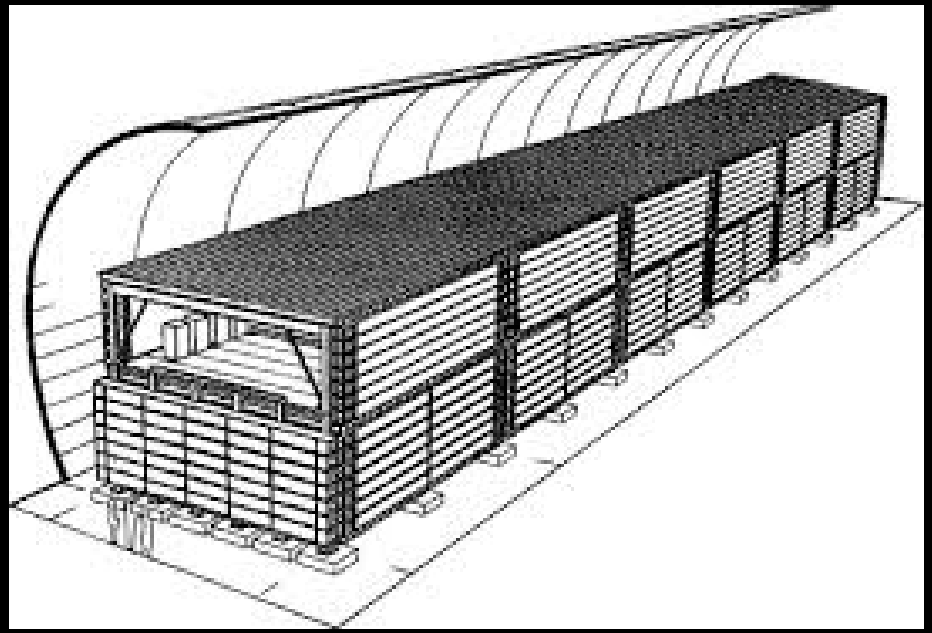
MACRO – 40 Years Later



Barry C Barish
27-June-2025

A Personal History – How did it all Begin?

Caltech Oral History – 1998
Interviewed by Shirley Cohen

- - Performed First Neutrino Experiment at Fermilab 1967-1972
- - Interested in Magnetic Monopoles, since I first saw Maxwell's Equations
- - Lectured at Scottish Summer School on Neutrino Physics in 1980
- - t'Hooft on Grand Unified Theories – Magnetic Monopoles

- This triggered my long-term interest in why we had found no magnetic monopoles in nature.

The Topological Mechanism for Permanent Quark Confinement in Quantum Chromodynamics

#4

Gerard 't Hooft (Utrecht U.) (Aug, 1980)

Contribution to: 21st Scottish Universities Summer School in Physics: Gauge Theories and Experiments at High Energies, 0337

cite reference search 0 citations

Neutrino Physics

#6

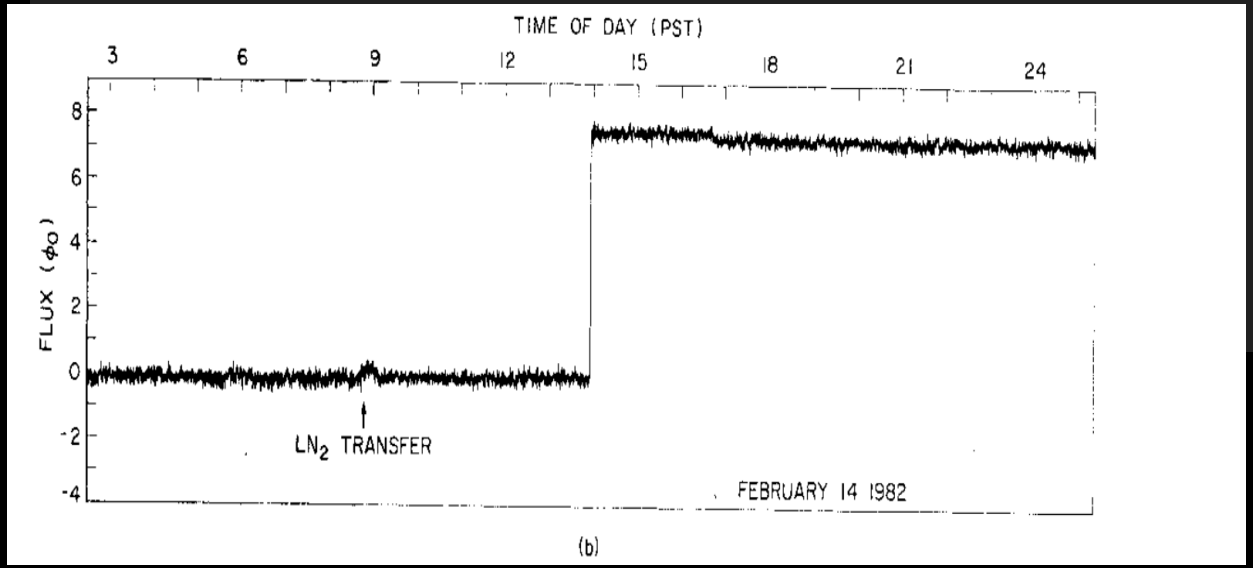
B.C. Barish (Caltech) (1980)

Contribution to: 21st Scottish Universities Summer School in Physics: Gauge Theories and Experiments at High Energies, 303-336

A Personal History – The Birth of Macro

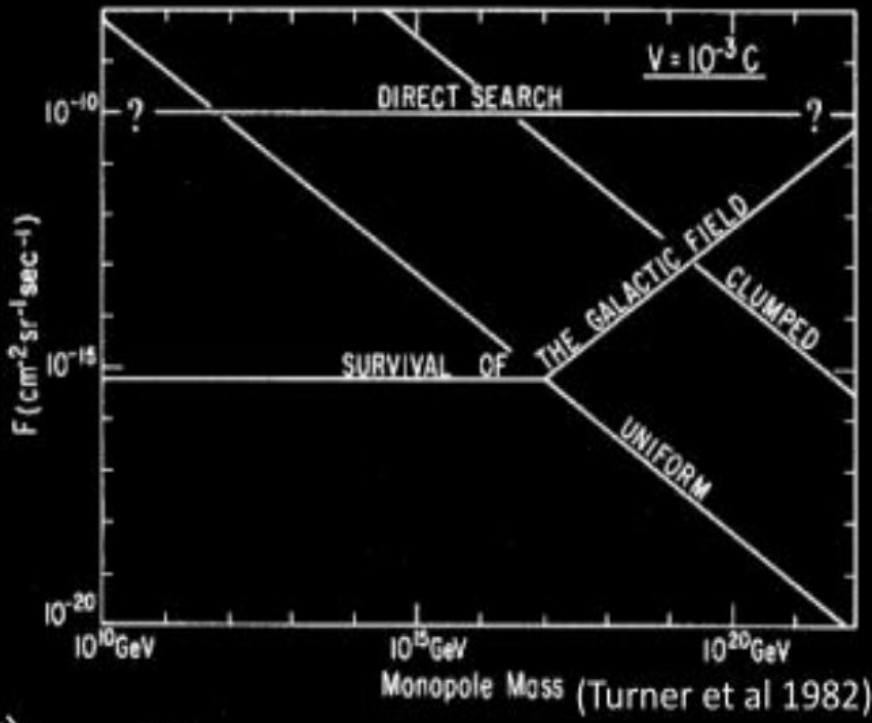
Caltech Oral History – 1998
Interviewed by Shirley Cohen

- - Announcement of Monopole Detection by Blas Cabrera in 1982



Monopole Problem

- Density constraint in terms of flux F: Monopoles hitting unit area per unit time



(Turner et al 1982)

- Uniform distribution:

$$F \approx \frac{n_{\mathrm{mon}} v}{4\pi} \lesssim 10^{-15} \left(\frac{10^{16}\,\mathrm{GeV}}{M}\right)\left(\frac{v}{10^{-3}c}\right) \mathrm{cm}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

Developments - U.S. toward Large Scale Detector (pre-MACRO)

- - I began a technical development program at Caltech toward building a large-scale detector
- - My idea was to use large Aluminum plates, readout magnetostrictively, to be shallow buried under ground below large athletic field
- - An informal group was formed in the U.S. to pursue large scale detector to be sensitive an order of magnitude below the Parker Bound.
- - We concluded that we could use ‘standard techniques,’ if we could build detector deep underground
- - Met Enzo Iarocci, began working on proposal for Gran Sasso
- - Wrote proposal at Caltech, submitted 1984-85

CONFERENCE HIGHLIGHTS AND SUMMATION - EXPERIMENTAL

Giorgio Giacomelli

CERN
Geneva, Switzerland

and

University of Bologna
INFN, Sezione di Bologna
Bologna, Italy

ABSTRACT

The experimental results presented at the "Monopole '83" workshop are reviewed and discussed.

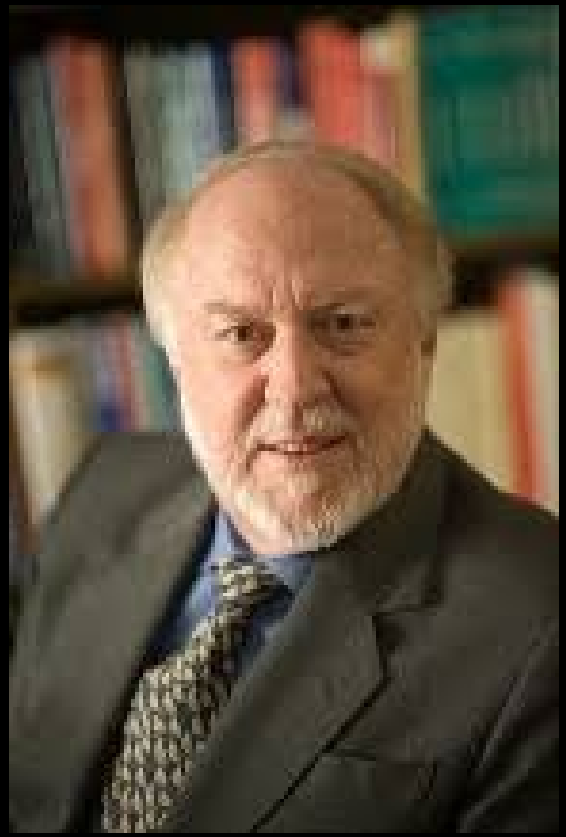
INTRODUCTION

Before 1931 the subject of magnetic monopoles had received little attention in isolated discussions concerning the symmetries of Maxwell's equations, the analysis of the pole-electron system and the magnetic content of matter.

In 1931 Dirac introduced the magnetic monopole in order to explain the quantization of the electric charge.[1] From 1931 until 1974 a number of experimental searches were performed in cosmic rays, at accelerators and in bulk matter in order to find what we may now call the "classical monopole," characterized by a large magnetic charge and a relatively small mass.[2] During the same period, a slightly larger number of theoretical and phenomenological papers tried to resolve some specific problems, like the energy loss of monopoles, the meaning of the "tail" of the monopole, etc.

In 1974 't Hooft and A.M. Polyakov proved that all gauge

J. L. Stone (ed.), *Monopole '83*



Published 1983 | Version v1

Book Metadata-only

The IMB proton decay detector

Svoboda, R.C.[1]; Gajewski, W.[2]; Kropp, W.R.[2]; Reines, F.[2]; Schultz, J.[2]; Smith, D.W.[2]; Sobel, H.[2]; Wuest, C.[2]; Bionta, R.M.[3]; Cortez, B.G.[3]; Errede, S.[3]; Foster, G.W.[3]; Greenberg, J.[3]; Park, H.S.[3]; Shumard, E.[3]; Sinclair, D.[3]; Stone, J.L.[3]; Sulak, L.R.[3]; Velde, J.C. van der[3]; Goldhaber, M.[4]; Blewitt, G.[5]; Lehmann, E.[5]; LoSecco, J.M.[5]; Bratton, C.B.[6]; Learned, J.[1]; Svoboda, R.[1]; Jones, T.W.[7, 3]; Ramana Murthy, P.V.[4, 3, 2]

Show affiliations

A description is given of the Irvine-Michigan-Brookhaven proton decay detector which is nearing completion in a salt mine in Cleveland, Ohio, U.S.A. The detector is a water Cerenkov one with a fiducial volume of 4,000 tons and a threshold of 24 MeV. Initial results indicate that the detector is working according to specification and has a high potential for deep underground cosmic ray applications. I will give a brief account of the IMB detector construction and operation and also its present status and possible cosmic ray applications. (orig.)

Writing the MACRO Proposal at Caltech (1984?)

Barish, Iarocci, Tarle, Giacomelli …

Name: Monopole, Astrophysics, and Cosmic Rays Observatory

Proposed: 1984,

Approved: Apr 30, 1985,

Started: Feb 27, 1989,

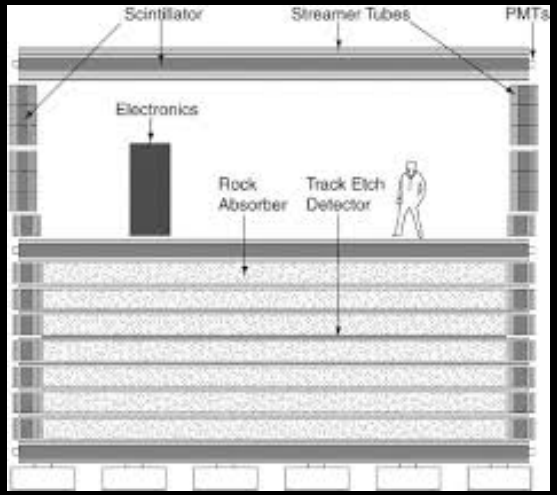
Completed: 2000

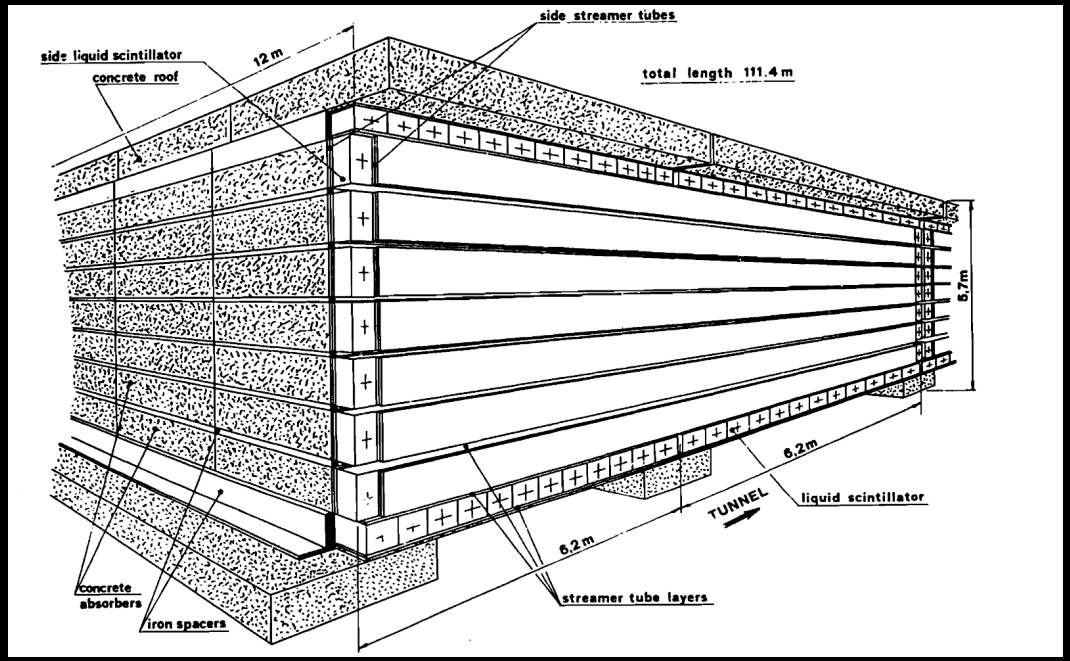
(Tarle – Reported on MACRO Concept at ICRC 1985)

MACRO Proposal Concept

MACRO at GRAN SASSO

Monopole, Astrophysics, and Cosmic Ray Observatory





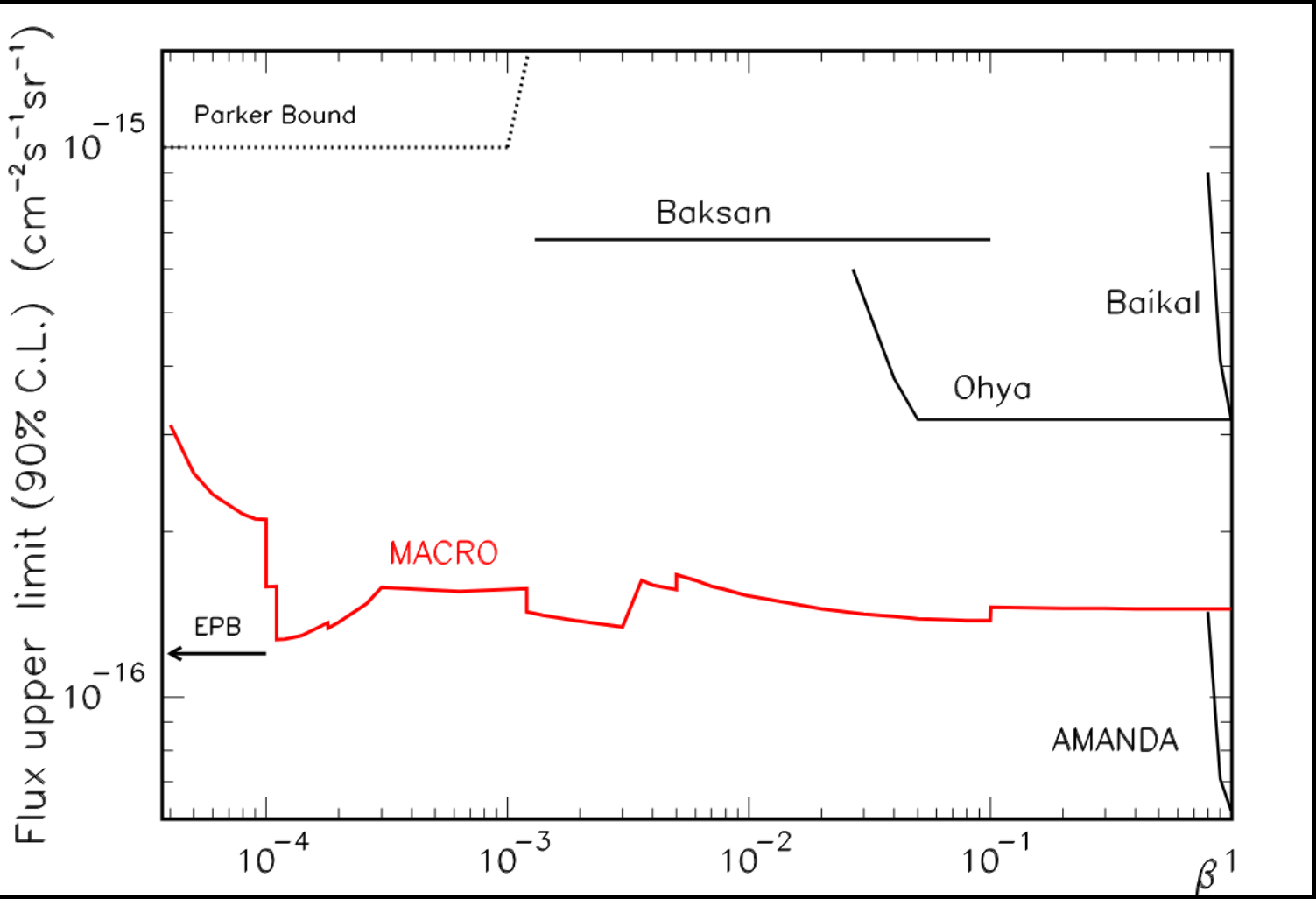
Magnetic Monopoles

Eur. Phys. J. C 25, 511–522 (2002)
Digital Object Identifier (DOI) 10.1140/epjc/s2002-01046-9

THE EUROPEAN PHYSICAL JOURNAL C

Final results of magnetic monopole searches with the MACRO experiment

Abstract. We present the final results obtained by the MACRO experiment in the search for GUT magnetic monopoles in the penetrating cosmic radiation, for the range $4 \times 10^{-5} < \beta < 1$. Several searches with all the MACRO sub-detectors (i.e. scintillation counters, limited streamer tubes and nuclear track detectors) were performed, both in stand alone and combined ways. No candidates were detected and a 90% Confidence Level (C.L.) upper limit to the local magnetic monopole flux was set at the level of 1.4×10^{-16} cm^{-2} s^{-1} sr^{-1}. This result is the first experimental limit obtained in direct searches which is well below the Parker bound in the whole β range in which GUT magnetic monopoles are expected.


Flux upper limit (90% C.L.) (cm^{-2}s^{-1}sr^{-1})
10^{-15}
10^{-16}
Parker Bound
Baksan
Baikal
Ohya
MACRO
EPB
AMANDA
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
β

Neutrino Oscillations

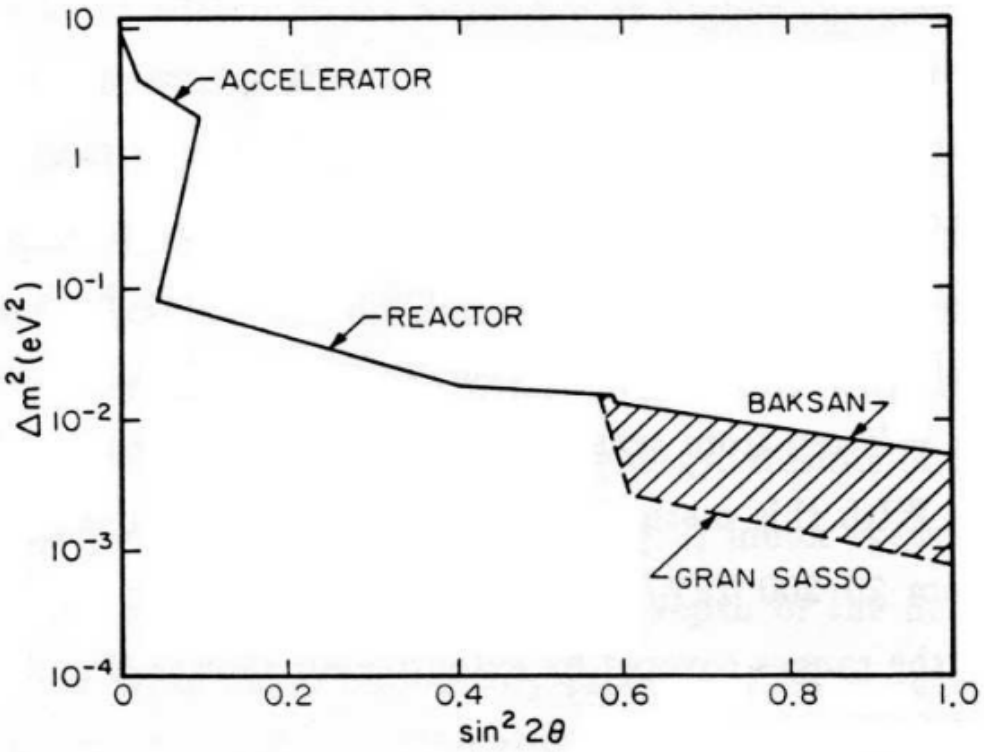
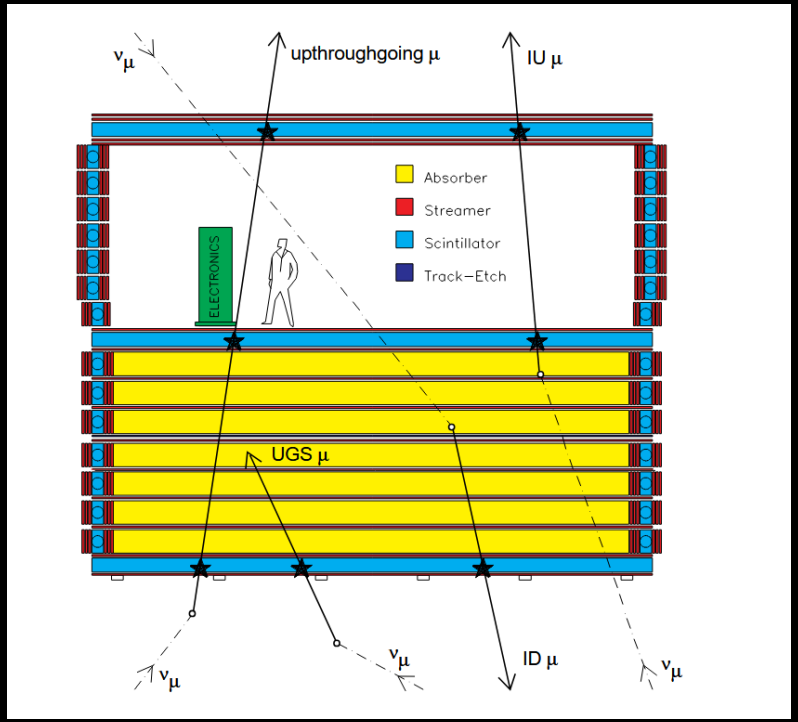
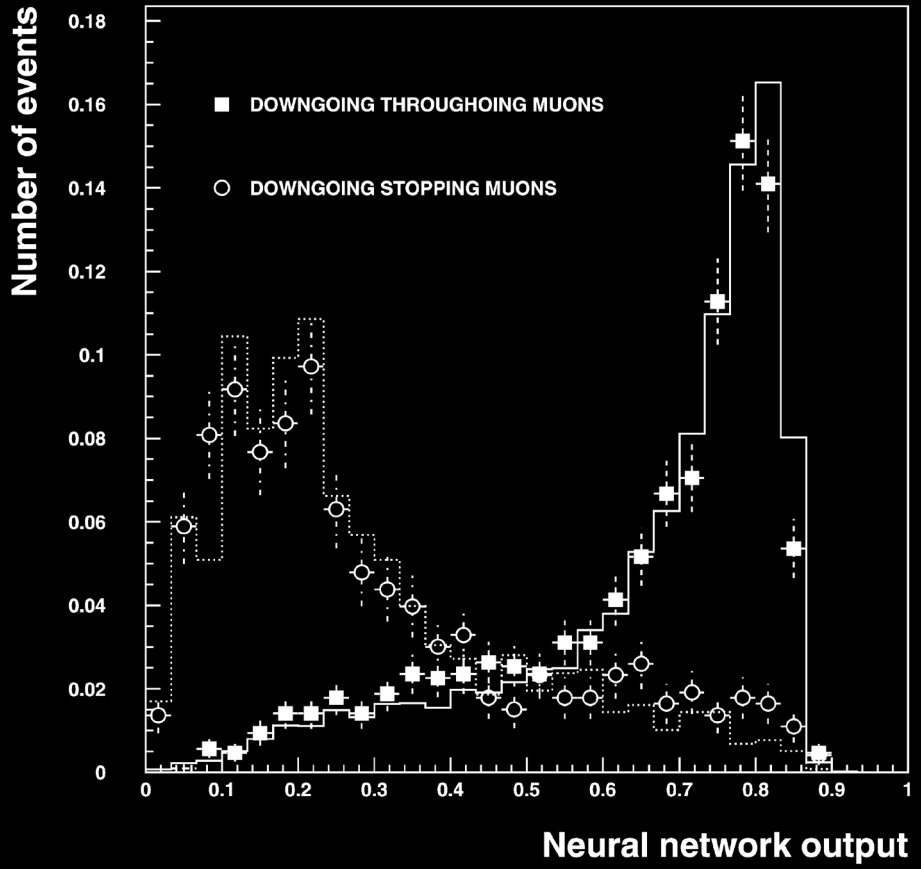


Fig. (2)13 Present best limits on Δm^2 vs. $\sin^2 2\theta$. The shaded region represents the improvement obtainable with our experiment.

Neutrino Oscillations





MACRO – Early Evidence for Neutrino Oscillations

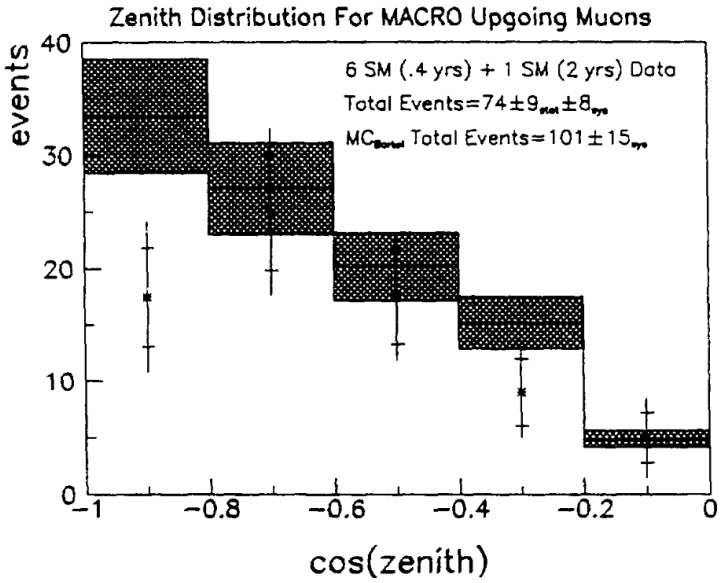


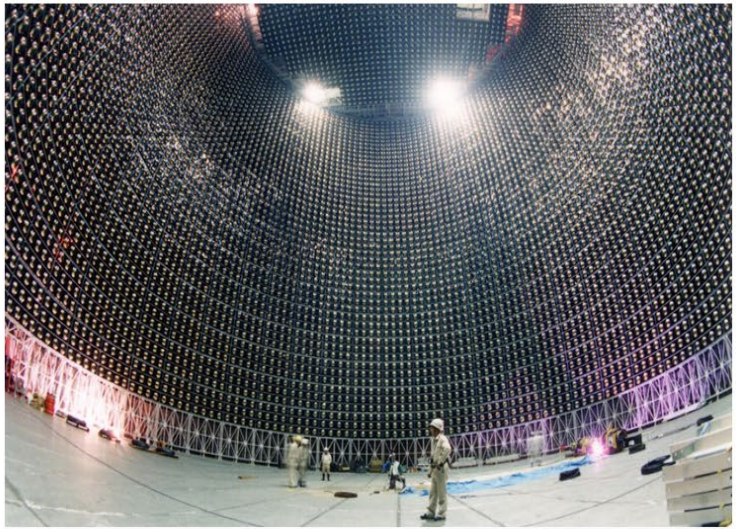
Fig. 7. Distribution of cos (*zenith*) for the upgoing muon flux for a data tacking period equivalent to 0.65 y with 6 lower supermodules. The extensions to the statistical error bars are the point-by-point estimates of the systematic error. The Monte Carlo expectation using the Bartol flux is shown in the shaded regions with a ±15% systematic error range.

Giacomelli at Trieste Mtg – July 1995

MACRO should be able to give an important contribution at the end of the current run and when all systematic uncertainties will be understood.

Giorgio Giacomelli

SuperKamiokande – Announces Evidence for Neutrino Oscillations – June 1998

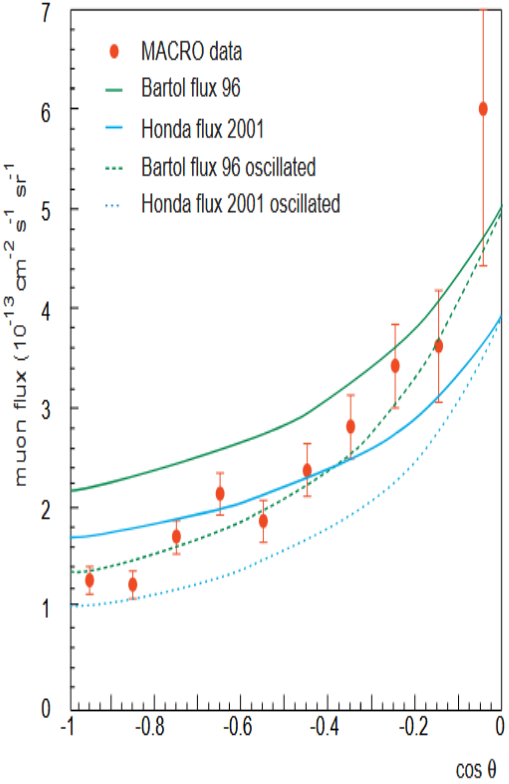


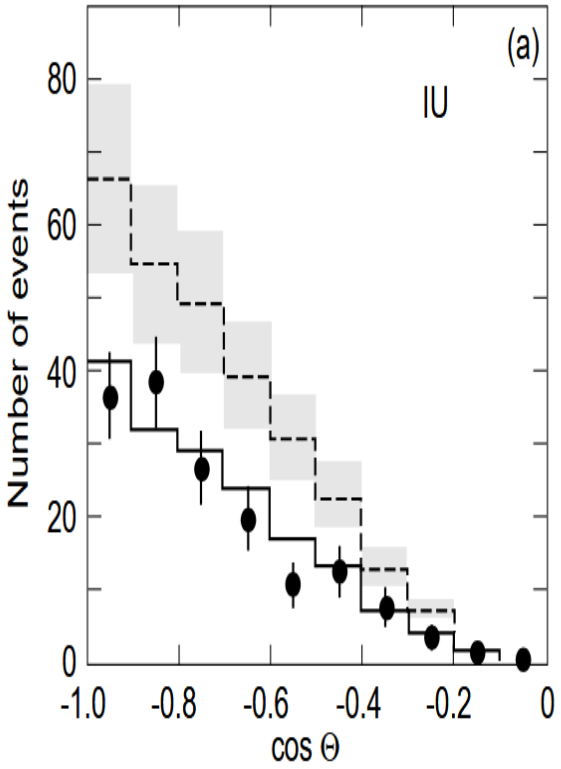
Inside SuperKamiokande

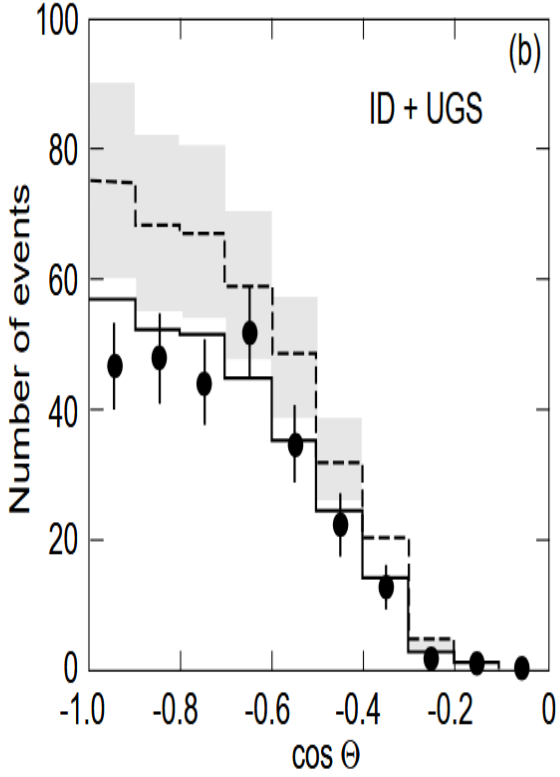
The debate has been solved by the SuperKamiokande experiment that started in 1996. After two years of data taking, SuperKamiokande announced in June 1998 the clear observation of a deficit of muon-neutrinos coming from the antipodes [Fuk98b]; this deficit has been almost immediately interpreted as an oscillation between muon-neutrino and tau-neutrino.

At the same time, the calorimetric MACRO [Amb98] and Soudan 2 [All97] experiments had observed the atmospheric neutrino anomaly, but with a statistical significance insufficient to claim that neutrinos would oscillate.

Neutrino Oscillations in MACRO (2002)





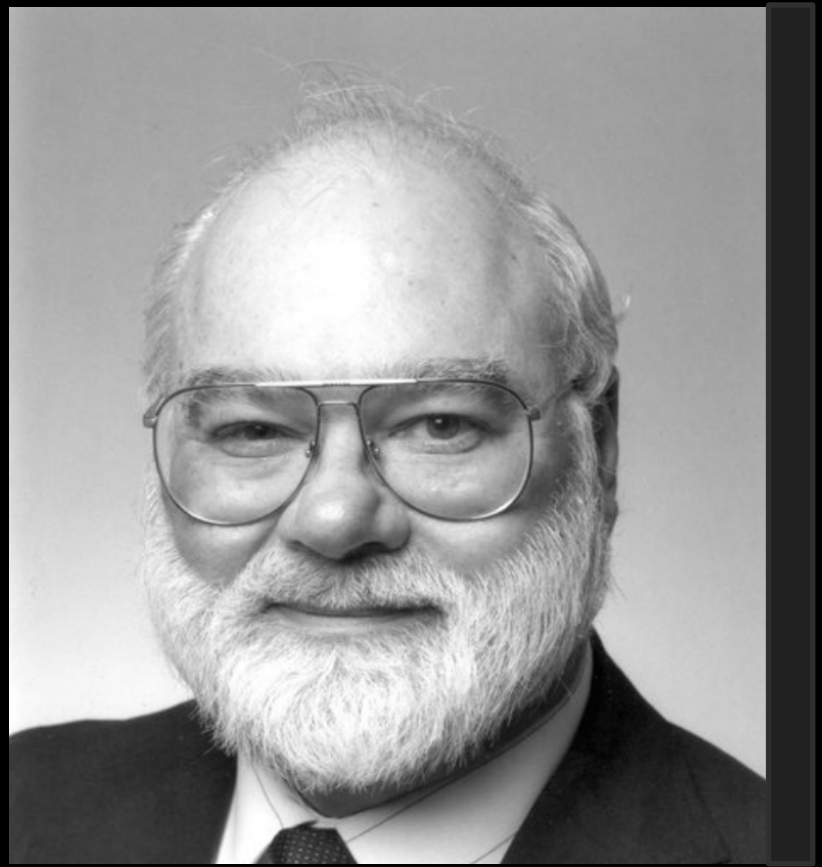


Tribute to Doug Michael

Doug did his graduate work in physics at Harvard, receiving his Masters degree in 1984 and his PhD in 1990. His thesis experiment, performed under the guidance of Frank Pipkin and Dick Wilson, was E-665, a study of deep-inelastic muon scattering at Fermilab's Tevatron. Upon graduation, he moved to Caltech, where he became an essential member of an energetic group building the MACRO experiment to search for magnetic monopoles at Gran Sasso. Doug's work on MACRO fuelled his strong interest in neutrino physics and led to his proposal in 1994 for GENIUS, a long-baseline neutrino-oscillation experiment at Fermilab. He became a founding member of the MINOS collaboration that same year and was instrumental in designing and constructing the MINOS long-baseline

From CERN Courier

Tribute to Charlie Peck



With his longtime friend and colleague Barry Barish, Ronald and Maxine Linde Professor of Physics, Emeritus, Peck was one of the leaders of a large international collaboration that performed a search for magnetic monopoles. Magnetic monopoles are the magnetic analog of single electric charges and have been sought for more than 100 years. They could provide a key confirmation of Grand Unified Theories that seek to unify three of nature's four forces—the electromagnetic, weak, and strong forces—into a single force. The experiment, MACRO (Monopole, Astrophysics, and Cosmic Ray Observatory), was located 3200 feet under the Grand Sasso mountain in Italy. Although the experiment did not find magnetic monopoles, it set what are still the most stringent limits on their existence.

"My favorite image of Charlie was 6000 miles from Pasadena deep under the Gran Sasso mountain, where he was patiently sitting and explaining physics to our graduate students," Barish says.

From Caltech Obituary

The MACRO experiment and its legacy: more than three decades of astroparticle and neutrino physics

MACRO at GRAN SASSO

Monopole , Astrophysics , and Cosmic Ray Observatory