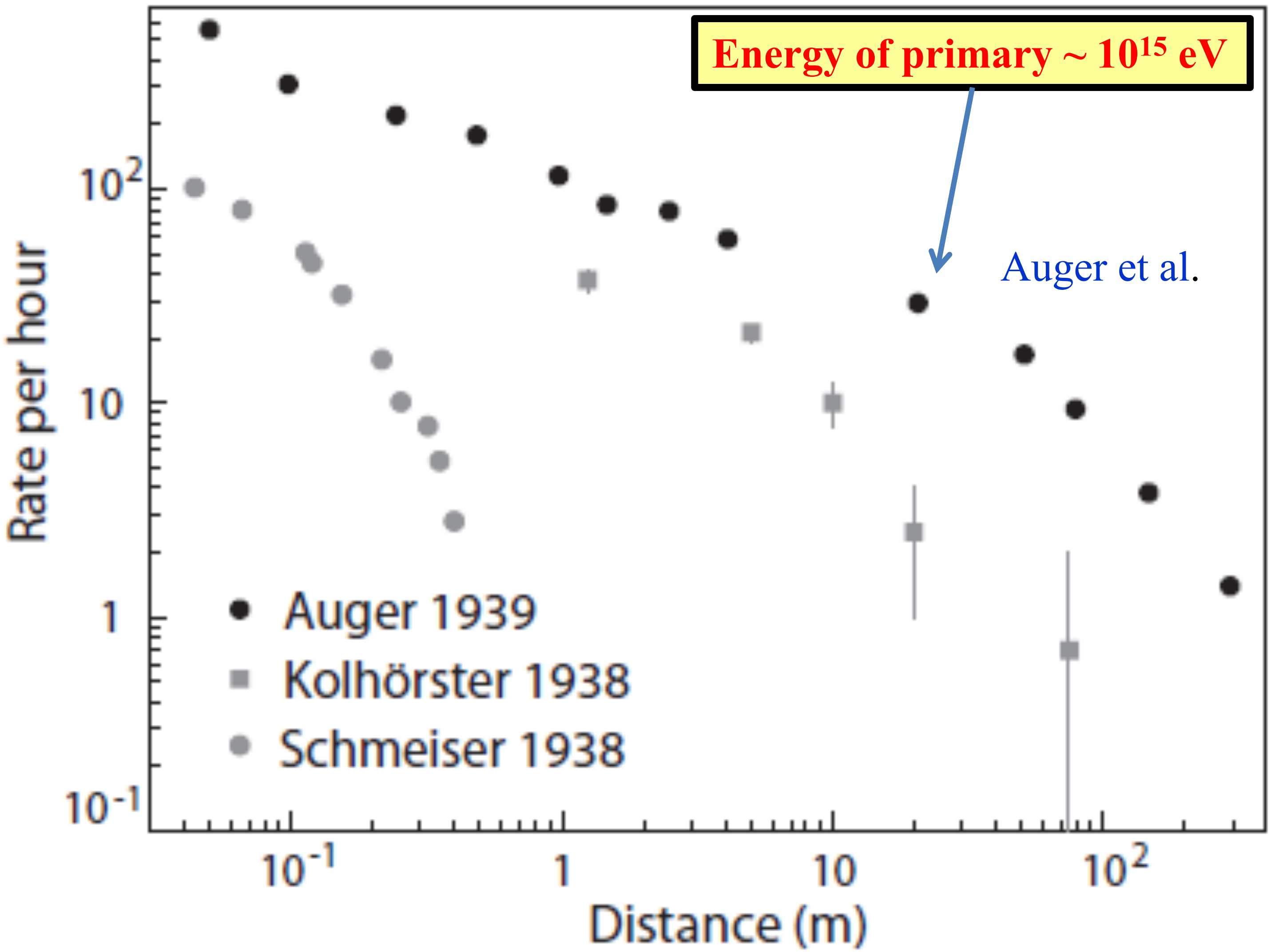
Discovery of Extensive Air Showers: Pierre Auger (1938)



Maze improved resolving time of coincidence circuit to nearly 1 μs

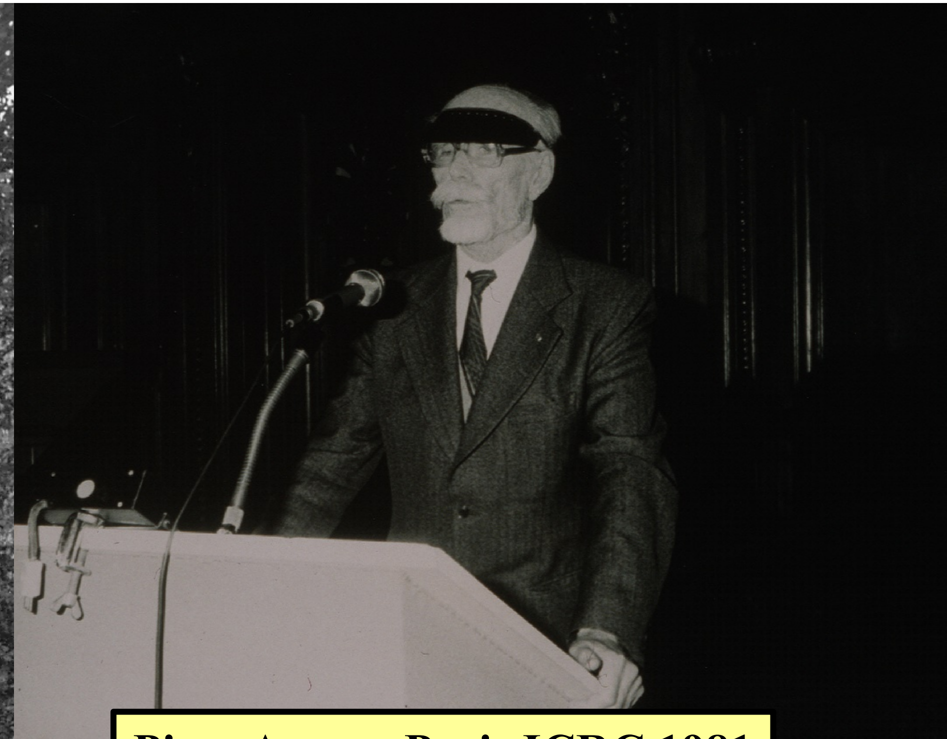
Known energy scale extended by ~10^6 to ~10^{15} eV

Observed Rate was found to be much higher than the Calculated Chance Rate ($2N_1N_2\tau$) – even when the counters were as far as 300 m apart



Measurements of Schmeiser and Bothe, Kolhöster et al., and Auger et al. **(Kampert and Watson 2012)**

Roland Maze and Joachim Trümper:
near Leeds during 2nd European CRS (1970)



Piere Auger: Paris ICRC 1981

- but Rossi had beaten everyone by about 4 years working in Eritrea

Rossi: *La Ricerca Scientifica* 1934

Rossi's translation (1990):

"The frequency of coincidences .....appears to be greater than would have been predicted from the resolving power of the coincidence circuit..........
.... it seem that once in a while the recording equipment is struck by *very extensive showers of particles........*

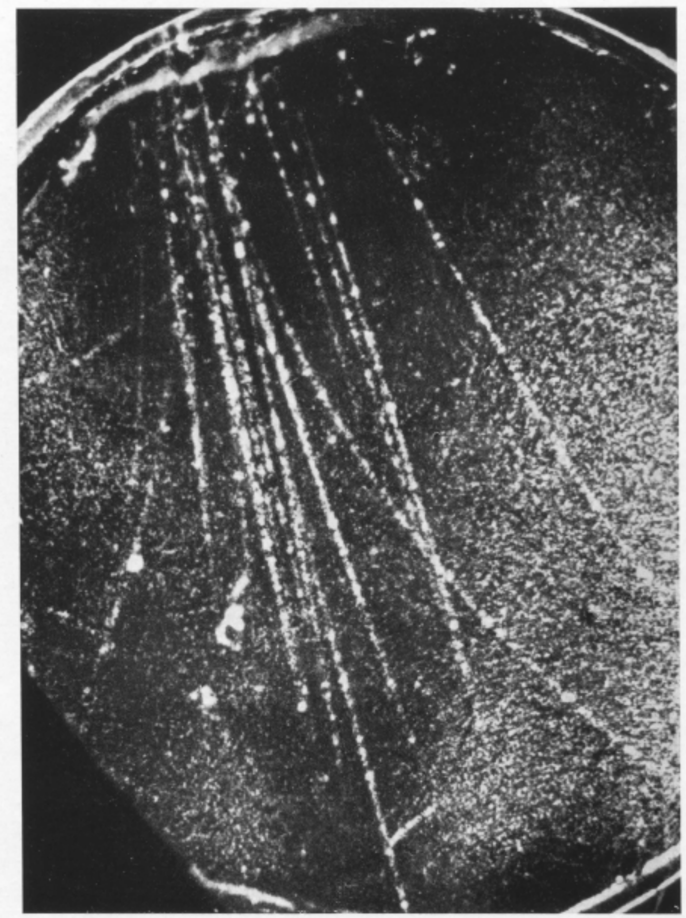
(he used 'sciami molto estesi di corpuscoli')

Unfortunately I did not have the time to study this phenomenon more closely."

Auger and Rossi left Europe for the US at about the same time (1938)
***En route* they spent time in Blackett's cosmic-ray group in Manchester.**
Rossi and Auger were friends from time working in de Broglie's private laboratory in Paris: Blackett knew both of them.

These visits had major long-term impact on UHECR research within UK

P. M. S. Blackett.



Counter-controlled cloud chamber:
Cascade Shower with positive and negatively charged particles
Blackett and Occhialini (1933)

…te 31. P. M. S. Blackett and G. P. S. Occhialini, Cambridge, Proc. Roy. Soc. A. 139, 699 (1933).

Auger continued shower work in Chicago before moving to Chalk River, Canada

Rossi worked first at Cornell (Greisen PhD student) and then on the Manhattan project

JULY-OCTOBER, 1939 REVIEWS OF MODERN PHYSICS VOLUME 11

Extensive Cosmic-Ray Showers

PIERRE AUGER
In collaboration with
P. EHRENFEST, R. MAZE, J. DAUDIN, ROBLEY, A. FRÉON
Paris, France

CONCLUSION

One of the consequences of the extension of the energy spectrum of cosmic rays up to 10^{15} ev is that it is actually impossible to imagine a single process able to give to a particle such an energy. It seems much more likely that the charged particles which constitute the primary cosmic radiation acquire their energy along electric fields of a very great extension.

Rossi returned from Los Alamos to MIT in 1946

- **Established a formidable cosmic-ray group including**

"..research program aimed at the study of extensive air showers, a program which, because of the originality of its conception and the significance of its results, ranks among the foremost accomplishments of the MIT group"

B Rossi *'Moments in the Life of a Scientist'* (1990)

Most of the ideas for analysis of air-shower data from ground arrays originated within Rossi's group

- **Many visitors from overseas including physicists from Italy and Japan**

Notably, for UHECR interests: M Oda, P Bassi and L Scarsi

1953: Bassi, Clark and Rossi – scintillators and fast timing

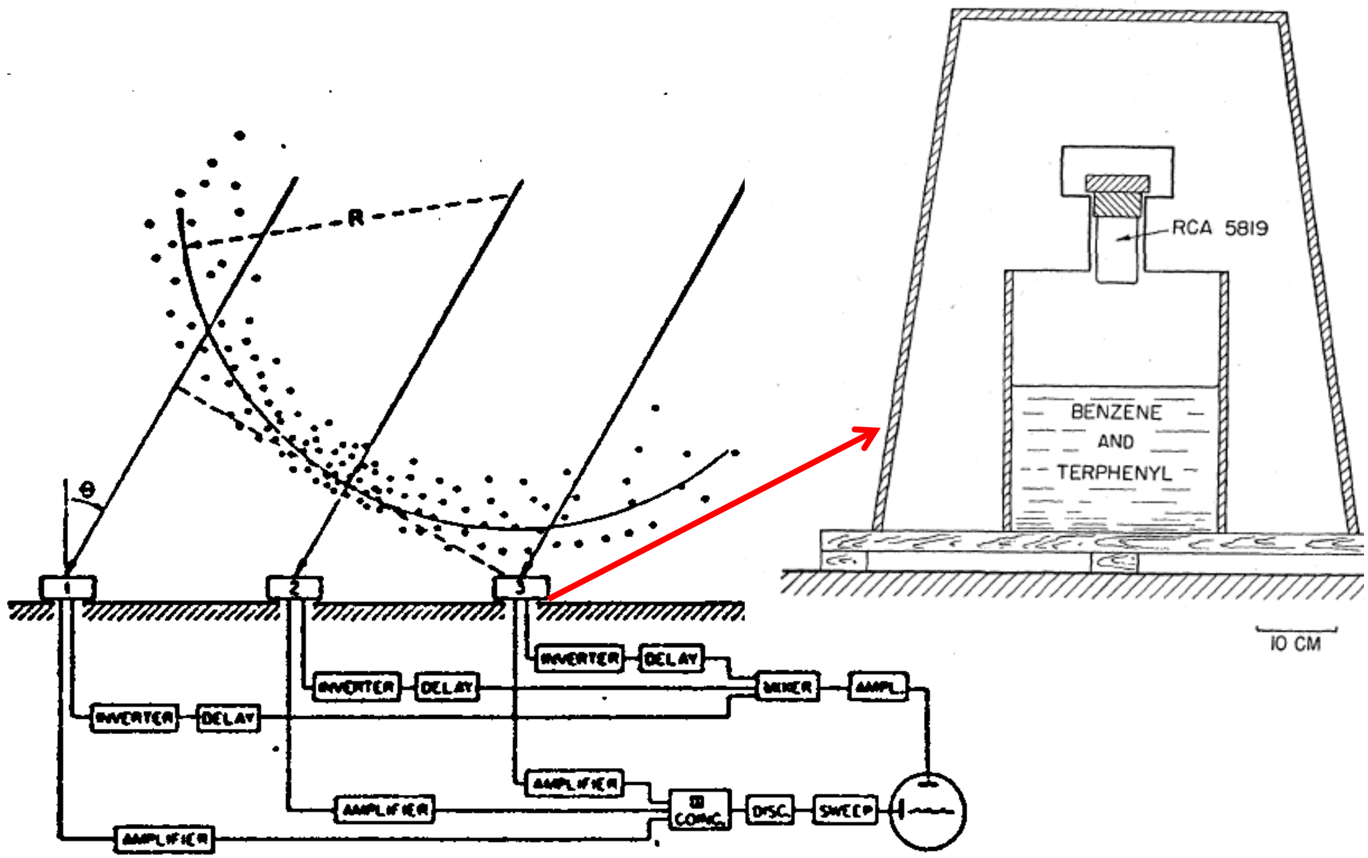
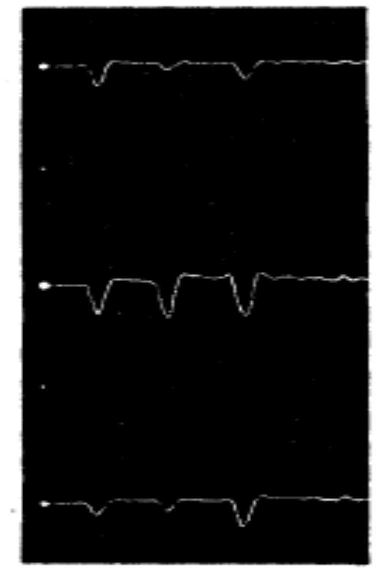
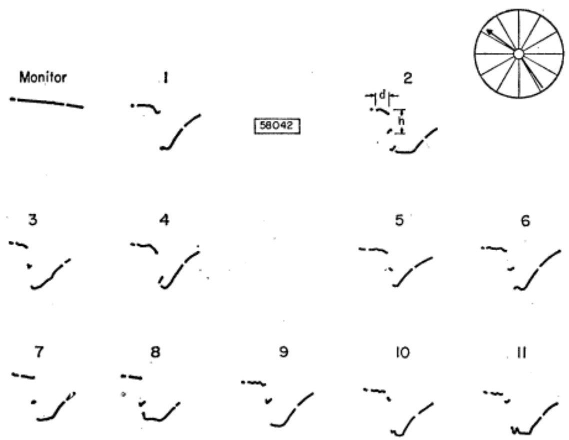


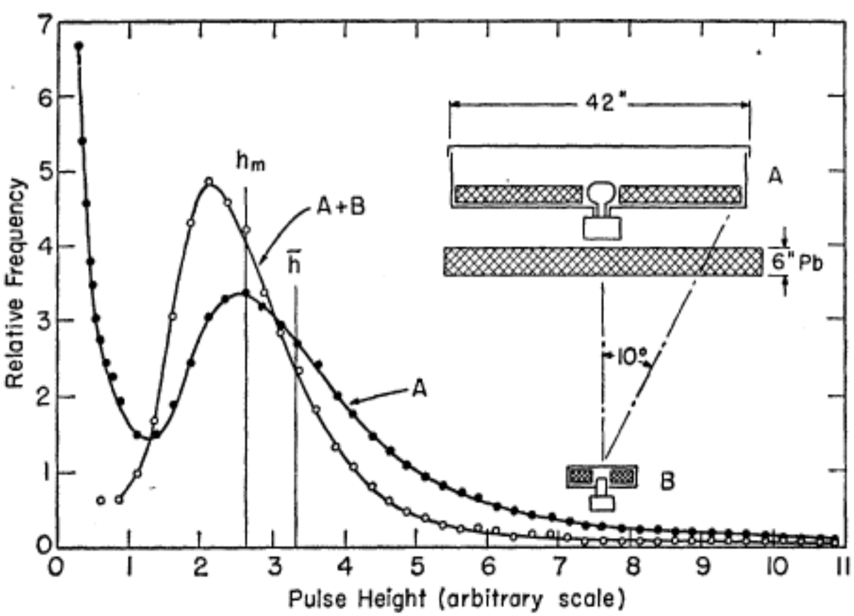
FIG. 2. Block diagram of the apparatus with a schematic representation of an air shower about to strike the counters. The counters are in arrangement II.

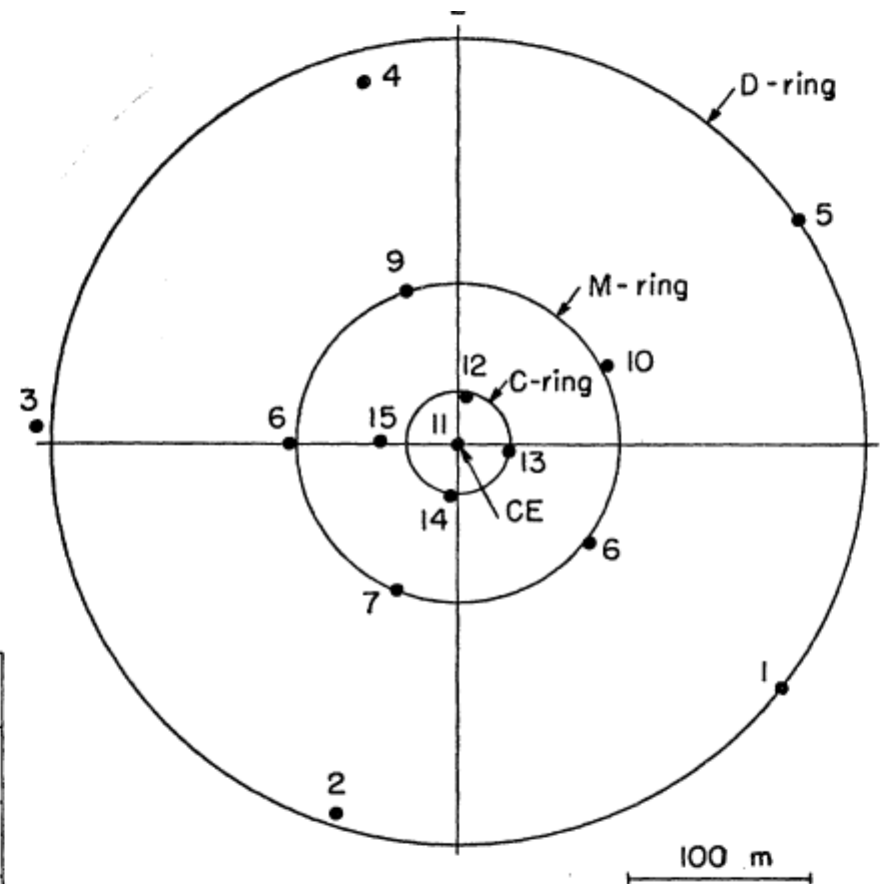


Thickness of electron disc: directional uncertainty ~7^{0}

MIT Agassiz Experiment





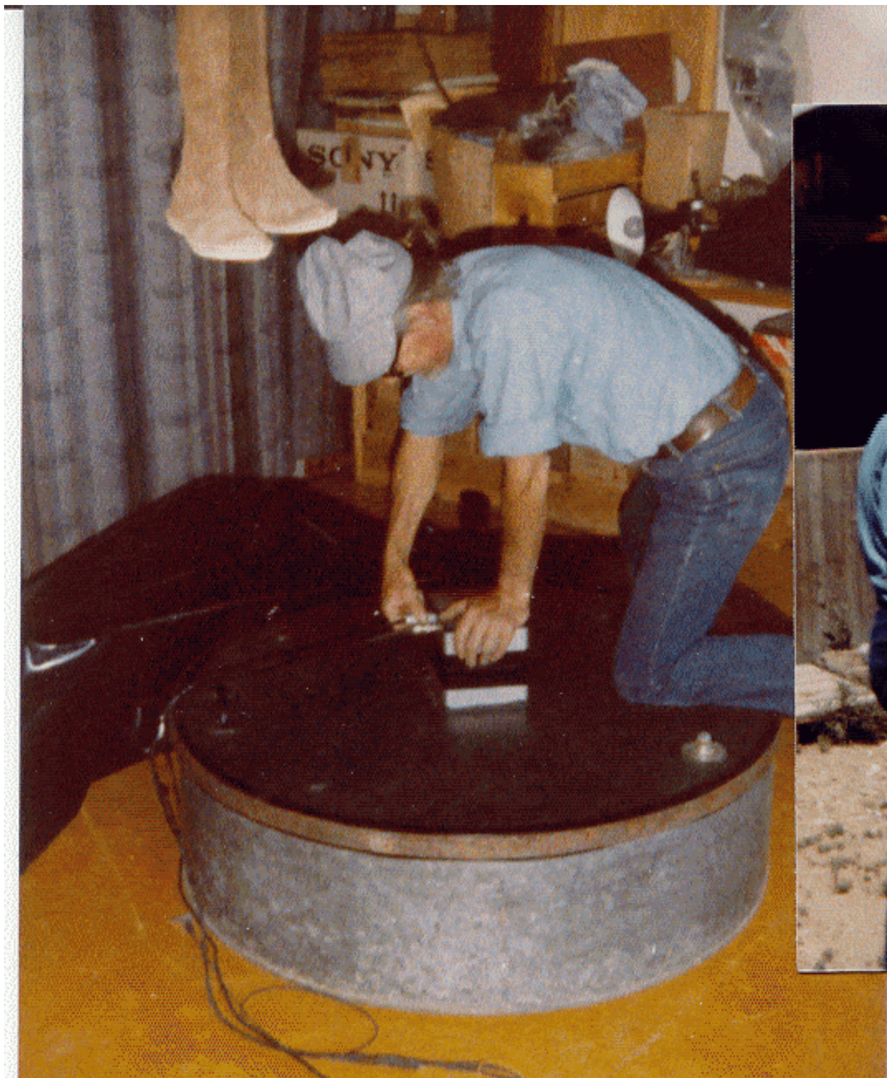


Largest event, N = 2.6×10^9

E ~ 3×10^{18} eV (1958)

MIT group then divided: arrays were built in Bolivia (El Alto 4200 m and Chacaltaya 5000 m (500 g cm^{-2})) and at Volcano Ranch 1770 m (834 g cm^{-2})

John Linsley was one of the last cosmic-ray physicists who fitted the description of Val Fitch: Two Nobel Prize nominations (by Auger)



The Volcano Ranch Array: Linsley (1963)

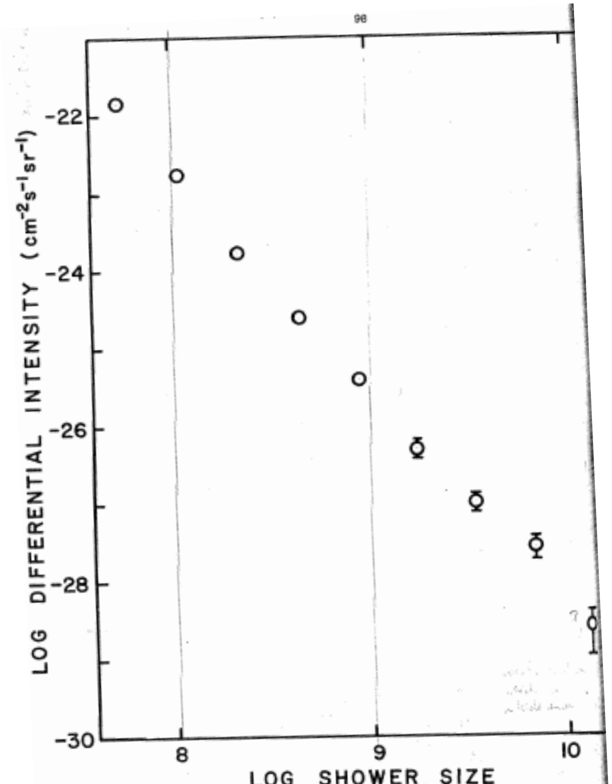
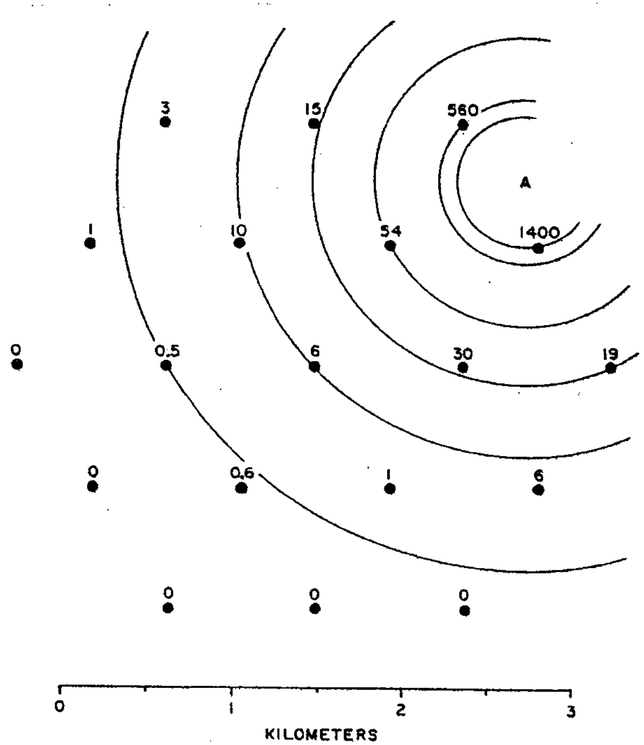


FIGURE 4. The differential shower size spectrum at 820 g cm^{-2}



Built and operated virtually single-handedly

Early help from Scarsi

500 electronic valves!

First evidence of Ankle:

ICRC Jaipur 1963

Energy ~ 10^{20} eV
- pre-GZK prediction

Geiger Counters – and cloud chambers to measure directions - were used well into the 1950s, particularly in UK and USSR

SOVIET PHYSICS JETP VOLUME 35(8), NUMBER 3 MARCH, 19

ON THE SIZE SPECTRUM OF EXTENSIVE AIR SHOWERS

G. V. KULIKOV and G. B. KHRISTIANSEN

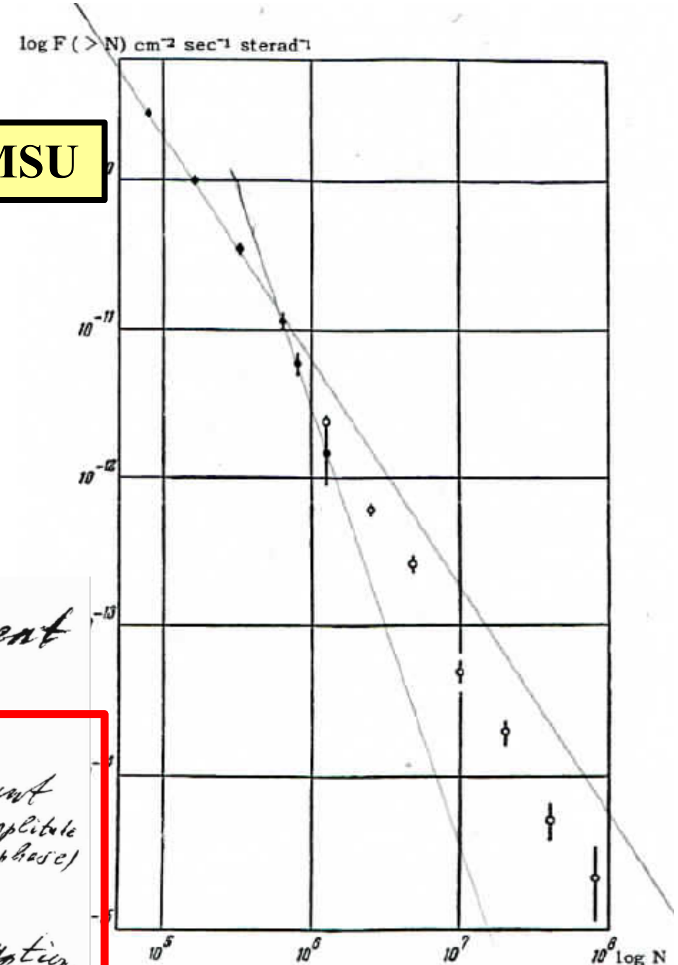
Moscow State University

Submitted to JETP editor April 22, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) 35, 635-640 (September, 1958)

Experimental data are presented on the size spectrum of extensive air showers in the region 10^5 to 2×10^8 particles. An analysis of these and other data available in the literature indicates that there is, very probably, an irregularity in the shower size distribution curve in the region between 10^6 and 10^7 particles. This is considered to constitute an argument in favor of the metagalactic origin of cosmic rays with energies above 10^{16} ev.

George Khristiansen at MSU



. Integral size spectrum of EAS. • – measurements
sent experiment, o – measurements of reference 7.

George Khristiansen to Gerd Schatz ~ late 1980s? 5 pages

Remarks for KfK EAS experiment "Kascade"

and for different N_μ/N_e

1. It is necessary to take into account possibility for anisotropy measurement (amplitude and phase) for $E_0 = 10^{14} \div 10^{15}$ ev. For this purpose "Kascade" must be worked without interruption.

2. Investigation of "knee" in primary energy spectrum (around "$3 \cdot 10^{15}$ ev") is the very important task of "Kascade" because "Kascade" give principal" improvment of systematical and statistical errors in EAS experiment. Systematicaly errors can be produced due to increasing role of fluction in cascade process for relative small primary energy.

Khristiansen (1991) had vision of EAS-1000 with scintillators in Kazakhstan: 4000 scintillators of 1 m²

Blackett's interests in UHECR were developed by 1938 visits of Rossi and Auger

- **Lovell and Wilson (Nature, 1939): showers observed in two cloud chambers**

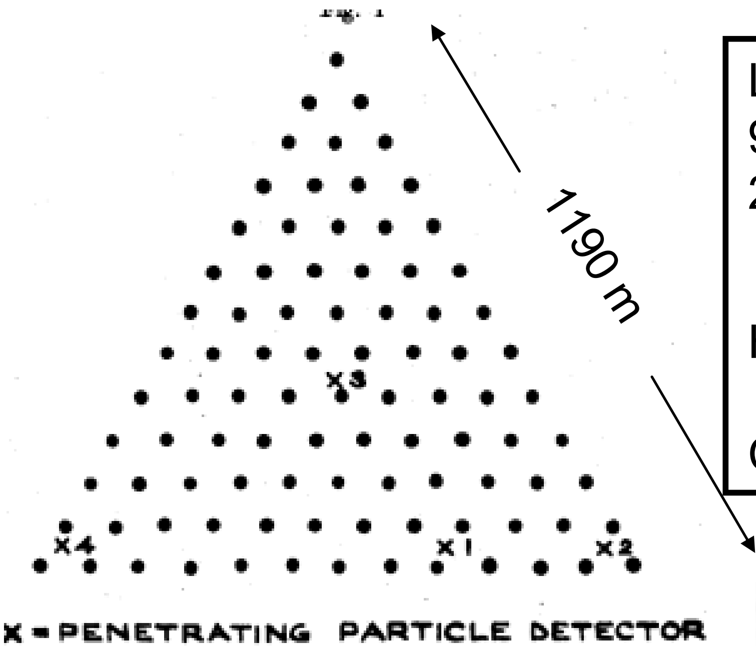
- **Trails seen on radar screens interpreted as due to showers**

  Blackett and Lovell (1941): promising idea

  Post-war unsuccessful search at Jodrell Bank

- **Stimulated work on air-Cherenkov light**

Harwell Shower Array of GM-tubes: built on airfield ‘Outside the Wire’

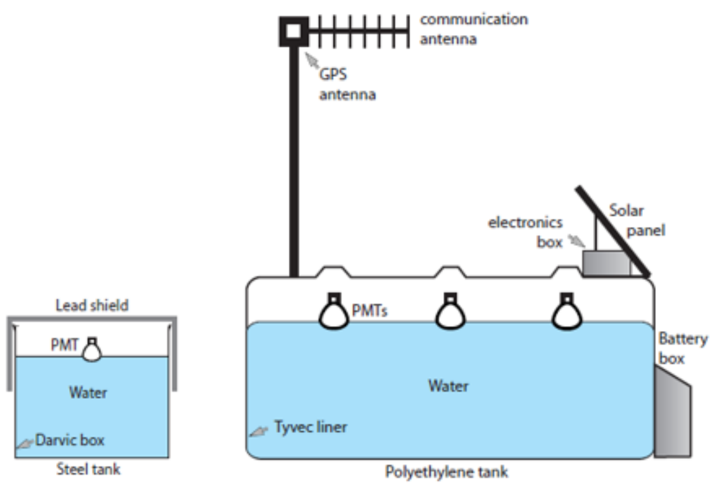


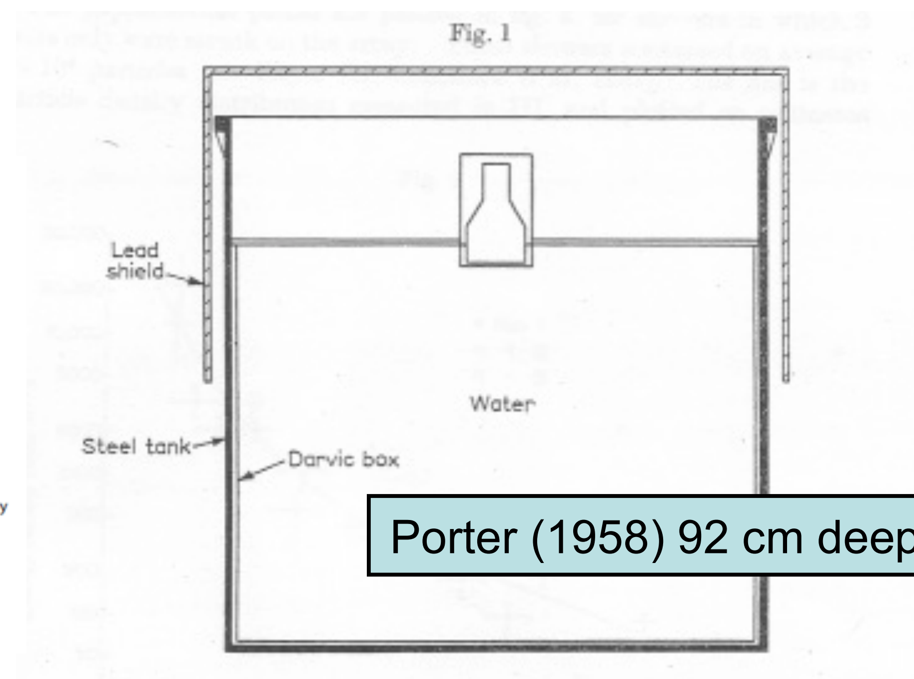
Position of shielded detectors on the array.

Large GM array at Harwell, UK in mid-1950s
91 stations
2 x 200 cm^2 and 1 x 15 cm^2

T E Cranshaw, W Galbraith, N A Porter, A M Hillas……..

Cherenkov light detection in 1953





Porter (1958) 92 cm deep

Interest in Cherenkov light at Harwell was largely driven by John Jelley following up ideas of Bruno Pontecorvo and P M S Blackett

1949: Pontecorvo (ex-Chalk River, where he worked with Auger) asked to design a shower array

Knew of work at MIT: could quantity of terephenyl be reduced?

Jelley: signals from muons in benzene alone- and in distilled water

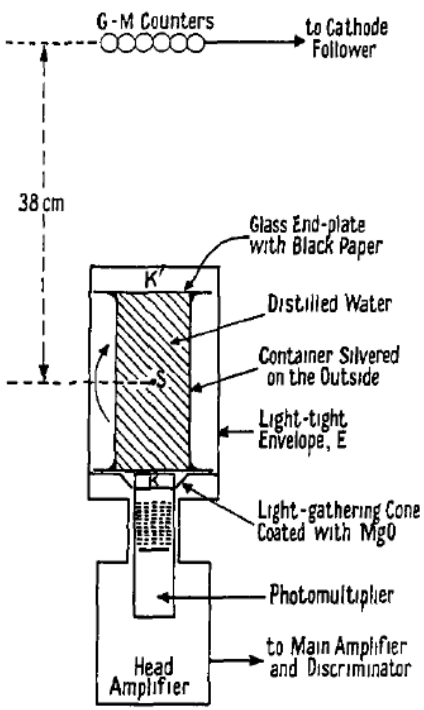


Figure 1 Essential features of apparatus

Jelley Proc Phys Soc A64 82 1951

Pontecorvo → Jelley → Porter →

Haverah Park → Auger Observatory

Blackett’s seems to have been first to calculate flux of Cherenkov light produced by electrons and muons in air (1948)

Cosmic rays produce ~10^{-4} of night-sky background

According to Lovell (1975), Blackett concluded that air-showers should produce a flash of light that could be seen if you were lying down and that Blackett carried out this search himself.

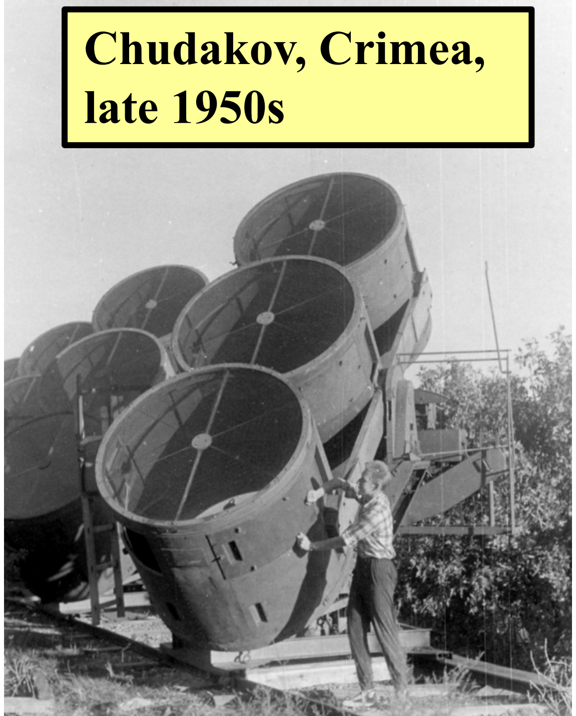
No record of any results

Blackett’s ideas led Jelley and Galbraith to search for Cherenkov light from extensive air showers (Nature 1953: experimental *‘tour de force’*)

Important developments in USSR followed

(and TeV gamma-ray astronomy)

Chudakov, Crimea, late 1950s

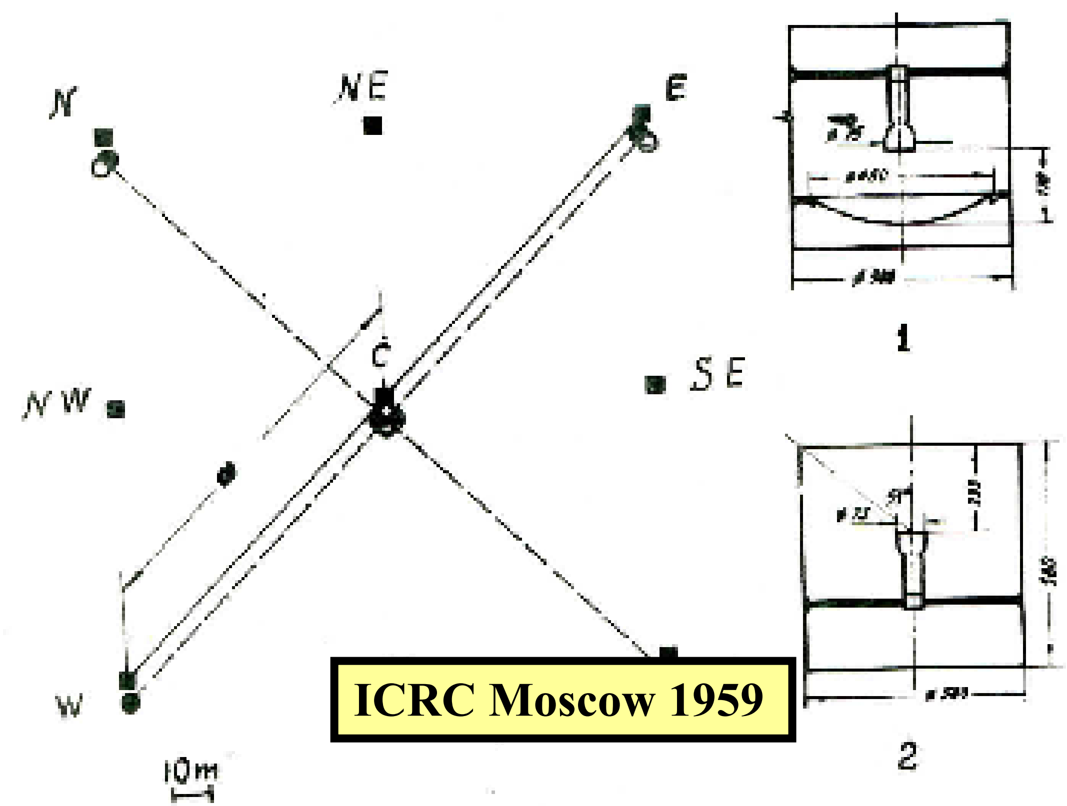


Zatsepin, Pylos, 2004

Use of Cherenkov light in studying showers:
Zatsepin and Chudakov
Developed very strongly in USSR from 1950s

Lead to CALORIMETRIC ESTIMATES of shower energy (Greisen, Nikolsky)

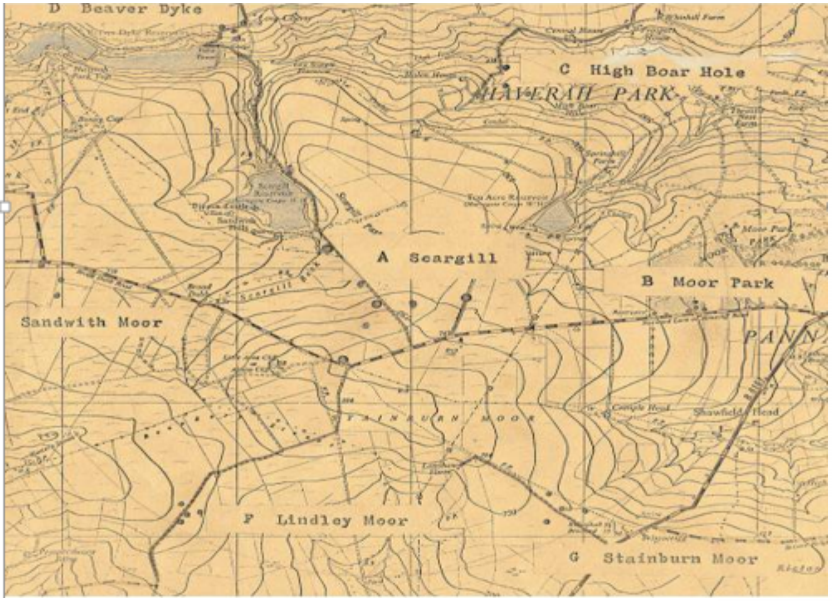
This work continues at Yakutsk, Tunka and TA site

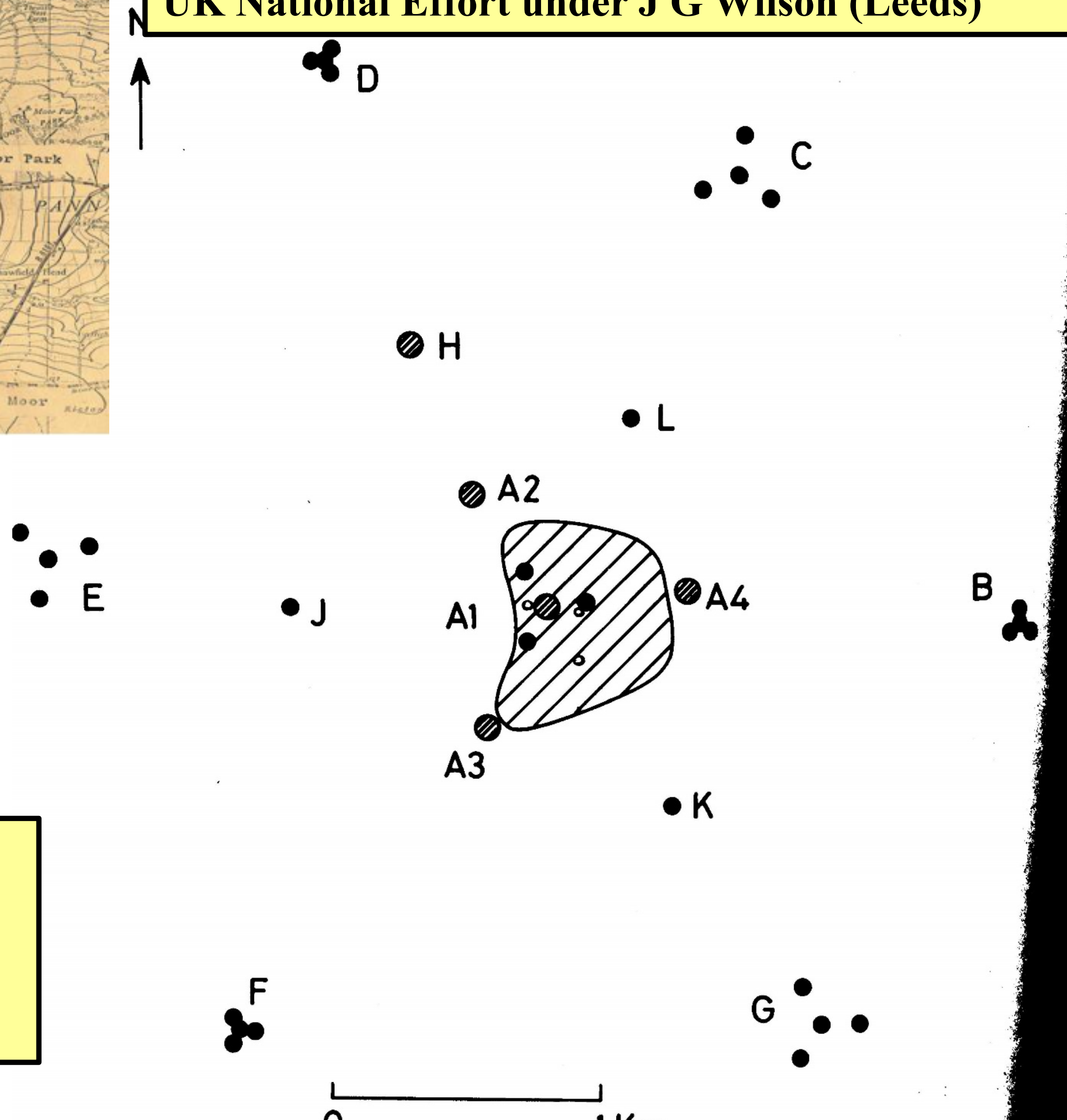


ICRC Moscow 1959

Strong push by Blackett after closure of Harwell:

UK National Effort under J G Wilson (Leeds)

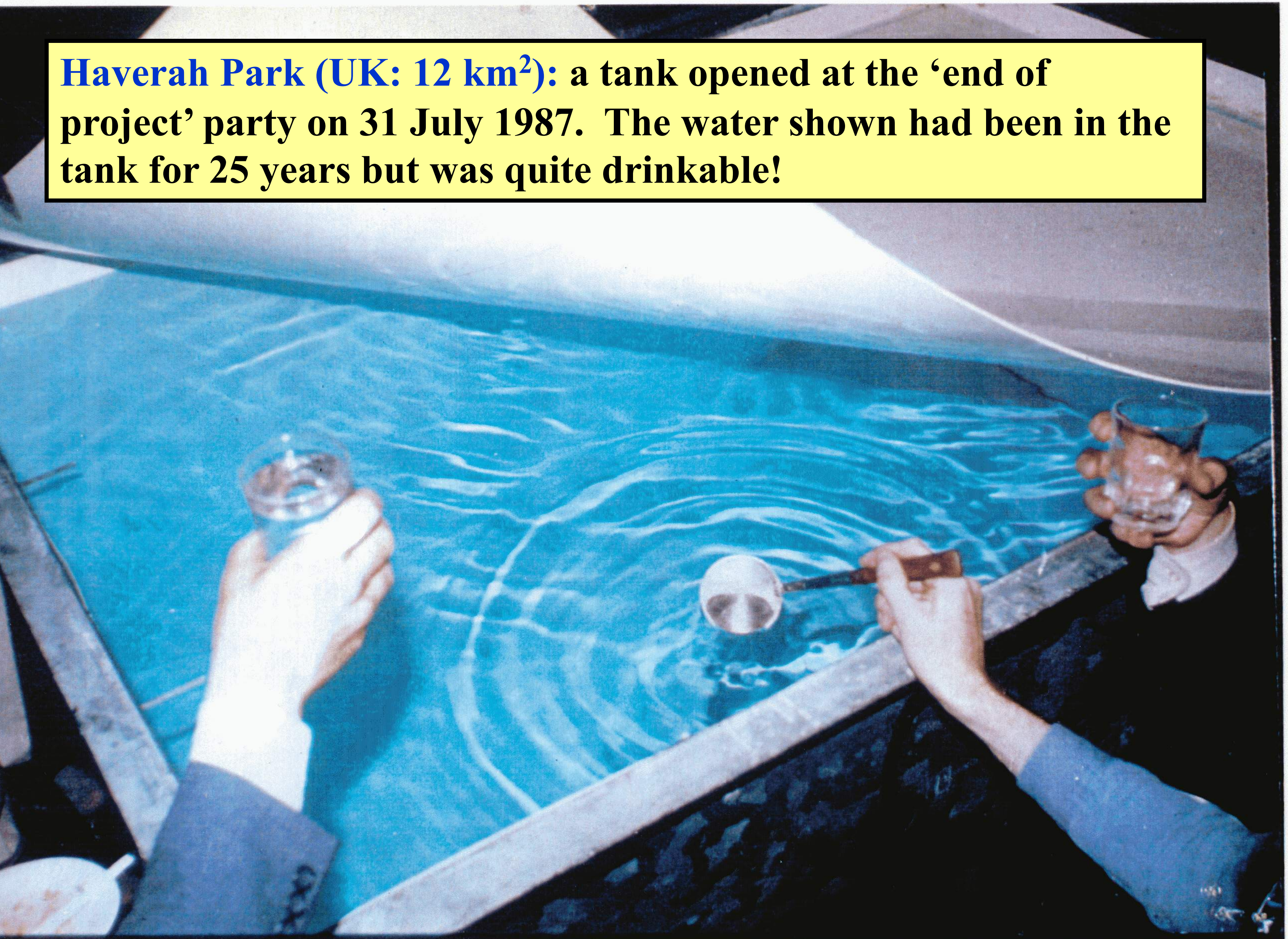




The shower array at Haverah Park. The area enclosed was ~12 km^2
Ran for 20 years

Each point in the diagram represents one or more tanks of water 120 cm deep

Haverah Park (UK: 12 km^2): a tank 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!



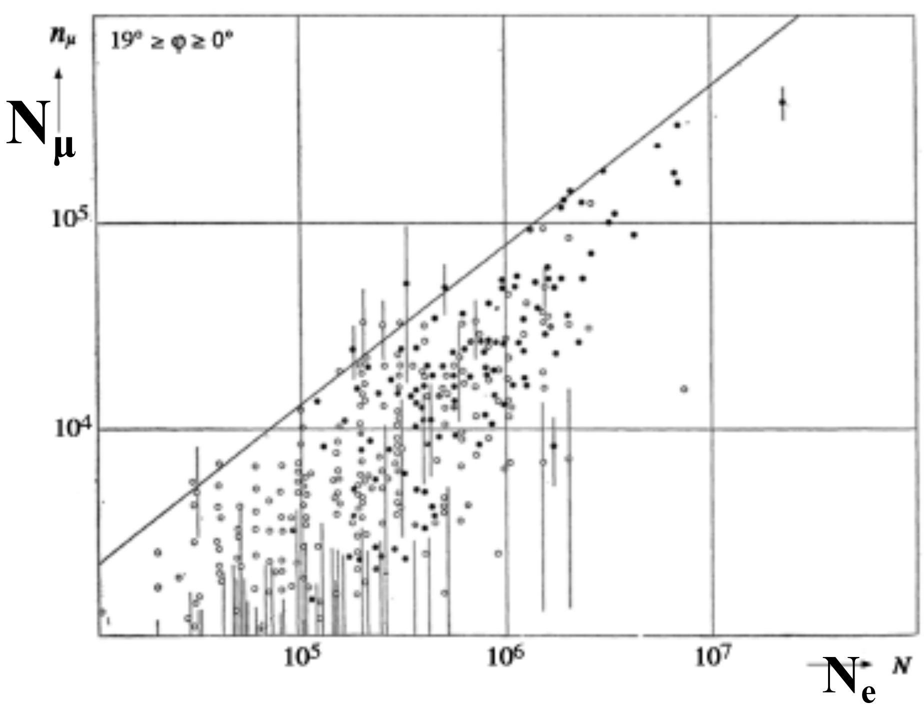
Japanese activities:

Post WWII, destruction of cyclotrons at RIKEN, Kyoto and Osaka

Tomanaga established shower work at Mt Norikura (2770 m) and helped establish Institute for Nuclear Studies in Tokyo

Oda returned from Rossi's group in 1956

Built series of ever more complex shower arrays with Suga



Also involvement of

Nishimura, Kamata, Nagano…

Major involvement in Chacaltaya of Suga, Kamata…

Connection with Rossi

Fluorescence Radiation:

Who had the idea first probably cannot be resolved

• **Chudakov knew of it in 1950s and explored properties in case it was a background for Cherenkov radiation.**
(Also see Belyaev and Chudakov: Bull Acad Sci USSR 30 1700 1966)

• **Oda and Suga developed ideas in Japan** (with Nagano and Tanahashi)

• **Greisen developed ideas in USA, perhaps building on work at Los Alamos (he was at the Trinity test) to detect fluorescence from nuclear explosions.**

Suga discussed idea internationally at La Paz Conference in 1962

From Alan Bunner: 10 July 2010

Bunner was a research student of Greisen's and created the iconic plot showing the geometry to be solved to deduce FD information for his MSc thesis.

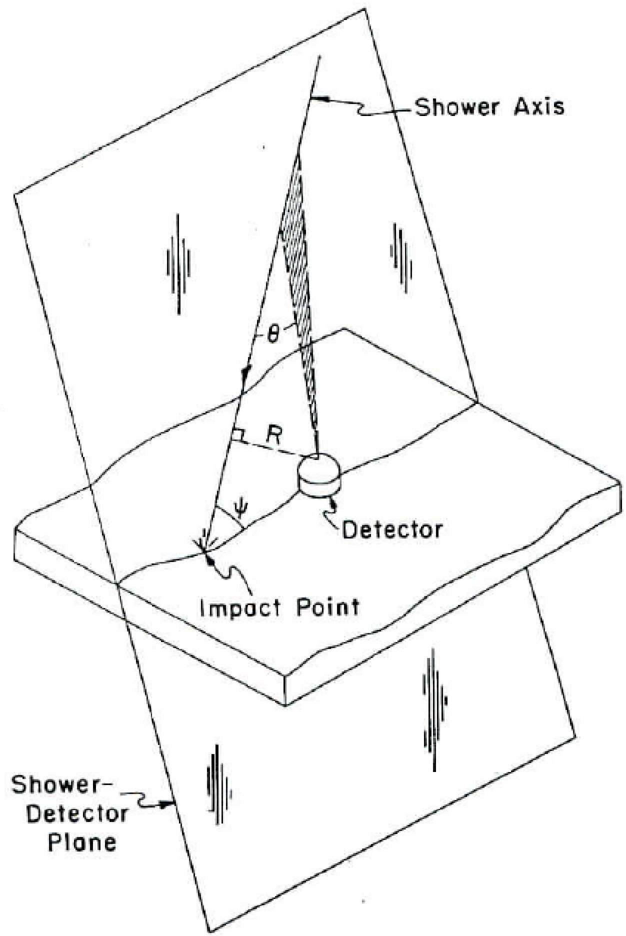


FIG. 1. Perspective view of shower geometry.

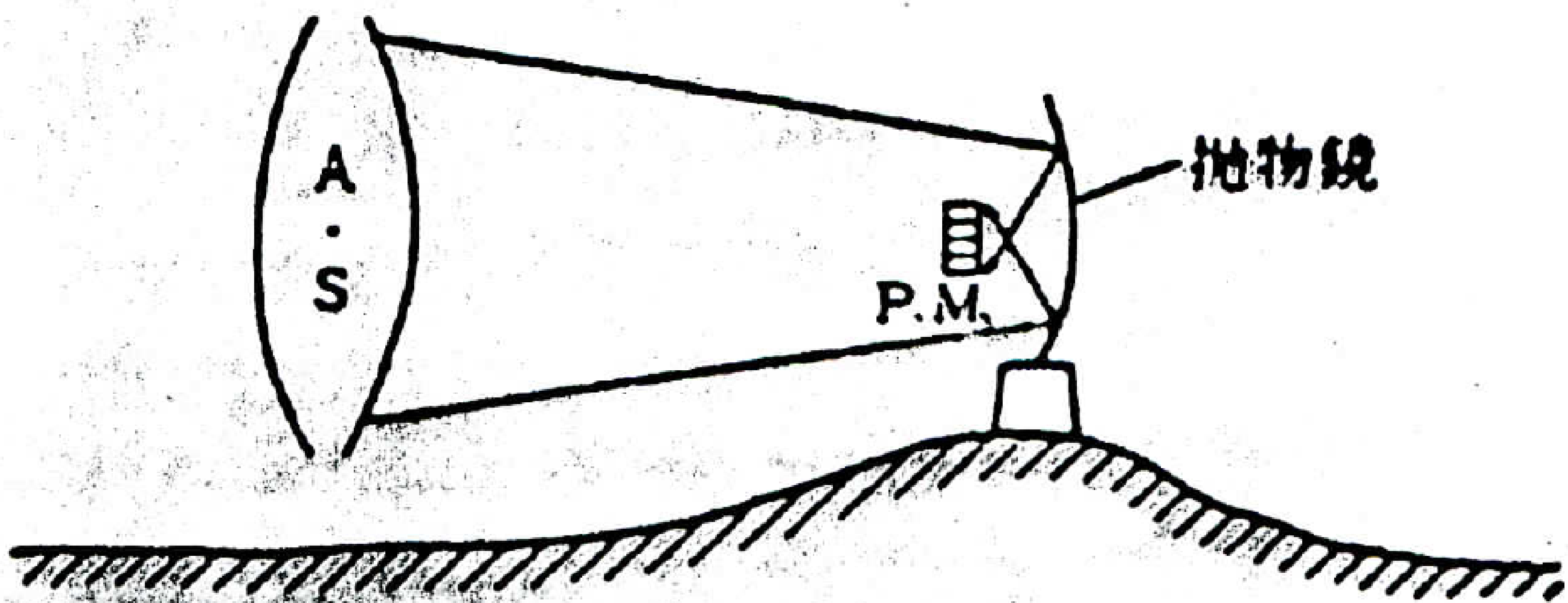
"I have the idea that the atmospheric bomb tests of 1958-62 made it quite obvious that there was a substantial fluorescence yield in air from ionizing radiation.

I tend to agree with Stirling Colgate that the idea of detecting EAS from atmospheric fluorescence probably came independently to several cosmic ray researchers during the 1957-58 period.

I guess I would credit Chudakov, Suga, and Greisen equally - and there may well have been others, especially as the reports of fluorescence from atmospheric bomb tests trickled out"

Proceedings of Norikura meeting in Summer 1957, published in 1958 in INS Report

Idea might have been brought from US by Oda who returned from MIT in 1956



第3図　1958年乗鞍シンポジウムで話されたシャワー・カーブ測定の提案

Goro Tanahashi (INS) worked as a post-doc in Greisen's group

On returning to Japan helped INS group set up a fluorescence system

Detections reported at Budapest ICRC (1969: Hara et al))

Have a copy of the letter of congratulations from Greisen to Tanahashi

Bruce Dawson also convinced that they saw fluorescence light
light (arXiv:1112.56860)

It became apparent that the detection of air showers by fluorescent light could only be made successful by (a) operating in a different part of the earth where the weather would permit observing during four times as many hours per year, and where the lower atmosphere is also free of the particles and aerosols *that cause Mie scattering;* and (b) taking full advantage of modern electronic technology in the information processing, so as to separate the air shower patterns from the background noise without loss or degradation of information in doing so. This would be an engineering task of considerable magnitude and cost.

With considerable relief at the termination of a long period of arduous and rather unrewarding effort, the recording stations were shut down in January, 1972, ten years after initiating the proposal that the work be begun.

From Greisen's final report to AEC, 1972

RESEARCH PROPOSAL

to

THE NATIONAL SCIENCE FOUNDATION

by

Department of Physics
University of Utah
Salt Lake City, Utah 84112

COSMIC RAY STUDY OF ULTRA-HIGH ENERGY PROCESSES

Third Renewal Request of NSF GP 24452

Proposed Starting Date: September 1, 1974

Amount Requested: $604,300
Proposed Duration in Months: 24

Principal Investigator:
J. W. Keuffel

0671-16-6733
Phone: (801) 581-6628

Department Head:
Peter Gibbs

Professor of Physics, Chairman
(801) 581-6901

Co-Principal Investigators:
H. E. Bergeson

528-40-1948
Phone: (801) 581-7115

G. L. Cassiday

578-54-0404
Phone: (801) 581-6930

Authorized Signature

The Fly's Eye Proposal – 1 September 1974

Research student of Regener

27. Hoerlin, H., "Air Fluorescence Excited by High Altitude Nuclear Explosions," LA-3417-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico (1965).

28. Mead, J.B., "Properties of Teller Light (Air Fluorescence) induced by 22-MeV Electrons," CRD Sigma 3, UCRL-7604, Lawrence Radiation Laboratory, Univ. of Calif., Livermore, California (1963).

In Section E is presented a Monte-Carlo simulation of the events to be expected. The effective area of the detector grows with the shower size, so that the rates fall off much slower than the cosmic ray spectrum. Assuming a constant spectral index, the rate of showers above 10^{16} eV would be 10^{6} yr^{-1}, about 10^{18} eV, 10^{4} yr^{-1}, and above 10^{20} eV, 20 yr^{-1}, where the rates quoted are the actual rates taking into account a duty cycle of 10% for clear, moonless nights. As an example, a shower of 10^{18} eV would produce ~ 500 photoelectrons in each of 15 phototubes against a background fluctuation of ~50 photoelectrons. Our simulation also indicates that only a very few showers would have been observable with the Cornell array and data handling system.

Measurement of Light Emission from Remote Cosmic-Ray Air Showers

H. E. Bergeson, G. L. Cassiday, T.-W. Chiu, D. A. Cooper, J. W. Elbert, E. C. Loh, D. Steck, and W. J. West
Department of Physics, University of Utah, Salt Lake City, Utah 84112

and

J. Linsley
Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico 87131

and

G. W. Mason
Department of Physics and Astronomy, Brigham Young University, Provo, Utah 84602
(Received 28 June 1977)

Extensive air-shower trajectories and sizes (numbers of charged particles) have been measured using an optical detection system at Volcano Ranch Station near Albuquerque, New Mexico. Light produced by atmospheric scintillation and Cherenkov emission by shower particles was measured at distances of 0.7 to ~10 km. The shower sizes determined by the optical measurements are in satisfactory agreement (an average of 10% higher) with measurements by the ground-level scintillation-counter array at Volcano Ranch.

PRL 1977: 44 coincidences between scintillator array and FD in 12 nights

Cosmic Rays in Australia

- Messel at Dublin Institute for Advanced Studies
- Photographed at meeting beside Pontecorvo and Fuchs
- Went to Australia in 1951
- Ended up as professor in Sydney
- Recruited McCusker from Dublin

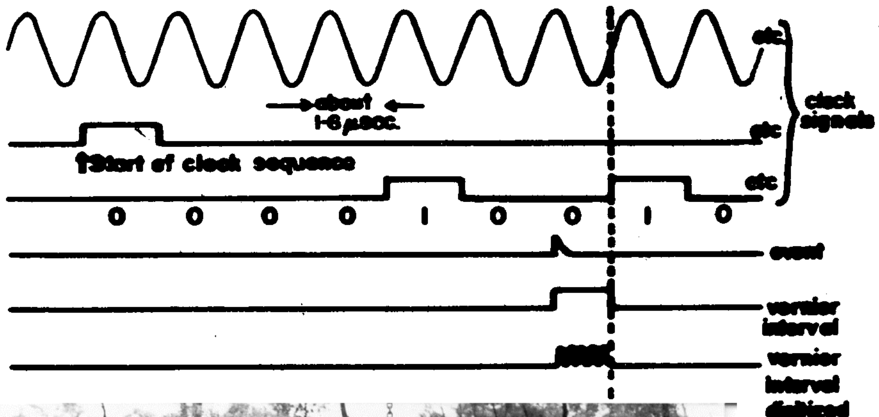
Dublin cosmic-ray work was driven initially by people who had been with Blackett in Manchester (McCusker and Janossy) and also with Powell in Bristol (Heitler)

TWO LARGE AIR SHOWER EXPERIMENTS

by

C.B.A. McCusker, H.D. Rathgeber & M.M. Winn
The University of Sydney

Son-in-law of Regener



Jaipur Conference 1963

First discussion of stand-alone operation of detectors

Murray Winn invented the method

Key idea for Auger and TA

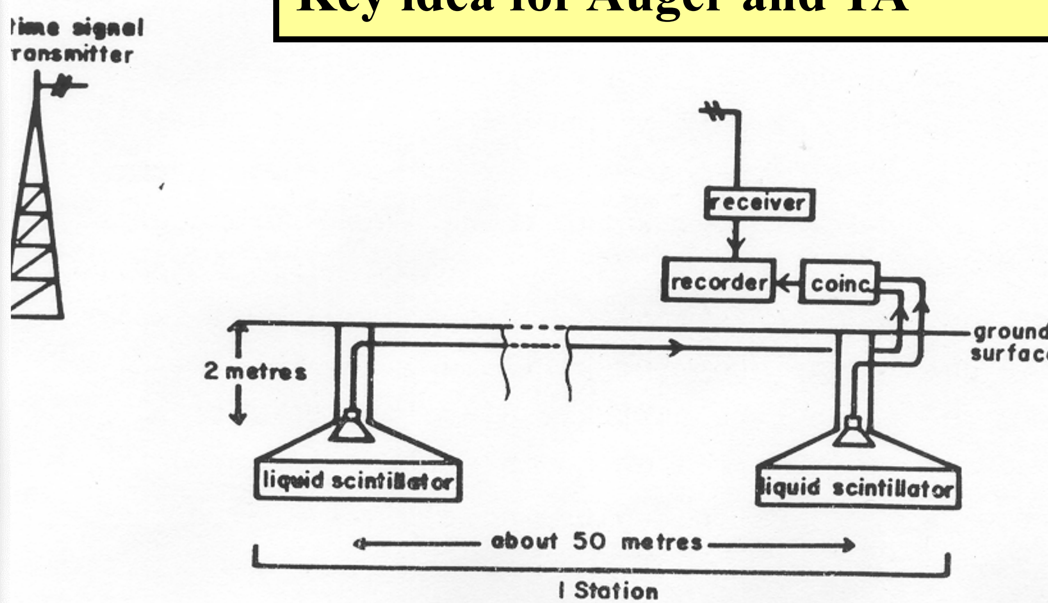


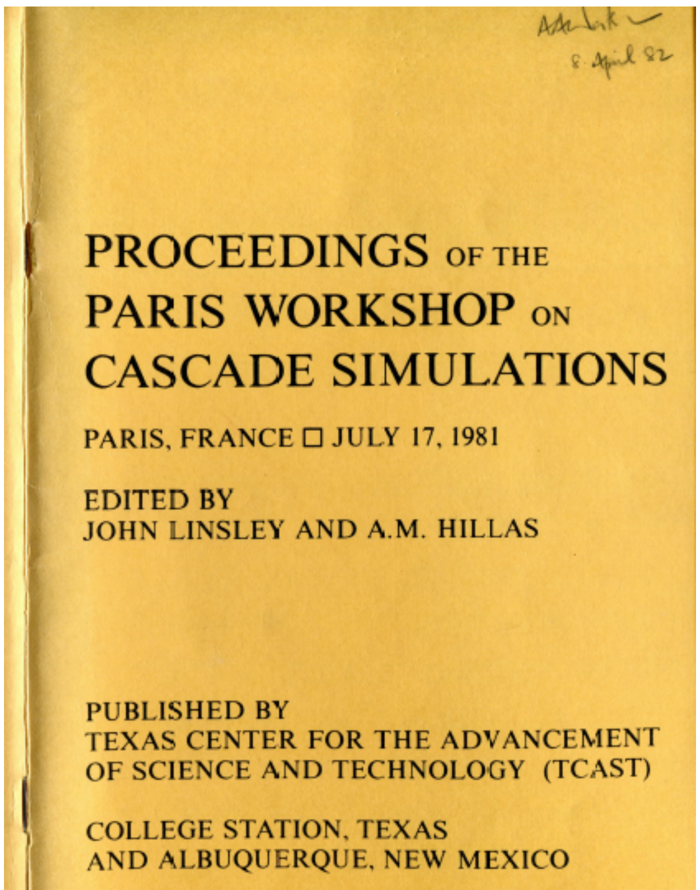
FIGURE 2

No time to discuss radio (again Jelley was key-player)

Monte Carlo Calculations

Impact of accelerator results

……..



8 April 82

PROCEEDINGS OF THE
PARIS WORKSHOP ON
CASCADE SIMULATIONS

PARIS, FRANCE □ JULY 17, 1981

EDITED BY
JOHN LINSLEY AND A.M. HILLAS

PUBLISHED BY
TEXAS CENTER FOR THE ADVANCEMENT
OF SCIENCE AND TECHNOLOGY (TCAST)

COLLEGE STATION, TEXAS
AND ALBUQUERQUE, NEW MEXICO

Meeting to honour Michael Hillas

Heidelberg 10 – 12 December 2018

Major Focus of this meeting

Reports from the various Working Groups

What to look out for from:

Reports of Spectrum and Mass Composition Groups

Workshop on Future on Friday

AAW words at CERN: UHECR2012
Concluding Remarks

'I believe that it is highly desirable for the Working Group on the Energy Spectrum to move next to a comparison of spectra from the same part of the sky. There are useful overlaps with TA and Auger and between TA and Yakutsk. I believe that there is much to be learned by making such comparisons and this would at the same time explore whether or not the fluxes seen in the Northern and Southern hemispheres are different as they might be if, for example, a local source such as Cen A is dominant in the data set recorded at the Auger Observatory (pre-TA hotspot)'.

Expect an extensive update on this from the Spectrum Working Group

Question of Mass Composition is very tough

"We remain with the dilemma: protons versus heavy nuclei. A clear cut decision cannot be reached yet. I believe that up to the highest energies the protons are the most abundant in the primary cosmic rays. However, I must confess that a leak proof test of the protonic nature of the primaries at the highest energies does not exist. This is a very important problem. Experimentally it is quite a difficult problem."

G Cocconi: Fifth ICRC, Guanajuato, Mexico, 1955

Good progress made by Working Group on Mass Composition

At Busan ICRC (2017) the statement *in the joint paper* was that the TA X_{max} distributions, in the energy range 18.2 < log E(eV) < 19.0, are

'as compatible with a pure proton composition as they are to the mixed composition reported by the Auger Collaboration'

This is an agreed conclusion

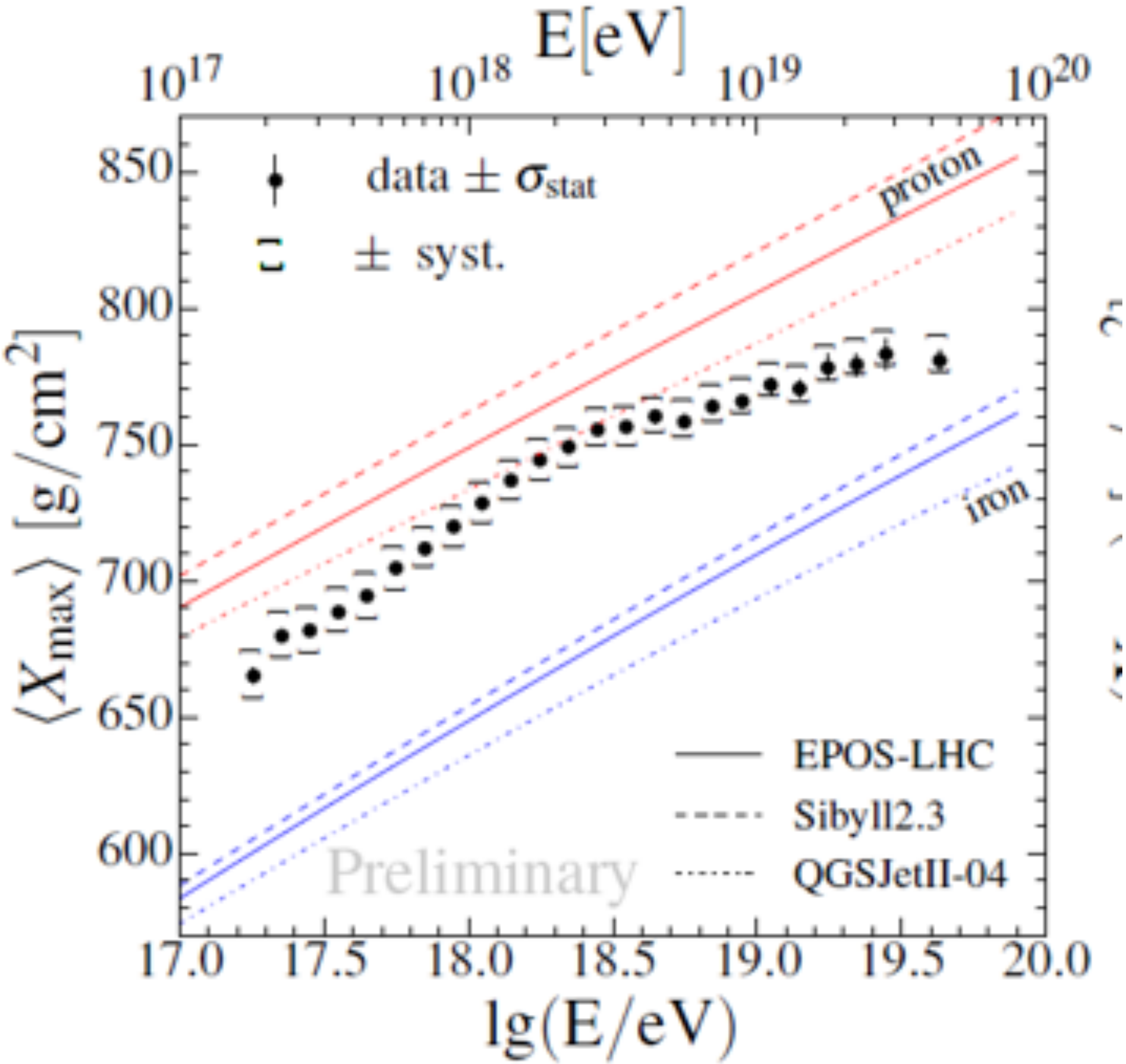
The Community should recognise this – please stop being so protonic!

The situation above 10^{19} eV is less clear, in part because the number of TA events (123) is about 1/7th of the Auger sample

There are subtle points to be understood when making direct comparisons as you will find in the Working Group report - but there has been significant progress

Is there simpler approach? Can we learn anything without recourse to models?

Auger Results reported at Busan, ICRC2017



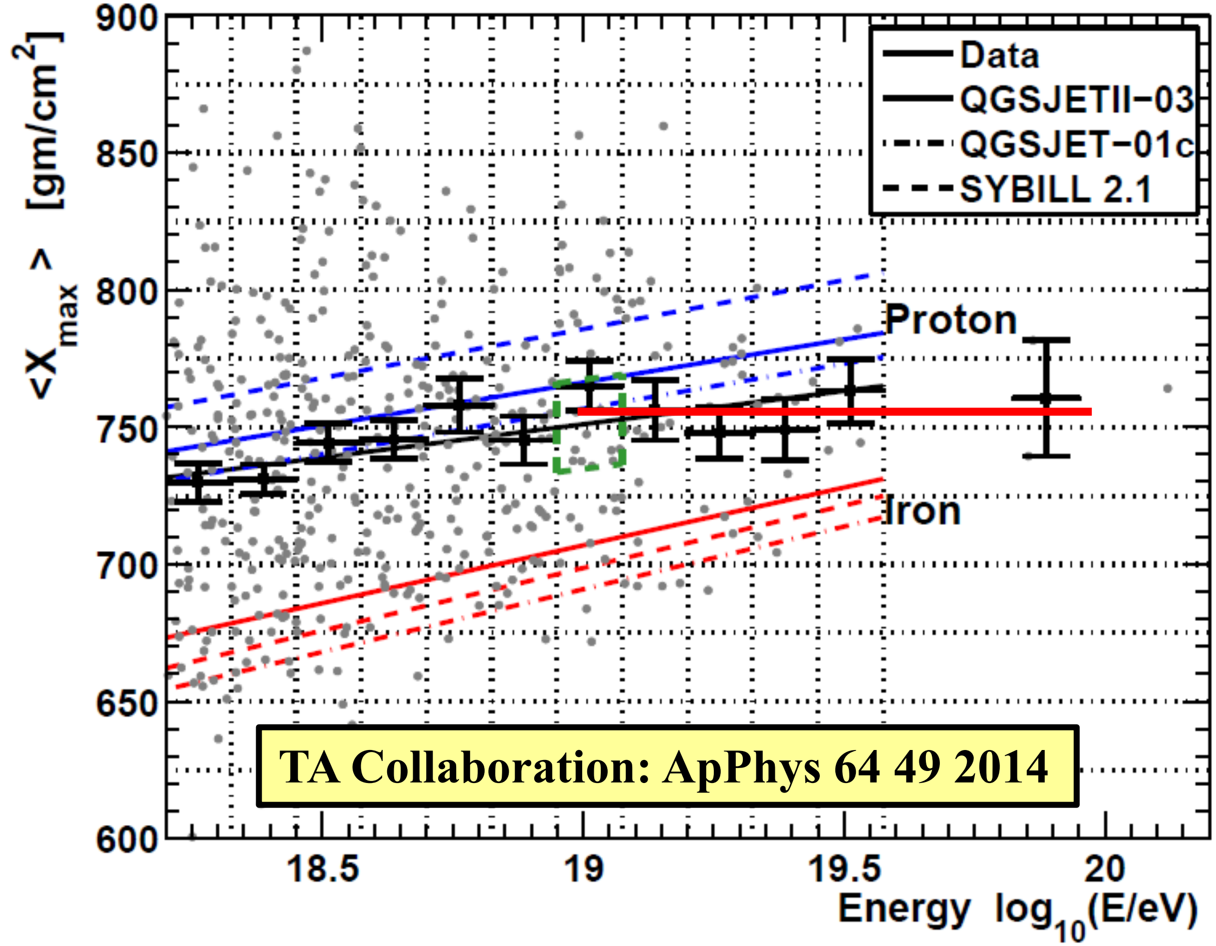
CRIS 2016: Ischia 4 – 8 July 2016

"What astrophysical conclusions can be drawn about the origin of high-energy cosmic rays without using hadronic models?"

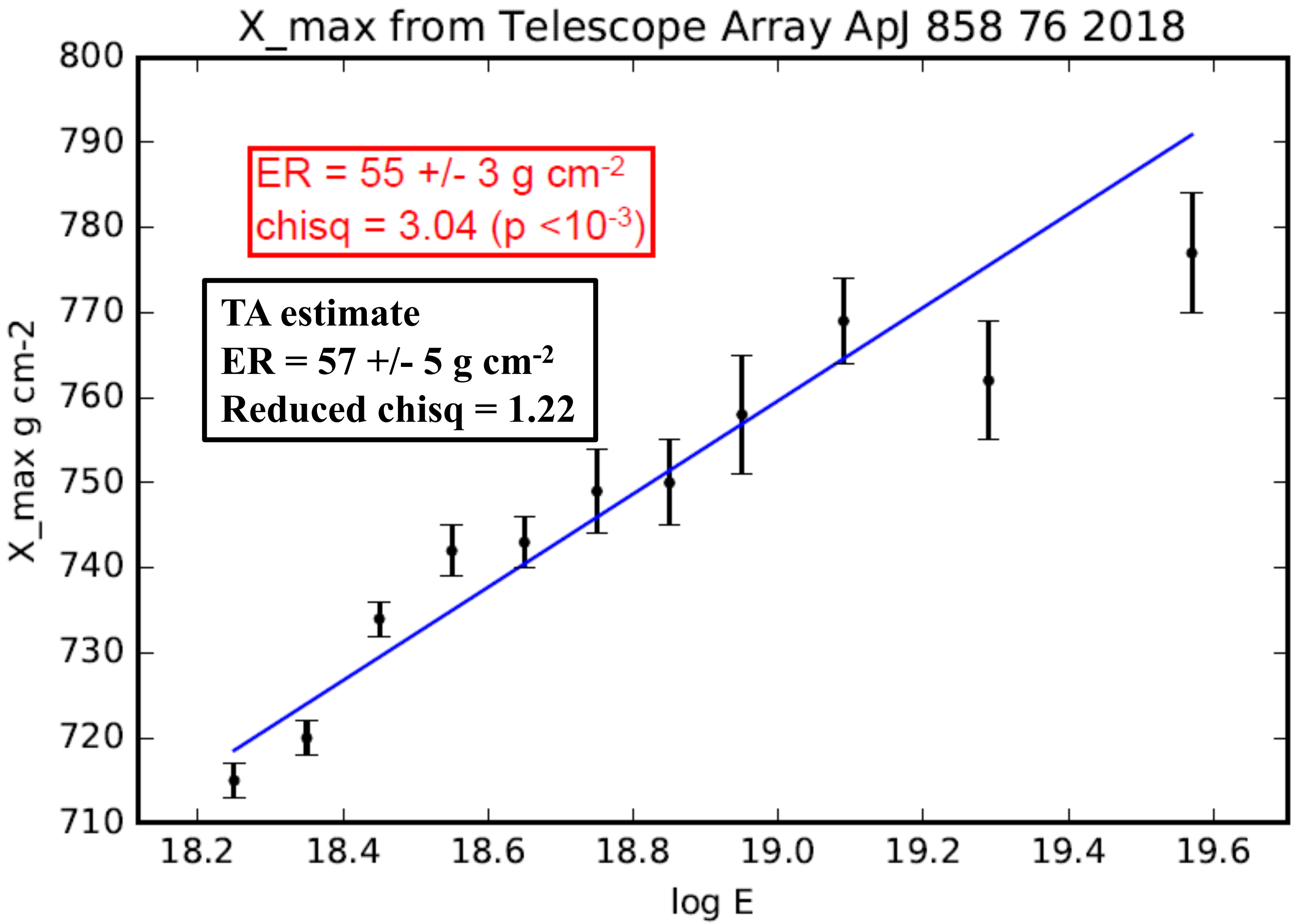
Watson: arXiv: 1610.09098

Reduced chisq = 7.1

for 10 degrees of freedom, $p < 0.001$

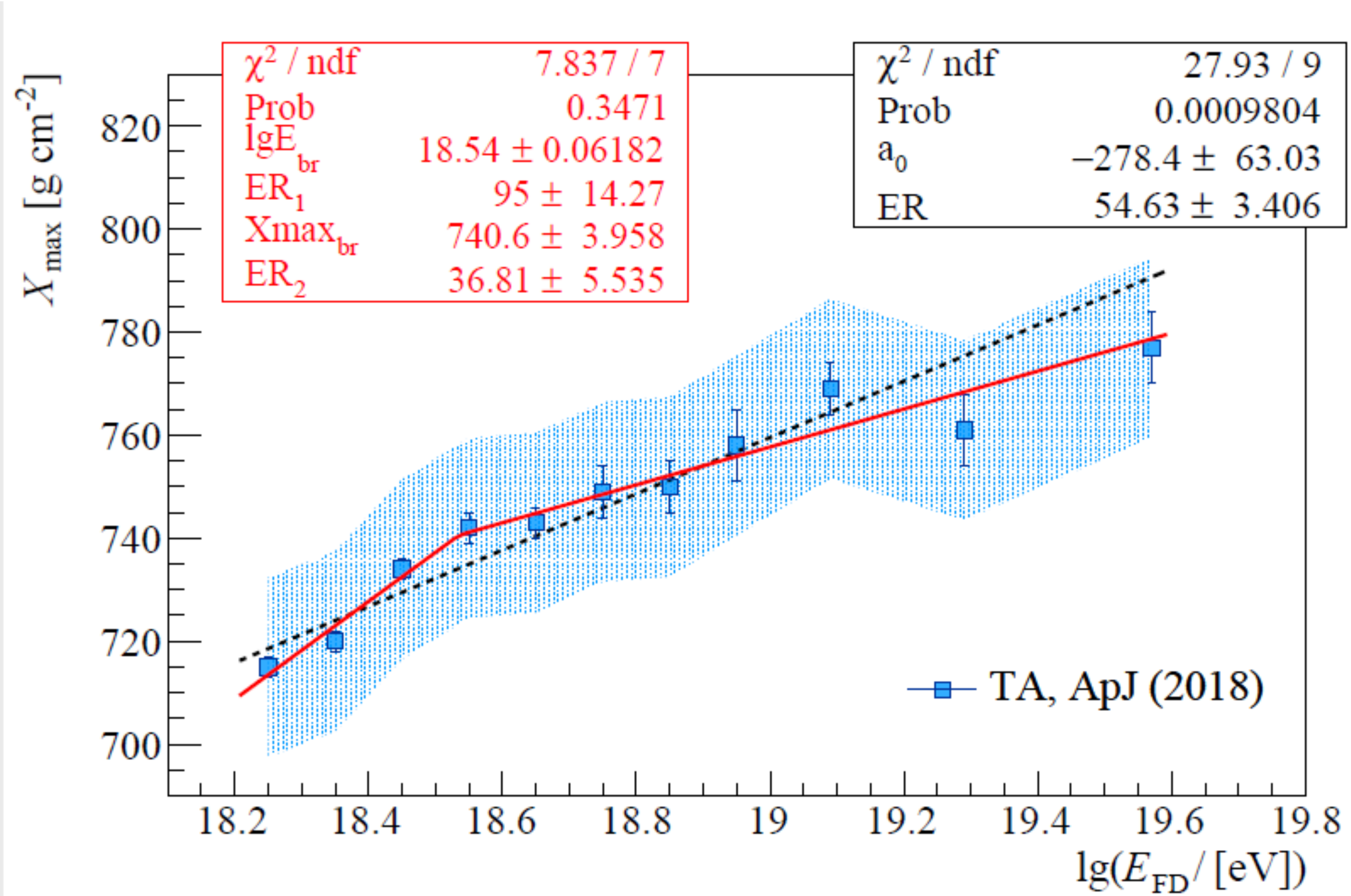


TA Collaboration: ApPhys 64 49 2014

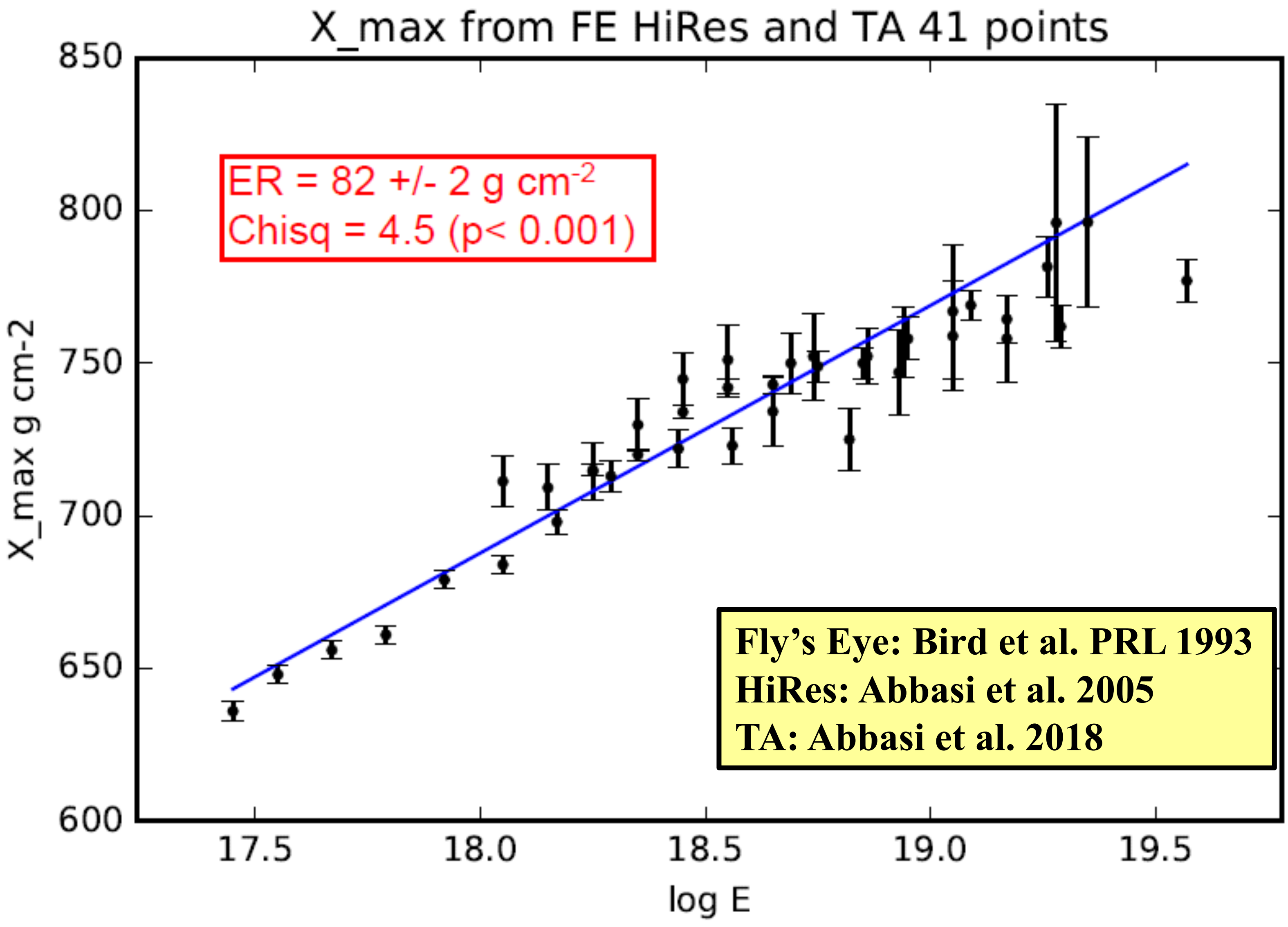


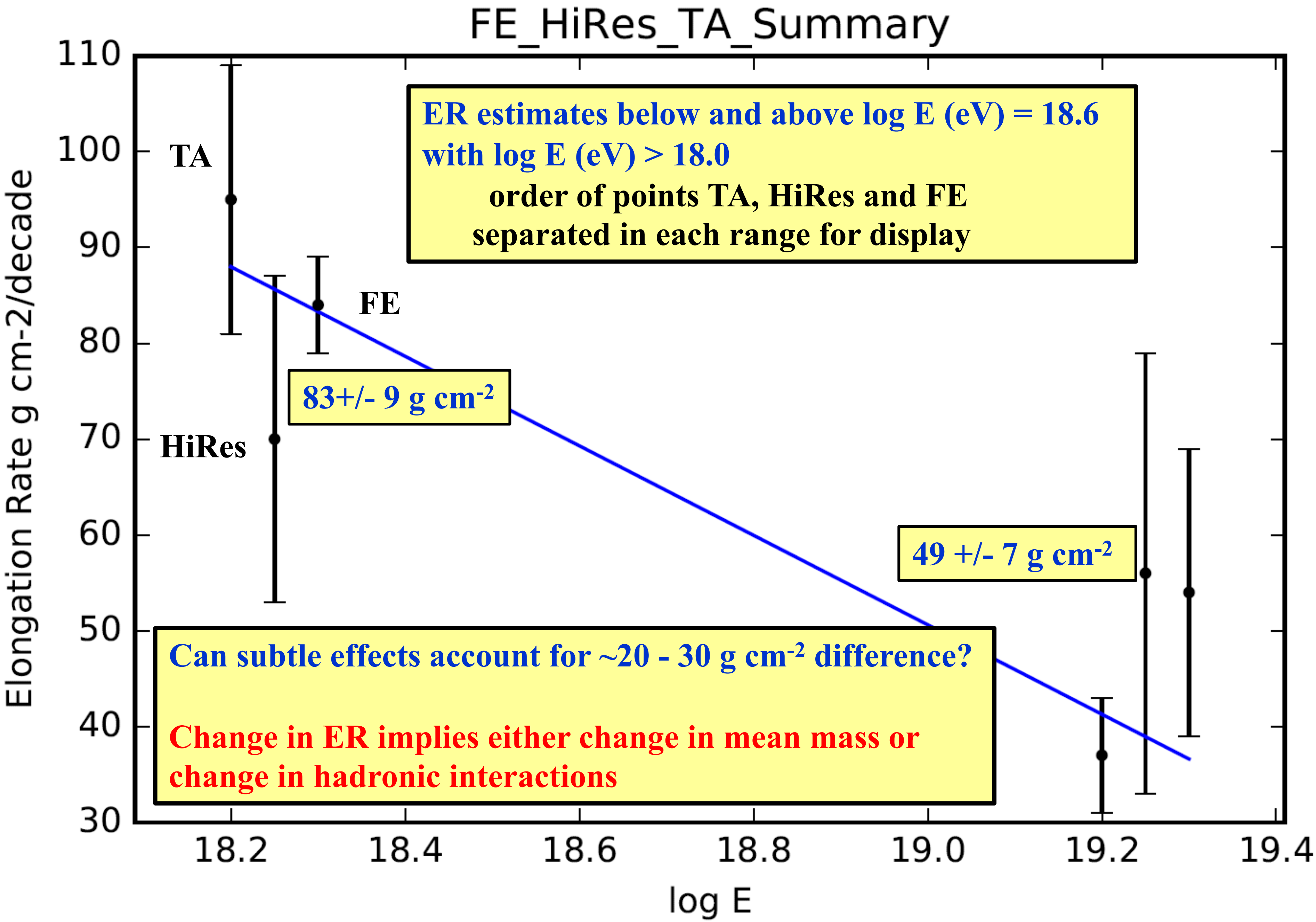
X_max from Telescope Array ApJ 858 76 2018
ER = 55 +/- 3 g cm-2
chisq = 3.04 (p <10-3)
TA estimate
ER = 57 +/- 5 g cm-2
Reduced chisq = 1.22
X_max g cm-2
log E
800
790
780
770
760
750
740
730
720
710
18.2
18.4
18.6
18.8
19.0
19.2
19.4
19.6

Search for a break: plot by Alexey Yushkov – thanks!



Note: break point is close to the ankle


X_max from FE HiRes and TA 41 points
ER = 82 +/- 2 g cm-2
Chisq = 4.5 (p< 0.001)
Fly's Eye: Bird et al. PRL 1993
HiRes: Abbasi et al. 2005
TA: Abbasi et al. 2018
X_max g cm-2
log E
850
800
750
700
650
600
17.5
18.0
18.5
19.0
19.5


FE_HiRes_TA_Summary
Elongation Rate g cm-2/decade
log E
110
100
90
80
70
60
50
40
30
18.2
18.4
18.6
18.8
19.0
19.2
19.4
TA
FE
HiRes
ER estimates below and above log E (eV) = 18.6
with log E (eV) > 18.0
order of points TA, HiRes and FE
separated in each range for display
83+/- 9 g cm-2
49 +/- 7 g cm-2
Can subtle effects account for ~20 - 30 g cm-2 difference?
Change in ER implies either change in mean mass or
change in hadronic interactions

How can the mass composition issue be resolved?

Devotees of the proton-hypothesis can always argue that the hadronic physics is different at centre-of-mass energies > 10 times that achieved at the LHC

- **In the 1950s Zatsepin and Gerasimova pointed out that photodisintegration in the photon field around the sun might lead to widely-separated showers at ground level. This has been re-examined (Medina Tanco and Watson (1999), and Harari et al (2000))**

Much larger instrument than present Auger area

Part of the science case for a future ground instrument?

But also potential target for POEMA? (Original idea of Linsley 1979)

- **At higher energies we may hope, with hugely increased event numbers, to identify a small number of sources unambiguously, and then use the galactic magnetic field as a magnetic spectrometer.**

For ground array, need two arrays to cover whole sky

China and Australia (or South Africa)

Link with GRAND?

Link with SKA?

Need to start planning now

Are there new techniques?

- **Radio looks promising but stand alone? 53 years since first detections**
- **Radar and microwave – No**
- **X-rays (suggested by Peter Fowler to Haverah Park group in 1970s) - No**

Present devices more cheaply?

From Jim Cronin: 12 Feb 2012

Dear Alan

…………………………………………………………………..

I hope there are a few people to follow up with some workshops to consider the next effort on the highest energy cosmic rays. We should go to a time-machine to reduce our ages by 20 years!

Sincerely, Jim

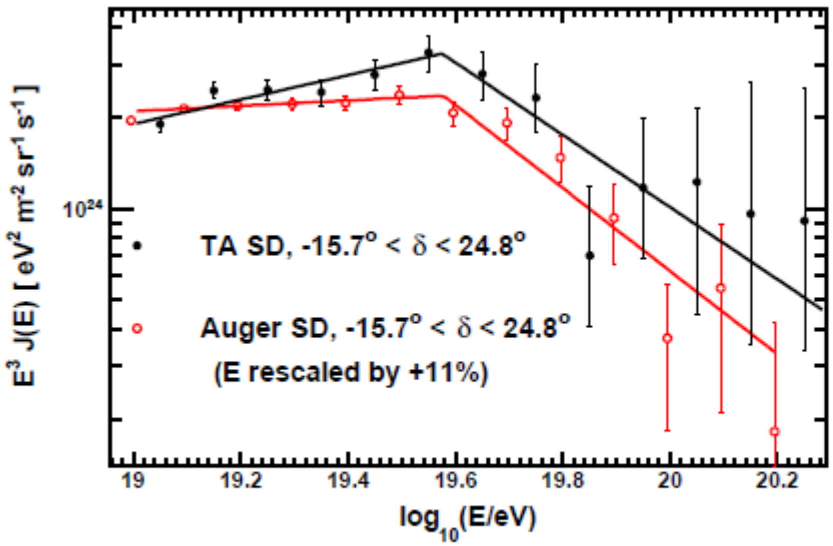
Back up slides

Question of Mass Composition

"We remain with the dilemma: protons versus heavy nuclei. A clear cut decision cannot be reached yet. I believe that up to the highest energies the protons are the most abundant in the primary cosmic rays. However, I must confess that a leak proof test of the protonic nature of the primaries at the highest energies does not exist. This is a very important problem. Experimentally it is quite a difficult problem."

"Fere libenter homines id quod volunt credunt!"

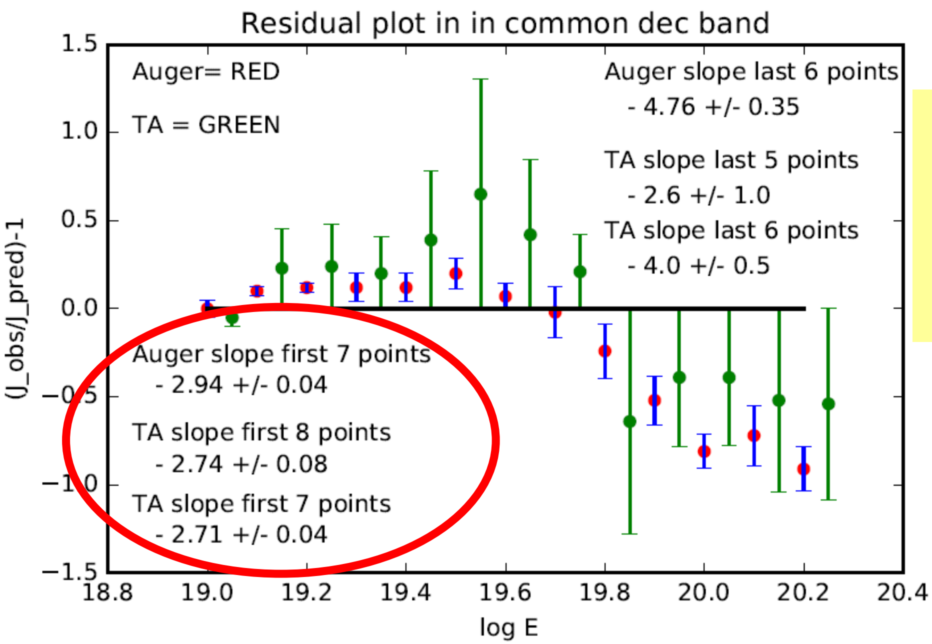
G Cocconi: Fifth ICRC, Guanajuato, Mexico, 1955



Telescope Array:
Abbasi et al. arXiv:1801.07820v1

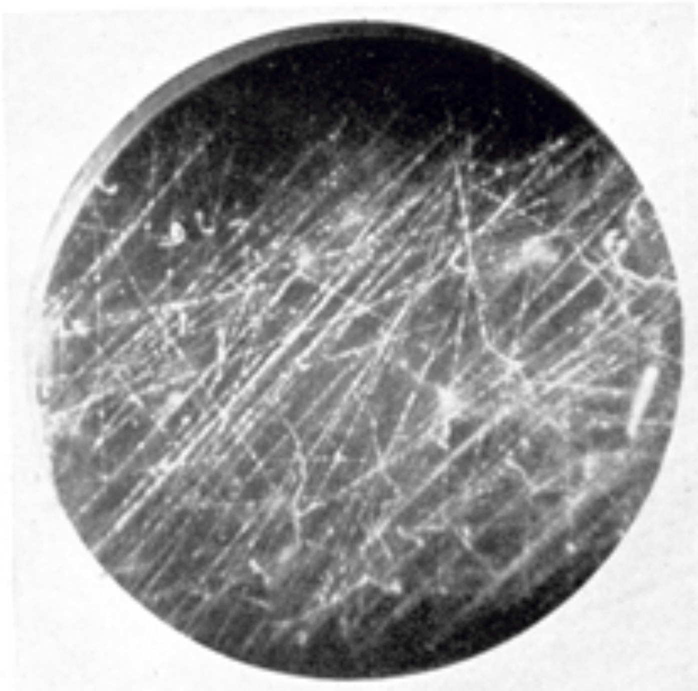
"When the spectra are fit to a broken power law function the cutoff energies agree at the ~0.5 sigma level"

Figure 3: Energy spectra of TA and Auger in the common declination band.

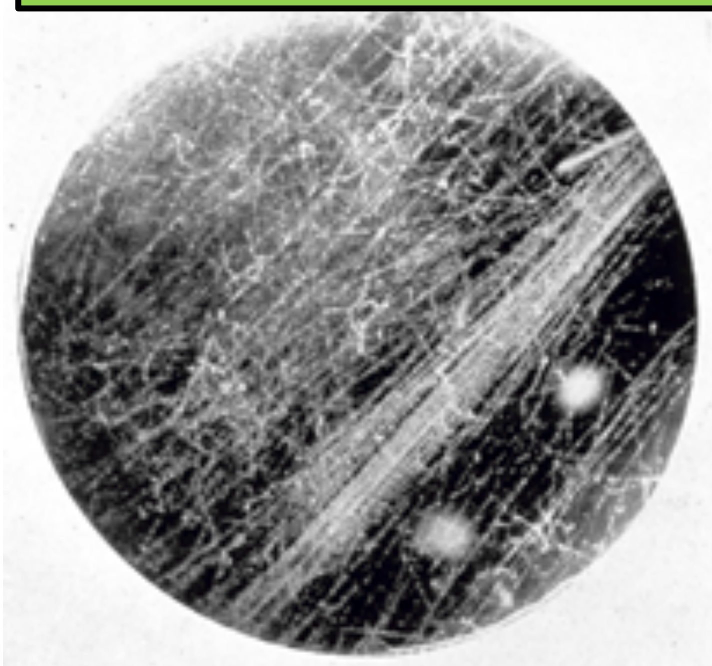


Not clear about status of this paper

Expect an extensive update in the Working Group Report



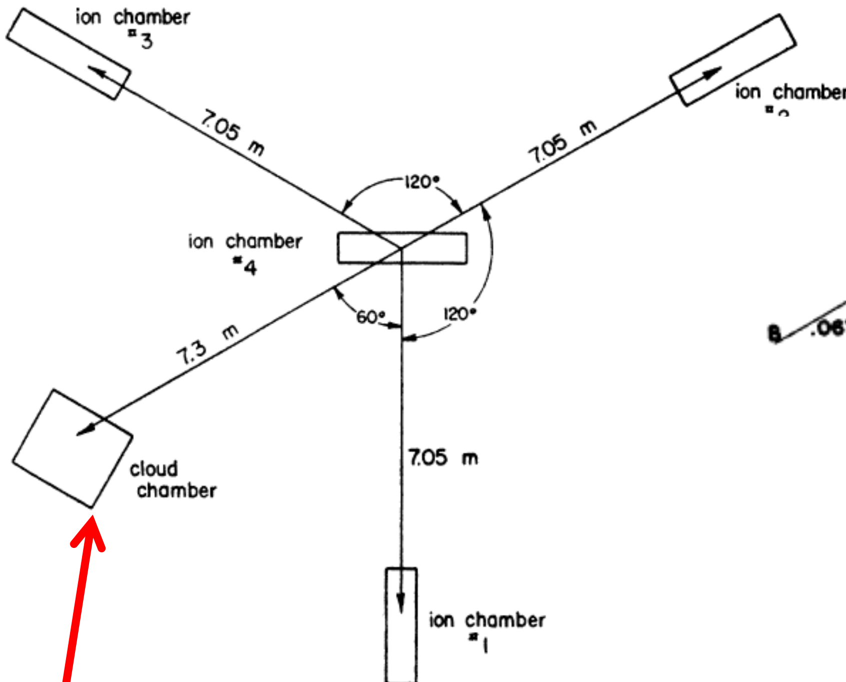
36 cm Aluminium



C B A Lovell and J G Wilson
Nature 144 863 1939

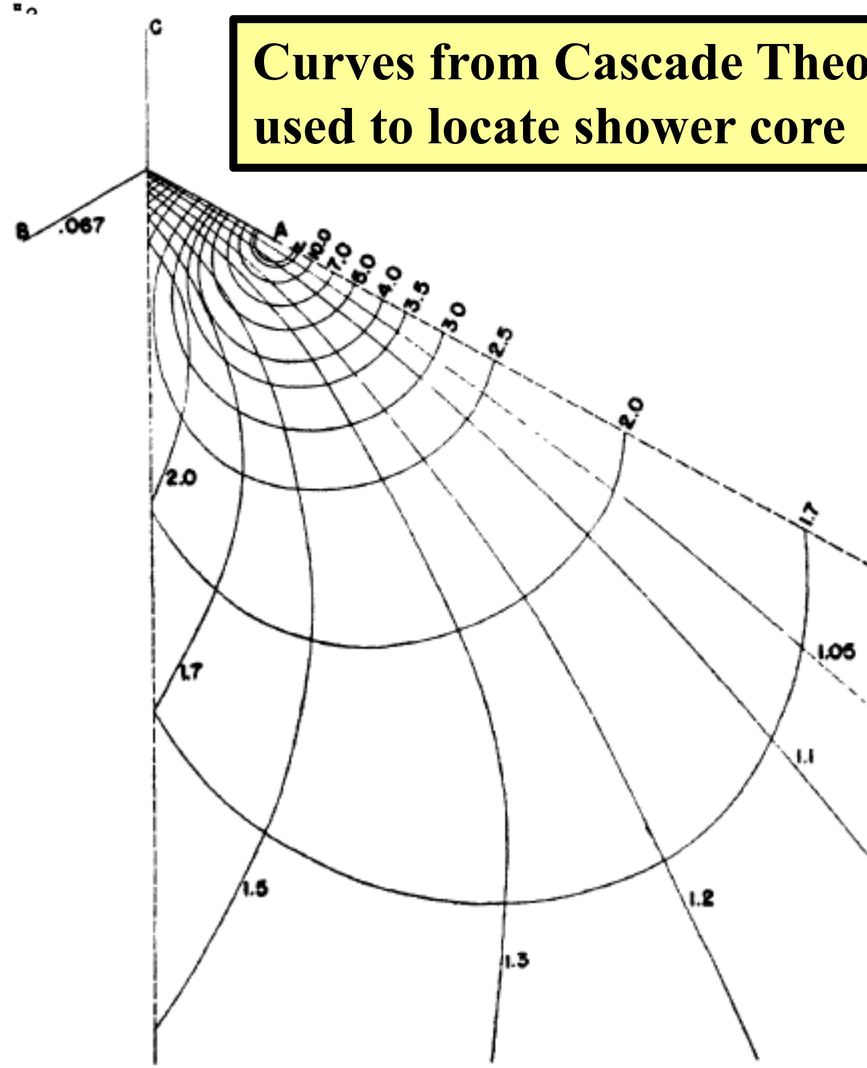
Investigation suggested by Auger

Core Location by Williams (1948)



Cloud Chamber (Hazen) used to show that most showers < 30 °

Curves from Cascade Theory – used to locate shower core



Linsley proposed that a fluorescence detector should be put into space in 1979.

Eventually led to EUSO (ESA phase A (with Livio Scarsi)
and then to JEM-EUSO and now POEMA

More from Alan Bunner:

"I also recall having the idea, about 1961-62, of using a satellite to look down on the night-time Earth to extend the effective area. I'm sure that others independently thought of that idea too. We also talked about whether the atmospheres of other planets might work."

Nature 23 January 1965

RADIO PULSES FROM EXTENSIVE COSMIC-RAY AIR SHOWERS

By Dr. J. V. JELLEY and J. H. FRUIN
Atomic Energy Research Establishment, Harwell

Prof. N. A. PORTER and T. C. WEEKES
University College, Dublin

AND

Prof. F. G. SMITH and R. A. PORTER
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank

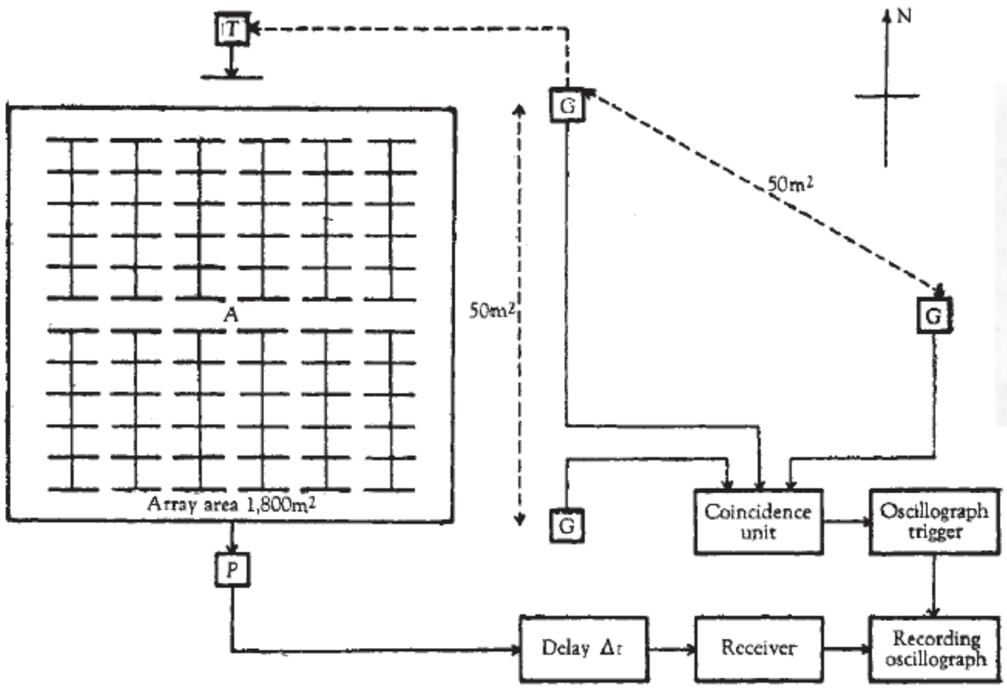
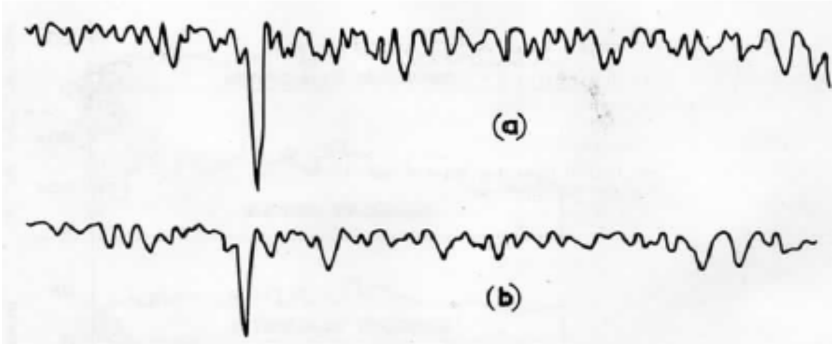


Fig. 1. Arrangement of the receiving apparatus. Coincident pulses from the Geiger counters G trigger an oscillograph which displays the output of the receiver delayed by Δt. P is a transistor pre-amplifier at the aerial array, A. The transmitter T can be triggered by a single counter G



Radio ICRC: London 1965

The detection of radio pulses of wavelength 6.8 m, in coincidence with extensive air showers, in the energy region 10^{16} - 10^{17} eV

F.G. SMITH*, N.A. PORTER† and J.V. JELLEY‡

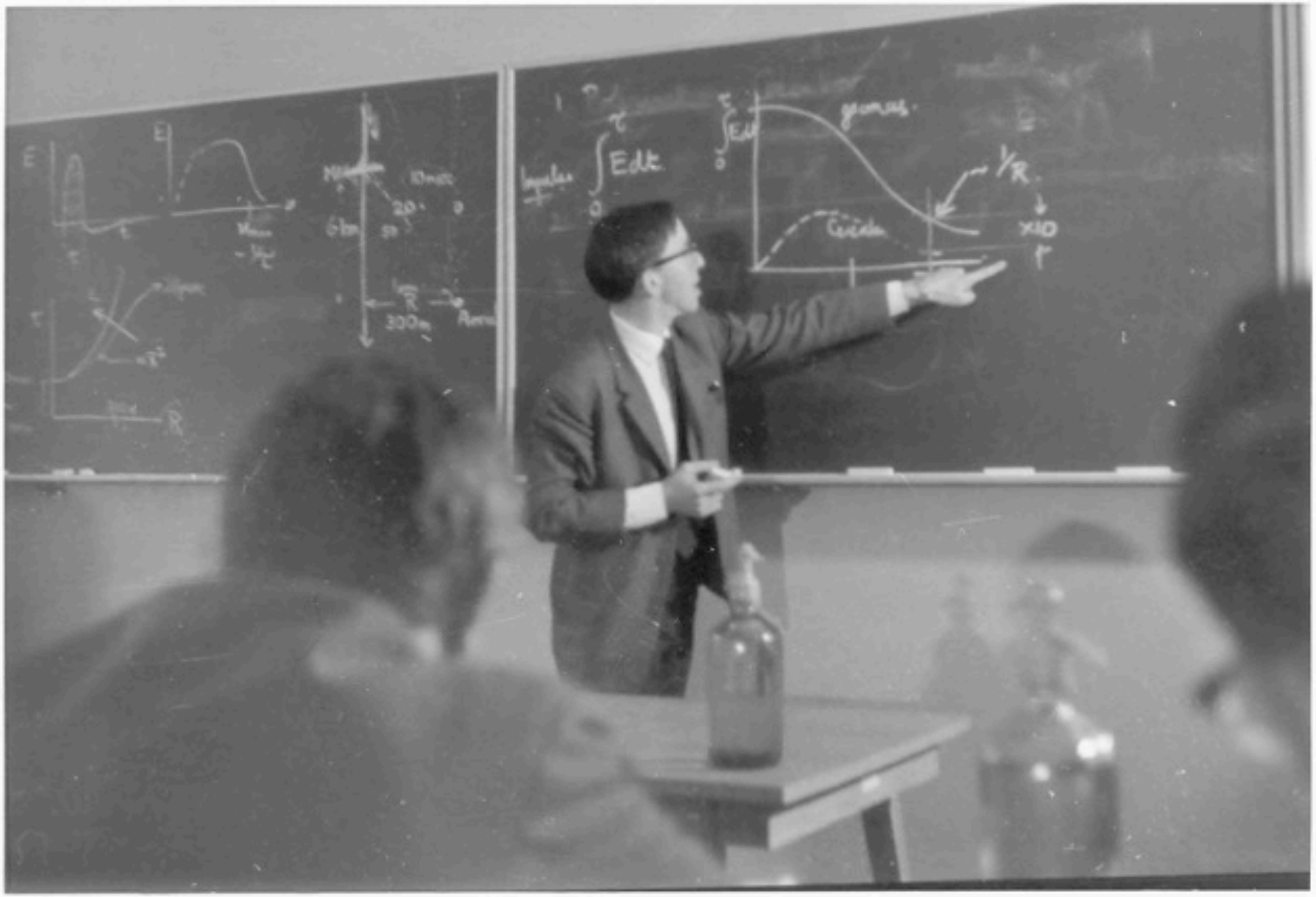
* Nuffield Radio Astronomy Laboratories, Jodrell Bank, Cheshire, England
† The Physics Department, University College, Dublin, Eire
‡ Nuclear Physics Division, Atomic Energy Research Establishment, Harwell, Berkshire, England

Abstract. A brief description is first given of the original experiment carried out at Jodrell Bank, and reported briefly in Nature. This was executed on the basis of the Askaryan hypothesis that a negative charge excess in showers should give rise to a considerable enhancement of the normal Cerenkov radiation, due to effects of mutual coherence. The results obtained so far are consistent with this hypothesis, though very preliminary results obtained in a polarization experiment tend to support alternative radiation mechanisms, namely those which arise from charge separation in the Earth's field, as indicated by the generalized treatment of Kahn and Lerche.

There follows a description of extensions to this work in progress at Jodrell Bank, namely studies of the radio spectrum, attempts to obtain radio pulses in coincidence with Cerenkov light pulses, and plans to commence an analysis of various types of pulse interference, using mobile equipment.

In conclusion, there follows a discussion on the future possibilities in this field, looking ahead to the hope that giant showers may be detectable by wholly radio methods.

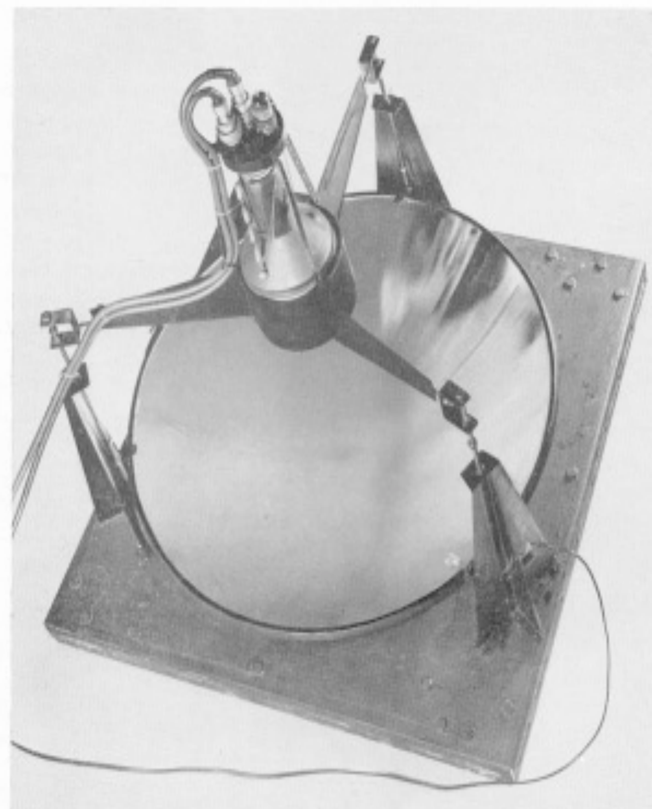
- **First discussion of work of Kahn and Lerche on separation of charges**
- **Hope that giant showers may be detectable by radio methods**



1st European Cosmic Ray Symposium: Lodz 1968

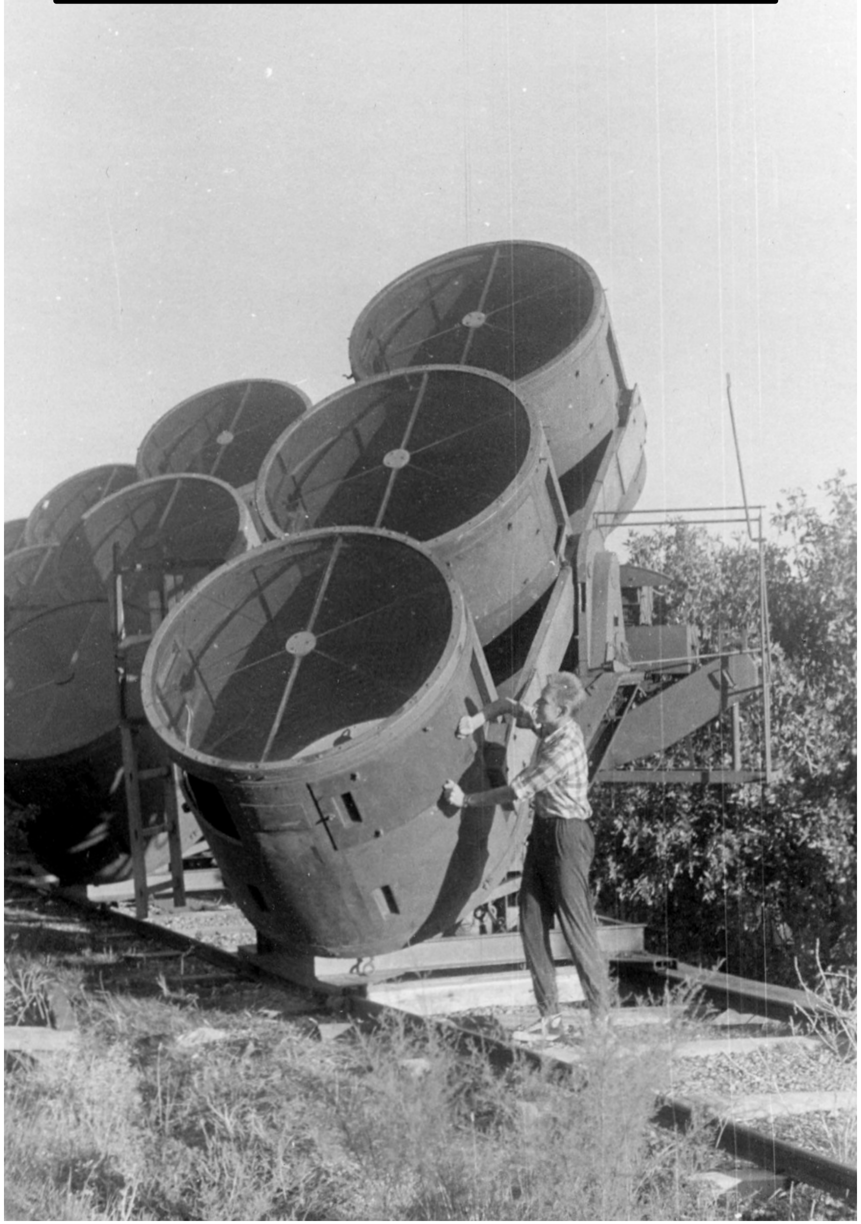
John Jelley and Bill Galbraith were stimulated by Blackett's ideas to make observations at Harwell (Nature 1953)

Observations made (i) with free-running time base on an oscilloscope and then (ii) with the scope triggered by small GM array. Data from only two dark periods in autumn 1952 used for first paper (Nature 1953)



Initial work at Harwell (need for a bed) and then at Pic du Midi where they measured properties of the radiation detected, including observing the polarisation. Experimental *tour de force*

A E Chudakov, probably in the late 1950s, in Crimea



G T Zatsepin at Pylos, 2004

What can one conclude?

There are surely subtle corrections to be made to the measured values, but can these be as great as to explain difference of ~30 g cm^{-2} and the chisq difference ?

My conclusion:
There appears to be a change in slope of the elongation rate at around log E (eV) = 18.6

A reduction in the Elongation Rate could be explained by an increase in the mean mass of the incoming primary cosmic rays

or

Is there a change in the hadronic physics?