Early Days of Particle Physics in India

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DTP, TIFR

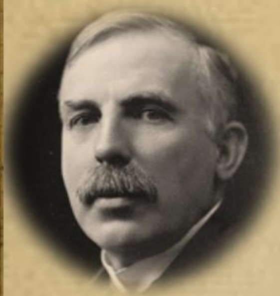
XVth ICFA School on Instrumentation in Elementary Particle Physics
TIFR, February 14, 2023

Discovery of Radioactivity

1896 Henri Becquerel (Paris) stumbles upon the discovery that uranium salts can affect photographic plates.

1898 Gerhard Schmidt (Münster) and Marie Curie (Paris) discover that thorium also affects photographic plates

1898 Pierre and Marie Curie (Paris) discover polonium and radium; Marie Curie coins the name 'radioactivity'.



1899 Ernest Rutherford (Montreal) discovers α and β rays; invents the concept of half-life

1900 Paul Villard (Paris) discovers highly penetrating radiation, later identified as γ rays

1902 Rutherford and Frederick Soddy (Montreal) suggest that radioactivity involves disintegration of atoms

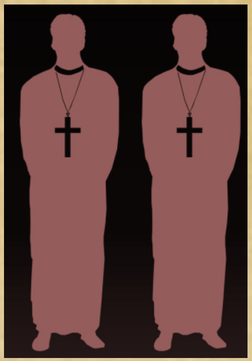
1907 Rutherford and Thomas Royds prove that α rays are just doubly-ionised helium atoms

1913 Soddy (Glasgow) and Kasimir Fajans (Manchester) discover the radioactive displacement law

1917 Soddy and Ada Hitchins (Aberdeen) discover the existence of isotopes

Radioactivity Research Starts in India

1910 – 1911 : Fr. Adolphus Steichen, a Göttingen graduate, was Professor of Physics at St. Xavier's College, Mumbai. With his colleague Fr. Heinrich Sierp, the Professor of Chemistry, he conducted a study of the radioactivity of hot springs at Tuwa, near Vadodara.



Prof. R.R. Ramsey (1872 – 1955) of Indiana University had claimed that radioactivity of hot springs increases with the flow of water and decreases when it falls.

Fr. Steichen's paper (*Phil. Mag.* 1916) states that he and Fr. Sierp found the exact opposite at Tuwa… attributed to dilution of eroded material…

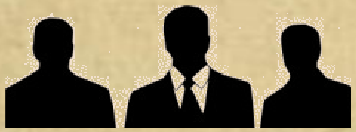
During World War I, Frs. Steichen and Sierp were interned as 'enemy aliens'. Hence the delay in publishing the paper.

Later Fr. Steichen carried out a study of hot springs in the Madras Presidency (1918 – 1923). We have a memoir that he was given a grant of Rs. 1000/- for this.

Radioactivity Research Starts in India

1914 : Herbert E. Watson, (1886 – 1980) a young Assistant Professor at the IISc, Bangalore, conducted a study of radioactivity in the rocks around the Kolar township and gold mine. These are some of the oldest rocks in the Earth's crust and the gold mines provided samples from 4 Km down.

Watson's assistants were Gosta Behari Pal (IISc) and W.F.S. Smeeth (Mysore Geological Department).



They didn't find any radioactivity in these rocks. Their negative result was published in the Proc. Ind. Acad. Sciences (1914) and then in the Phil. Mag. (1914).

In 1916, Watson left India to join the University of London as Prof. of Chemistry. He is credited with having invented neon lighting independently of Georges Claude, who patented it.

Nuclear Physics

1908 – 1910 : Hans Geiger and Peter Marsden, students of Rutherford (Manchester), make a careful set of observations of α particles scattering from Au atoms…

1911 : Rutherford (Manchester) proves that the data of Geiger and Marsden can only be explained if the positive charge occupies a tiny fraction (10^{-15}) of the volume of an atom… he names this the 'nucleus'.

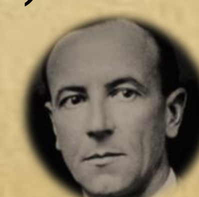
It follows that the hydrogen nucleus must be an elementary particle – the proton.

1913 : Niels Bohr (Manchester) explains atomic line spectra using the new quantum theory.

Henry Moseley (Oxford) proves that the charge on the nucleus is equal to the atomic number

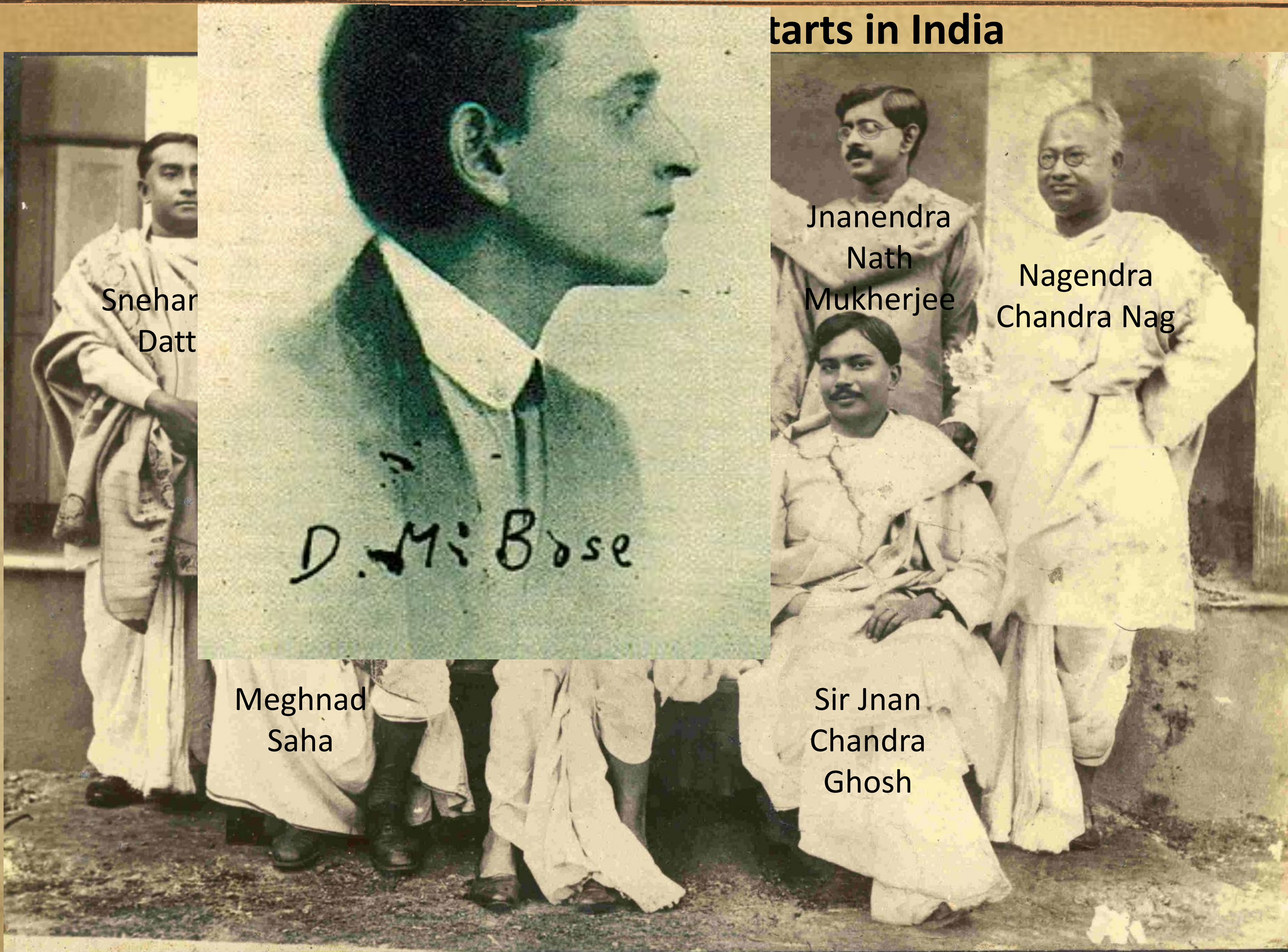
1920 : Rutherford (Cambridge) predicts the neutron – but is not sure.

1931 : Viktor Ambartsumian and Dmitry Ivanenko (Leningrad) predict the neutron based on quantum mechanics.



1932 : James Chadwick (Cambridge) discovers the neutron.

tarts in India



Nuclear Physics Research Starts in India

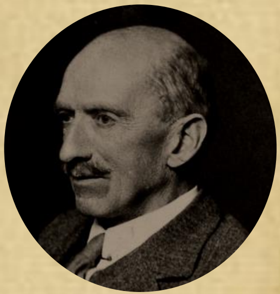
A.M. Bose

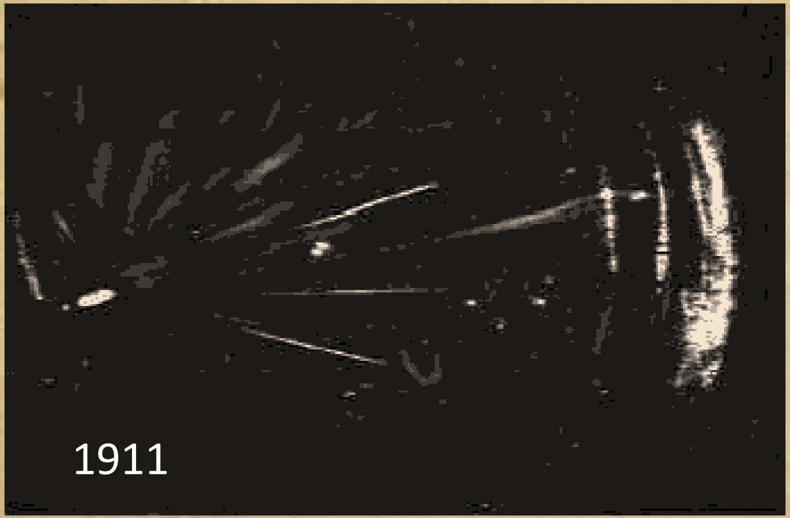
J.C Bose

1907 : Debendra Mohan Bose sailed to England and enrolled in Christ's College, Cambridge.

J.J. Thomson

C.T.R. Wilson

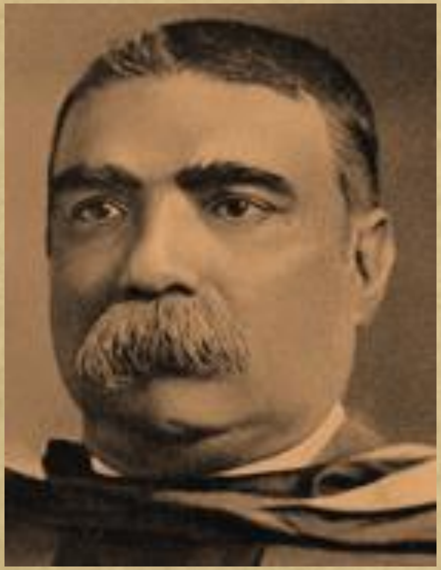




Nuclear Physics Research Starts in India

1913 : D.M. Bose returned to India and joined the City College (founded by his uncle A.M. Bose) as Lecturer.

1914 : He was appointed the Sir Rashbehary Ghose Professor of Physics at the new Department of Physics of the University of Calcutta.



Sir Ashutosh Mukherjee (1864 – 1924) mathematician and jurist, was the 2nd Indian Vice Chancellor of CU and he founded all the PG Departments.

Sir Rash Behary Ghosh (1845 - 1921) eminent jurist, donated more than Rs. 21,00,000/- to CU for this purpose.

(At today's valuation, about Rs. 250 Cr i.e. 3 million US dollars)

1914 : The Ghose Professorship came with a Ghose Travelling Fellowship, which D.M. Bose immediately used to make a visit to the laboratory of Erich Regener in Berlin…

Cosmic Ray Research Starts in India

Erich Regener (1881 – 1955) held a professorship at the Berlin Agricultural University. From his laboratory came a stream of precise measurements of cosmic ray fluxes.

"In the late 1920s and early 1930s the technique of self-recording electroscopes carried by balloons into the highest layers of the atmosphere or sunk to great depths under water was brought to an unprecedented degree of perfection by the German physicist Erich Regener and his group. To these scientists we owe some of the most accurate measurements ever made of cosmic-ray ionization as a function of altitude and depth." – Bruno Rossi

D.M. Bose's choice to go to Regener's laboratory in 1914 shows his early interest in the subject of cosmic rays. They had only been discovered in 1912…

Hardly had Bose settled down in Germany when World War I broke out. As a British subject, Bose became an 'enemy alien'.

But the Germans treated him well. He was not interned but only required to report regularly to the police. Regener and Max Planck stood guarantor for him, and he was allowed to carry out his research work unimpeded.

Cosmic Ray Research Starts in India

1916 : In Berlin, D.M. Bose successfully built a cloud chamber and managed to record the recoil tracks of ‘H particles’ i.e.protons, produced by fast α particles.

This was the first time the ‘H particles’ had been detected experimentally … It also proved that momentum was conserved at the atomic scale – later used brilliantly by Compton to explain photon-electron scattering.

1919 : Bose was awarded a Ph.D. by the University of Berlin for this work. Part of this work was published in the *Physikalischer Zeitschrift* ***7****, 388 (1916).*

In fact, Bose made the most of his enforced stay in Germany…

“After attending Planck’s lectures, (I learnt) what a system of physics meant in which the whole subject was developed from a unitary standpoint and with a minimum of assumptions.”

“…*Planck’s lectures were among the worst I ever attended.*”

– Sir Rudolf Peierls

Cosmic Ray Research Starts in India

1919 : D.M. Bose returned to Kolkata to resume his position as Sir Rash Behary Ghose Professor.

He now had a colleague of comparable seniority – Sir Taraknath Palit Professor of Physics – *Chandrasekhara Venkat Raman*.

A former civil servant, in 1917 he had been persuaded by Sir Ashutosh to abandon his Government job and take up an academic position at half the salary.

Other bright sparks in the CU Physics Department at the time were

S.K.Mitra

S.N.Bose

B.B.Roy

M.N.Saha

Cosmic Ray Research Starts in India

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Tracks of α-Particles in Helium.

In a recent issue of Nature (January 27, p. 114), Messrs. Ryan and Harkins have published some photographs of the ionisation tracks of recoiling atoms produced by collision of α-particles with air molecules. We have been also engaged in photographing the tracks of α-particles from polonium in helium, and have obtained some interesting photographs. Besides the long range recoil helium atoms, we have obtained a few photographs in which are shown the ionisation tracks of all the constituent parts of a helium atom, namely, of the nucleus and the two bound electrons. They are shown in Fig. 1 (i and ii).

Further experiments are in progress.

Subodh Kumar Ghosh

D. M. Bose.
S. K. Ghosh.
University College of Science, Calcutta,
February 21.

Nuclear Physics Research Starts in India

Maharajah's College, Jaipur

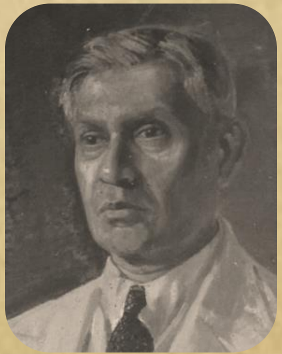
M.F. Soonawala wrote a paper in *Ind. J. Phys.* suggesting that all nuclei are made up of electrons, protons and noble gas nuclei… an early version of *aufbau* principle…

A.C. Banerji, a Wrangler from Cambridge, joined Allahabad U. and was the first Indian to apply (with M.N.Saha) quantum mechanics to the study of nuclear spectroscopy…

University of Allahabad

Rajshahi College

B.M. Sen, also a Wrangler from Cambridge, wrote in *Nature* and *Phil. Mag*. on beta rays, applying relativity to try and explain the spectral features, proving that the neutron is a Dirac fermion…



Particle Physics Research Starts in India

Meghnad Saha

At Allahabad University, in 1933, D.S. Kothari was doing his M.Sc. Project work with M.N.Saha, who had moved there in 1923.

The problem was to explain the continuous energy distribution of the beta rays emitted from a radioactive nucleus.

Daulat Singh Kothari

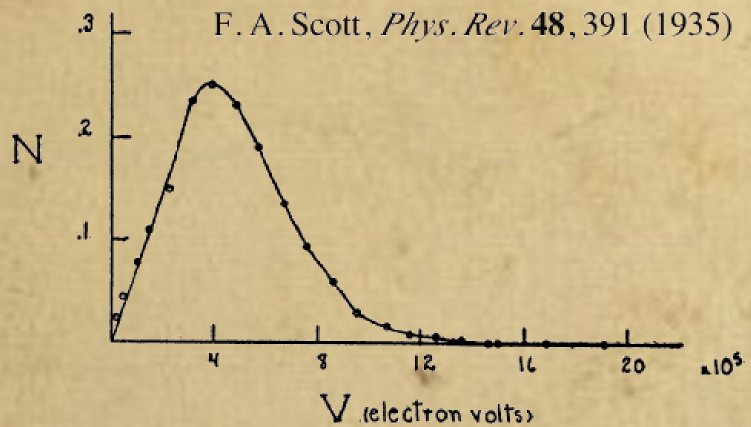


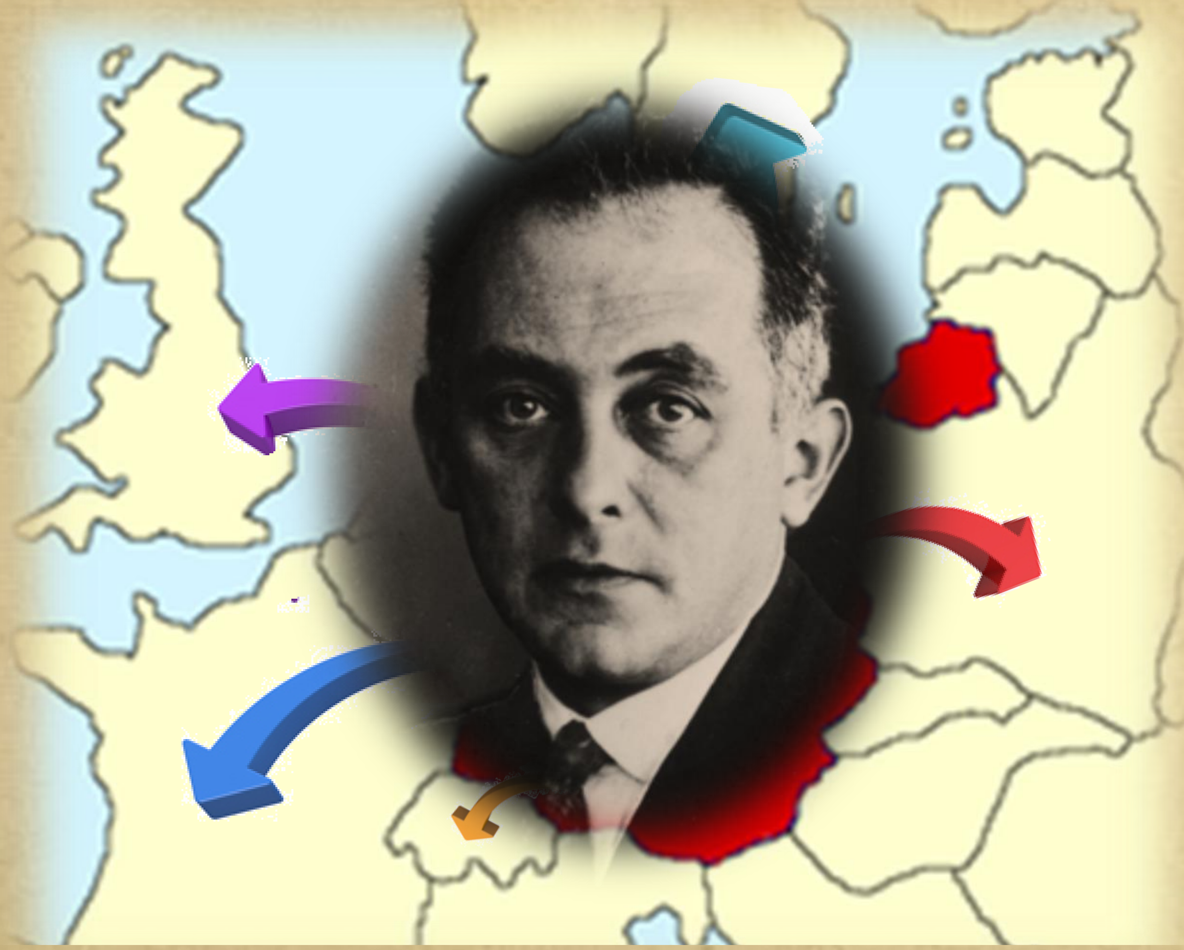
FIG. 5. Energy distribution curve of the beta-rays.

According to Saha and Kothari (*Nature* 1933), every beta decay process is actually a gamma ray emission from an excited nucleus. Some of the gamma rays escape, appearing as gamma decay. A few undergo pair creation in the field of the nucleus. One of the e+e- pair is absorbed by the nucleus, the other escapes as a beta ray. The excess momentum is taken up by the nucleus.

This is a perfectly plausible theory because (we now know that) beta decays are usually followed by gamma decays, and hence both are seen in the same sample. This theory does not require a neutrino – then considered an eccentricity of Pauli's…

Fermi's theory of beta decay (1934) and its verification by Kurie (1936) killed the Saha-Kothari theory, which gave a different-shaped spectrum from that measured by Kurie.

The Max Born Interlude



Sir C.V. Raman tried hard to catch Erwin Schrödinger and Max Born. Schrödinger refused but Born was interested… Hans Bethe and Rudolf Peierls wrote that they might be interested if Born set up a school…

The Max Born Interlude

In the winter of 1935-36, Max Born and his wife Hedwiga came to visit IISc, Bangalore

Professor and Frau Born liked Bangalore so much that they wanted to settle there for good, far away from the madness that had gripped Europe in those days.

Raman, then Director of IISc, gave Born a one-year Visiting Professorship in the Department of Physics. Here Born found a young collaborator in N.S. Nagendranath, with whom he wrote a paper in the Proceedings of the Indian Academy of Sciences, called '*The neutrino theory of light*.' This pursued an idea – then fashionable – that the photon is a composite of a neutrino-antineutrino pair. The motivation was the masslessness of both particles. Though proved wrong, the idea survives in the fact that the ρ meson is a composite of a quark-antiquark pair.

Raman's attempt to get Born a regular position in IISc as Professor of Theoretical Physics ended in disaster.In the IISc Faculty – Professors only – an Englishman called William Aston, an electrical engineer, stood up and said that the IISc should not create a Chair for `a "second-rate foreigner, who could not find a place in his own country." Even Meghnad Saha, then a member of the IISc Review Committee, criticized Raman for trying to employ a 'mathematician whose work has no relevance to industrial research'.

Max Born writes "… after the meeting, I went home to Hedi and cried."

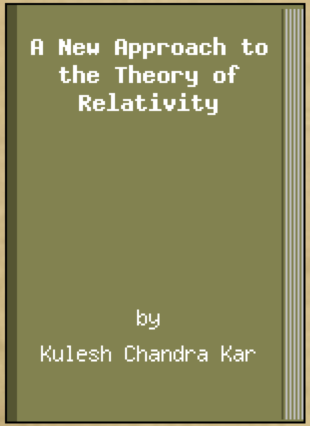
The Tranquil Thirties

The disorders and turbulence of Europe in the 1930's did not affect India much.

Meghnad Saha developed his theory of monopoles. He tried out a theory that the newly-discovered neutron is a bound state of two monopole of opposite but magnetic charge. This would explain why the neutron is neutral but has a magnetic dipole moment. This theory did not last, but Saha's derivation of the monopole is more elegant (if less intuitive) than Dirac's…

Now we know that the magnetic moment is due to the neutron having electrically charged components.

Kulesh Chandra Kar (1899 - 1990) and his collaborators, A. Ganguly and K.K. Mukherjee, developed a theory of the atomic nucleus based on a hard negative core surrounded by alpha particles – a mini-atom, in fact. The original idea was Rutherford's, but the Calcutta group tried to explain nuclear spectroscopy using the Schrödinger equation applied to this model… It was a naïve forerunner of the nuclear shell model (1949).



Today, Kar is better remembered as one of the first critics of Einstein's relativity on scientific (as opposed to racial) grounds, and his book finds pride of place in listings of `alternative science'.

Homi Bhabha – the Cambridge years

Hormusji Jehangir Bhabha (1909 – 1966) was a young Parsee boy, from a wealthy family closely related to the Tatas, who was sent to Cambridge to study engineering…

In Cambridge, he heard lectures by Thomson, Wilson and Dirac, and determined to become a physicist.

The brilliant young Indian was a protégé of Dirac, and he spent a total of 9 years in Cambridge. He worked, among others, with Fowler, Dirac, Pauli, Bohr, Fermi and most famously, Heitler.

Bhabha's 1936 paper '*Scattering of positrons by electrons with exchange on Dirac's theory of the positron'* was the first calculation of what was to remain forever enshined in textboooks as **Bhabha scattering**.

It was one of the foundational works in the newly developing subject of *quantum electrodynamics*, or QED.

This was long before the days of Feynman diagrams, so everything had to be done from first principles…

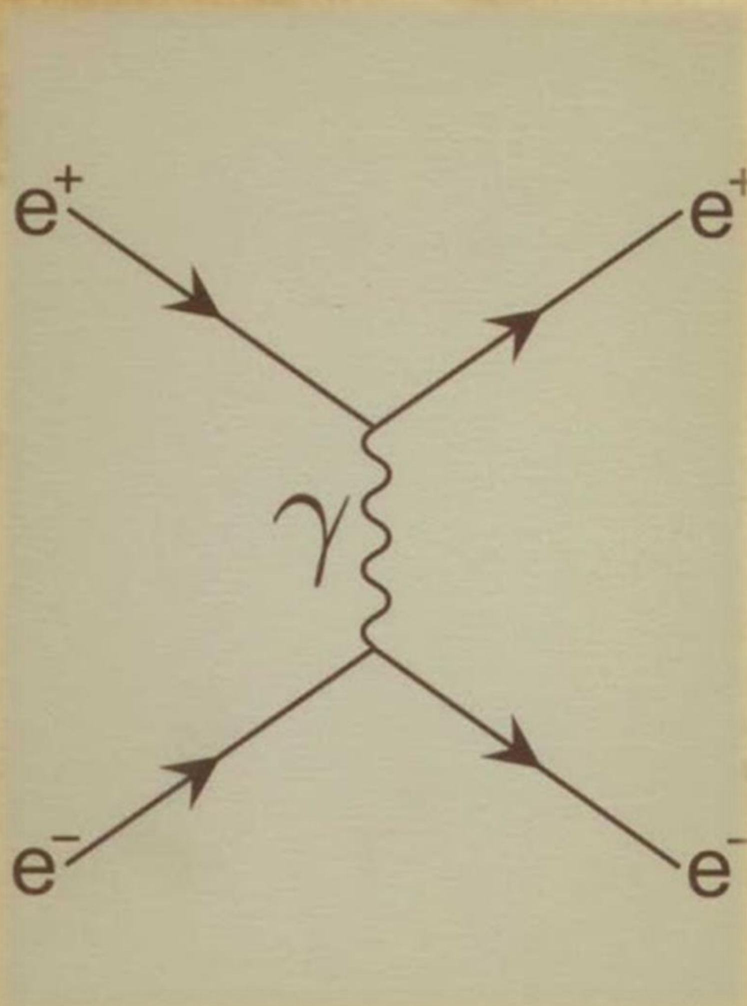
Bhabha Scattering

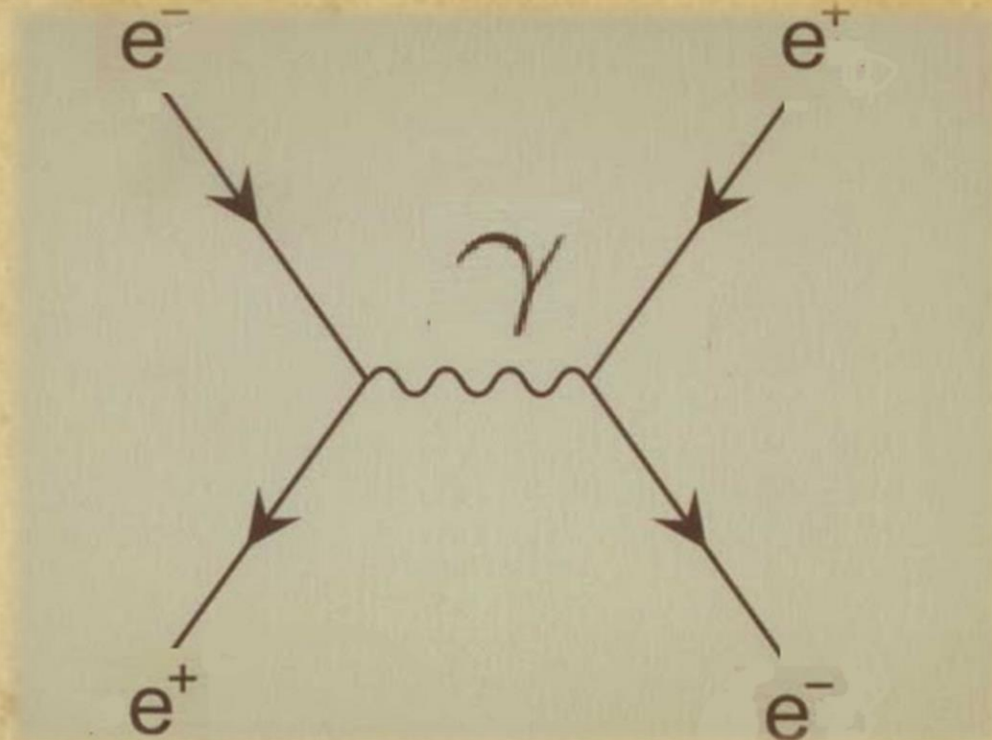
Dirac's 1928 paper on the relativistic theory of the electron included negative energy states. To prevent a positive-energy electron from emitting energy catastrophically and getting into successively lower negative energies, Dirac postulated a sea of filled-in negative energy states. The Pauli Exclusion Principle would then keep the electron in positive energy states, by preventing it from occupying any of the negative energy states.

However, identical electrons could keep getting exchanged between positive and negative energies, leading to the totally bizarre concept of *zitterbewegung.* To prevent this required one to forbid this type of exchange, and led directly to the 'hole' theory .

In 1932, Anderson discovered the positron, the first so-called 'antiparticle'. In 1933 Pauli and Weisskopf invented quantum field theory as a theory of particles and antiparticles. The question now arose: is the positron really the antiparticle of the electron corresponding to a 'hole', or is it just a different particle which happens to have the same mass and opposite charge?

Bhabha (1935) set himself to calculate the cross-section for electron-positron scattering under the two assumptions – the theoretical predictions could be compared with data to see which was true.





Annihilation diagram

The annihilation diagram would be absent if the positron was a different particle...

Scattering diagram

$$\frac{d\sigma}{d\Omega} = \frac{e^4}{32\pi^2 E_{\rm cm}^2}\left[\frac{1+\cos^4\frac{\theta}{2}}{\sin^4\frac{\theta}{2}}\right]$$

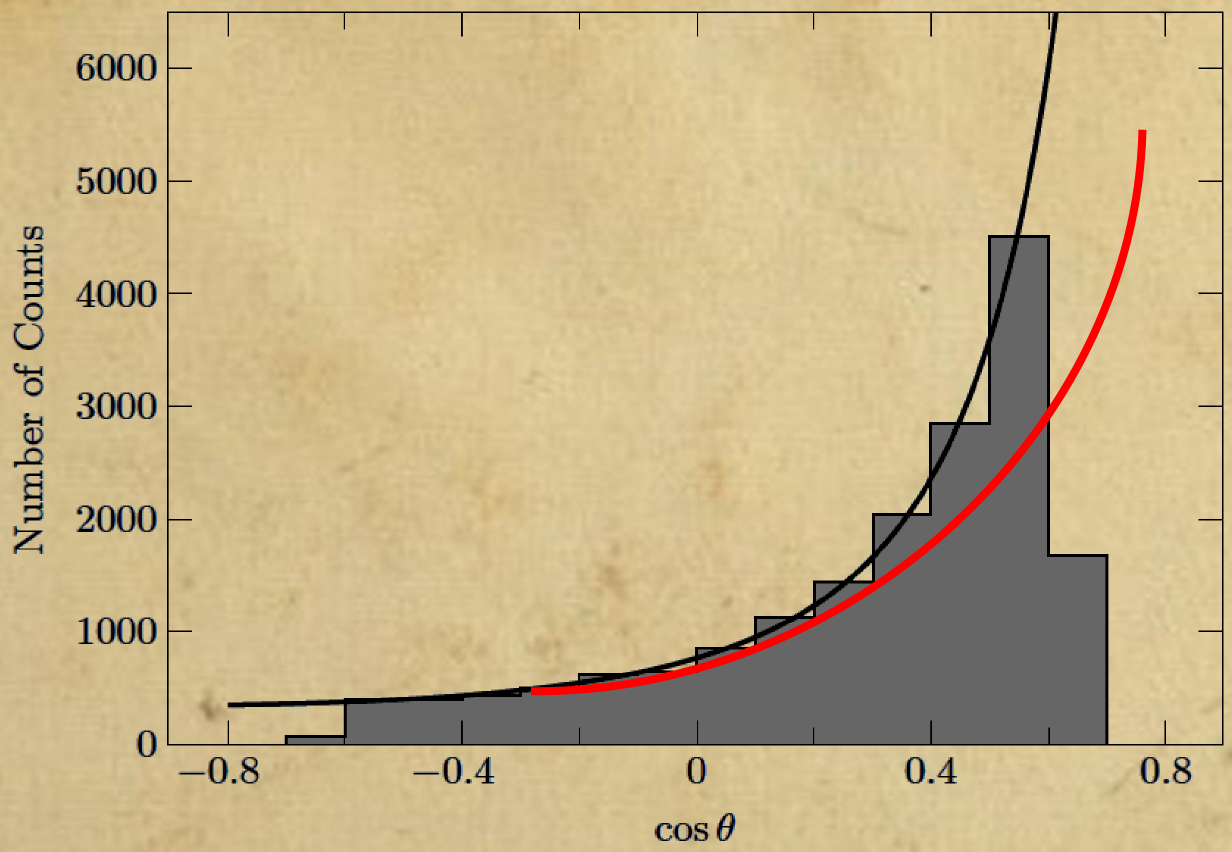


Figure 3.2. Measurements of the electron-positron scattering event rate at $E_{\rm cm} =$ 4.8 GeV, taken at Stanford's SPEAR collider in the early 1970s. The horizontal axis is $\cos\theta$, so θ increases from right to left. The data are grouped into bins, each

Bhabha's work <u>proved</u> that the positron is an antiparticle and that QFT is right

The Bhabha-Heitler Theory

Walter Heinrich Heitler (1904 - 1981) was already famous when Bhabha met him in 1935. Working at Zurich in 1930 with Fritz London, Heitler had developed the quantum theory of the chemical bond. He had a faculty position at Göttingen in 1933, when he was dismissed by the Nazis as a Jew. He sought asylum in England and got a position at the Wills Laboratory at Bristol.

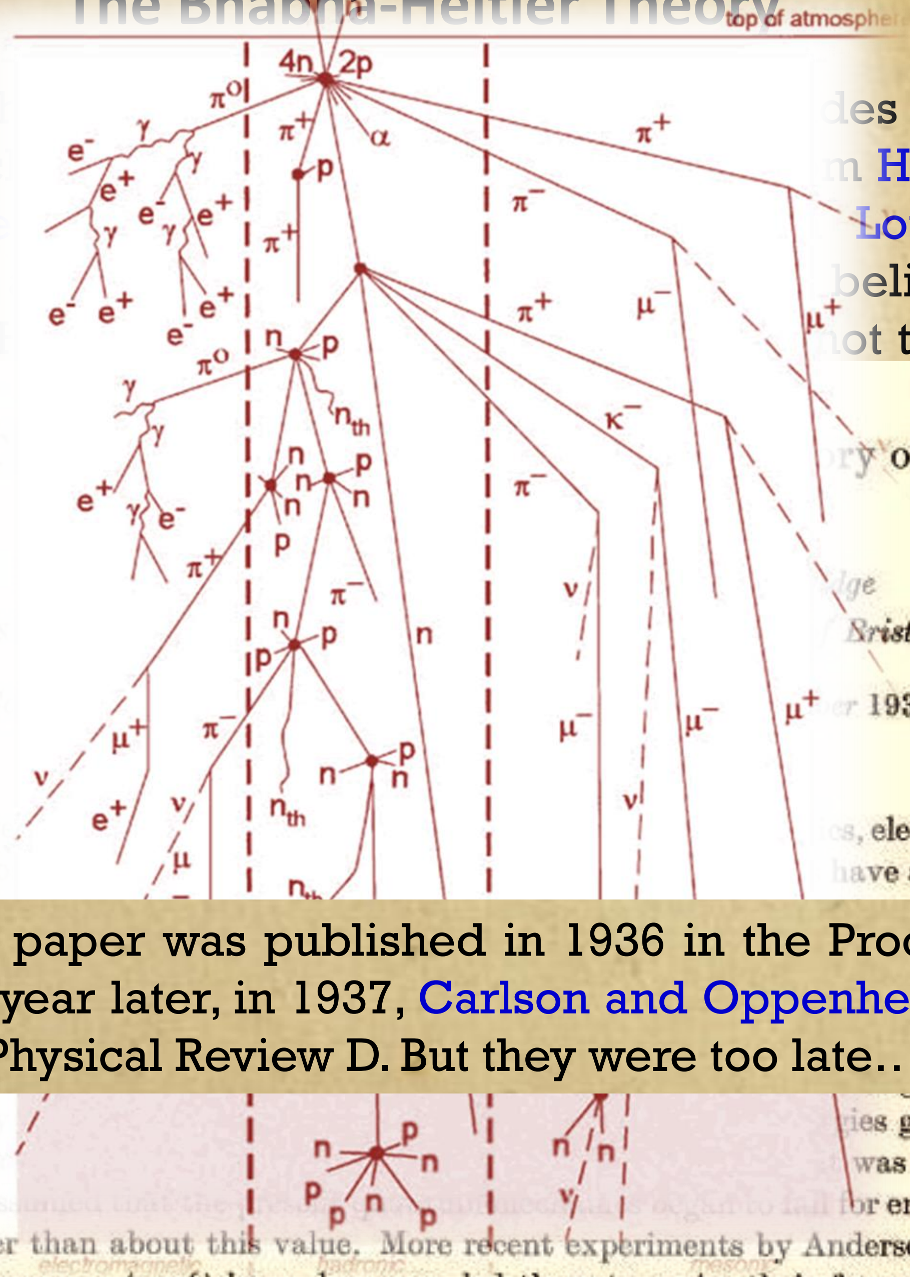
Bhabha and Heitler were both interested in the same problem: how do high energy electrons in cosmic rays penetrate 8 – 10 km of atmosphere and reach sea level?

Hans Bethe and Heitler had already calculated the energy loss by a high energy electron in the field of multiple nuclei of Nitrogen and Oxygen. They concluded that there was no way such electrons could penetrate more than 2 km.

But electrons are regularly produced in cosmic ray electrons at the top of the atmosphere (8 - 10 km above sea level) and also observed on the ground.

The Bhabha-Heitler Theory

The idea t... des like an avalanc... n Hugh Carmicha... Lothar Nordheim ... believe the Bethe-... ot trust QED.



The Bhabha-Heitler paper was published in 1936 in the Proceedings of the Royal Society. One year later, in 1937, Carlson and Oppenheimer published the same results in Physical Review D. But they were too late…

The Midas years…

In 1936, Bhabha suggested that the 'hard component' of the cosmic rays might be due to a new particle, similar to the electron, but about 100 times more massive. In 1937, Anderson and Neddermeyer discovered the μ which is like the electron, but is 200 times more massive and decays into electrons just as Bhabha predicted.

In 1935, Yukawa predicted the pion ('mesotron') as a spin-0 particle mediating interactions between spin-½ nucleons.

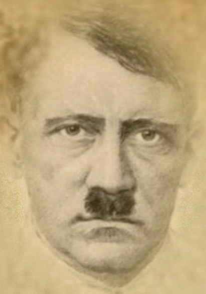
In 1937, Bhabha pointed out that ½ + ½ = 0 + 1 and predicted the existence of vector messengers of the strong interaction. The corresponding ρ mesons were discovered only in 1961.

In 1938, Bhabha proved that the long lifetime of cosmic ray muons might be due to time dilation. This provided a firm basis for Einstein's theory of relativity in the days when it was being attacked as 'Jewish metaphysics'…

Today, every M.Sc. Student does this as an exercise…


John
Wheeler
Hideki
Yukawa

Banishment from Eden



In summer 1939, Homi Bhabha came home from Cambridge to spend a well-earned vacation with his family. Before he could return, World War II broke out and civilian passengers were banned from ships because of the U-boat menace. It would be six years before he could visit Cambridge again.

Forced to seek a job in India, Bhabha dithered for a while between Allahabad U., IACS, Calcutta and IISc, Bangalore – eventually succumbing to Raman's blandishments and joining the latter. Raman then allotted him a couple of rooms to start a cosmic ray group in IISc.

For the first time in his life, Homi Bhabha faced the reality of doing science in a colonised country..

For six years, he laboured manfully in Bangalore, trying to set up an experimental cosmic ray unit, while at the same time pursuing some of his theoretical ideas.

None of this theoretical work has the impact of his Cambridge work.

General classical theory of spinning particles in a Maxwell field

By H. J. Bhabha, Ph.D. and H. C. Corben, Ph.D.

(*Communicated by P. A. M. Dirac, F.R.S.—Received* 17 *December* 1940)

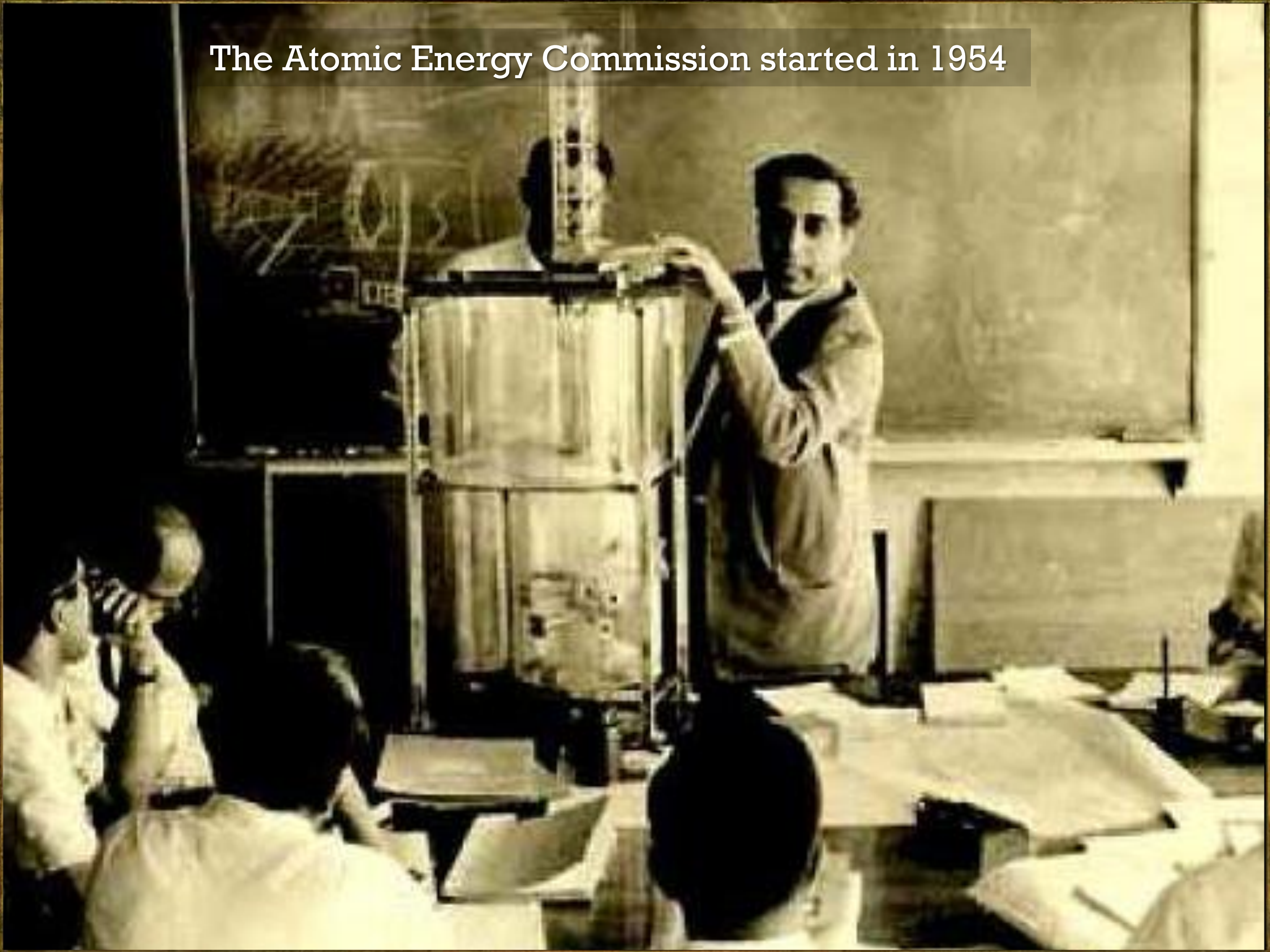
The purpose of this paper is to give the complete classical theory of a spinning particle moving in a Maxwell field. The particle is assumed to be a point, and its interaction with the field is described by a point charge g_1 and a point dipole g_2. The Maxwell equations are assumed to hold right up to the point representing the particle. Exact equations are then derived for the motion of the particle in a given external field which are strictly consistent with the conservation of energy, momentum and angular momentum, and hence contain the effects of radiation reaction on the motion of the particle. It is shown that in the presence of a point dipole the energy tensor of the field can and must be redefined so as to make the total energy finite. The mass, the angular momentum of the spin, and the moment of inertia perpendicular to the spin axis appear in the equations as arbitrary mechanical constants. Reasons are given for believing that for an elementary particle the last constant is zero, in agreement with relativistic quantum theory.

In the general theory there is no relation between the electric and magnetic dipole moments of the particle and the state of its translational motion. A procedure is given for deriving from the general equations specialized equations consistent with the condition that the dipole is always a purely magnetic or electric one in the system in which the particle is instantaneously at rest. The radiation reaction terms are very much simpler in the former of these specialized cases than in the general case. The effect of radiation reaction is to make the scattering of light by a rotating dipole *decrease* inversely as the square of the frequency for high frequencies, just as for scattering by a point charge.

The quantum treatment of a point charge and its interaction with quantized fields gives rise to a number of difficulties, for example, those connected with self-energies, which become very much greater when the particle has an *explicit* spin interaction with the field, as in the case of protons or neutrons and their interaction with the meson field. These difficulties are due at least in part to a neglect of the effects of radiation reaction. For a point charge the effects of the radiation reaction can be estimated by a comparison with the classical theory of Lorentz, and it is generally assumed that the quantum theory will give correct results in those energy regions and for those processes where the effects of this radiation reaction are negligible. For a point dipole the position is less satisfactory; for in the absence of a classical theory giving the effects of radiation reaction on the motion of the

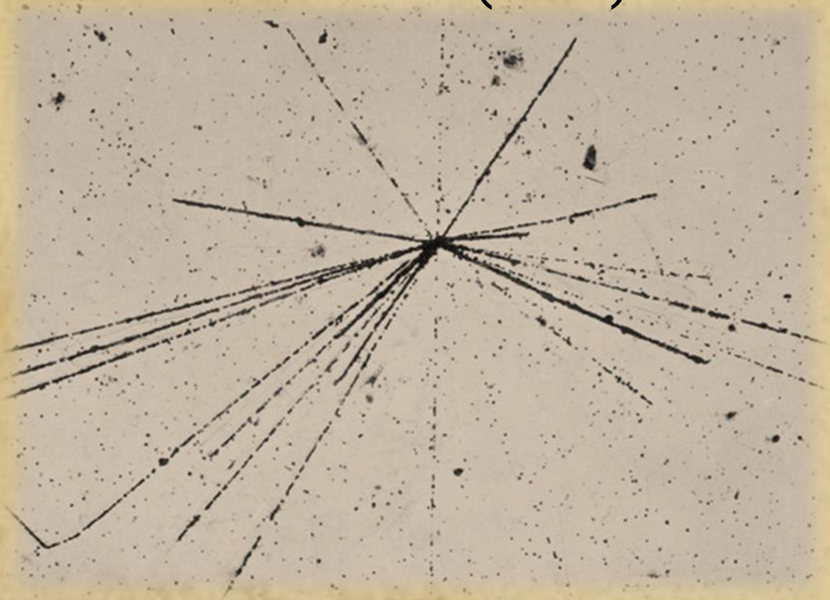
Institution Builder

The Tata Institute of Fundamental Research was founded in 1945


The Atomic Energy Commission started in 1954

The Sandakphu Experiments

Charged particles leave tracks in photographic emulsion (AgBr, AgI)
S. Kinoshita (1910)



The use of photographic plates as cosmic ray detectors was pioneered by

Marietta Blau (1894 - 1970)

and

Hertha Wambacher (1903 - 1950)

at the Radium Institute, Vienna.

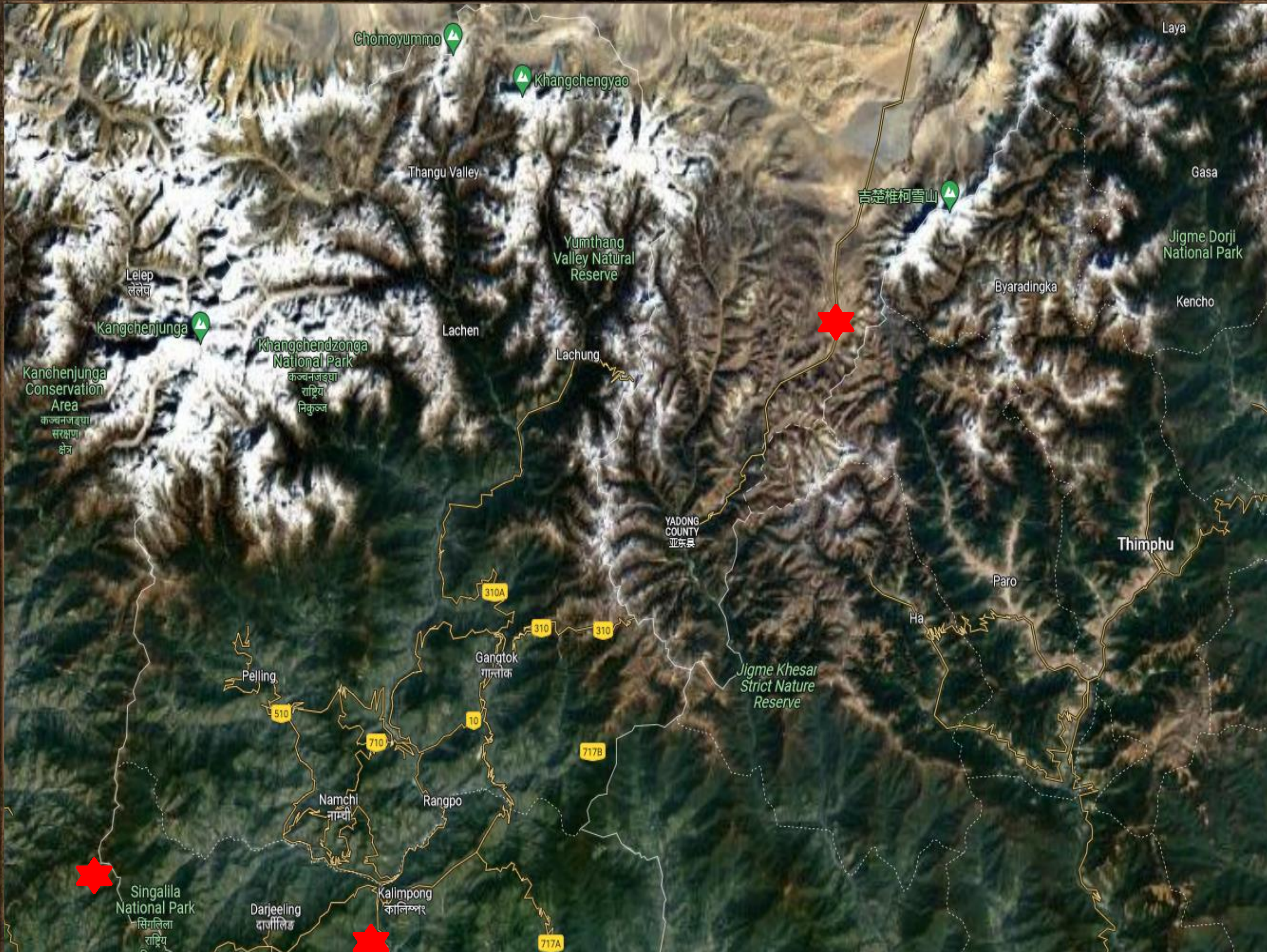
Though this work was of Nobel-worthy quality, both women were victims of severe gender and political discrimination all their lives.

The 25th session of the Indian Science Congress was held at Kolkata in 1938 and attended by various luminaries from around the world. In the cosmic ray session there was a lively discussion on cosmic ray detection techniques, led by

Walter Bothe and Goeffrey Taylor. Bothe, in particular, discussed the new photographic emulsion techniques of Blau and Wambacher, with which he was familiar.

These discussions fell on fertile ground. D.M. Bose, then 53 years old and just become Director of Bose Institute, decided to try out this new technique with help from student Biva Chowdhry.

Lacking a balloon facility, they trekked to Tiger Hill (8,500 ft), Sandakphu (11,9500 ft) and Phari Jong (15,000 ft) to expose photographic plates to cosmic rays.



Chomoyummo
Khangchengyao
Laya
Thangu Valley
Gasa
吉楚椎柯雪山
Jigme Dorji National Park
Yumthang Valley Natural Reserve
Lelep
Byaradingka
Kencho
Kangchenjunga
Lachen
Khangchendzonga National Park
Lachung
Kanchenjunga Conservation Area
YADONG COUNTY
亚东县
Thimphu
310A
Paro
310
310
Ha
Gangtok
Pelling
Jigme Khesar Strict Nature Reserve
510
10
710
717B
Namchi
Rangpo
Singalila National Park
Kalimpong
Darjeeling
717A

associated with energy loss in the target. We may expect these advantages in experiments of a similar character with high-energy deuterons, where the scattered primary particles may be accompanied by disintegration products.

In general, we may conclude that, using the photographic method of detection, it becomes possible to take advantage of the high-energy particles provided by the cyclotron to make experiments of the kind which have hitherto only been undertaken with direct current generators at relatively low energies.

C. F. POWELL.

Wills Physical Laboratory,
University of Bristol.

A. N. MAY.

King's College, London.

J. CHADWICK.
T. G. PICKAVANCE.

George Holt Physics Laboratory,
University of Liverpool.

Photographic Plates as Detectors of Mesotron Showers

DURING the last two years we have been using photographic plates (Ilford R_2 and New Halftone) for the study of cosmic rays at different altitudes. Both treated and untreated plates have been used for the purpose. In the present communication is reported the results obtained by keeping for five months untreated New Halftone plates in cardboard containers, vertically on their long sides, at Darjeeling (Mayapuri Research Station, elevation 2,130 m.) and at Sandakphu (Dak Bungalow, elevation 3,660 m.).

In the plate kept at Sandakphu, on an area of 0·5 cm.^{2} were observed 40 long single tracks, 15 double, 8 three-star, 12 four-star, 3 five-star, and one each of six- and seven-star tracks. Blau and Wambacher[1], whose technique we have followed, kept similar untreated plates at Hafelekar (2,300 m.) for five months. They obtained a large number of long single tracks and also a number of stars, but apparently no double tracks. On the assumption that the tracks are due to protons, they have calculated their kinetic energies. For this purpose they have used a calibration curve expressing the kinetic energies of the ionizing particles as a function of the mean grain distance along their tracks. The maximum energy for a star was found to be 103×10^6 ev., with a mean energy of 16×10^6 ev. per track.

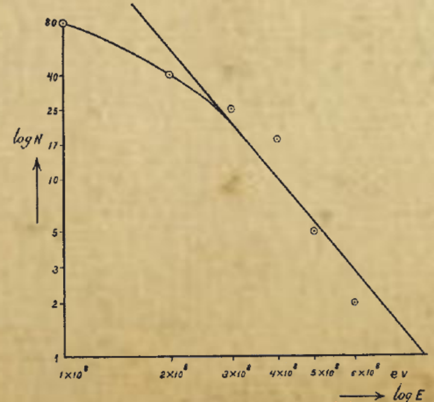
In the absence of such a calibration curve, we have calculated the energies of the particles in our plate from their measured track lengths on the emulsion. We also made the tentative assumption that the tracks are due to protons, and their kinetic energies were found to be of the order of 10^6 ev. This represents a minimum estimate of their kinetic energies. In view of the recent discussions on the nature of the small-angle penetrating showers, attributed to mesotrons by Bothe and Schmeiser[2], our attention was first directed to the pair tracks found in the plate kept at Sandakphu. Of the fifteen pair tracks, thirteen had angles between 6° and 21°, and one had an angle of 24° and the other 35°. Their kinetic energies varied from 2 to 4 Mev. It appeared plausible to make the assumption that these tracks were due to mesotron pairs, and to apply to them the formula given by Wentzel[3], limiting the angular spread θ of such showers, where $\theta \lesssim \frac{\bar{\lambda}}{a} \lesssim \frac{\hbar c}{\varepsilon a}$, in our case $\varepsilon = z(x + \bar{\varepsilon})$ where x is mass energy of a mesotron $\sim 10^8$ ev., $\bar{\varepsilon}$ is average kinetic energy of mesotrons in these pairs, $\sim 2{\cdot}9 \times 10^6$ ev.; and $\bar{\theta}$ is mean angle of scattering, $\sim 8°$.

In view of the relative order of magnitudes of x and $\bar{\varepsilon}$, not much error is introduced in calculating $\bar{\varepsilon}$ on the assumption that the tracks are due to protons and not mesotrons. For low velocities, the densities of ionization along the tracks of protons and mesotrons, for equal range in air, are of the order of 1·3 to 1.

We have calculated the value of a, the linear dimension of the scattering centres inside a nucleus on which mesotron packets, created by the impact of high-energy cosmic-ray particles on nuclear protons or neutrons, are scattered. The value of a is found to be $6{\cdot}7 \times 10^{-13}$ cm., which is comparable with the electron radius $2{\cdot}8 \times 10^{-13}$ cm.; it is of the right order of magnitude.

Next we proceed to the consideration of the origin of the star-like tracks. All of them contain tracks of the same nature, but in a few can be seen in addition one or two tracks due to heavier charged particles. For calculation we have assumed them all to be due to mesotrons. It is not clear whether the reasoning used by Wentzel can be applied to a multiple track shower. We have therefore made use of the hypothesis of multiple particle emission introduced by Heisenberg[4], according to which during the impact of a high-energy cosmic-ray particle with a nuclear proton or neutron, a part of the virtual mesotron field of the latter is radiated away as a mesotron wave packet. The latter is confined initially to a very small volume, but due to interference between parts of the wave packet, a number of secondary mesotrons are produced. If ε is the energy made available during the impact, then on an average $\bar{n}$ mesotrons will be produced where $\bar{n} = \varepsilon/n \log \varepsilon/x$, and the mean energy of a mesotron is $x \log \varepsilon/x$, which is nearly a constant. To a first approximation our results appear to be in agreement with the above. Each star on our plate represents an energy transformation, $\varepsilon = n(x + \varepsilon^*)$, where $n = 1, 2, \ldots 7$, and $\varepsilon^* \sim 10^6$ ev.

In the accompanying graph, we have plotted the curve $N = A\varepsilon^{\gamma}$, where N represents the number of



stars with energies greater than ε. The value of γ, the tangent to the straight portion of the curve, comes out to be 2·5, which is of the accepted order, as others have found it to vary from 1·8 to 2·5.

It therefore appears probable that the tracks found in the Ilford Halftone plates are mostly due to secondary mesotrons. We have computed the total energies of these mesotron tracks per unit area of the plates kept at Sandakphu and at Darjeeling; their ratio is found to be 2·3, which is near the value of 2·0 obtained for the ratio of the ionization at these two altitudes from the curve given in Swann and Danforth's paper[5].

The soft component of the cosmic radiation may be considered to be responsible for their origin. The pair tracks give no indication of being due to any fast primary ionizing particles, and are probably of photonic origin. Their kinetic energies are of the order of $10^6 - 10^7$ ev., and they are of the same nature as the slow mesotrons postulated as accompanying fast mesotrons by Maier Leibnitz[6]. That a portion of these slow mesotrons can be of photonic origin is admitted by the latter. Further evidence about the existence of these slow mesotrons will be found in Bothe's paper. A detailed account will be published in the *Transactions of the Bose Institute.*

D. M. BOSE.
BIVA CHOWDHRY.

Bose Research Institute,
Calcutta.

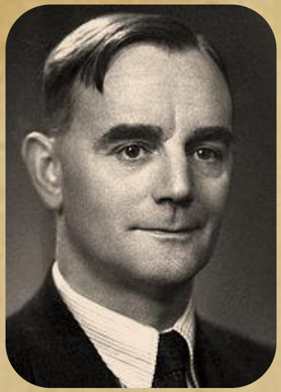
April 6.

[1] Blau and Wambacher, *Wien Akad.*, Abt. II A, **146**, 469, 623 (1937).
[2] Bothe, *Rev. Mod. Phys.*, **11**, 282 (1939).
[3] Wentzel, *Phys. Rev.*, **54**, 869 (1938).
[4] Heisenberg, *Z. Phys.*, **113**, 61 (1939).
[5] Swann and Danforth, *J. Franklin Inst.*, 48 (1939).
[6] Maier Leibnitz, *Z. Phys.*, **112**, 569 (1939).

Some Physico-Chemical Properties of 3 : 4,Benzpyrene

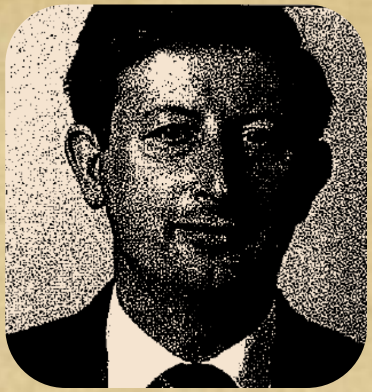
IN contrast with the characteristic fluorescence spectrum (Curve 1) which 3 : 4,benzpyrene always emits when it is dissolved in solvents, we have observed three different types of fluorescent spectra (Curves 2, 3, 4) when the hydrocarbon was excited in the solid state. The needles of a commercial benzpyrene (La Roche) emit a green fluorescent light and we call it therefore the 'green' form. Curve 2 exhibits a broad rather symmetrical band with its flat maximum between 500 and 510 mμ. On pouring an acetone solution of the green form of benzpyrene into cold water there results the well-known colloidal suspension of benzpyrene which emits a yellowish fluorescence. The spectrogram of this 'yellow' form has its maximum between 530 mμ and 540 mμ, and a typical inflection at the short wave-length side of the band (Curve 3). On heating the green form in an evacuated tube, a white sublimate is formed on the tube walls which fluoresces brightly blue. The spectrogram of this 'blue' form shows a maximum between 445 mμ and 450 mμ, and an inflection on the short-wave-length side which appears as a contrast band at about 425 mμ (Curve 4). The sublimed crystals are small plates with typically curved edges. We believe that they are identical with the modification of benzpyrene which Iball[1] obtained from a solution in amyl acetate. According to his X-ray analysis, they are orthorhombic, while the needles (our green form) belong to the monoclinic system. Iball did not examine the fluorescence of either form.

The Discovery of the Pion



Cecil Francis Powell
(1903 – 1969)

Giuseppe Occhialini
(1907 – 1993)

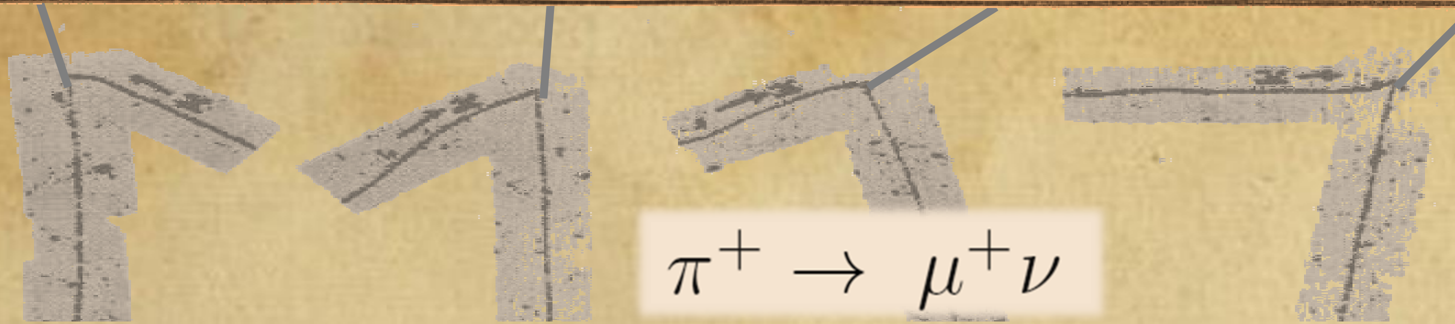


Hugh Muirhead
(1911 – 1983)

César Lattes
(1924 – 2005)

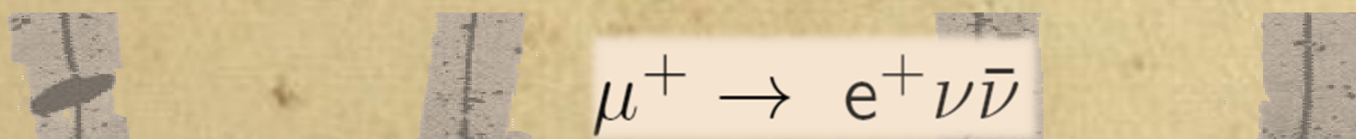
After the War, the British Government, spurred by Blackett, asked the plate manufacturers to produce improved ‘high density’ plates for the Cold War effort. Thanks to his war work, Powell had easy access to these. Lattes suggested adding more boron to the emulsion. This worked like magic…

“It was as if, suddenly, we had broken into a walled orchard, where protected trees had flourished and all kinds of exotic fruits had ripened in great profusion.” – Powell



$$\pi^+ \rightarrow \mu^+ \nu$$

The 1947 work of Powell et al clearly showed the existence of two mesons, one of which (pion) decayed into the other (muon). The plentiful production of the pion made it clear that it was Yukawa's 'mesotron'. This had been suggested by Tanikawa (1942) and by Sakata and Inoue (1943), but their work went unnoticed because of the War. Bethe and Marshak made the same proposal in 1947, unaware that Powell *et al* had already seen it.



$$\mu^+ \rightarrow e^+ \nu \bar{\nu}$$

Cecil Powell walked away with a very well-deserved Nobel Prize in 1950.
Giuseppe Occhialini returned to Italy and won the Wolf Prize in 1979.
Cesar Lattes returned to Brazil to lead the cosmic ray research there.
Hugh Muirhead worked on parity violation and wrote a famous textbook.
Marietta Blau never got a regular paid position, dying of cancer in1970.
Hertha Wambacher, a Nazi, was imprisoned and died of cancer in 1950.

"TIS BETTER TO HAVE TRIED AND LOST THAN NEVER TO HAVE TRIED AT ALL."

[redacted]

ALFRED TENNYSON

THE RANGES OF α PARTICLES IN PHOTOGRAPHIC EMULSIONS

By H. J. TAYLOR, M.Sc., and V. D. DABHOLKAR, M.Sc.,
Department of Physics, Wilson College, Bombay

Received October 18, 1935. *Read in title January* 24, 1936

ABSTRACT. Numerous α-particle tracks on Ilford *R* plates have been measured. From measurements of the tracks of a homogeneous group of α particles of range *R*, a distribution curve may be drawn, from which a length *L*, known as the extrapolated length of the tracks, can be determined. The ratio L/R is shown to be constant to within 1 per cent for α particles of various ranges, and hence *R* can be found for a group of unknown tracks if *L* is measured. The method is applied to determine the ranges corresponding to the tracks produced by the disintegration of boron and lithium under slow-neutron bombardment. These are found to be $1 \cdot 14 \pm 0 \cdot 02$ cm. in air and $6 \cdot 64 \pm 0 \cdot 06$ cm. in air, respectively. Samarium has also been investigated, and is found to emit α particles of range $1 \cdot 13 \pm 0 \cdot 02$ cm. in air. Other particles from samarium, of longer range, have also been found.

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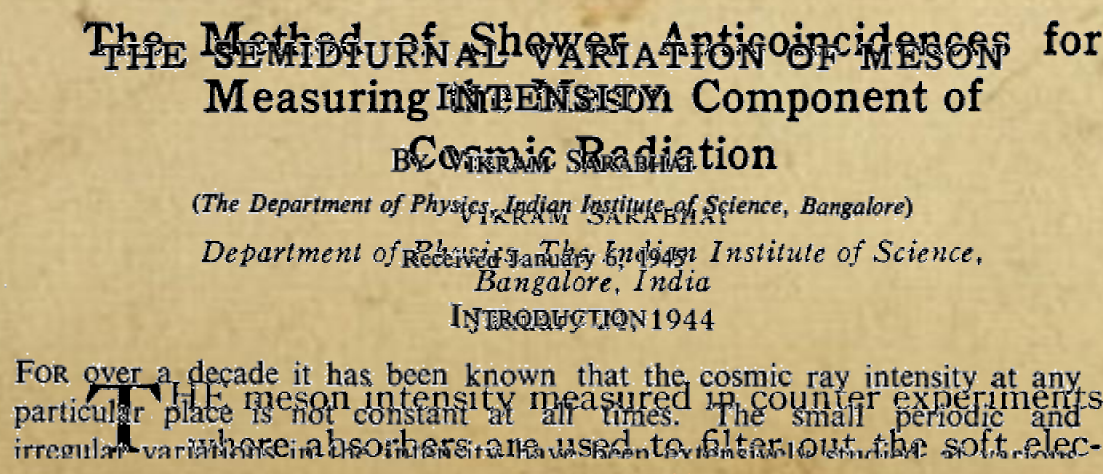
§ 1. INTRODUCTION

It has been known for many years that it is possible to record the tracks of α particles in a photographic emulsion. In earlier papers[1, 2] estimates are given

Vikram Sarabhai

Vikram Ambalal Sarabhai (1919 – 1971), another scion of a rich industrial house with a passion for science, completed his Mathematical Tripos at Cambridge in 1940. Risking his life on the sea voyage, he returned to India, and was promptly offered an Assistantship at the IISc by Raman.

The 21-year old Sarabhai was interested in cosmic rays, but he did not attach himself to Homi Bhabha, who was then in IISc and already an established figure. Scientifically, Sarabhai preferred to plough a lonely furrow and he had the courage and confidence to do so.



The Method of Shower Anticoincidences for Measuring [illegible] Component of Cosmic Radiation

By Vikram Sarabhai

(The Department of Physics, Indian Institute of Science, Bangalore)

Introduction

For over a decade it has been known that the cosmic ray intensity at any particular place is not constant at all times. The small periodic and irregular variations in the intensity have been [illegible]

THE SEMIDIURNAL VARIATION OF MESON INTENSITY

VIKRAM SARABHAI

Department of Physics, The Indian Institute of Science, Bangalore, India

1944

THE meson intensity measured in counter experiments where absorbers are used to filter out the soft elec-

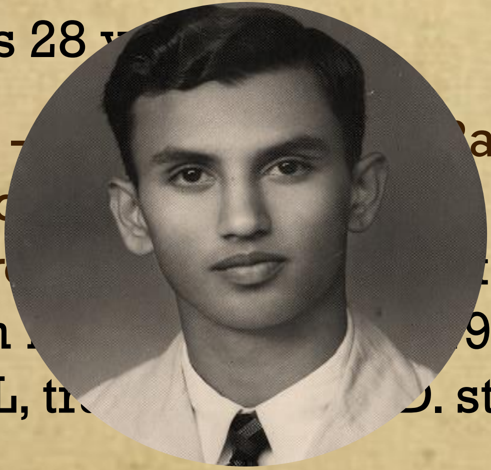
Sarabhai wrote 6 single-author papers during 1940 – 45 from the IISc, in which he mainly investigated the effects of the Earth's magnetic field on the cosmic rays.

In 1946, he went back to Cambridge and won his Ph.D. with a thesis entitled *Cosmic ray investigations in tropical latitudes*, based on his Bangalore work.

In 1947 he came back to India, and collected money from his family and rich industrialist friends to found the

Physical Research Laboratory (PRL)

at Ahmedabad. He was 28 y



K.R. Ramanathan (1893 - ... Raman student who had retired from the Ind ... Department, was roped in as the first Dir ... over as Director only when Ramanathan ... 965. Before that he remained a simple Professor in PRL, tr ... D. students, among whom was the late U.R. Rao.

Sarabhai was a simple person and worked immensely hard, dying at 52.

The Cosmic Ray Group at TIFR in the 1950s

Homi Bhabha founded the group in 1945. He was then mostly involved in setting up BARC and the DAE.

Bernard Peters (1910 – 1993) who had worked on the Manhattan Project, fled the USA to join TIFR in 1951. He remained in India till 1959.

M.G.K. Menon (b. 1928), a student of Powell, joined TIFR in 1955. He later succeded Bhabha as Director of TIFR.

Devendra Lal (1929 - 2012) student of Peters, later moved into Earth Science and Oceanography.

B.V. Sreekanthan (b. 1925) a Ph.D. student of Bhabha, became TIFR Director after Menon.

Yash Pal (b. 1926), later a Ph.D. with Rossi at MIT, later became Chairman of the UGC.

Name	Surname	Thesis title	Guide Name	Guide Surname	Bombay University Result
R.P.	Thatte	Measurements of cosmic Ray Intensity of High Altitude	H.J.	Bhabha	1950
A.S.	Apte	Investigation in the Meson Field	H.J.	Bhabha	1952
Surya	Prakash	Generalised wave equation (solution of certain types of differential equation which are generalised of usual waved equations	H.J.	Bhabha	1953
K.K.	Gupta	Determination of decay energy of electron-capturing isotopes	H.J.	Bhabha	1954
B.V.	Sreekantan	Experimental investigation on the nature & interaction of cosmic ray particles underground	H.J.	Bhabha	1955
G.S.	Gokhale	Studies in cosmic radiation High altitude intensity measurements at 3 zeroN (mag) and 19 zeroN in India.	H.J.	Bhabha	1955
D.	Sankaranarayana	Studies in cosmic Rays (Theoretical).	H.J.	Bhabha	1959
L.S.	Kothari	Thermal Neutron Scattering in solids and Liquids	K.S.	Singwi	1959
V.P.	Duggal	Neutron slowing donw attenuation in different moderators	R.	Ramanna	1959
R.K.	Gupta	Determination of Decay Energy of Electron capturing isotopes	B.V.	Thosar	1959
D.	Lal	Investigations of Nuclear Interaction produced by Cosmic Rays	B.	Peters	1960
M.C.	Joshi	Measurement of internal conversion coeffcients and Energy Levels of Some Nuclei	B.V.	Thosar	1961
	Rama	Investigations on the cosmic Ray produced Radio Isotopes Bo, p33 and S35	M.G.K.	Menon	1961
R.	Vijayaraghavan	Nuclear Magnetic Resonance Study of some solids & Liquds	S.S.	Dharmatti	1962
P.V.S.	Rao	Cathode Ray Tube display of digital computer outputs	S.S.	Dharmatti	1962

The Fabulous Fifties

Yang-Mills theory
1954

IVB hypothesis
1957

π^0	(1951)	K^0	(1951)
Δ^+	(1952)	Λ^0	(1952)
Σ^+	(1953)	Ξ^+	(1953)
p^-	(1955)	ν_e	(1955)
$\underline{n}^0$	(1956)	Σ^0	(1957)
$\underline{\Lambda}^0$	(1958)	Ξ^0	(1958)

Parity violation
1956

V-A theory
1958

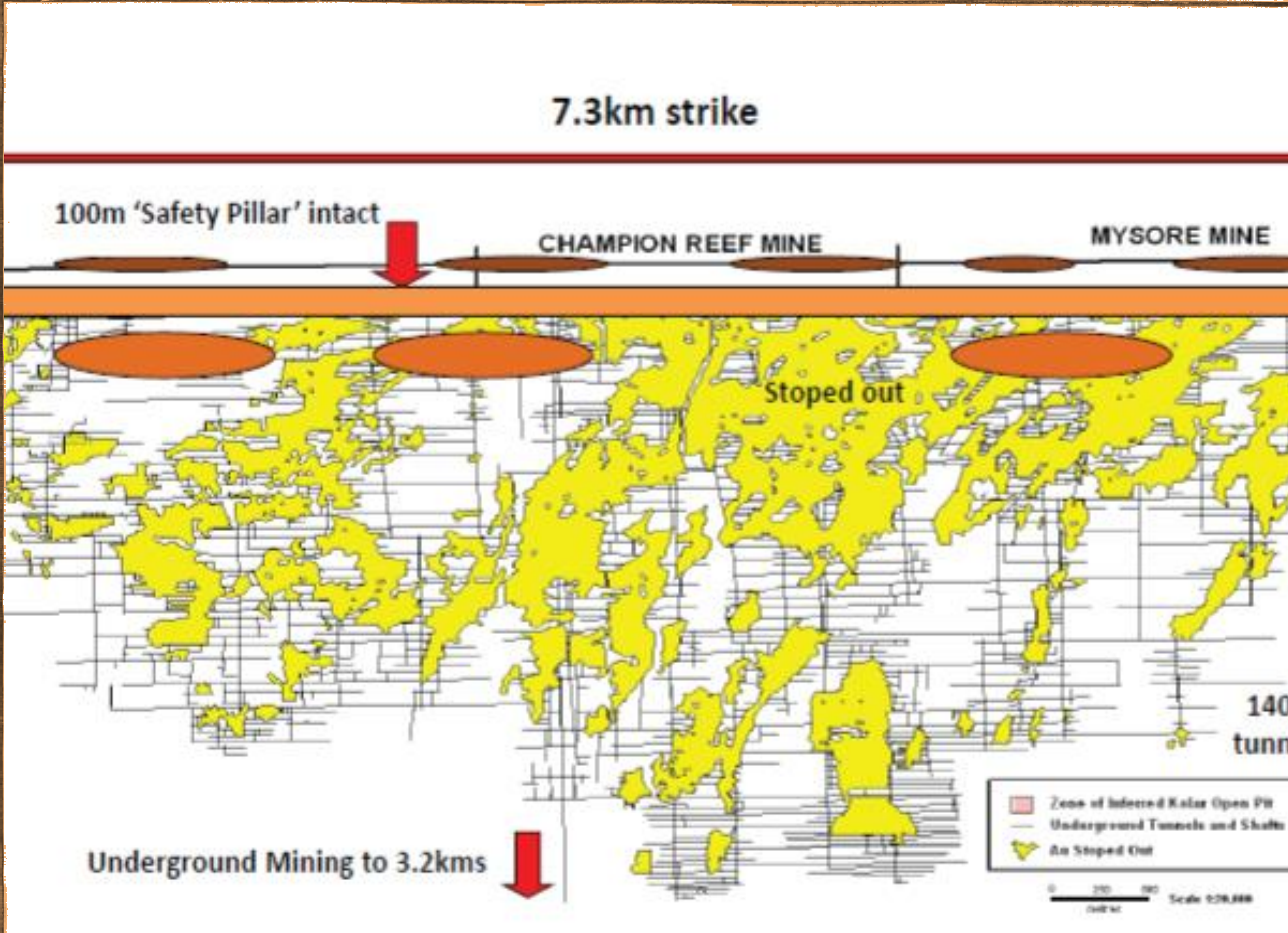
Renormalization Group
1953

The TIFR group in particular and Indian cosmic ray research in general were nowhere involved in these momentous developments.

Bernard Peters diverted much of the work to production of exotic nuclei in cosmic rays, which lost out to reactor/accelerator-based experiments.

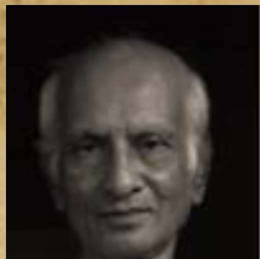
TIFR lacked another theorist of Bhabha's calibre, and he was too busy. Bose and Saha were past 60, Kothari was advising the Defence Ministry.

The Kolar Experiment



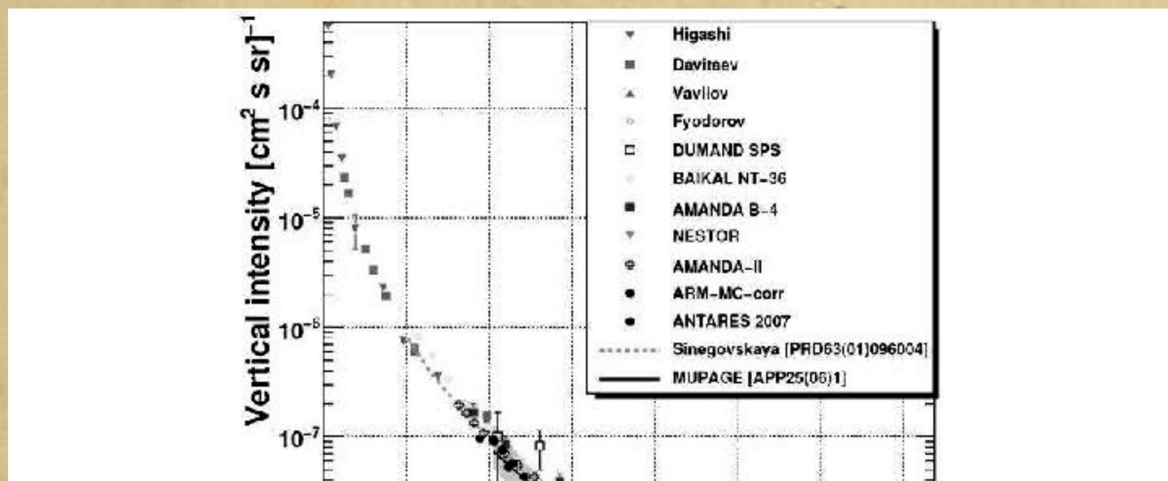
7.3km strike
100m 'Safety Pillar' intact
CHAMPION REEF MINE
MYSORE MINE
Stoped out
Underground Mining to 3.2kms

Muon measurements at Kolar

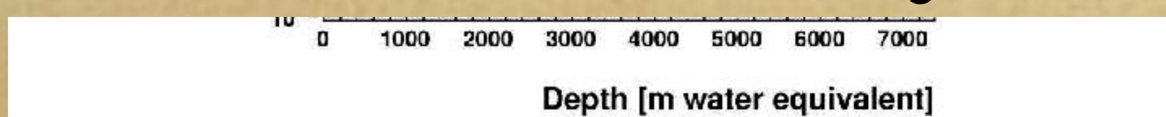


As early as 1948, Bhabha sent Sreekantan to Kolar, to go down the Champion Reefs mine and measure the cosmic muon flux at depths of 10,000 feet or more. He was assisted by

S. Naranan and P.V. Ramanamurthy.

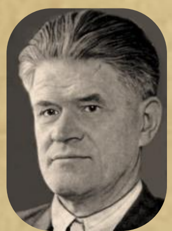


The flux initially declined as expected, but then unexpectedly began to rise. Bhabha correctly guessed that this was due to some radioactivity in the rocks. In fact, there is some Th-232 in Kolar at depths just above 2 km. This flux vanishes as we go down further.



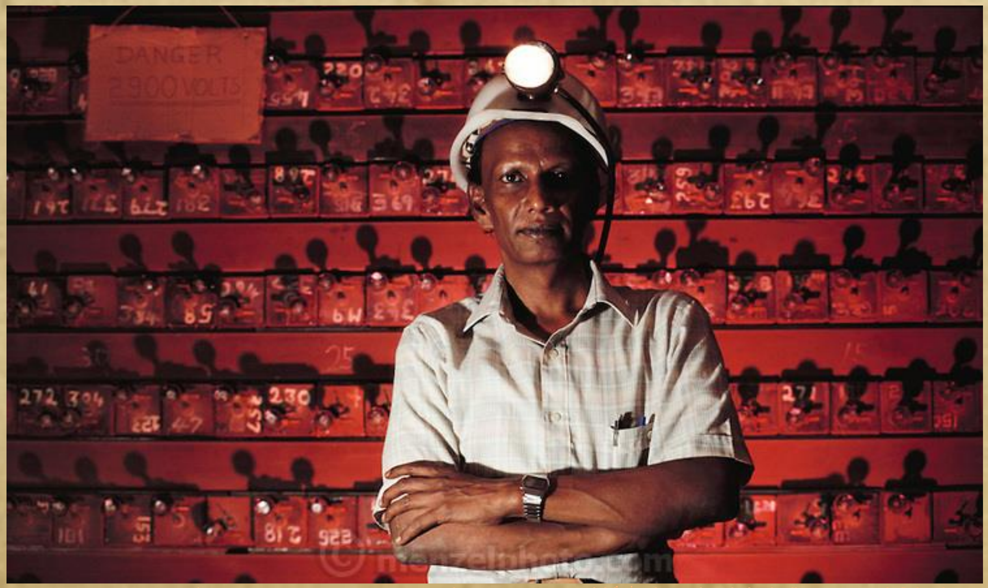
Atmospheric neutrinos

At a depth of 2.7 km, the cosmic ray muons were completely shielded out. This meant that if the surrounding rocks were inert, nothing would be detected. (This was before the discovery of the neutrino in 1955.)



In 1957, Moisey A. Markov realised that *neutrinos* could easily penetrate to such depths, and would then interact with the rocks to form muons by inverse beta decay.

The TIFR group took up this suggestion with enthusiasm, since Kolar was the ideal setting to measure this…



V.S. Narasimham

DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

C. V. ACHAR, M. G. K. MENON, V. S. NARASIMHAM, P. V. RAMANA MURTHY and B. V. SREEKANTAN,
Tata Institute of Fundamental Research, Colaba, Bombay

K. HINOTANI and S. MIYAKE,
Osaka City University, Osaka, Japan

D. R. CREED, J. L. OSBORNE, J. B. M. PATTISON and A. W. WOLFENDALE
University of Durham, Durham, U.K.

Received 12 July 1965

1965 : first observation of atmospheric neutrinos...

EVIDENCE FOR HIGH-ENERGY COSMIC-RAY NEUTRINO INTERACTIONS*

F. Reines, M. F. Crouch, T. L. Jenkins, W. R. Kropp, H. S. Gurr, and G. R. Smith

Case Institute of Technology, Cleveland, Ohio

and

J. P. F. Sellschop and B. Meyer

University of the Witwatersrand, Johannesburg, Republic of South Africa
(Received 26 July 1965)

Particle Physics in North India

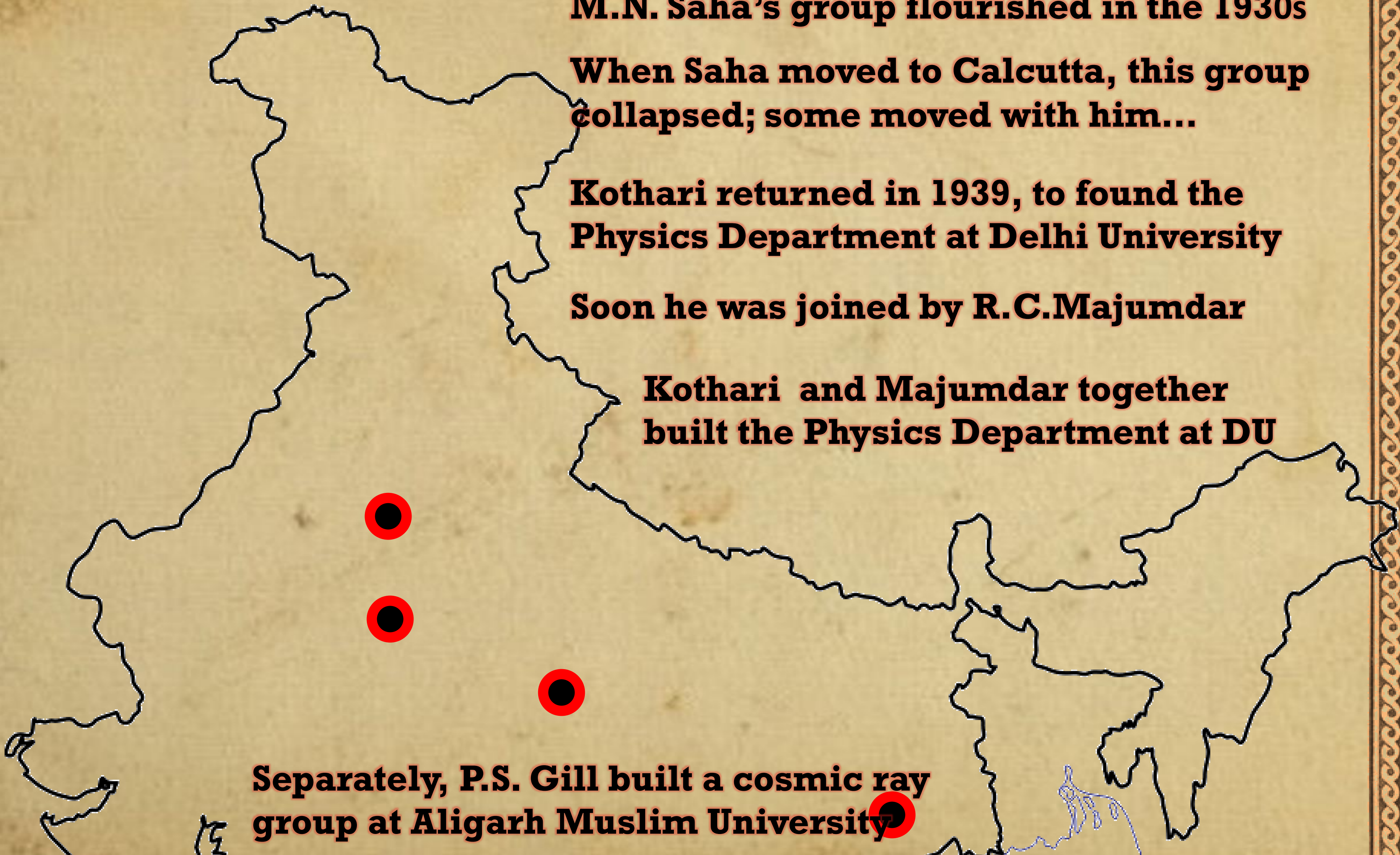
M.N. Saha's group flourished in the 1930s

When Saha moved to Calcutta, this group collapsed; some moved with him…

Kothari returned in 1939, to found the Physics Department at Delhi University

Soon he was joined by R.C.Majumdar

Kothari and Majumdar together built the Physics Department at DU



Separately, P.S. Gill built a cosmic ray group at Aligarh Muslim University

Piara Singh Gill

In 1936, Gill moved to

P.S. Gill (1911 – 2
family in Hoshiarp
km to school ever
and worked his w
Panama City. Soon

that cosmic ray pri
from the solar wind
showed that the p
zero. He won his Ph.

Gill could have found a job in the USA, but he preferred to come back to India. He became a lecturer at Forman Christian College in Lahore (1941-46) and started cosmic ray studies at high altitudes, first at Gulmarg, then on warplanes.

In 1946, Gill went on a lecture tour of USA and Europe, where he met Homi Bhabha, who brought him to TIFR in 1947.

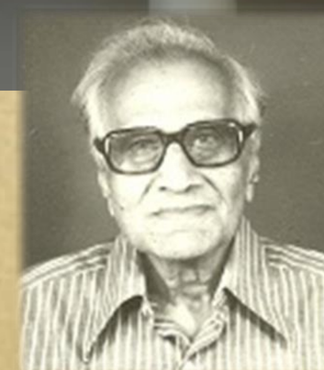
Within a year, Gill had

n in a farming
sed to walk 5
a job on a ship
a taxi driver in
s...

ray group at
the main focus
r reactions, geo-
and shower-

In 1963, Gill left Aligarh to found the Central Scientific Instruments Organisation (CSIO) at Chandigarh. Retiring in 1971, he set up a business manufacturing magnetic heads for tape recorders. Eventually he sold his business and went to live with his daughter in the USA.

Kothari & Majumdar formed a complementary pair. While Kothari did a lot of Government work, as Chairman of the UGC, etc, Majumdar ran the Physics Department.



As early as 1942, Majumdar published a paper on electron-meson interactions with a young M.Sc. student from St. Stephen's College, called Suraj N. Gupta…

3-2 QUANTIZED RADIATION FIELD

The above thermodynamical example leads us at once to the radiation field. Indeed, Planck's blackbody spectrum was historically the first instance of field quantization. We have simply to generalize the preceding construction to the degrees of freedom described by the potential $A_\mu(x)$. Since we insist upon the local character of the theory, we cannot make use of the gauge-invariant tensor $F_{\mu\nu}$ as the fundamental dynamical variable. We have to face the gauge dependence of A_μ already discussed at length in Chap. 1. Various devices have been used to circumvent this difficulty. We shall not try to quote all of them here and present the Gupta-Bleuler indefinite metric quantization.

3-2-1 Indefinite Metric

We recall that the lagrangian

$$\mathscr{L} = -\tfrac{1}{4}F^2 \tag{3-97}$$

where F is expressed in terms of A, is unsuited for canonical quantization since the conjugate momentum of A_0 vanishes. If we were not to worry about manifest Lorentz covariance we could content ourselves with $\mathbf{A}$ by constraining A^0 and using a condition of the type div $\mathbf{A} = 0$. This of course is physically reasonable, but does not fit our goals. We therefore use the procedure of modifying the equations

Another student of Delhi University, was Jogesh C. Pati, who, in 1974, wrote the first Grand Unified Theory with Abdus Salam and predicted proton decay…

PHYSICAL REVIEW D VOLUME 10, NUMBER 1 1 JULY 1974

Lepton number as the fourth "color"

Jogesh C. Pati*
Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy and Imperial College, London, England

(Received 25 February 1974)

Universal strong, weak, and electromagnetic interactions of leptons and hadrons are generated by gauging a non-Abelian renormalizable anomaly-free subgroup of the fundamental symmetry structure $SU(4)_L \times SU(4)_R \times SU(4')$, which unites three quartets of "colored" baryonic quarks and the quartet of known leptons into 16-folds of chiral fermionic multiplets, with lepton number treated as the fourth "color" quantum number. Experimental consequences of this scheme are discussed. These include (1) the emergence and effects of exotic gauge mesons carrying both baryonic as well as leptonic quantum numbers, particularly in semileptonic processes, (2) the manifestation of anomalous strong interactions among leptonic and semileptonic processes at high energies, (3) the independent possibility of baryon-lepton number violation in quark and proton decays, and (4) the occurrence of $(V+A)$ weak-current effects.

Samarendranath Biswas (1926 – 2005), did his Ph.D., with H.S. Green at Adelaide and then came to TIFR in 1959, but left for DU in 1964. He worked extensively on current algebras and S-matrix theories. Two generations of students grew up under his tutelage and he was affectionately known as '*Dada*' Biswas.

THE NUCLEAR THREE-BODY PROBLEM

A. N. Mitra

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1. INTRODUCTION AND SUMMARY

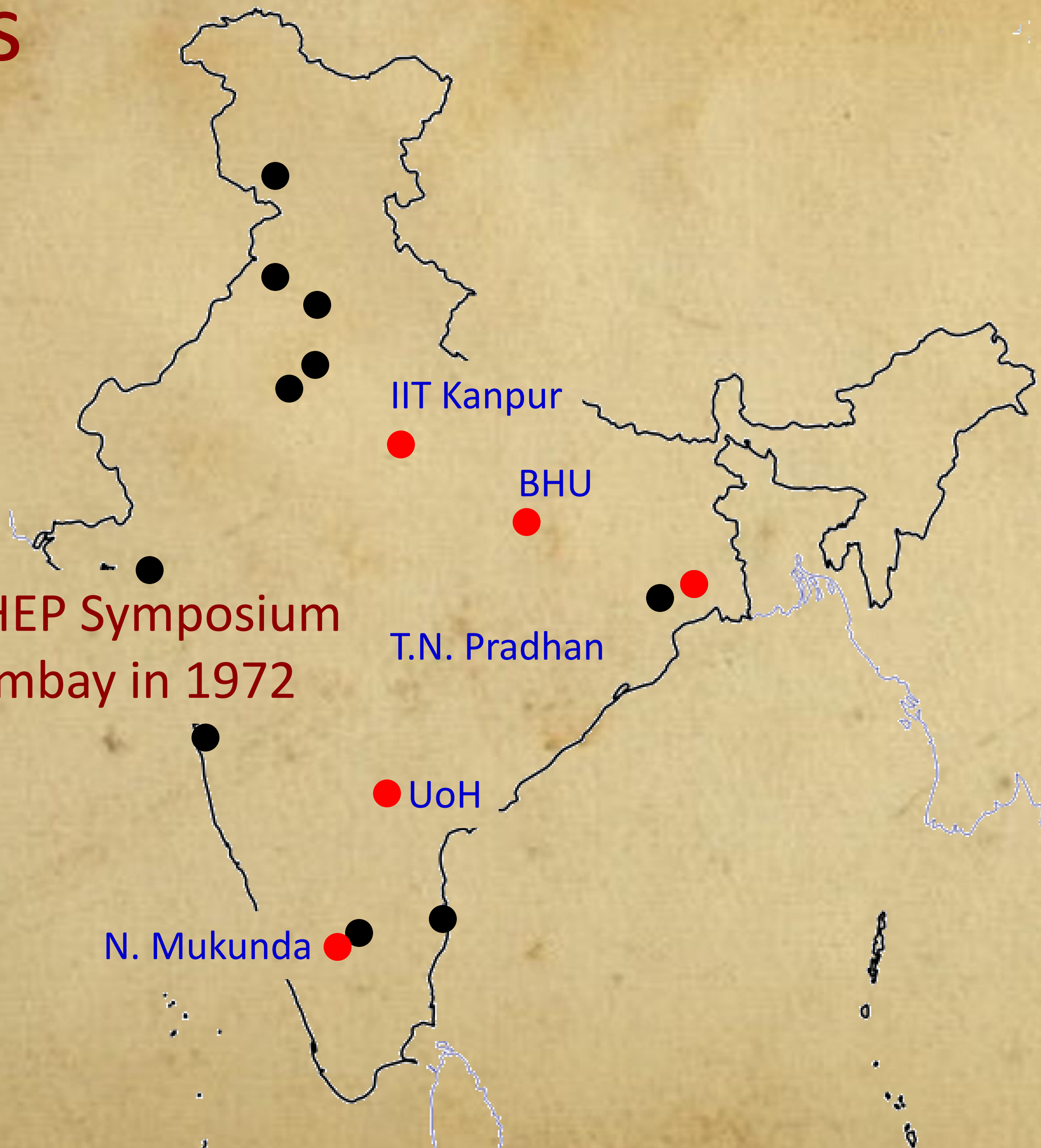
Ashoke Nath Mitra (1929 – 2022), did a Ph.D. with R.C. Majumdar and then again with Hans Bethe at Cornell. Joining DU in 1963, he has spent five decades there, training generations of students. He specialisation has always been in dispersion relations and bound states in quantum field theory.

Alladi Ramakrishnan and Matscience

Alladi Ramakrishnan (1923 – 2008), joined TIFR in 1947 and was introduced by Bhabha to the theory of cosmic ray showers. Alladi was perhaps the first to introduce stochastic methods in particle physics, and is thus the father of all the heavy Monte Carlo simulation work that is done today (without acknowledgment…)

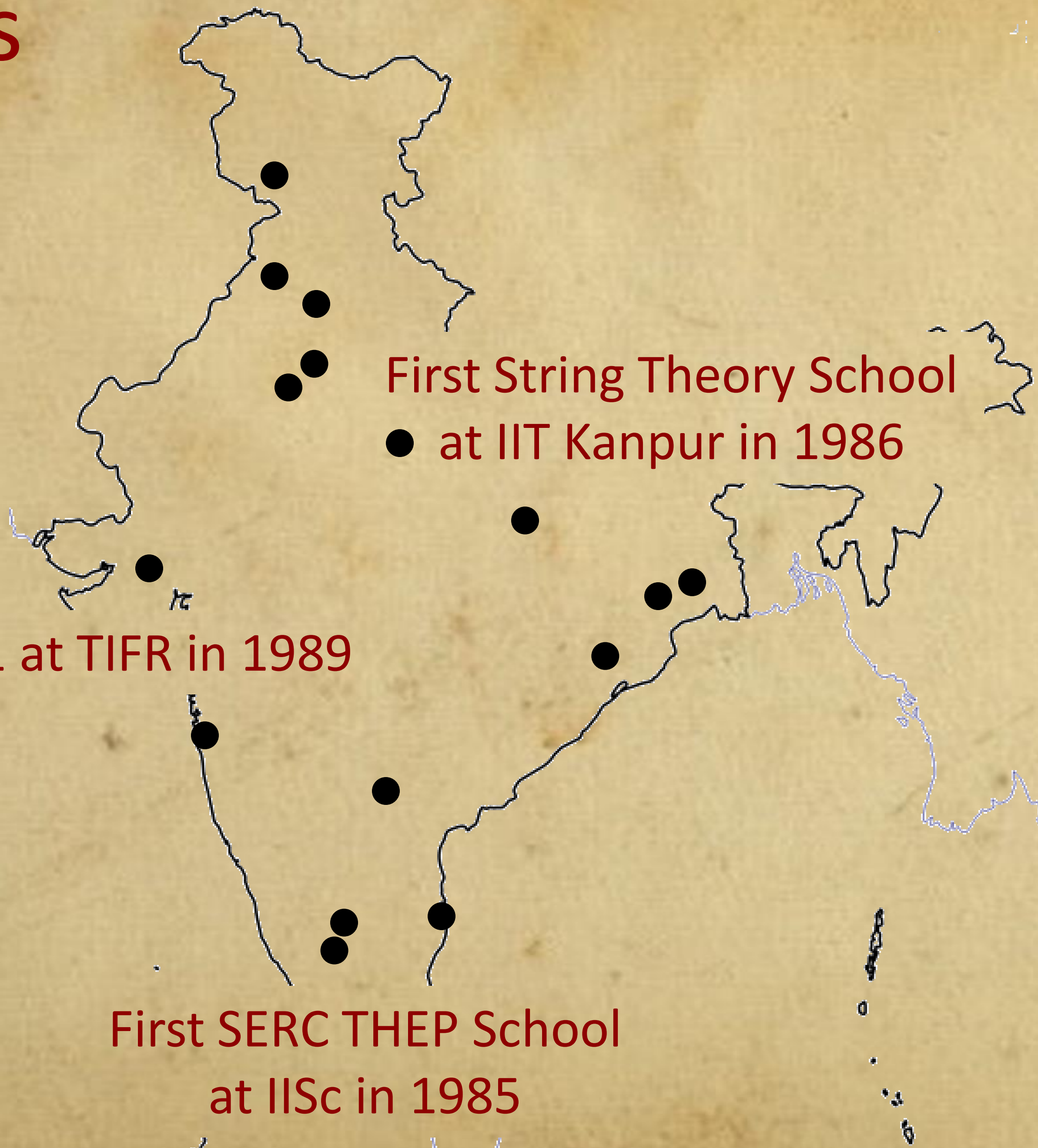
Returning to India, Alladi joined the University of Madras and soon started a 'Theoretical Physics Seminar' at his home. In 1960, this was visited by Niels Bohr. Later, Bohr went to Delhi and said that the two things which impressed him most in India were Bhabha's grand TIFR and Alladi's intense little group. This appeared in *The Hindu* etc. and impressed Prime Minister Nehru, who later met Alladi at Chennai and asked him how he could help… Matscience was started in 1962…

1970s

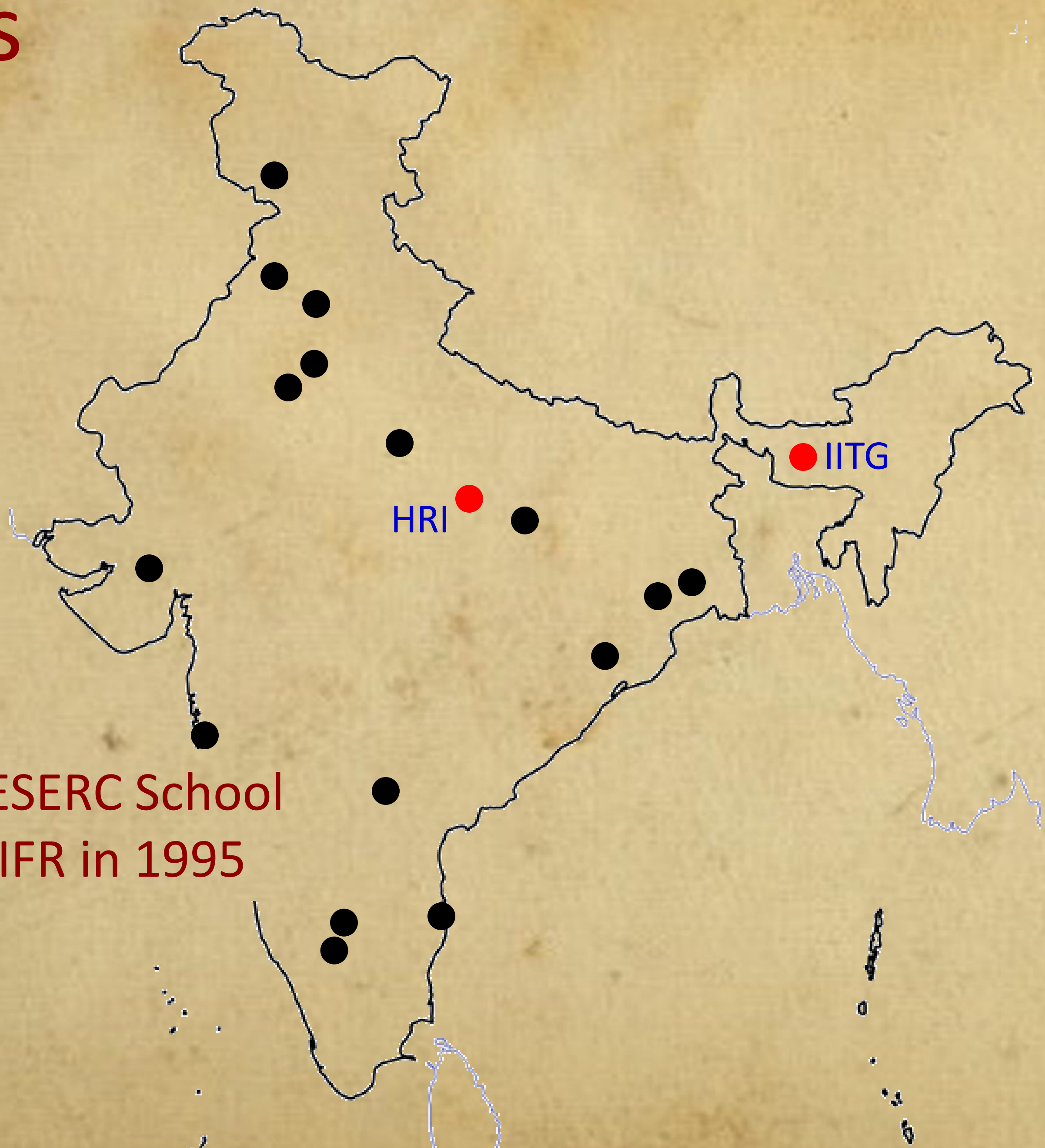


First DAE HEP Symposium at IIT Bombay in 1972

1980s

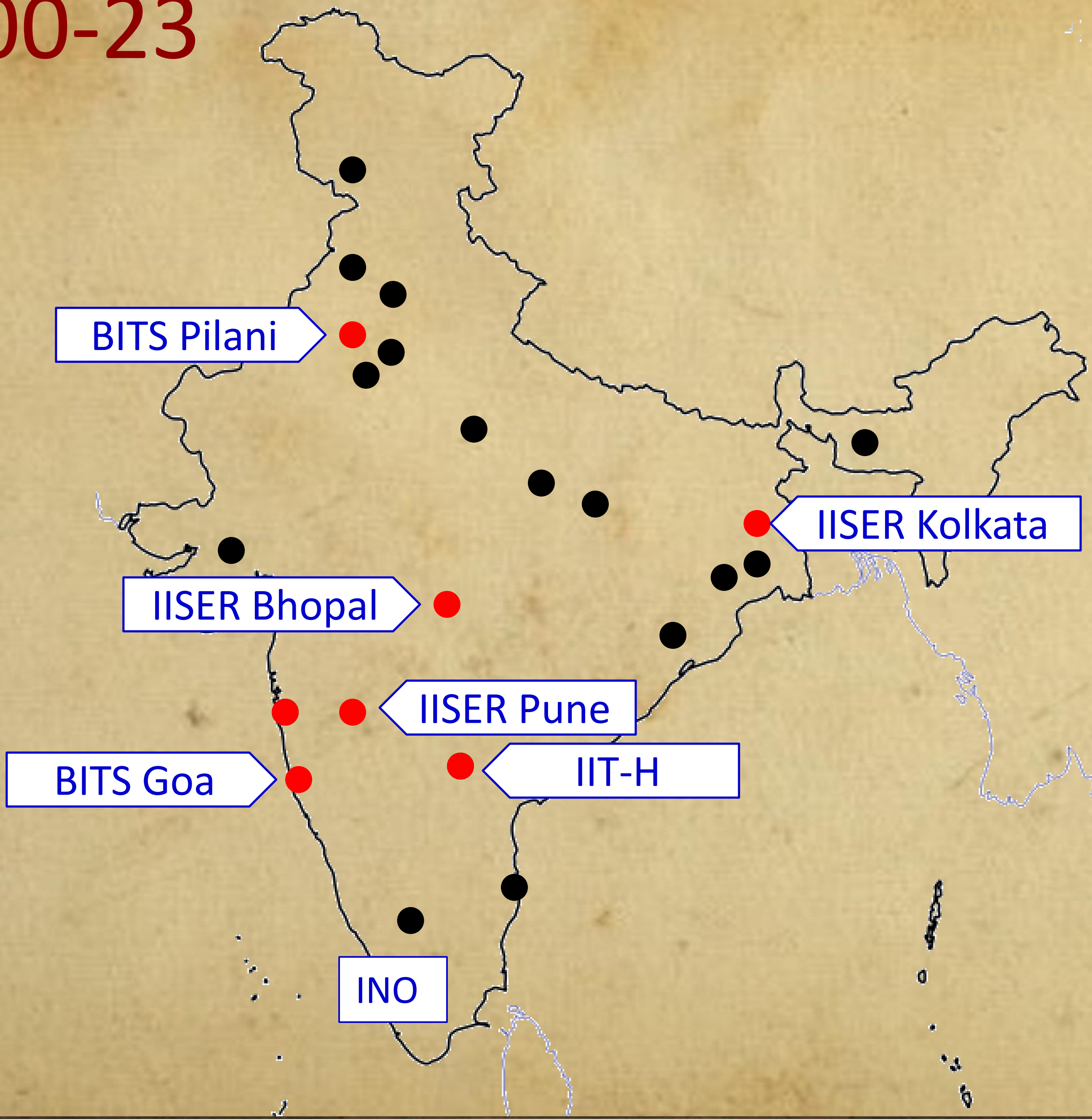

First String Theory School
at IIT Kanpur in 1986
WHEPP-1 at TIFR in 1989
First SERC THEP School
at IISc in 1985

1990s



First ESERC School
at TIFR in 1995

2000-23



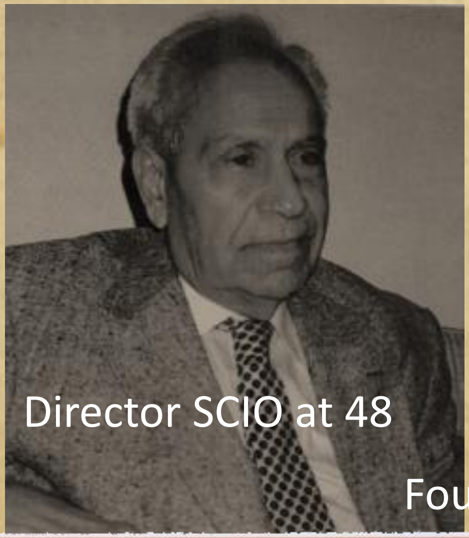
BITS Pilani
IISER Kolkata
IISER Bhopal
IISER Pune
BITS Goa
IIT-H
INO

2033

Some observations…

The tremendous influence of Cambridge University and the Cavendish laboratory

The attraction of administrative posts…



Minimal participation by women

These pioneers of science in India were fearless, energetic and confident. They tackled cutting-edge problems without fear of failure or ridicule. They were often wrong, but this did not deter them from coming up with fresh ideas. They were willing to tackle the most difficult of problems with minimum equipment and sometimes money out of their own pockets. They had huge ambitions and they worked tirelessly to see them fulfilled… This is perhaps the most important lesson to draw from their story.