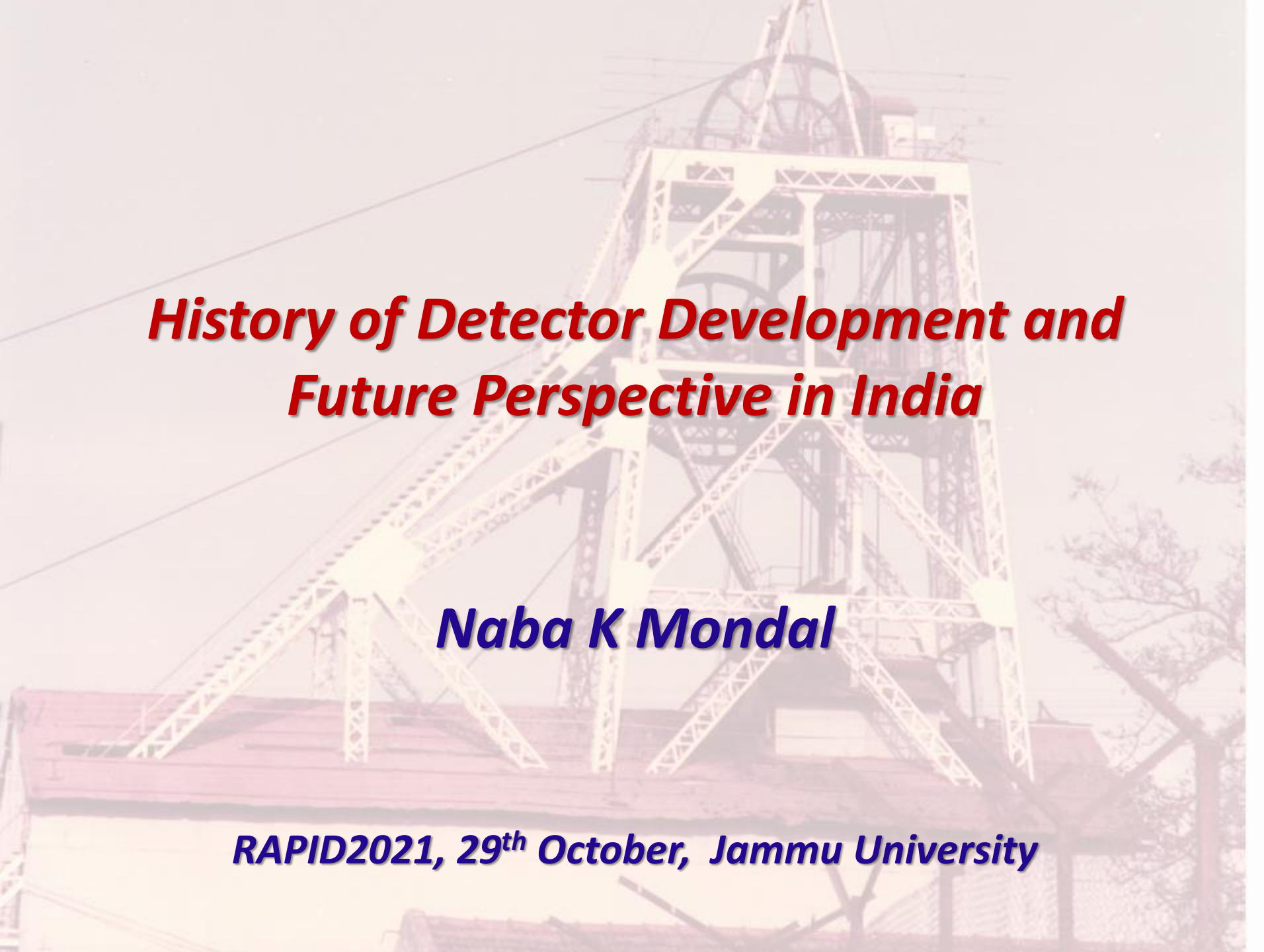


History of Detector Development and Future Perspective in India

Naba K Mondal

RAPID2021, 29th October, Jammu University

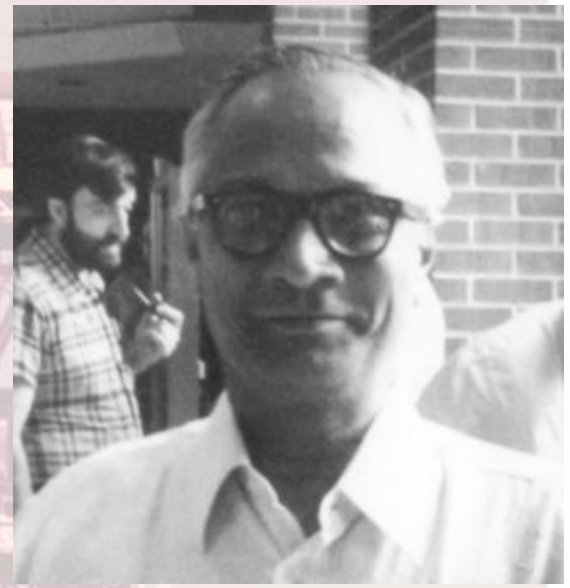
Cosmic Ray Research at Calcutta in colonial India

- **D. M. Bose**
  - 1906 : M.A. in Physics from Presidency College
  - 1907- 1913 at Christ's College, Cambridge. Worked with J. J. Thomson and C.T.R. Wilson
  - 1914- 1934, Rashbihari Ghose Professor at Calcutta University
  - 1914-1919 At Berlin worked with Cosmic Ray Pioneer Erich Regener using Cloud Chamber
  - 1934-1937, Palit Professor at Calcutta University
  - 1938-1967, Director, Bose Institute
  - S. K. Ghosh
  - R. L. Sengupta
  - M. S. Sinha
  - Biva Chowdhry

Cloud Chamber at Calcutta University/ Bose Institute

- *First Cloud Chamber in India was built by D. M. Bose and his student Subodh K Ghosh as soon as Bose returned from Berlin during 1920s.*
- *Photographed the recoil tracks of radioactive nuclei during the process of α emission.*
- *Earliest evidence of disintegration of nitrogen nucleus under the bombardment of α particles.*
- *Published their results in Nature and Philosophical Magazine.*
- *This work got discontinued for some time and later picked up again in late 30s when D. M. Bose restarted Cloud Chamber activities along with Haraprasad De, Rajendralal Sengupta and Mriganka Shekher Sinha.*

Mriganka Sekhar Sinha (1915-2006)



- *M.Sc from Calcutta University in 1936.*
- *Joined research group of D. M. Bose.*
- *In 1941, Sengupta and Sinha made a large cloud chamber of 30” diameter triggered by a counter telescope.*
- *In 1943 Sinha was invited by Homi Bhabha to IISc to built the 12” Cloud Chamber– First detector with which TIFR started its experimental program.*
- *Built a Muon Spectrometer at R. E. College, Durgapur (now NIT).*
- *Adjunct Prof. of Physics at Burdwan University.*

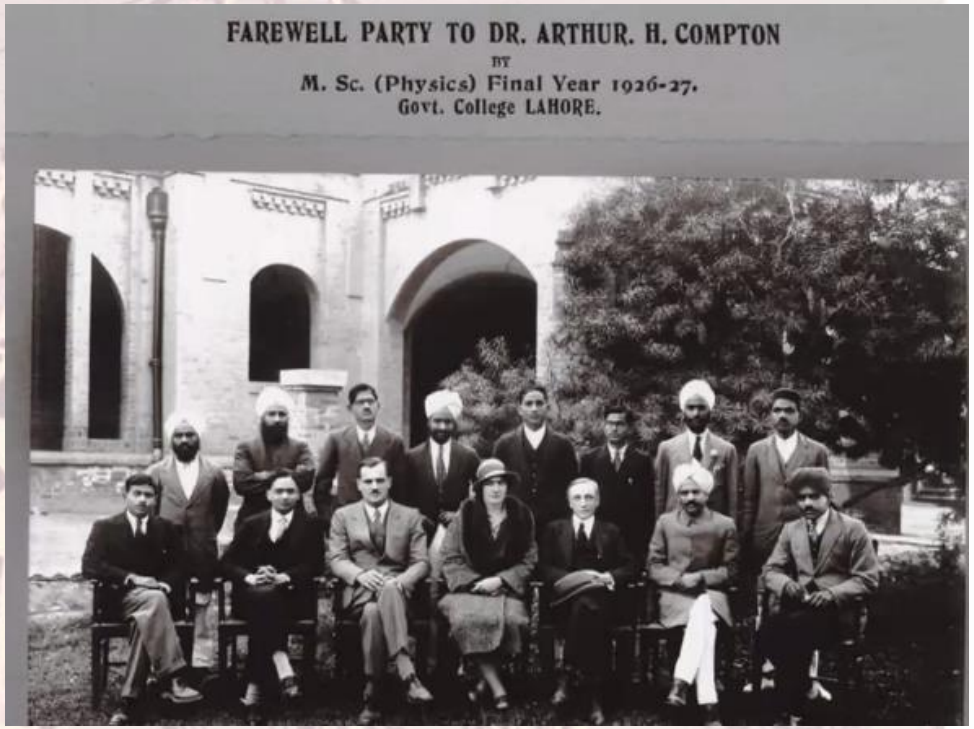
Biva Chowdhry (1913-1991)

- First Women High Energy physicist in the country.
- M.Sc. From Calcutta University in 1936
- Approached D.M. Bose for joining his research group.
- Used Photographic emulsion plates invented by another unsung Women Scientist Marietta Blau.
- Idea of using photographic emulsion plates came from a discussion with Walther Bothe during the Science Congress held at Calcutta in 1938.
- Exposed photographic emulsion plates to study mesotron shower at
  - Darjeeling (7000ft)
  - Sandakphu (12000 ft)
  - Pharijong (14000 ft)

Biva Chowdhry

- *Measured track length, scattering and mean grain density to determine particle properties (mass, energy, momentum).*
- *Published four papers in Nature in quick succession during 1940-42.*
- *Could identify two particles with masses close to that of mu meson and pi meson.*
- *Did not have the resolution to precisely identify the pion.*
- *Pioneered the method of measuring particle energy using multiple scattering.*
- *Moved to Manchester University to work with P.M. Blackett.*
- *Studied Extensive Air Shower using Cloud Chamber.*
- *Joined TIFR in 1949, Ecole Polytechnique, France, 1954, Michigan University, B.E.College, Sibpur, PRL in 1962*

Piara Singh Gill (1911-2002)



- *A pioneer Cosmic Ray Physicist.*
- *Bachelor's and Master's degree from Univ. of South California.*
- *Ph.D. in Cosmic Rays under Arthur Compton at Chicago University.*
- *Thesis title " Further studies of Cosmic Rays on the Pacific Ocean" – Established "Cosmic Ray Latitude effect" using ionisation chamber.*

Piara Singh Gill & Early Cosmic Ray Research at AMU

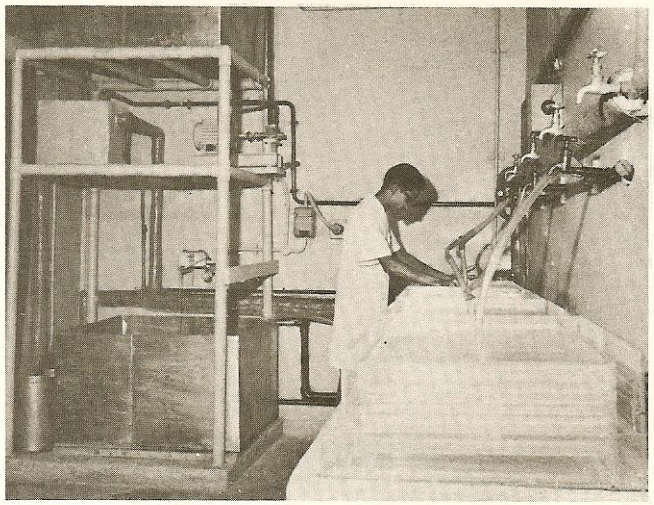
- *1940- Gill returned to Lahore and joined Forman Christian College. Setup experiments to study Azimuthal effect of Cosmic Rays.*
- *Joined TIFR in July 1947. He led balloon flights to high altitudes.*
- *1949 : Appointed prof. & HOD of Physics Dept of AMU*
- *Setup High Altitude Laboratory at Gulmarg using G.M. counters and nuclear emulsions developed at AMU.*
- *1963- 1971 Director of CSIO.*
- *During 70s all heads of Physics Depts in North India from Kashmir to Kalyani were old students of P. S. Gill.*

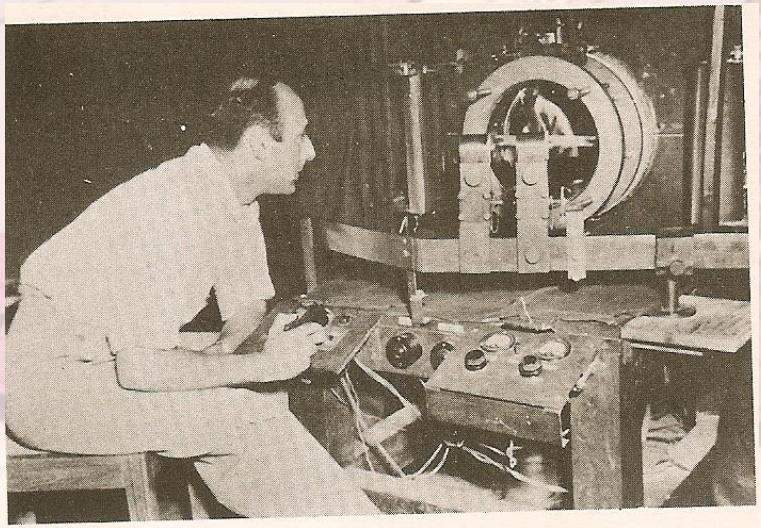
Cosmic Ray Research Unit at IISc Bangalore

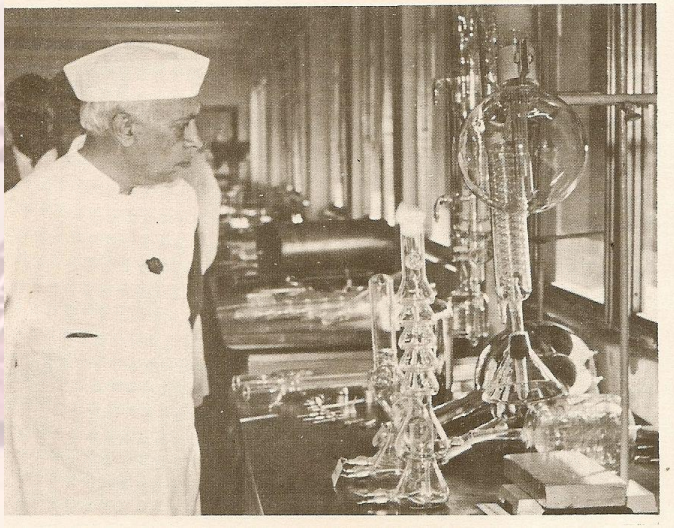
- *Seeds for Experimental High Energy Physics research at TIFR were really sown even before TIFR came into existence on 1st June, 1945.*
- *In December, 1944 Homi Bhabha flew two telesopes with GM counters sandwitched with lead plates using US airplanes stationed at Bangalore during the war.*
  - *First measurement of high altitude meson intensities at equatorial latitude.*
- *Invited M. S. Sinha to built a 12" circular cloud chamber similar to one available at Blackett's Lab in UK.*
  - *Used it to study the scattering characteristics of mesons*

Early Particle physics experiments at TIFR

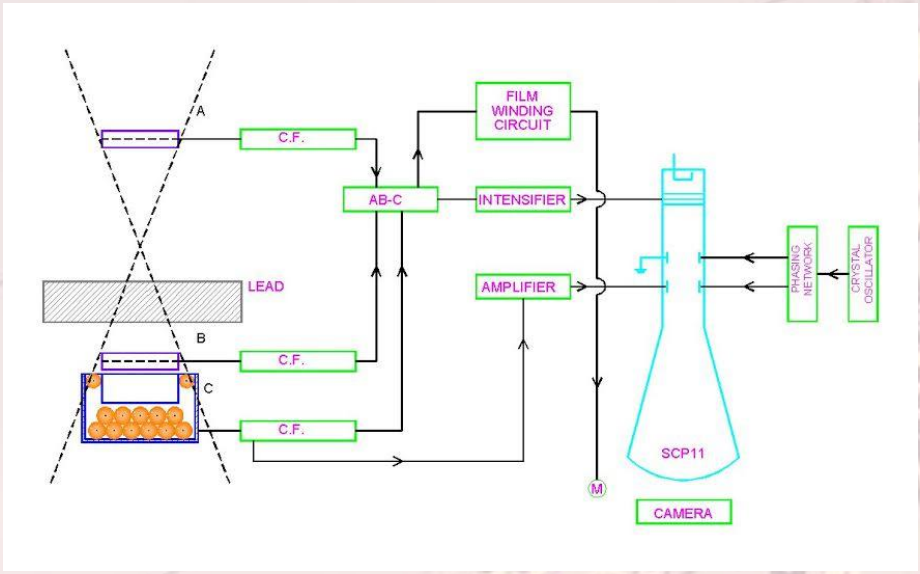
- Cloud Chambers.
- G.M. Counters.
- Emulsions.

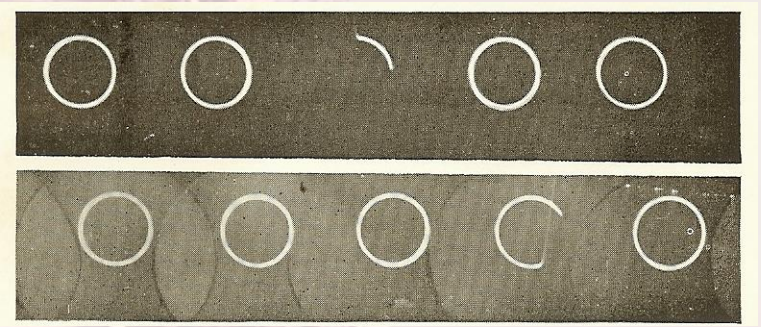


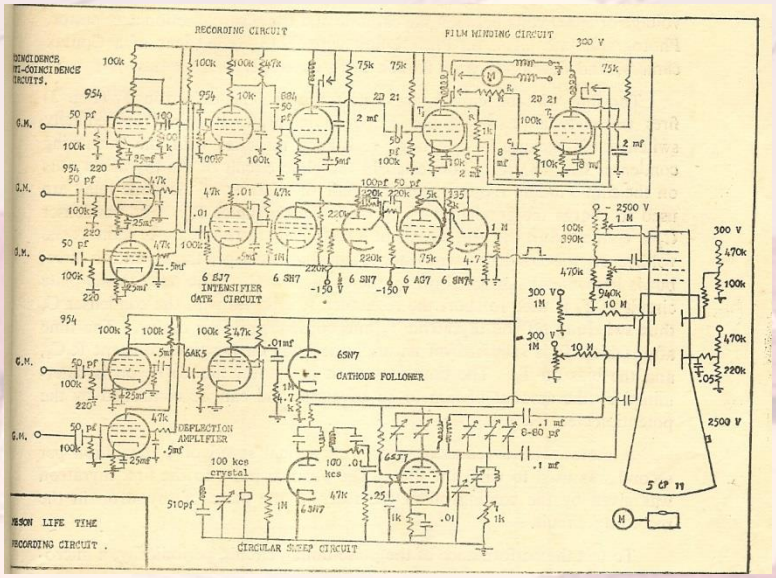


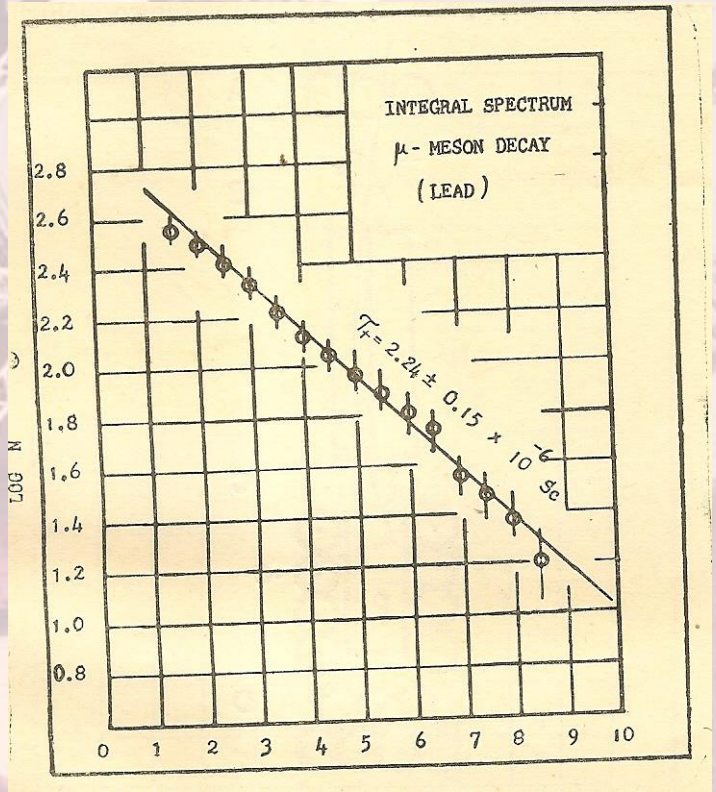


Muon Life Time measurement (1948-1950)
by B. V. Sreekantan

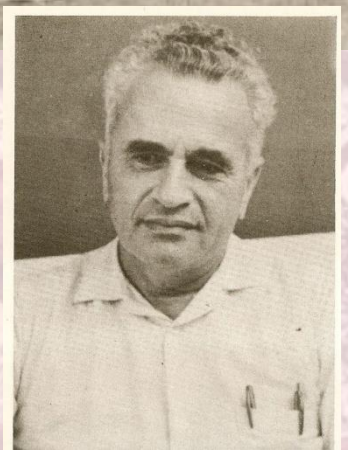








Conference on Elementary Particles at TIFR in 1950



Homi Bhabha
(1909 – 1966)

Bernard Peters
(1910 – 1993)

Biva Chowdhry
(1913 – 1991)

Roy Daniel
(1923 – 2005)

Sukumar Biswas
(1924 – 2009)

B.V. Sreekantan
(1925 –2020)

Yash Pal
(1926 – 2017)

Devendra Lal
(1929 – 2012)

M. G. K. Menon (1928-2016)

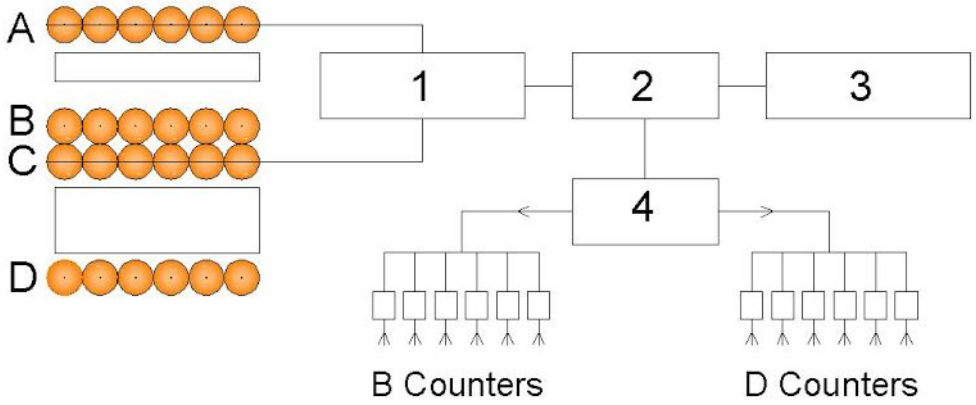
Pioneers

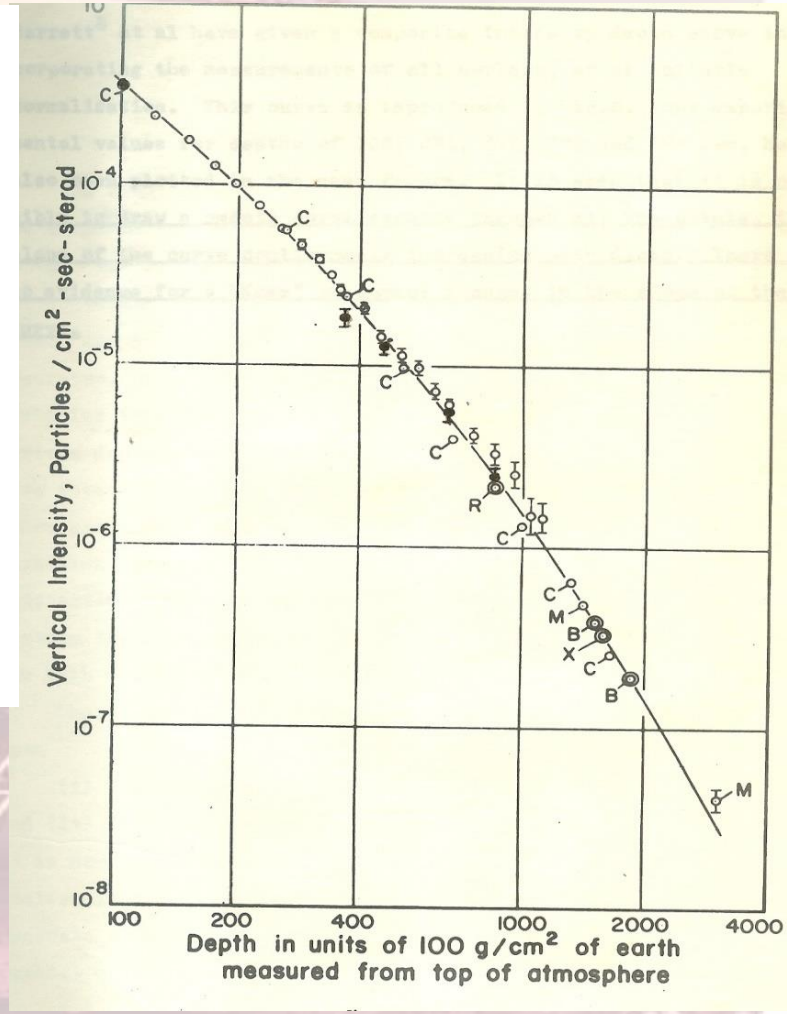
1951 Start of KGF activities

First set of measurements were carried out at Nundydurg Mines

TIFR High Energy Cosmic Ray Group during late 70s

KGF 1951-1954 - GM Counter array upto a depth of 900 ft (E_μ ~ 200 GeV)



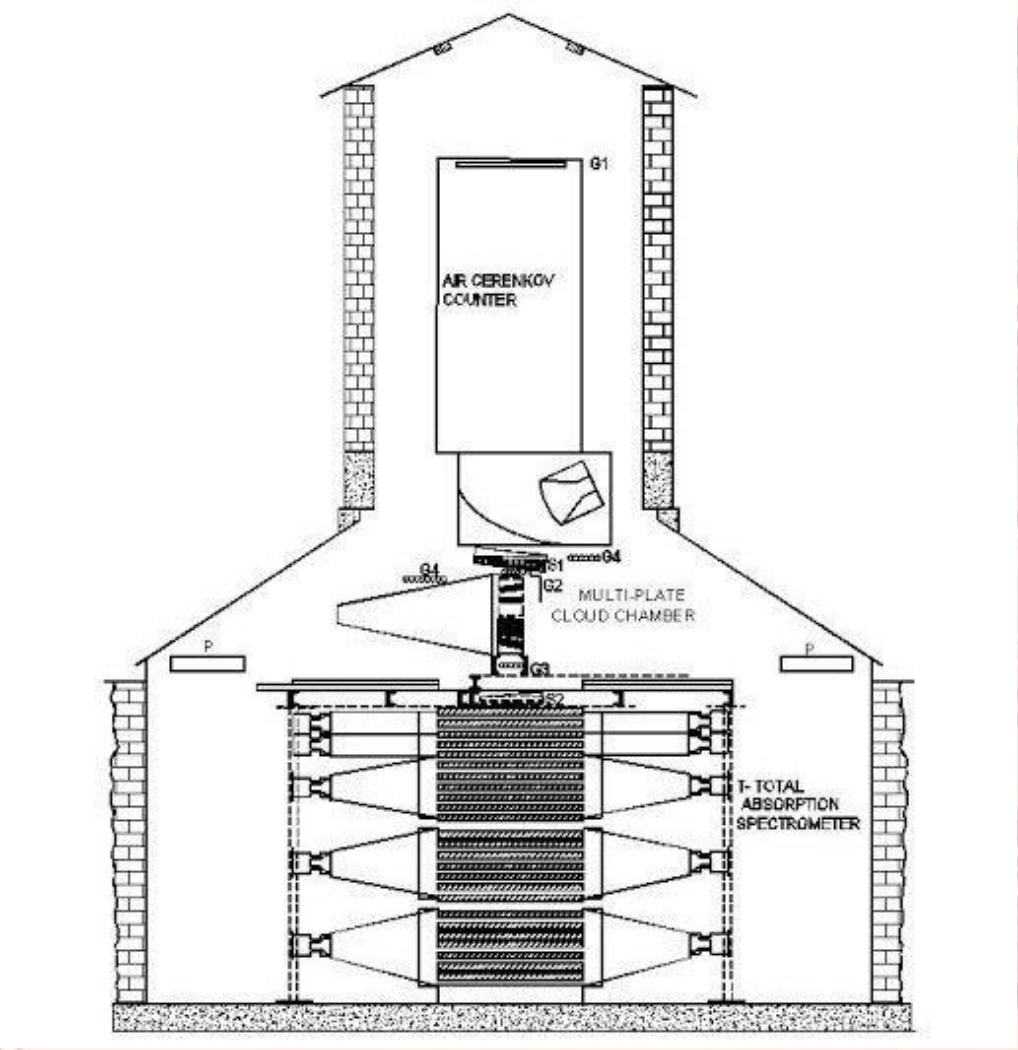


1. *Double coincidence circuits.*
2. *Cathode follower.*
3. *Film advancing circuits.*
4. *Inverter.*

Temporary closure of KGF activities

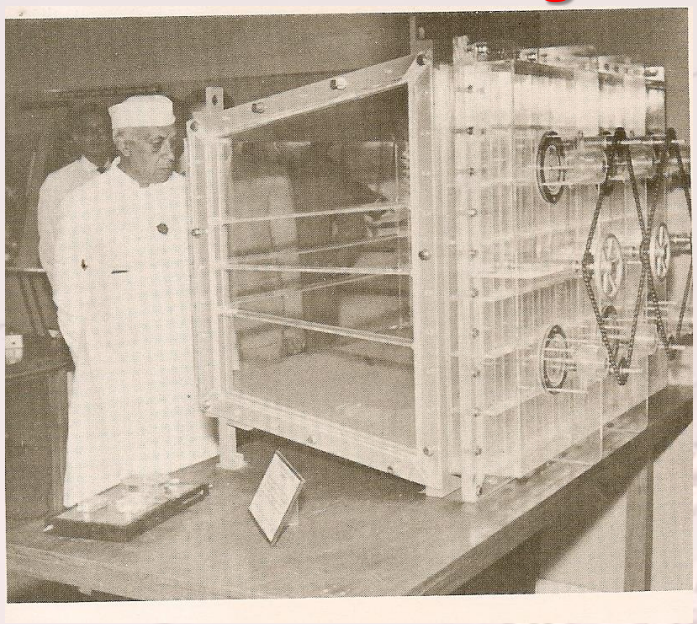
Underground experiments at KGF, however, came to an abrupt halt as the news of the imminent closure of the gold mines spread. Sreekantan and his collaborators, therefore, left KGF in 1954 after these initial series of experiments.

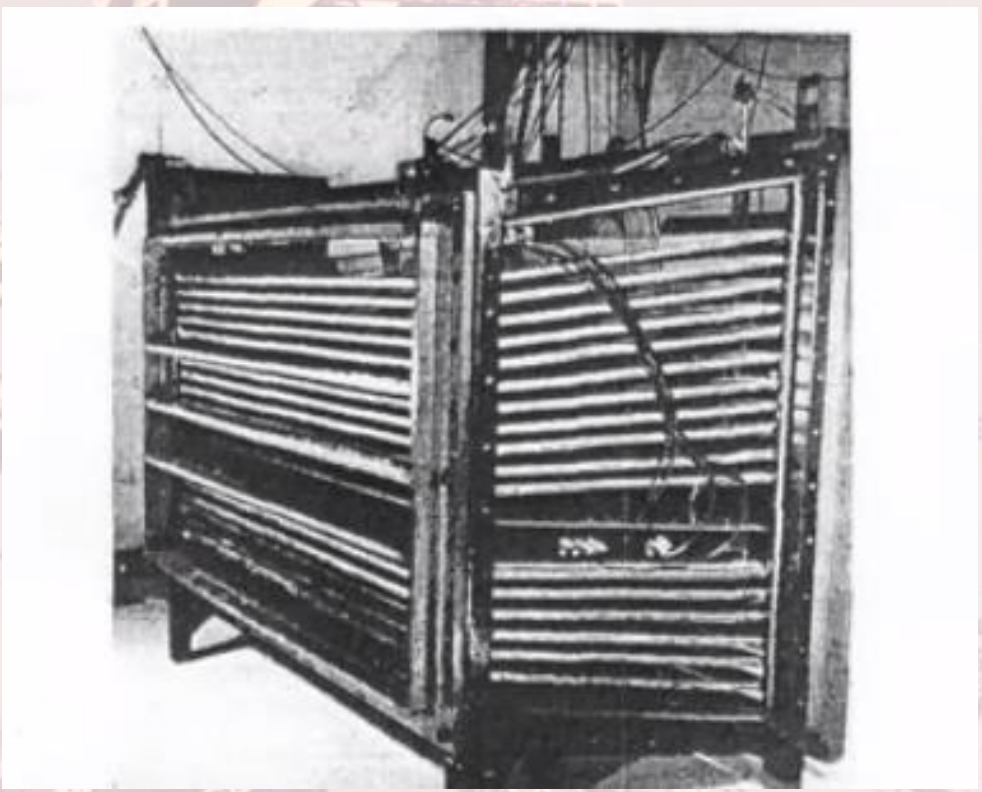
High Energy Physics using Cosmic Ray beam
Total Absorption Spectrometer at Ooty



- *Air Cerenkov counter to distinguish Between pion & proton.*
- *Cloud chamber to study the interaction in detail.*
- *A calorimeter of Iron & liquid scintillator stack to measure energy.*

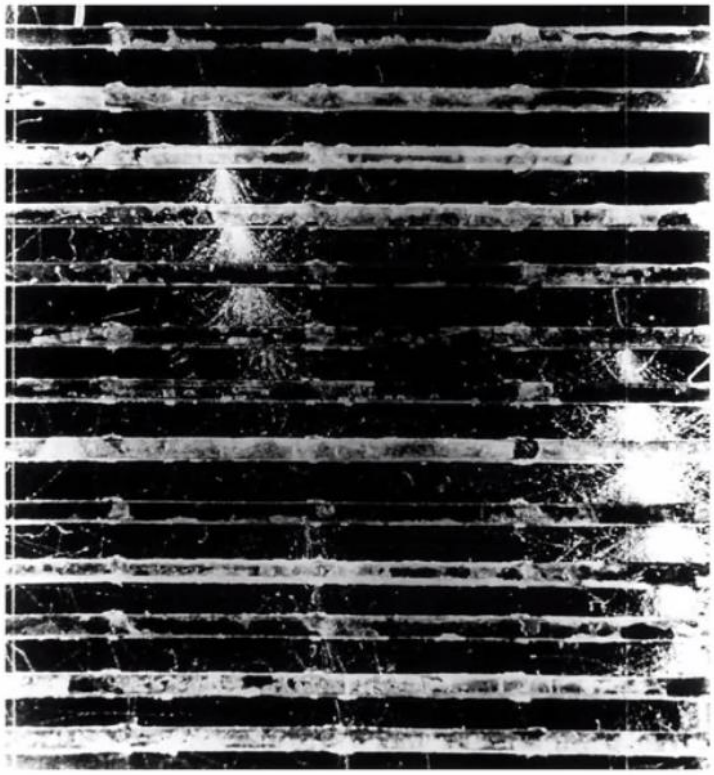
Large Cloud Chamber at Ooty

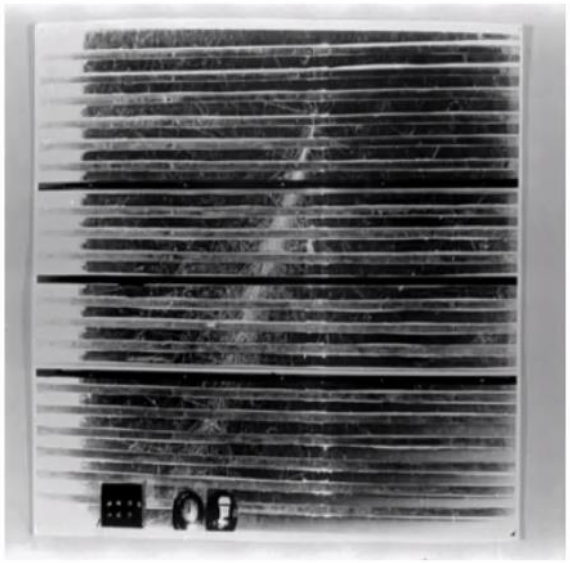




2m X 1m X1.5m Cloud Chamber during mid 60s – used for many years at Ooty Cosmic Ray Lab for interaction studies.

Cloud Chamber Pictures of Cosmic ray Interactions

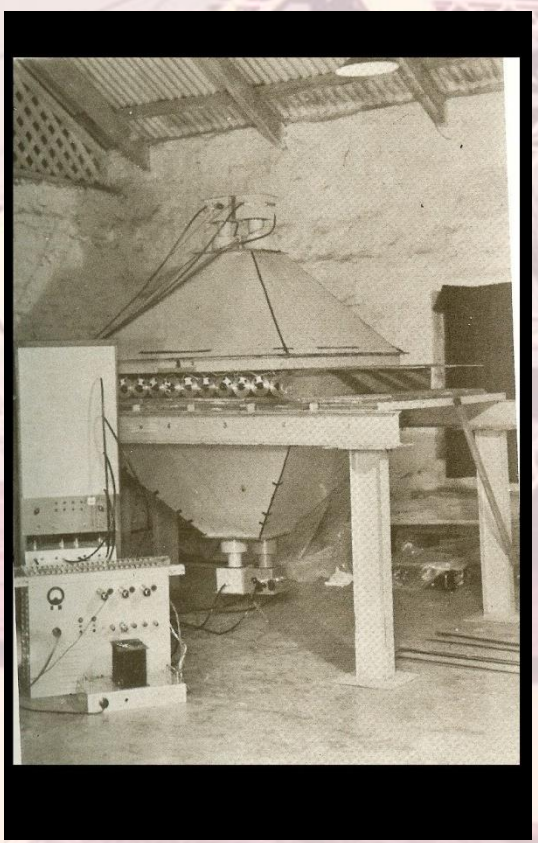




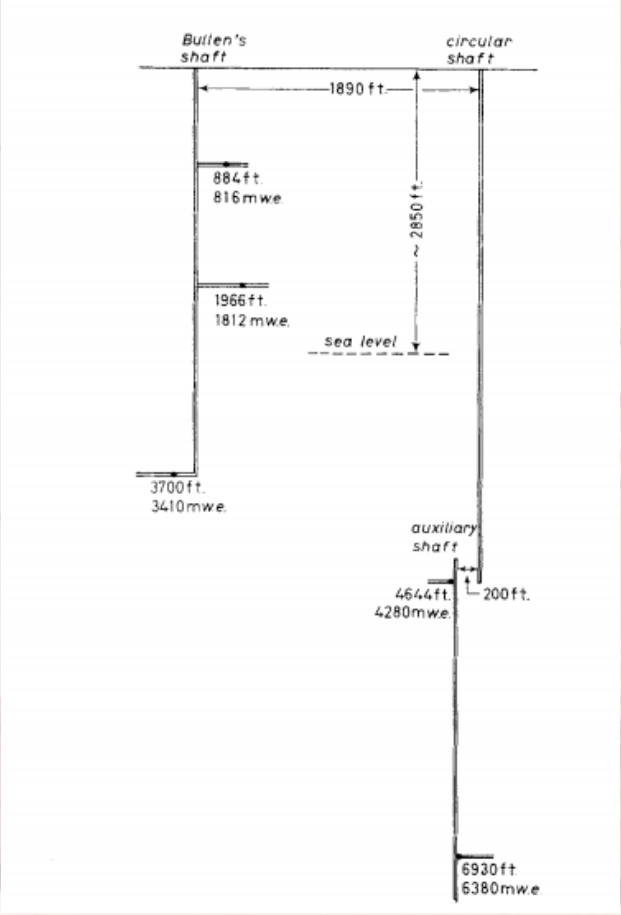
A New Lease of Life for KGF activities

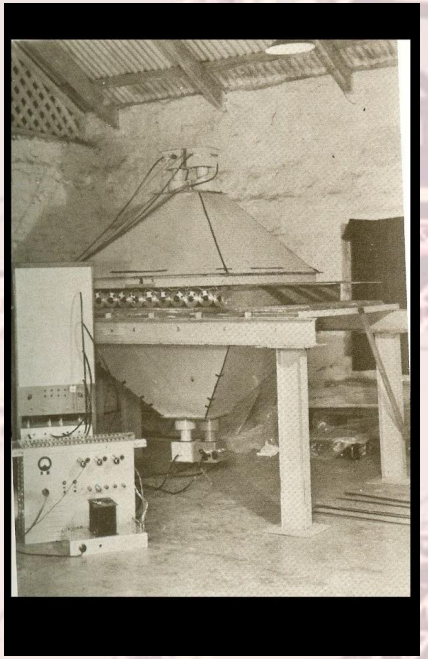
- ***The KGF mines got a new lease of life as the management was taken over from the private players, first by the Government of Mysore in 1956 (Kolar Gold Mines Undertakings), and later by the Government of India (Bharat Gold Mines Ltd.), as a public sector undertaking.***

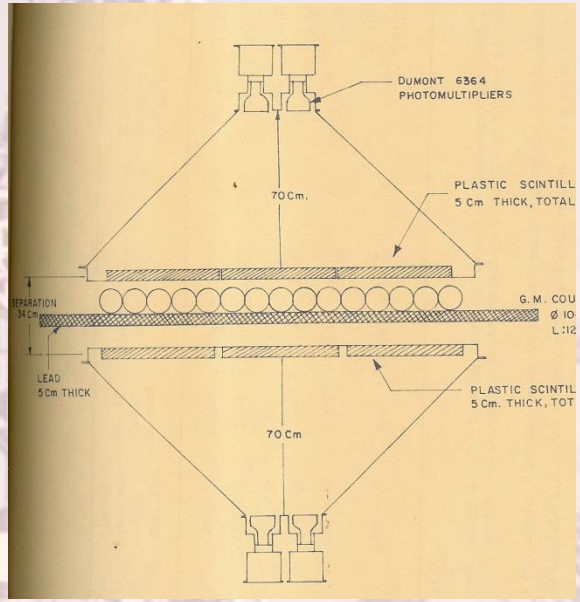
Kolar Gold Fields Lab restarted in 1960



KGF 1960-1963
Up to a depth of 2.7 km. (800 – 8400 mwe)

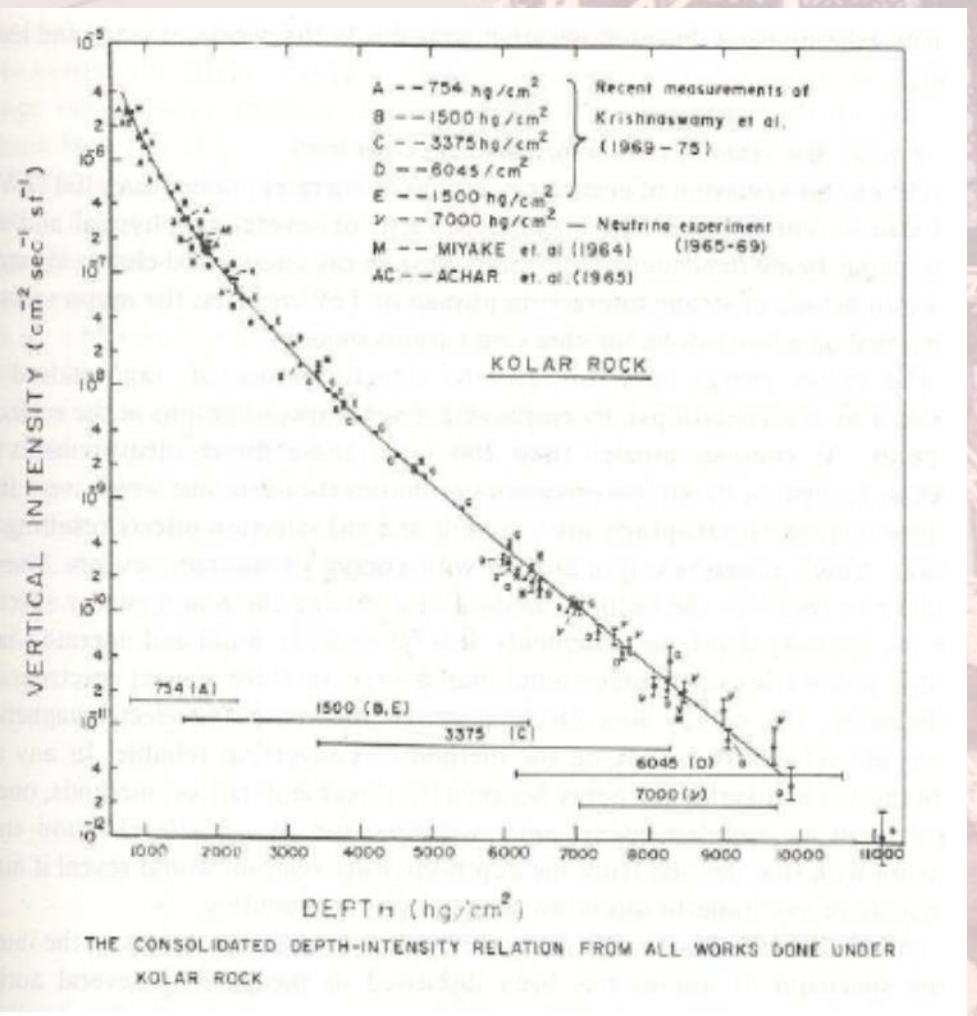






Miyake, Narasimham, Ramanamurthy

Most comprehensive Depth-intensity curve



THE CONSOLIDATED DEPTH-INTENSITY RELATION FROM ALL WORKS DONE UNDER KOLAR ROCK

Proposal to Detect Neutrinos

- ***Menon, Ramanamurthy, Sreekantan and Miyake, Nuovo Cimento, 30, 1208, 1963.***
  - ***Ideal place for carrying out experiments to study cosmic neutrinos.***
  - ***Improve the lower limit on proton lifetime, estimated at that time to be around 10^{26} years.***
  - ***Probe the existence of the Intermediate Vector Boson, the predicted mediator of weak nuclear force.***

This paper started the ball rolling for a series of important experiments to be conducted at KGF over the next 30 years to study neutrinos and also to explore ideas of baryon non-conservation.

- ***Miyake, Narasimham, Ramanamurthy, Nuovo Cimento, 32, 1505, 1964.***

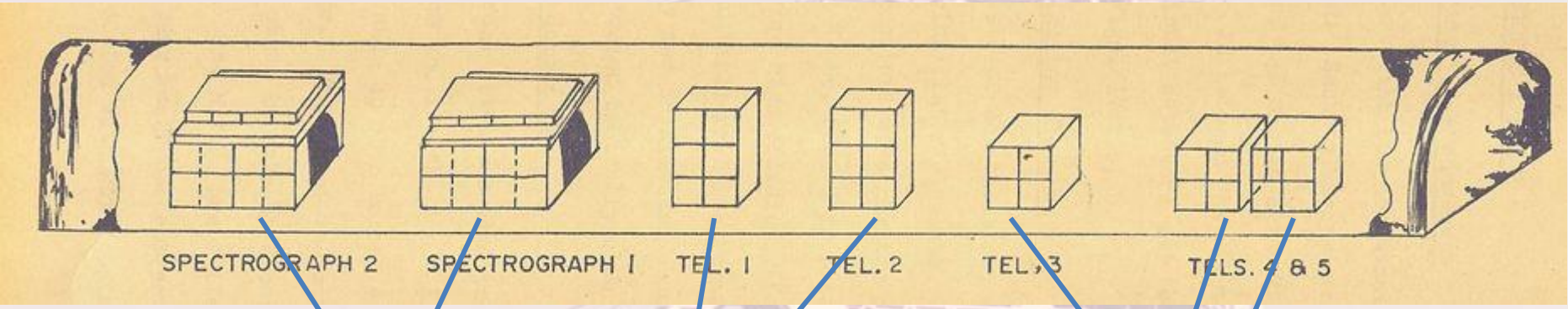
International Cosmic Ray Conference, Jaipur, 1963

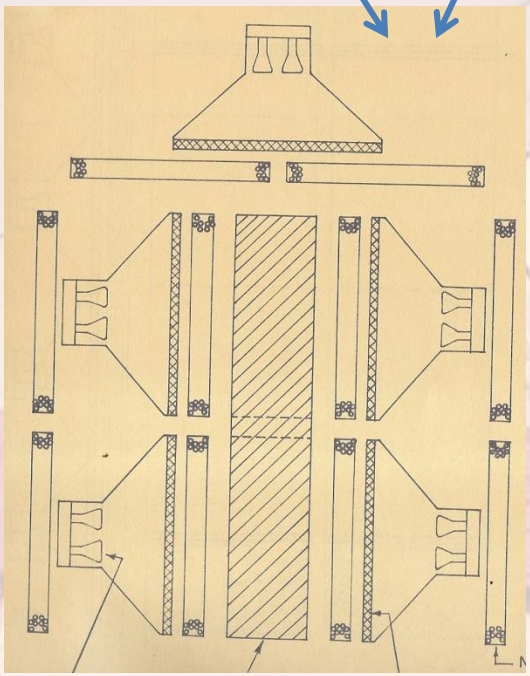
- *Ramanamurthy presented the muon depth-intensity results from KGF.*
- *M. G. K. Menon discussed the plan to setup neutrino experiment at KGF.*
- *Frederick Reines discussed the plan to setup neutrino experiment in South African Mines.*

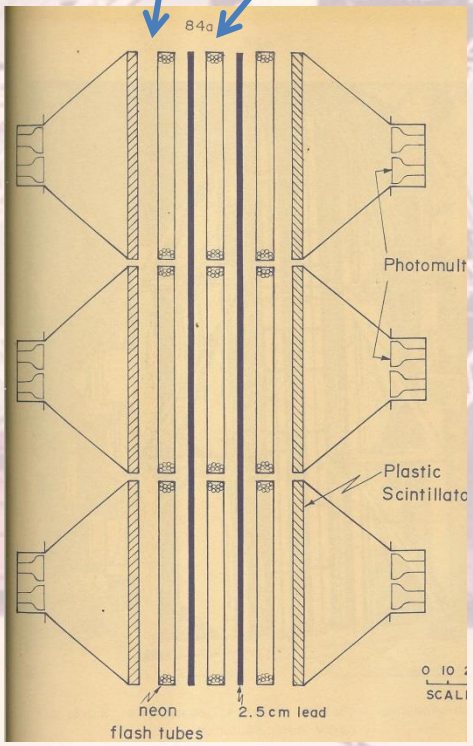
Tata-Durham-Osaka Neutrino Experiment

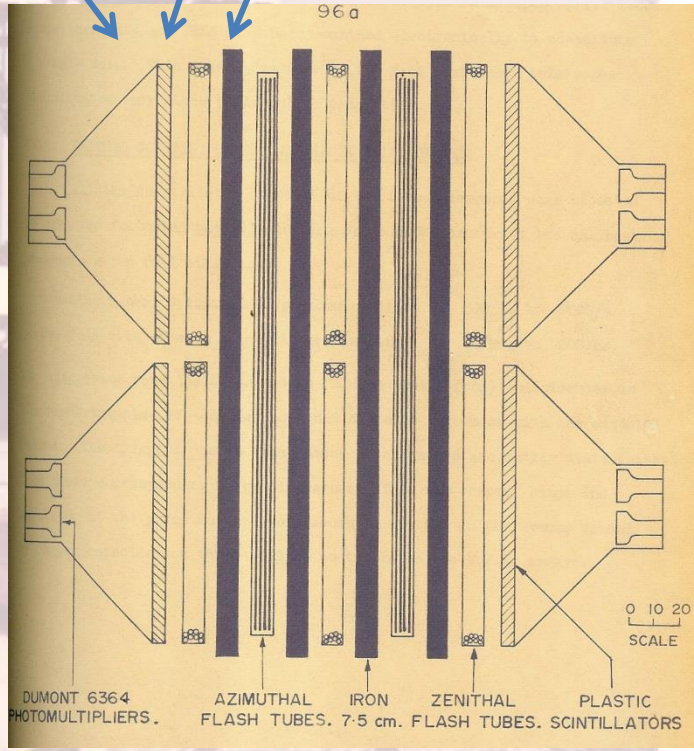
- *Arnald Wolfendale and his group from Durham University, UK and Saburo Miyake and his group from Osaka City University, Japan joined the experiment.*
- *It was already known that high energy cosmic ray particles interact with the Earth's atmosphere and produce pions and kaons. These in turn, decay into muons and neutrinos.*
- *Georgy T. Zatsepin and Vadim A. Kuzmin from Soviet Union had already made careful calculations of the flux and angular distribution of these neutrinos.*
- *In 1962, an accelerator based neutrino experiment at Brookhaven had established the existence of a muon neutrino ν_μ, distinct from the electron neutrino ν_e, and measured the neutrino-nucleon cross-section to be about 10^{-38} cm^2.*
- *These inputs allowed KGF group to estimate the expected rates of neutrino interactions underground and to optimise the size and type of detectors required to detect them.*
- *A long tunnel at 2300 m depth in Heathcote shaft in the Champion Reef mines was chosen as the site for the experiment.*

Neutrino Experiment at KGF 1965 onwards





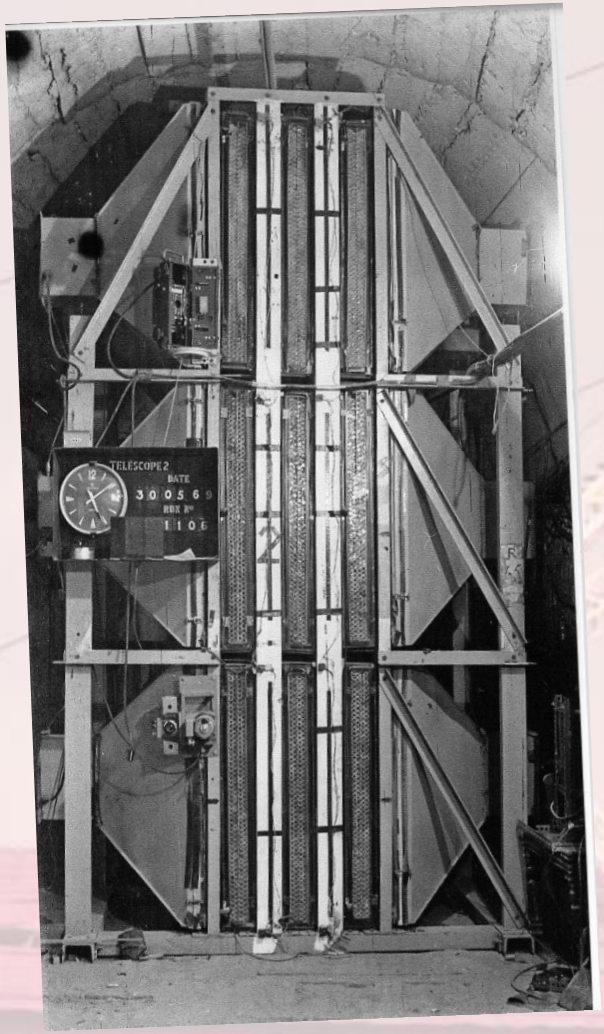




KGF Neutrino Experiment

- *Telescope 1 & 2 became operational in early 1965*
- *Telescope 3, 4 & 5 by March 1966*
- *Telescope 6 & 7 in June 1967*
- *First neutrino event was detected in early 1965 and reported in Plys. Lett. On 15th August, 1965. Two weeks later F. Reines et al. reported their observation in Phys. Rev. Lett.*

Atmospheric neutrino detection in 1965



Atmospheric neutrino detector
at Kolar Gold Field –1965

DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

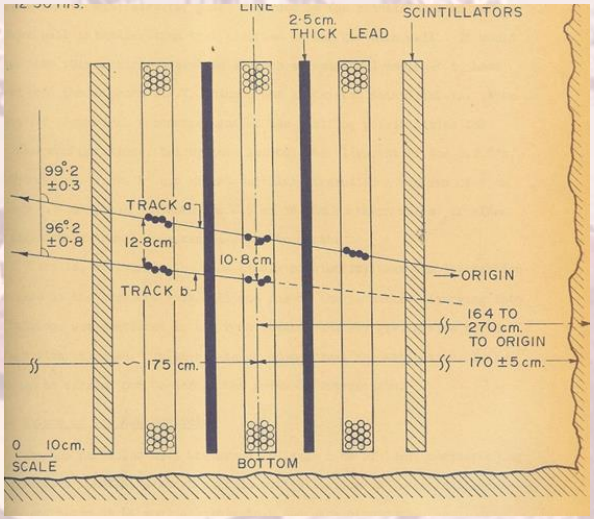
C. V. ACHAR, M. G. K. MENON, V. S. NARASIMHAM, P. V. RAMANA MURTHY and B. V. SREEKANTAN,
Tata Institute of Fundamental Research, Colaba, Bombay

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

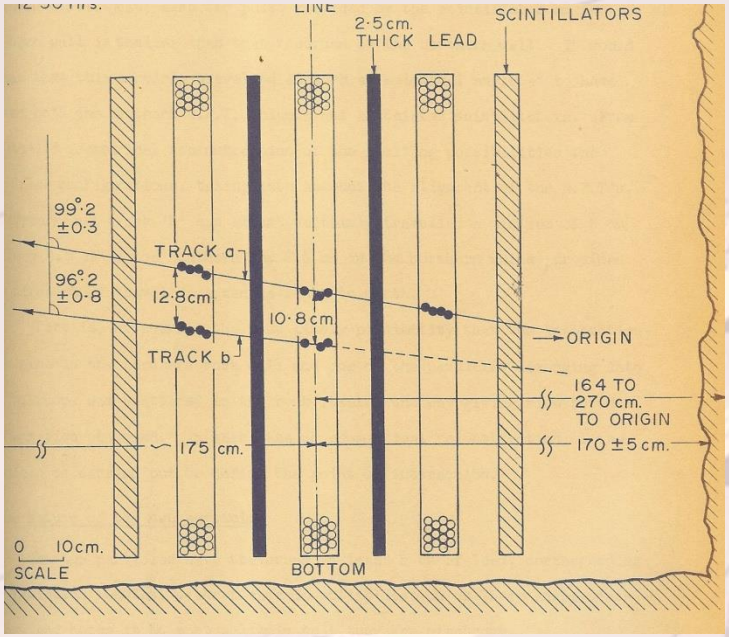
D. R. CREED, J. L. OSBORNE, J. B. M. PATTISON and A. W. WOLFENDALE
University of Durham, Durham, U.K.

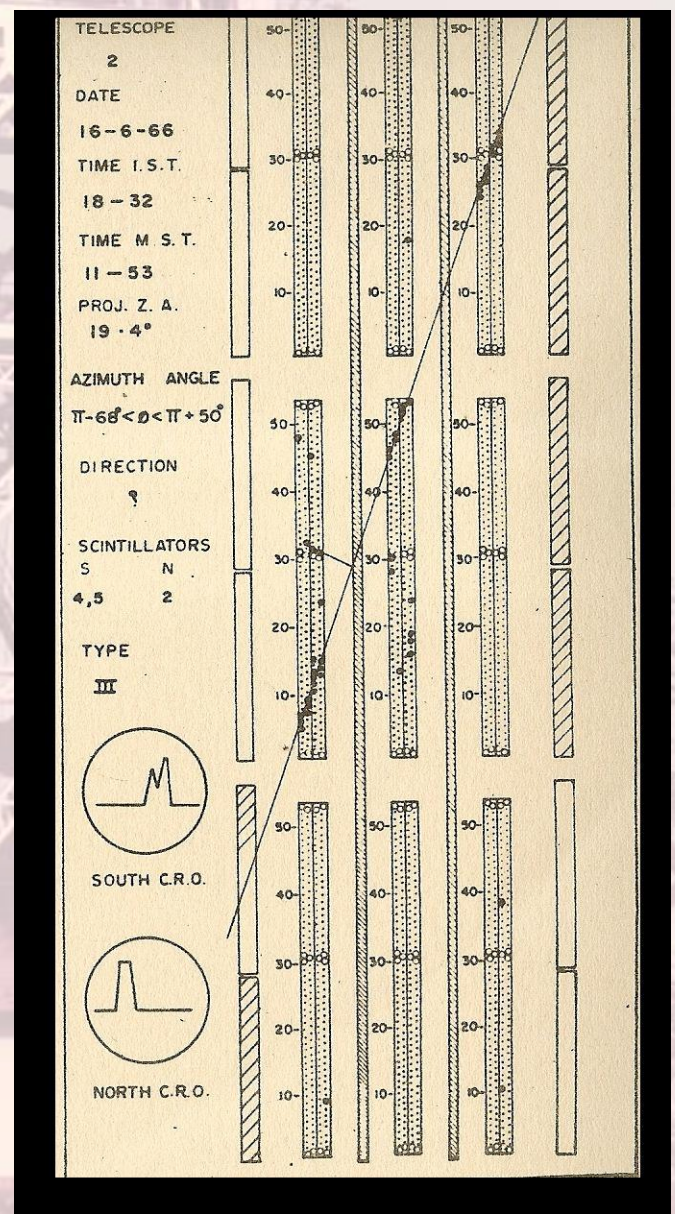
Received 12 July 1965

Physics Letters 18, (1965) 196, dated 15th Aug 1965



Neutrino Events at KGF

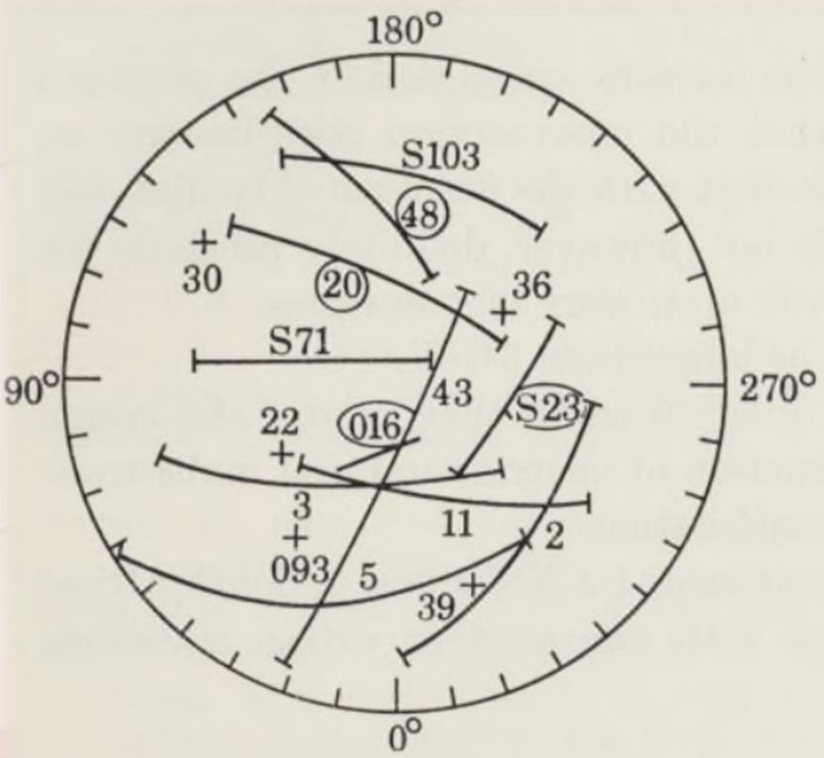




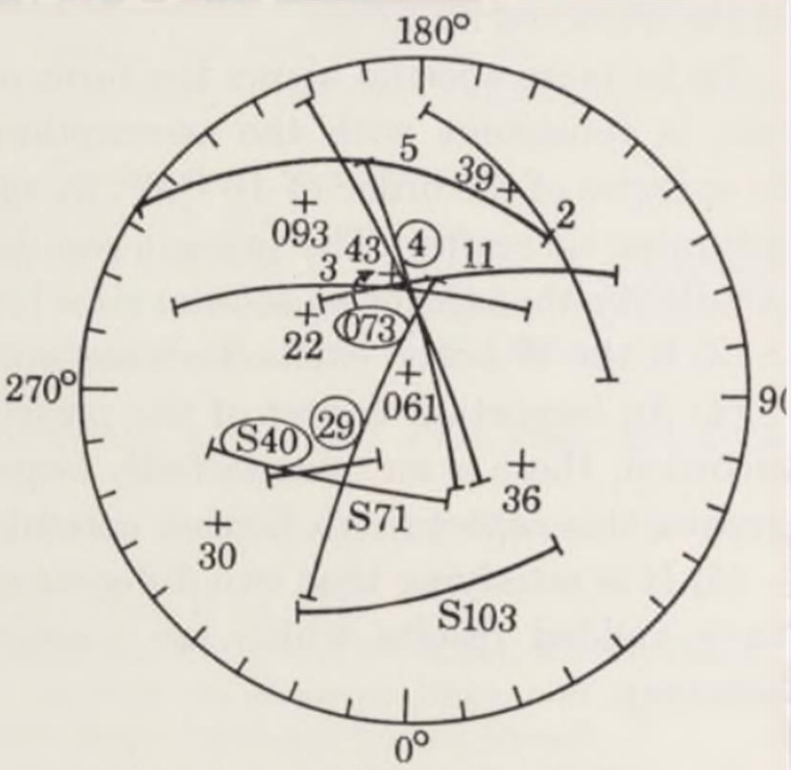
Importance of KGF Neutrino Experiment

Study of neutrinos underground became an important area of research in the field of particle physics around the world later and several Nobel Prize-winning discoveries were made using neutrinos underground. Even today atmospheric neutrinos remain an exciting area of research in particle physics.

Beginning of Neutrino Astronomy

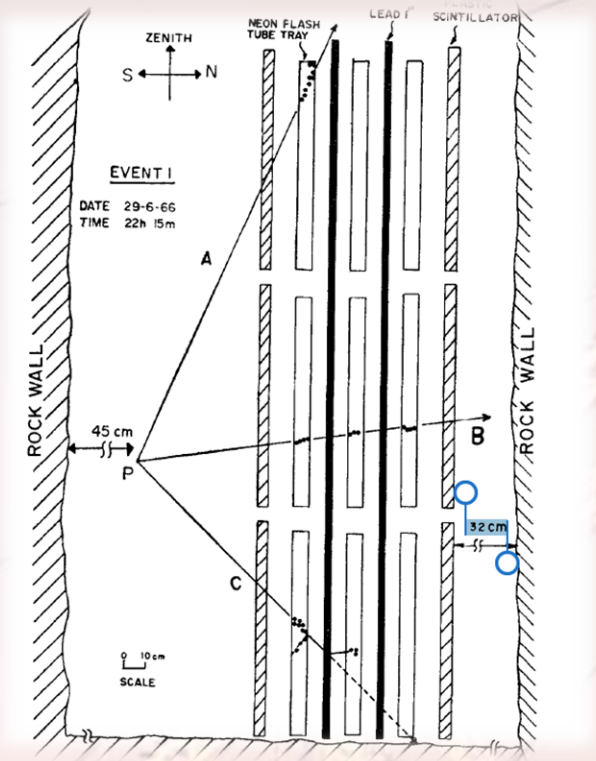


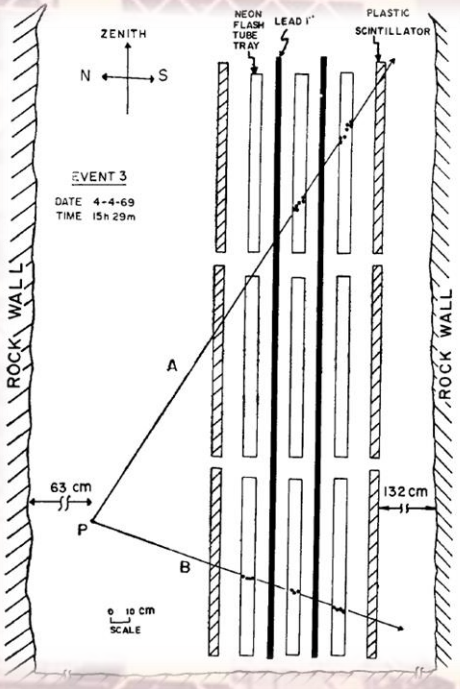
(*a*) Northern Celestial Hemisphere



(*b*) Southern Celestial Hemisphere

Puzzling Kolar Events



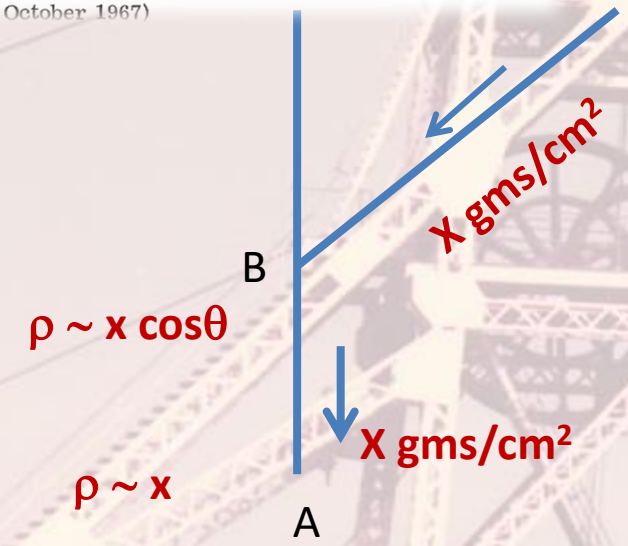


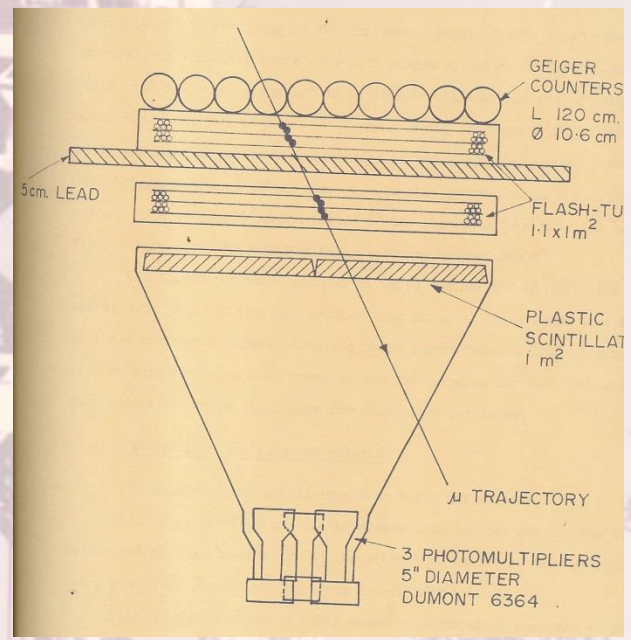
Decay of some long live particles of mass around 2 GeV and lifetime around 10^{-9} sec. ?

Muon Angular Distribution Deep Underground

EVIDENCE FOR A NEW PRODUCTION PROCESS FOR 10^{12}-eV MUONS*

H. E. Bergeson, J. W. Keuffel, M. O. Larson,† E. R. Martin,‡ and G. W. Mason
University of Utah, Salt Lake City, Utah
(Received 26 October 1967)

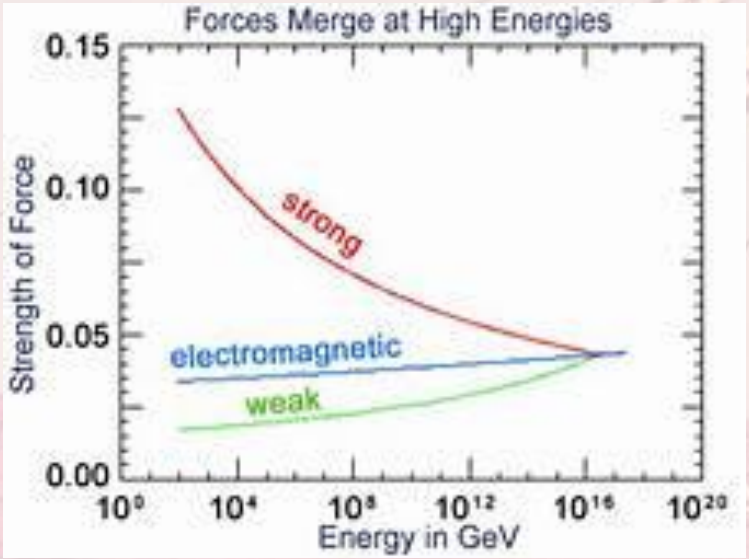


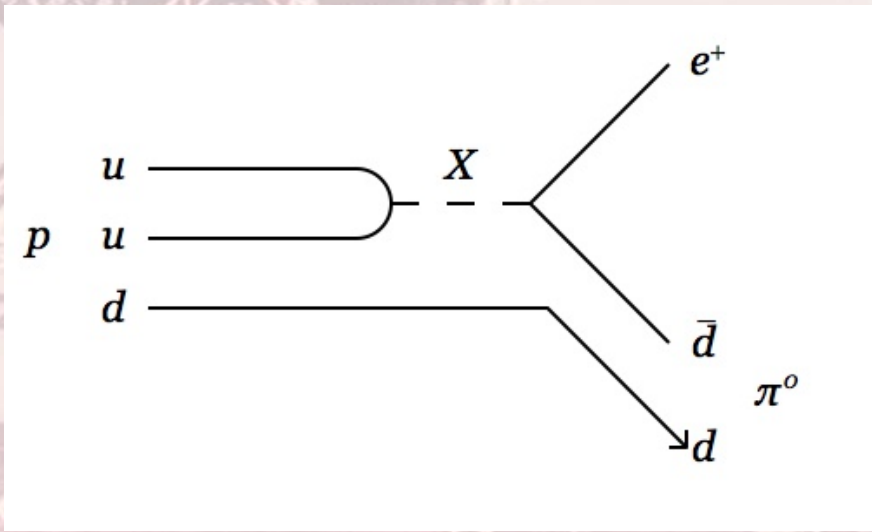


- *At very small residual thickness of the atmosphere, (< 200 gms/cm²), the density of air is proportional to the thickness of the atmosphere itself.*
- *Decay probability is inversely proportional to density and thus increases as secθ*
- *Any deviation from this secθ will suggest new source of atmospheric muons other than pion/kaon decay.*

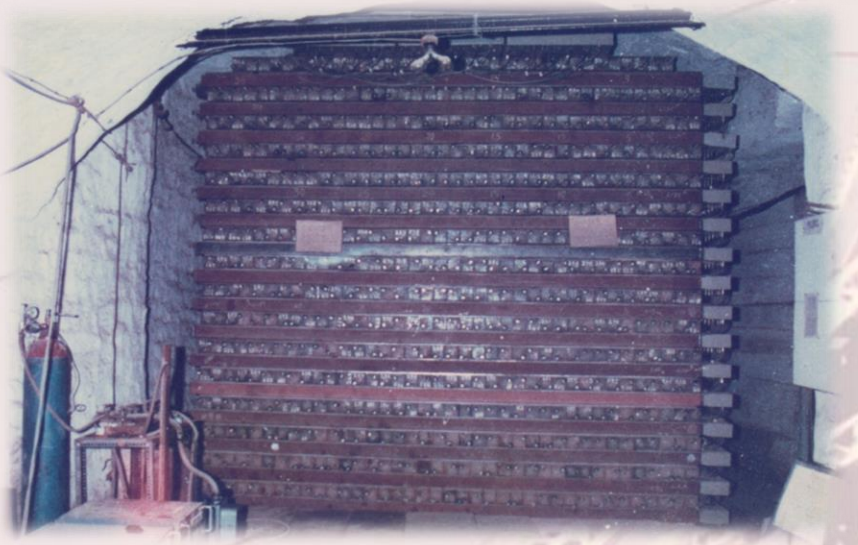
"Diamonds aren't forever."-- Sheldon Glashow

Grand Unified Theory and Proton Decay

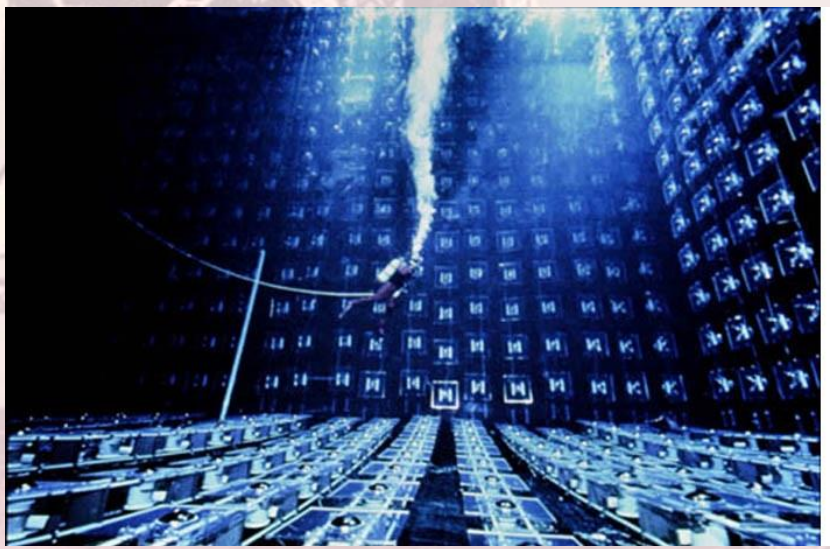




Experiments



Tracking Calorimeter



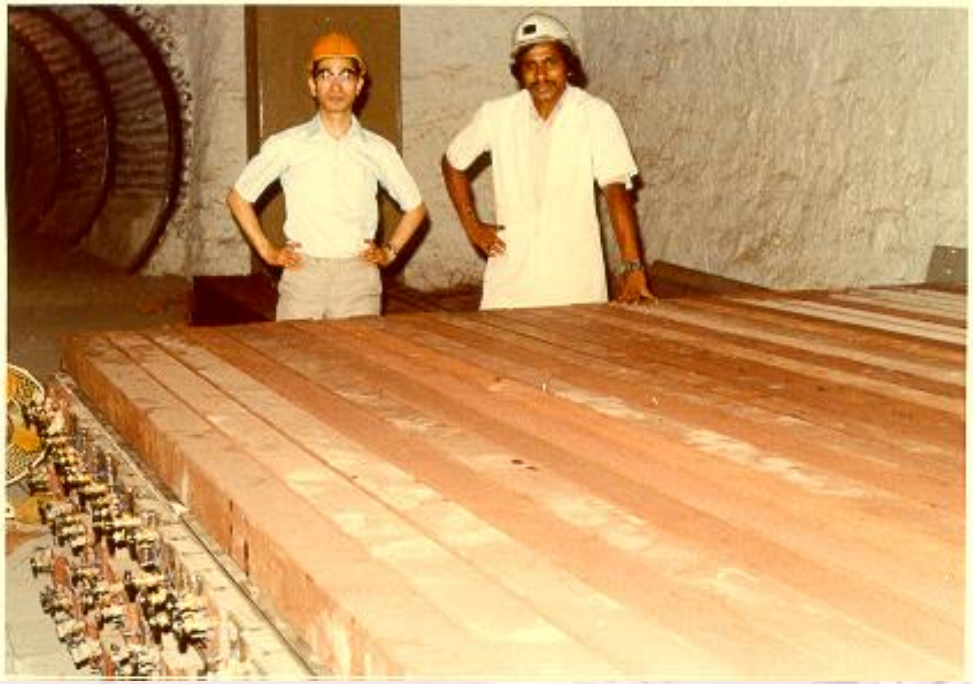
Homogeneous Water Cherenkov

KGF Phase I Nucleon Decay Detector (1979-1992)

Testing Proportional counters

Designing and Fabrication of Electronics

Commissioning of KGF Phase-I Proton Decay Experiment



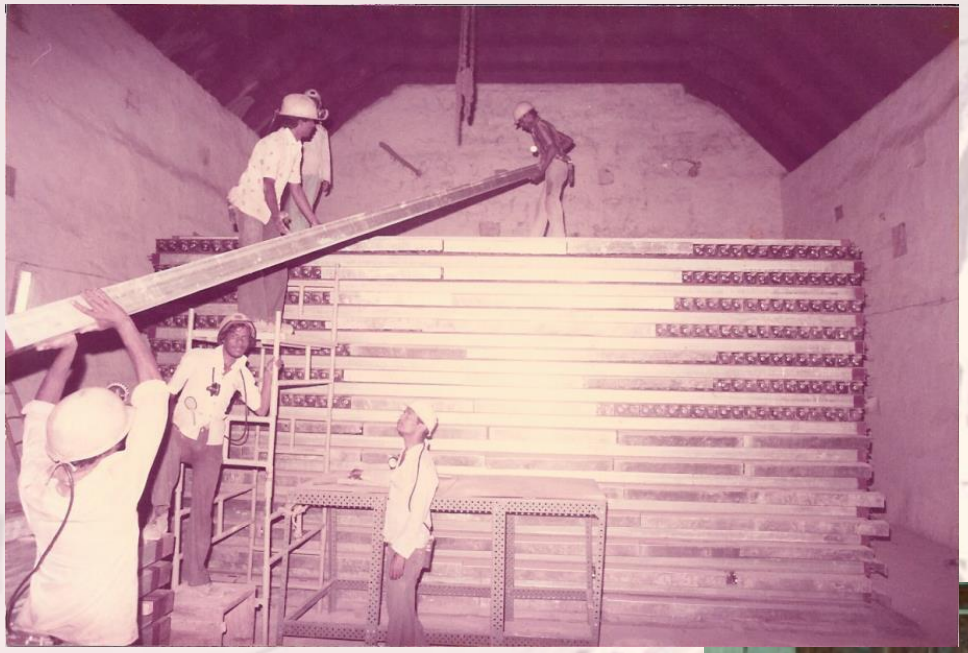
Construction of Detector and Electronics

KGF Phase-I Nucleon Decay Detector

ICOBAN 1982

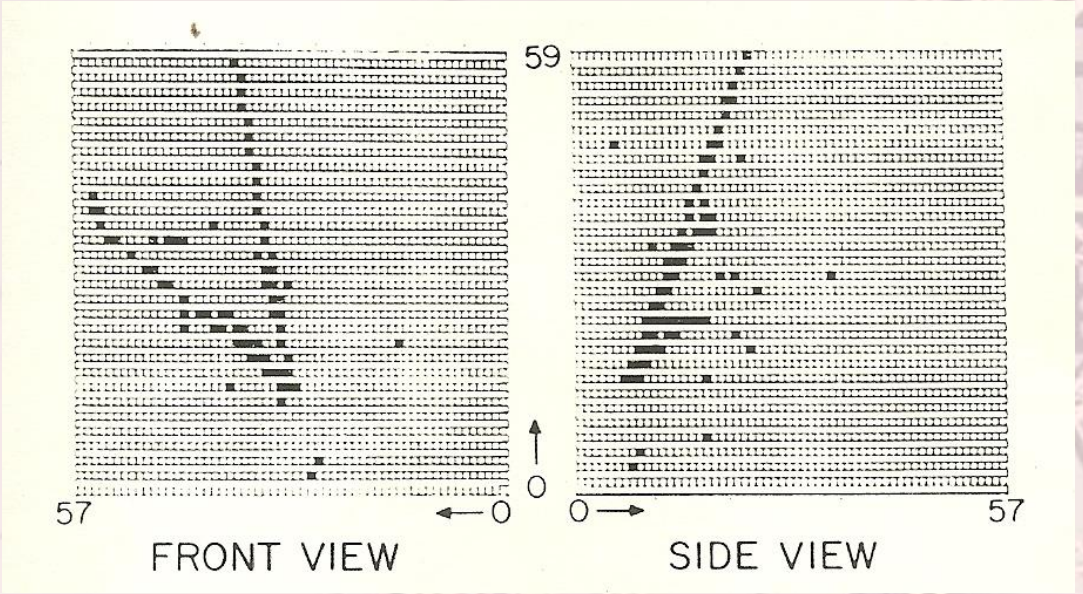
Inauguration of KGF Phase-II Nucleon Decay Laboratory (1983)

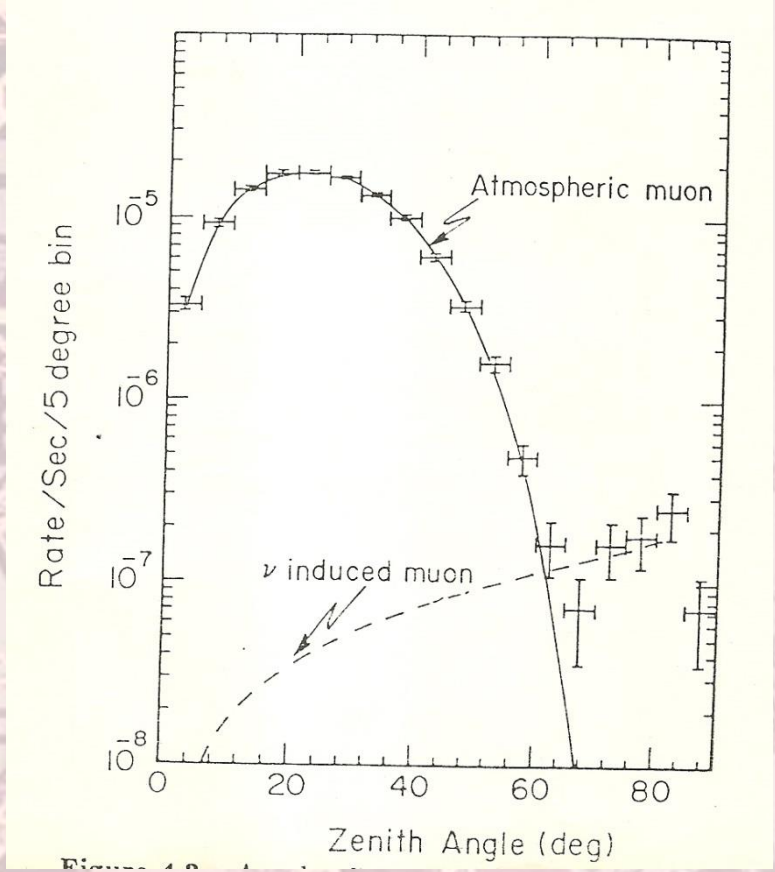
KGF Phase-II Nucleon Decay Experiment 1984-1992



KGF Phase –III Detector

Neutrino Events



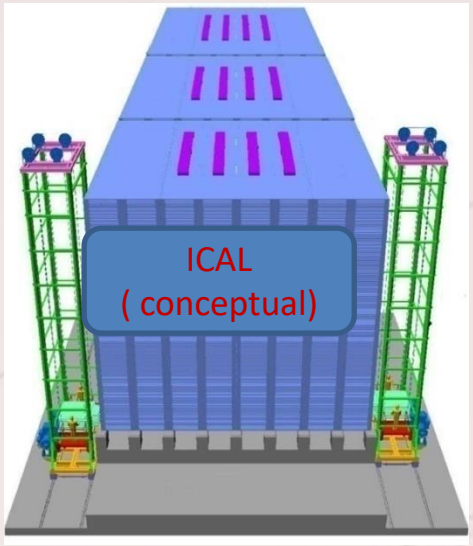


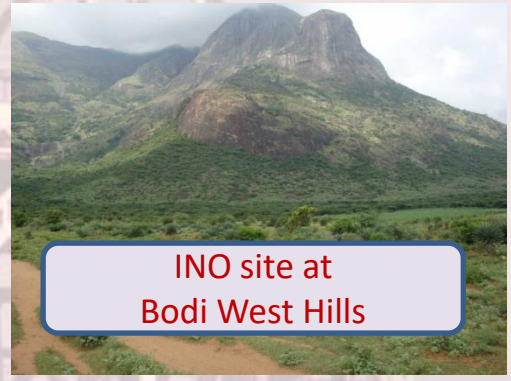
End of Road for KGF Experiments

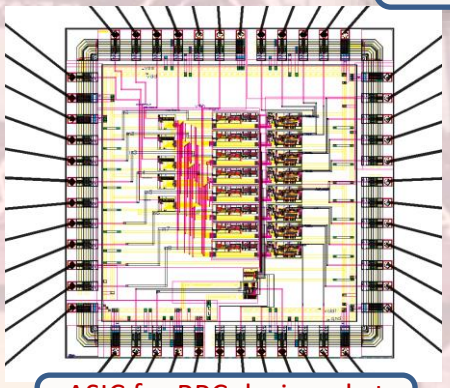
- ***The KGF Experiments, which rode piggy-back on the mining activities, had to be closed down when the mines themselves closed down in 1992.***
- ***A glorious chapter of cutting-edge experimental particle physics research in India using in-house facilities and technologies got ended.***

Champion Reef Mine- Then & Now

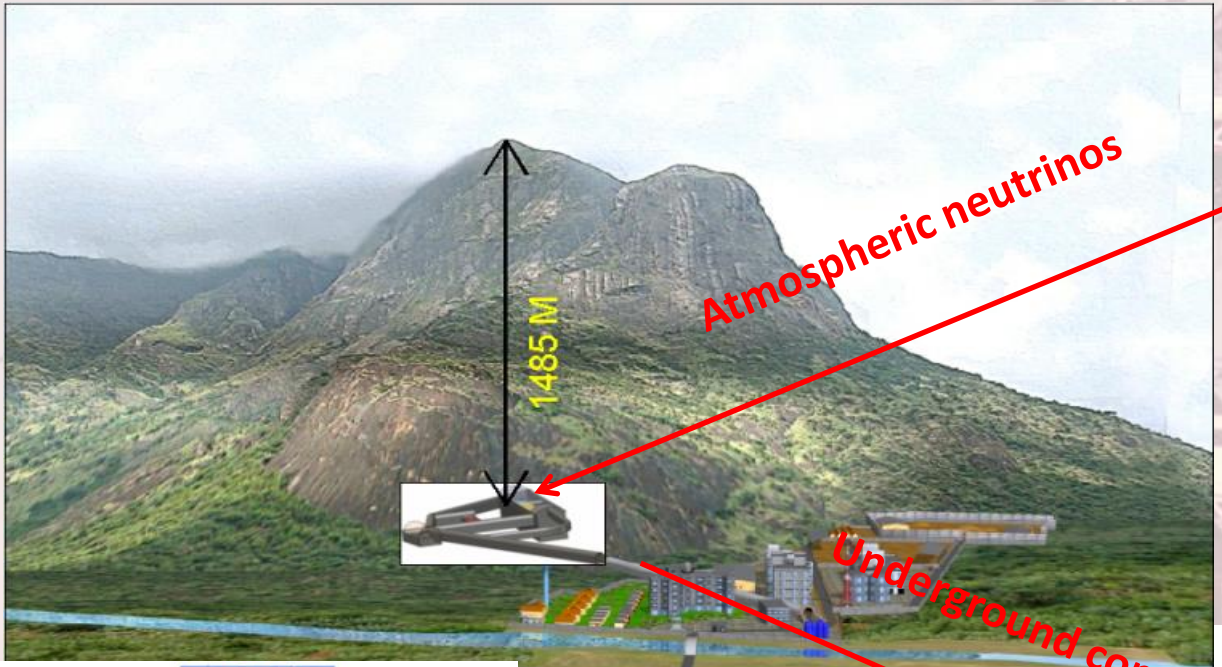
India-Based Neutrino Observatory (INO)

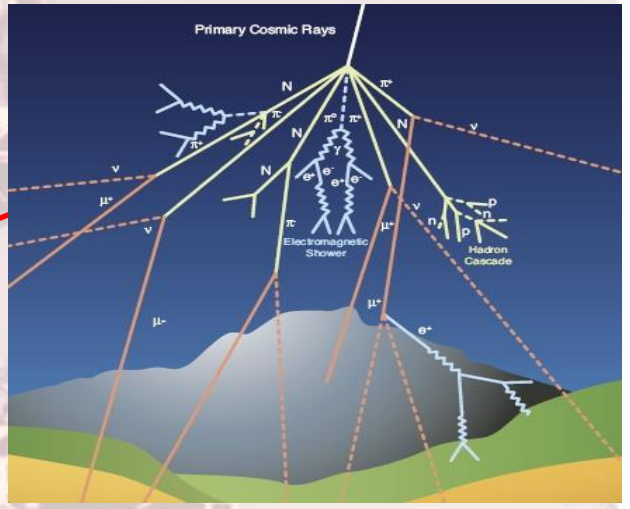


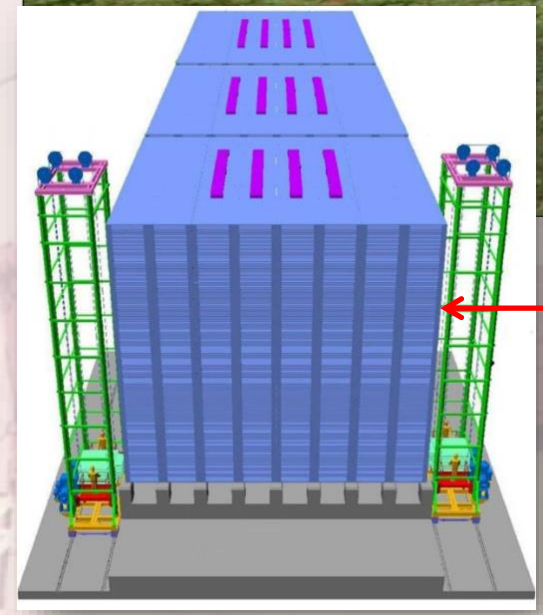


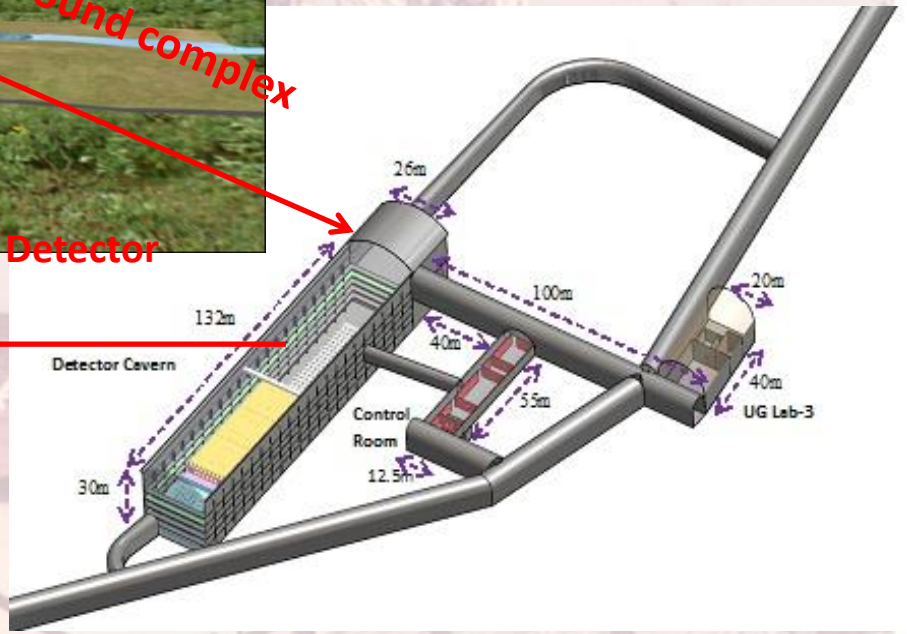


INO site at BodiHills

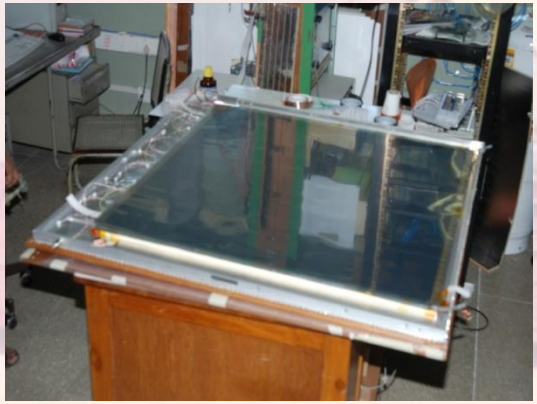






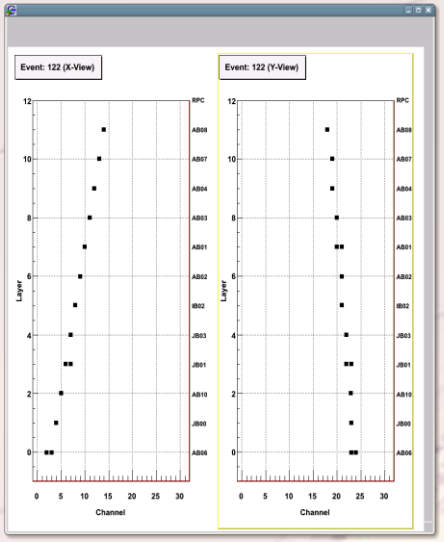


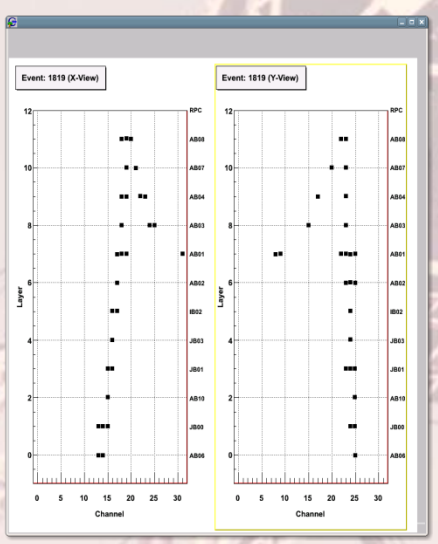
Fabrication of 1m x 1m RPCs

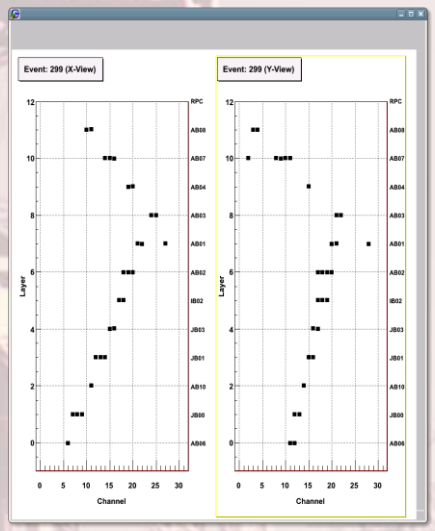


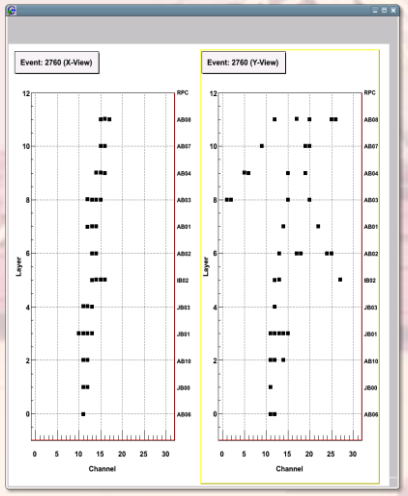
Full size RPC

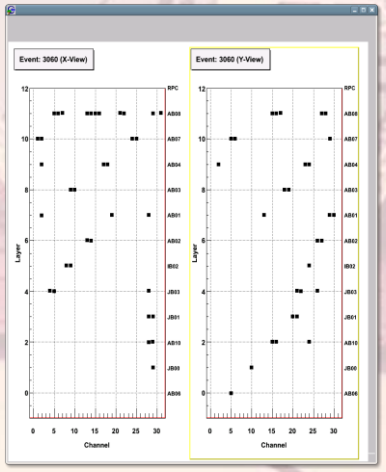
cosmic ray tracks in the RPC stand











Demonstrate the Tracking Capability of the RPC system

mICAL magnet assembly

‘C’ and ‘U’ section Coils

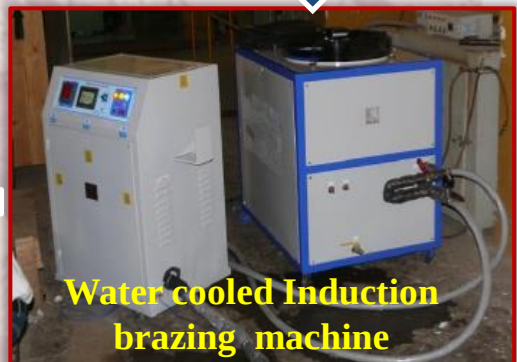
Placement of ‘U’ coils

Iron plate lifting using gantry

Iron plate placing on Pedestal

Coil Hydrostatic Pressure test

Description	Size
Size of magnet	4m x 4m x 1.1m
Weight of the magnet	~ 85 tons
No of Iron detector layers	11
No of RPC detector layers	10
No coils	2



Induction brazing in progress

In-situ brazing of upper “C” and lower “U”

Future perspective

Our field allows students, engineers, scientists to put their heads together, develop technologies, tools, before even starting the experiment. This is a great learning experience. Students and engineers who will go through this grilling period will be better equipped to face the new technological challenges of the emerging world --whether they continue in the field or venture out to other areas later. They will always go out with a "we can do it" mind set.

Why India should be interested in neutrino detection ?

- *Excitement of carrying out front ranking research in the exciting area of neutrino physics.*
- *Will address a key question in neutrino physics- Neutrino mass ordering.*
- *Help us to pick up the correct theory beyond Standard Model of particle Physics.*
- *Will learn how matter behaved at extremely high energies existed in the early stage of our universe.*
- *Will develop various cutting edge technologies for developing state of the art particle detectors.*
  - *Massive 50 kton magnet*
  - *Sophisticated state of the art electronics*
  - *Online monitoring and Data Acquisition System*
- *Science students across the country will have the opportunity to participate in building each of these components from scratch . Many are already doing it.*
- *It will create an ambiance of doing things with our own hands. A culture that is lacking in India*

Future Possibilities - my personal views

- ***Explore the possibility of exploiting some of the existing or upcoming facilities in the country.***
- ***Upcoming 1 GeV high current proton accelerator can be exploited to study muon and kaon physics.***
- ***There is scope for low background underground experiments for Dark Matter, Axions.***
- ***Possibility of building a coherent neutrino detector around the proposed neutron spallation source - that can be ultimately used to detect supernova neutrinos.***
- ***Solar neutrino spectroscopy – this is going to be the next frontier in solar neutrino studies.***
- ***Take advantage of high neutrino flux from Kudankulam reactor complex.***

Future outlook

- *India had a glorious past in the area of Cosmic Rays/High Energy Physics Experiments using detectors/instrumentation developed in-house.*
- *While efforts to setup a new atmospheric neutrino experiment is unsuccessful so far due to non-scientific hurdles created by activists and politicians- We should not give up hope.*
- *There are many ways to exploit the existing or upcoming facilities with new ideas for setting up HEP experiments.*
- *A strong Experimental HEP program at home is also important for developing expertise for our meaningful participation in international programs.*
- *I urge you all to have a brainstorming session to take stock and move forward.*