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NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

SEARCH FOR STELLAR GRAVITATIONAL COLLAPSE BY MACRO: CHARACTERISTICS AND RESULTS

The MACRO Collaboration

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The first MACRO lower supermodule has been sensitive to antineutrinos from stellar gravitational collapse since spring 1989. The results with the 44 tonnes of liquid scintillator which have been instrumented to search for stellar gravitational collapse are discussed here.

The first MACRO lower supermodule (SM1) has been operational since spring 1989 [1]. The detection of $\overline{\nu}_e$ bursts from collapsing stars is based on $\overline{\nu}_e$ interactions in the liquid scintillation counter system, via the primary reaction $\overline{\nu}_e + p \rightarrow n + e^+$, followed by delayed neutron capture in hydrogen $n + p \rightarrow \gamma + d$ with $E_\gamma = 2.2$ MeV. In this note detector improvements and a search for stellar gravitational collapse [2] are reported. At present, MACRO has three lower super modules running with liquid scintillators and six with streamer tubes.

Every one of the six lower supermodules (12 m$\times$12 m$\times$4.5 m) has two horizontal layers each composed of 16 scintillation counters; vertical coun-

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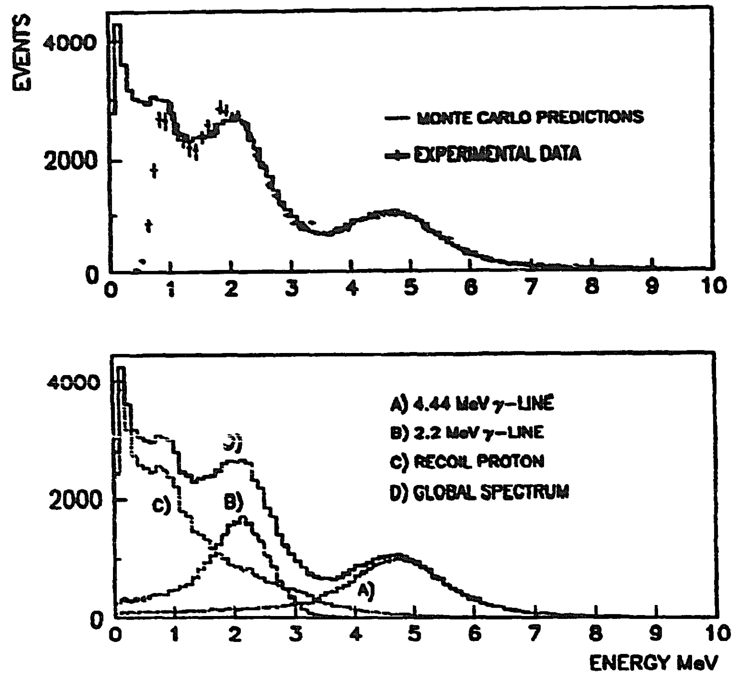

Fig. 1. a) Energy spectrum for events from the Am/Be source. The 4.44 and the 2.2 MeV γ-lines are visible. The histogram is a Monte Carlo simulation. b)The decomposition of the Monte Carlo global result into different contributing processes.

ters cover the sides of the supermodule (21 counters for the three sides of SM1). The horizontal counters were used for the search for stellar collapse (total scintillator mass $\approx$ 44 t); vertical counters were only used to improve the cosmic-ray rejection. Each horizontal liquid scintillator tank is 12 m long and has two 20 cm diameter phototubes at each end; the light transmission along one counter is approximately exponential with $\lambda_{att} \approx 12$ m. The determination of a low-energy event position and energy is based on the measurement of light arrival times and light intensities at the two counter ends.

Two main background sources are present: cosmic rays and natural radioactivity. The cosmic-ray background is small in an underground experiment and may be largely rejected since it yields 'tracks' crossing MACRO. The natural radioactivity background (mostly photons) is concentrated at low energies ($E < 5$ MeV).

The MACRO stellar collapse electronics performs the following functions: i) It provides a trigger for events with an associated energy $E > E_{pth}$, the primary energy threshold, in $\simeq$ 80 ns. Typical E_{pth} values are $5 < E_{pth} < 7$ MeV. ii) It lowers the energy threshold for that counter (and for the adjacent counters) to a secondary energy threshold $E_{sth} \simeq 1.5$ MeV for a time $\simeq$ 1 ms after a primary event in a counter. Secondary events occurring during this time are recorded (a maximum of 14 events), thus allowing the detection of possible 2.2 MeV γ's from delayed neutron capture in hydrogen. iii) It measures with high accuracy ($\sigma \simeq 1$ ns) both the time of each event relative to the experimental atomic clock standard time and the difference in time between the signals from the two counter ends. iv) It digitizes and stores waveforms (100 MHz) relative to the

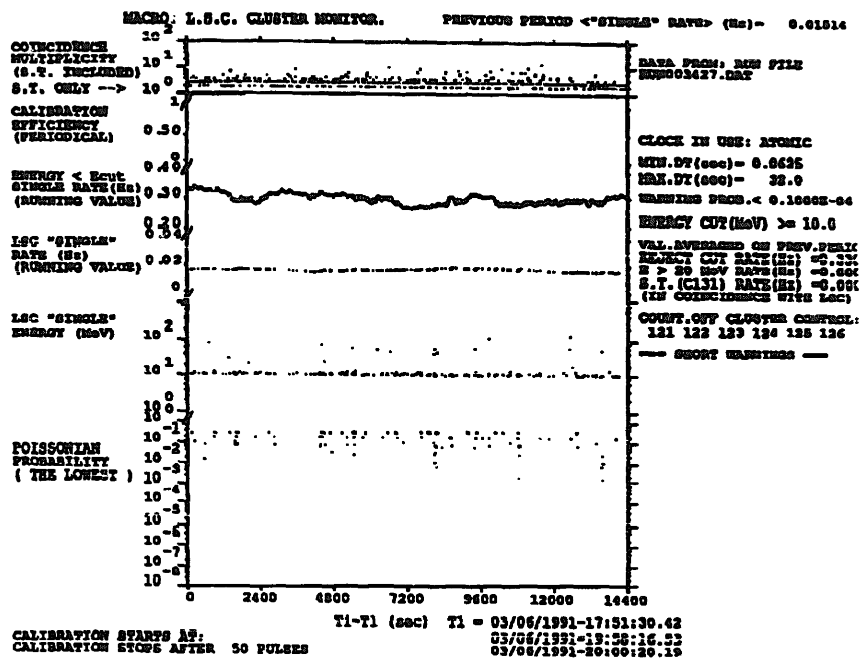

Fig. 2. The on-line monitor. Rates, event multiplicities, etc., are continuously recorded.

primary and secondary events. These waveforms and the time information are used for the off-line event energy and position reconstruction.

An absolute calibration of the energy scale is obtained by analysing cosmic-ray muons, which have an energy loss $\simeq$ 40 MeV in a counter. For relative calibration and test purposes, a variable intensity UV-light laser and an optical fibre system were used. Unavoidable non-linearities over a large energy range and the small cosmic-ray rate ($R \simeq 1$ m^{-2} h^{-1}) suggest the need for an independent absolute energy calibration at low energies ($1 < E < 10$ MeV). This was obtained by the use of a low-intensity Am/Be source, a neutron and γ-ray emitter via the reaction ^{9}Be$(\alpha, \gamma$n$)^{12}$C with $E_\gamma = 4.44$ MeV, externally applied to the scintillation counters [3]. The 2.2 MeV signal from n-capture, which occurs in $\simeq$ 180 μs, is a unique signature to identify $\overline{\nu}_e$ events.

Figure 1 shows the energy spectrum when the Am/Be source is applied to one counter; the 4.44 MeV and the 2.2 MeV γ-lines are both visible. The experimental data are compared with a Monte Carlo calculation, which simulates the Am/Be source emission, γ absorption and detection, n-moderation (by n–p and n–C scattering), n-capture in the liquid scintillator, and the counter geometry. A simultaneous fit to the γ-lines of Fig. 1 gives a measurement of the energy resolution: $\sigma_E \approx 0.6$ MeV at $E = 4.44$ MeV.

The resolution in the longitudinal position along the counter for the 2.2 MeV γ-ray, obtained by the (uncollimated) Am/Be source, is $\sigma_z <$ 1 m. The efficiency for delayed n-capture detection following a primary $\overline{\nu}_e$ event in a counter is $\simeq$ 25%.

Since the data are collected with a rather low energy threshold, they are useful for monitoring the correct behaviour of the scintillation counters and the associated electronics.

A monitor is shown in Fig. 2: rates, event multiplicities, etc., are continuously recorded. In the case of 'anomalies' of any nature (from stellar collapse candidates to apparatus misbehaviour) an alarm is generated; this allows a prompt, more-refined analysis. After gaining sufficient experience about the performance of this monitor, one could transform this device into a 'supernova watch', which might be used to alert, within a few hours, observers interested in studying the early stages of a new supernova.

We present the data collected during a period of about 14 months, from 31 March 1990 to 4 June 1991. The live-time of SM1 during this period was $\simeq$ 84%; the inefficiency was mainly due to interventions for regular maintenance (this problem will be avoided in the near future when most of MACRO will be active even in the case of repairs to one of the supermodules). Events with $E > 10$ MeV were used in this analysis. After applying simple cosmic-ray μ-rejection criteria which make use of the information from all counters and of the μ-trigger signal from the streamer tube system, the final rate obtained was $\simeq$ 15 mHz. We have searched for event clusters within sliding 2 s bins. The resulting multiplicity distribution is shown in Fig. 3 along with the expected Poisson distribution corresponding to the measured rate (histogram). No cluster with more than 3 events was found. If a stellar gravitational collapse equivalent to the one from SN1987A had occurred at the galactic centre, it would have produced $\simeq$ 7 detected events in a 2 s time window. Figure 4 shows the number of times in which clusters of multiplicities 1, 2, 3, or 4 occurred as a function of cluster duration. The expectations according to Poisson statistics are also shown.

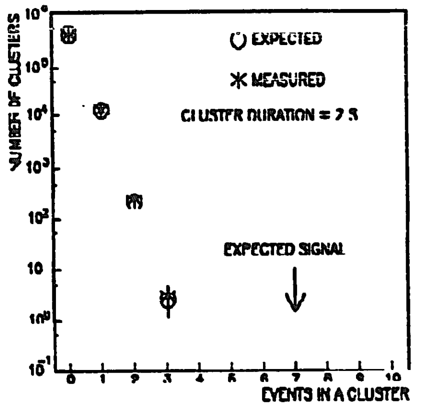

Fig. 3. Number of clusters plotted against number of events in a cluster for a cluster duration of 2 s. Data (*) and expectations (histogram) for the 14 month period.

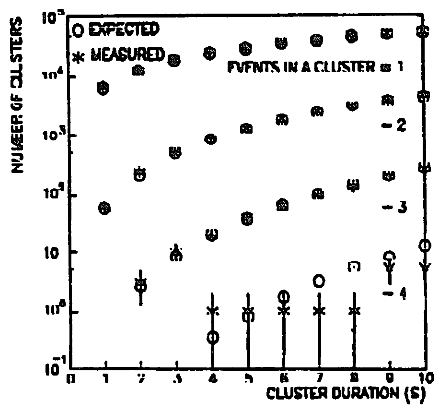

Fig. 4. Number of clusters plotted against cluster duration for different numbers of events in a cluster. Data (*) and expectations (o) for the 14 month period.

References

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