CONF-900122--8

ANL-HEP-CP--89-92

DE90 005648

ANL-HEP-CP-89-92
PDK-402
AUGUST 23, 1989

HE 4.5-10

CONTAINED EVENTS IN SOUDAN 2

W. W. M. Allison[3], G.J. Alner[4], I. Ambats[1], D. Ayres[1], L. Balka[1], G.D. Barr[3], W.L. Barrett[1], D. Benjamin[5], P. Border[2], C. B. Brooks[3], J. H. Cobb[3], D.J.A. Cockerill[4], H. Courant[2], B. Dahlin[2], J. Dawson[1], V.W. Edwards[4], B. Ewen[5], T. Fields[1], L. M. Kirby-Gallagher[3], C. Garcia-Garcia[4], R. H. Giles[3], M.C. Goodman[1], S. Heppelmann[2], N. Hill[1], D.J. Jankowski[1], K. Johns[2], T. Kafka[5], J. Kochocki[5], P. J. Litchfield[4], N. Longley[2], F. Lopez[1], M. Lowe[2], A. Mann[5], M. Marshak[2], E. May[1], L. McMaster[5], R. Milburn[5], W. Miller[2], A. Napier[5], W. Oliver[5], G. F. Pearce[4], D. H. Perkins[3], E. Peterson[2], L. Price[1], D. Roback[2], D. Rosen[2], K. Ruddick[2], B. Saitta[5], D. Schmid[2], J. Schlereth[1], J. Schneps[5], S. Schubert[2], P. D. Shield[3], N. Sundaralingam[5], M. A. Thomson[3], J. Thron[1], S. Werkema[2] and N. West[3]

1. Argonne National Laboratory, Argonne IL 60439, USA;
2. University of Minnesota, Minneapolis MN 55455, USA;
3. University of Oxford, Oxford OX1 3RH, UK;
4. Rutherford-Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX, UK;
5. Tufts University, Medford MA 02155, USA

Abstract

A search for contained events in the Soudan 2 nucleon decay detector has been made for the initial exposure of the first quarter of the 1.1 kiloton detector. This corresponds to an exposure of .083 kiloton years in the fiducial volume. We observe 5 ν_μ candidate events and 5 ν_e candidate events. Results of Monte Carlo simulations of neutrino events and proton decay events in Soudan 2 are compared.

Introduction The Soudan 2 detector began contained-event data acquisition with the first quarter of the main detector (275 tons) in September 1988, and has accumulated a total exposure of 0.159 kton-year (.083 fiducial kton-year) to date (August 1, 1989). Ten contained neutrino scattering events have been identified. Completion of the 1100-ton detector is planned for 1992. This report describes the analysis techniques that are being developed to identify the contained event candidates, which would include the atmospheric neutrino interactions and any candidates for nucleon decay. The analysis chain includes the hardware trigger, an offline filter program, physicist scanning, and incorporation of information from a 4π active shield. Several events are used to illustrate features of the detector which will help identify neutrino induced events and thereby achieve low backgrounds in many possible nucleon decay modes.

The analysis chain The detector has been described previously.[1,2] Briefly, it will be a 1100 ton tracking iron calorimeter with excellent spatial resolution, particle identification capability and low trigger threshold. Each one of the 256 modules consists of 3780 15-mm diameter by 1 m long plastic drift tubes in a honeycomb matrix of 1.6-mm thick corrugated steel sheets. Information along the drift direction is pulse height analysed and time digitized with a clock running at 5 Megahertz. The pulse is shaped by electronics with a rise-time of 200 nanoseconds. Tubes are oriented to line up with vertically running anode wires and horizontally connected rows of cathode pads. The information from each event then consists of anode channel versus time and cathode channel versus time pulse profiles (See Figure 1.) Pulse height in each time bin is digitized by a 6-bit flash ADC. In the figure, the space between channel numbers is used to indicate the pulse height profile. Time information and pulse shape profiles are then used to match anode and cathode pulses and give a full three dimensional reconstruction for each gas crossing in the event.

The trigger consists of ≥ 7 anode "edges" on 16 adjacent channels anywhere in the detector.

SUBMITTED TO 21ST INT'L COSMIC RAY CONF., UNIV. OF ADELAIDE, AUSTRALIA, JAN. 6-19, 1990

Work supported by the U.S. Dept. of Energy, Div. of High Energy Physics, Contract W-31-109-ENG-38.

An edge is defined as the beginning of a pulse at a unique time. Several clock cycles of a single pulse count towards a single edge. More importantly, several different channels which start at the same clock cycle count only towards a single edge. This distinguishes the trigger from a local multiplicity trigger. The edge trigger was needed in order to successfully exclude low energy Compton electrons from natural radioactivity which traverse along the wire plane directions adjacent to a large number of anode wires. The edge requirement in the trigger also reduces our acceptance to events that lie in the plane of constant drift time in the detector. Monte Carlo studies show that this loss of acceptance is less than 10% for most proton decay modes. As the detector size increases, a cathode edge trigger requirement will be added to the hardware.

With the quarter of the full detector (275 tons) running, the measured trigger rate for ≥ 7 anode edges was 0.25 Hz. For the .083 fiducial kiloton year exposure, this corresponds to about 4.5 million triggers. About half of these events are cosmic ray muons, and the other half are random coincidences of radioactivity hits which are summed together from different locations in the detector. A filter program has been developed to quickly identify both through-going muons and random radioactivity hits in order to create a manageable scan load with no loss of efficiency for real contained events. That program has been evolving as experience has been gained with these backgrounds. Here we describe the latest version of the filter program.

Most throughgoing muons enter the detector near the top and exit it through the bottom. Although many anode and cathode channels are summed together in the electronics readout systems, the relative track orientation with respect to the edge of the detector is preserved. For example, the top cathode layer in one module is only summed with top cathode layers in other modules. Thus without event reconstruction, those channels which correspond to locations within 50 cm of the outside surfaces of the detector in anode and cathode directions (x and y) are immediately identifiable. The filter program rejects events where a simulated anode trigger of 6 edges, or a simulated cathode trigger of 4 edges is satisfied within 50 cm of the detector outside surfaces.

The filter program also eliminates triggers which are caused by random coincidences of local radioactivity in different parts of the detector. This happens when hits are summed by the electronics so that they appear to be in nearby adjacent anode channels. These events are eliminated by requiring 4 cathode edges in a group of 16. The filter program also identifies events which project such that they may enter and leave through the cracks between modules.

Events which pass the filter are then scanned by two or more physicists. About 0.1% of the events are presently scanned. Events caused by local radioactivity are thrown out. Others are clearly not contained because there are hits outside of the fiducial volume, or they entered or exited at cracks. For the remaining events, the hits in the shield are examined. A two layer hit in the shield, time coincident with the event in the main detector, is an indication that the event is not contained. The remaining events are the contained event sample and are candidate neutrino events. A total of ten contained events were so identified, all of them apparently quasielastic charge current ν scatters: 5 were ν_e events, 3 were ν_μ and 2 were $\overline{\nu_\mu}$, determined by the presence of a decay electron. A candidate ν_μ event is shown in Figure 1. A candidate ν_e event is shown in Figure 2.

Our ability to cleanly separate ν_e and ν_μ events is based on event topology criteria developed from the study of monte carlo events and test beam e and μ events at the Rutherford ISIS beam. Analysis of the test beam data is in progress.

<u>Atmospheric Neutrino Monte Carlo</u> A Monte Carlo program has been written to simulate atmospheric neutrino interactions in our detector.[3] The atmospheric neutrino spectrum has been calculated from a solar cycle dependent neutrino flux.[4] Resonance production is modelled using the phenomenology developed by Rein & Sehgal.[5] Cross sections for nonresonant high multiplicity processes are calculated using the deep inelastic formalism of the parton model.[6] KNO scaling determines the hadronic multiplicity of nonresonant inelastic events. The total charged

current event rate and trigger efficiency are given in Figure 3 as a function of energy.

A trigger simulation program and the contained event filter program have been run on Monte Carlo generated events within the first quarter of the detector. For the .083 Kty exposure, we expect to have detected 9 events to date, assuming a scanning efficiency of 1.0. Our scanning efficiency will be thoroughly checked in subsequent studies.

Conclusion and Prospects We expect to detect about 140 neutrino events per fiducial kiloton year of running. We will be able to measure the ν_e/ν_μ rate and compare with our expected rate of .82 for all charged current events and .81 for quasi-elastic interactions. The Soudan 2 detector should enable our experiment to perform a nucleon decay search with much better background rejection than other experiments have been able to achieve.

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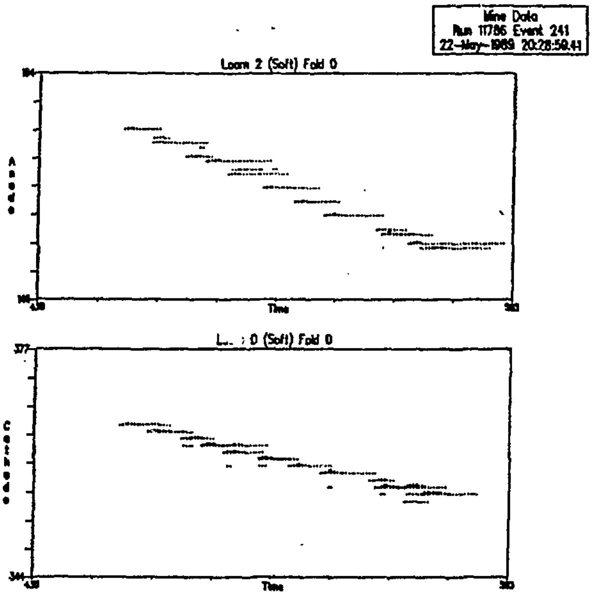

Figure 1. Two views of a quasi-elastic ν_μ event. The anode (top) view shows a region of the detector 68 cm (vertical scale) by 22 cm (horizontal scale). The cathode (side) view shows a region 17 cm by 22 cm. Each hit is displayed as a time sequence of digitized pulse height. The μ range is 3ɜ cm which corresponds to a μ momentum 180 MeV/c.

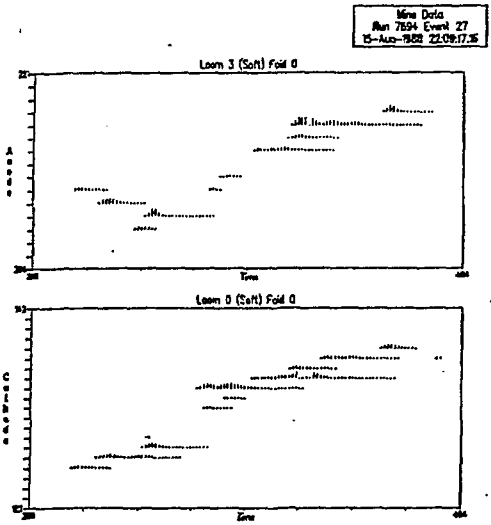

Figure 2. Two views of a quasi-elastic electron neutrino event. The anode (top) view shows a region of the detector 23 cm (vertical scale) by 14 cm (horizontal scale). The cathode (side) view shows a region 20 cm by 14 cm. The hit count gives an electron energy of 200 MeV; comparison with test beam events shows the vertex to be at the lower left in both views.

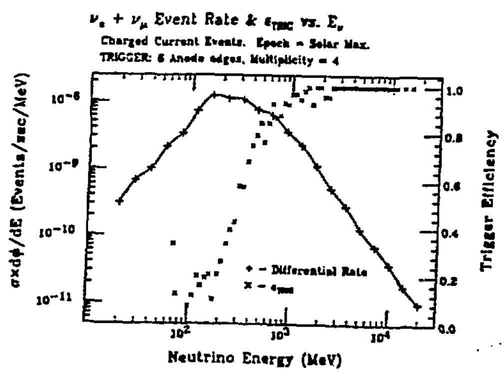

Figure 3. The expected charged current event rate and trigger efficiency.