ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-86/59

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Estratto da:
Nuovo Cimento 9C, 551 (1986)

Servizio Documentazione
dei Laboratori Nazionali di Frascati
Cas. Postale 13 - Frascati (Roma)

IL NUOVO CIMENTO VOL. 9 C, N. 2 Marzo-Aprile 1986

Limit on Monopole Flux in the Mont Blanc NUSEX Experiment.

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(ricevuto il 12 Agosto 1985)

Summary. — A trigger dedicated to the search of superheavy monopoles operates since about two years in the NUSEX apparatus, installed in the Mont Blanc tunnel. Monopoles are identified by time of flight and visualization of the pulses involved in a trigger. The present upper limit on monopole flux is $2.3 \cdot 10^{-13}$ cm^{-2} s^{-1} sr^{-1} (90% c.l.).

PACS. 94.40. – Cosmic rays.

The NUSEX apparatus, installed in the Mt. Blanc tunnel at a depth of about 5000 hg/cm^2 standard rock, has been running since May 1982. It is composed of iron plates 1 cm thick, interleaved with plastic streamer tubes planes, operated in a gas mixture of Ar-CO_2-npentane, in the proportion 1:2:1. The apparatus is a cube 3.5 m side and is sketched in fig. 1. It has been described in detail elsewhere ([1]).

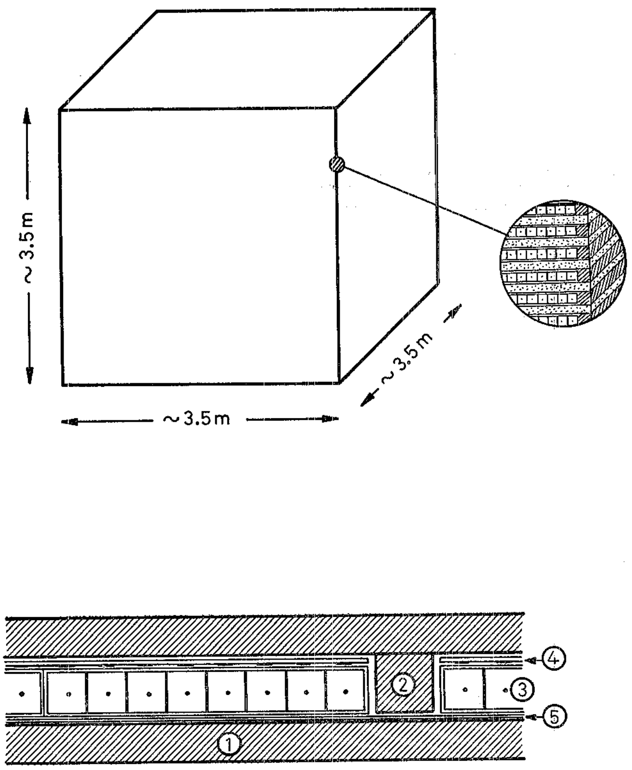

Fig. 1. – NUSEX calorimeter sketch with the detail of the single tubes layer: 1, 2 iron plate and spacer, 3 plastic streamer tubes section, 4, 5 *x*, *y* pick-up strips.

Although designed for detecting nucleon decay, the apparatus can provide information on monopole flux by exploiting two features of the streamer tubes, *i.e.* their time resolution, with a $\sigma_T \sim 30$ ns, and their efficiency for the detection of a single ion pair, measured to be 10% ([2]). This latter characteristic allows the build up of a trigger sensitive to low ionizing particles.

For monopole search we constructed a dedicated trigger for particles with β down to 10^{-4}, and ionization as low as a few percent that of minimum particle.

([1]) G. Battistoni, E. Bellotti, G. Bologna, P. Campana, C. Castagnoli, V. Chiarella, D. C. Cundy, B. D'Ettorre Piazzoli, E. Fiorini, E. Iarocci, G. Mannocchi, G. P. Murtas, P. Negri, G. Nicoletti, P. Picchi, M. Price, A. Pullia, S. Ragazzi, M. Rollier, O. Saavedra, L. Trasatti and L. Zanotti: *Phys. Lett. B*, **118**, 461 (1982).
([2]) G. Battistoni, P. Campana, U. Denni, B. D'Ettorre Piazzoli, E. Iarocci, M. Meschini and F. Ronga: *Nucl. Instrum. Methods A*, **235**, 91 (1985).

To guarantee the required sensitivity, the streamer tubes planes are divided in 16 groups of 8. The 8 planes of each group are OR-ed together, ensuring a good detection efficiency for low ionizing particles. Two successive groups of 8 planes are in turn OR-ed together, except the two outermost ones, where the singles counting rate due to the natural radioactivity of the surrounding rock is higher.

These nine signals are the inputs of a ninefold delayed coincidence, with total acceptance time of 125 μs corresponding to a velocity $\beta \geqslant 10^{-4}$. The trigger is symmetric for upward-going and downward-going monopoles. In fig. 2 the scheme for the coincidence of two successive groups of planes is shown.

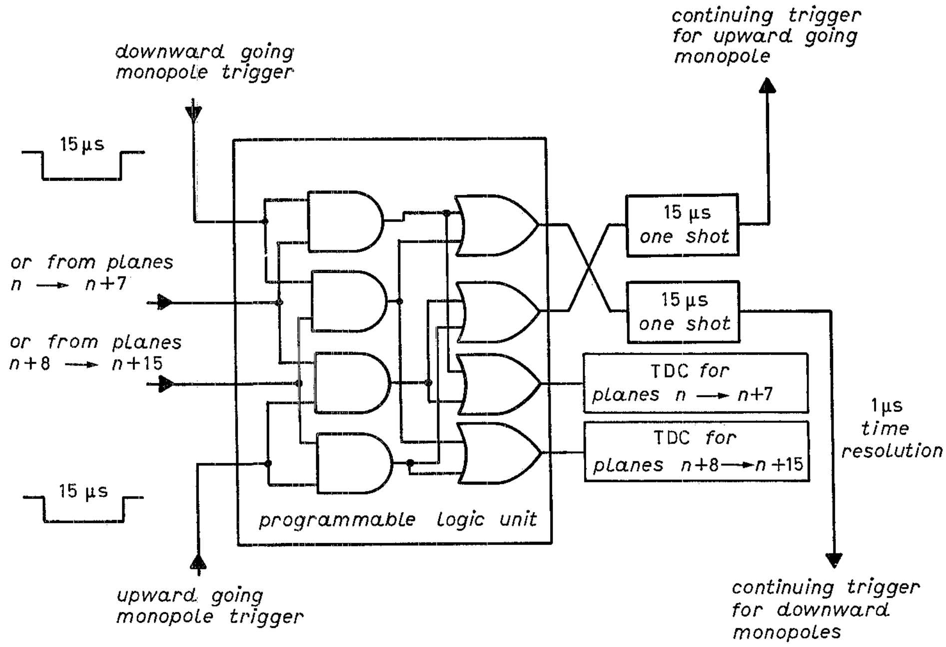

Fig. 2. – Logic unit for the monopole trigger that refers to the 16 planes OR-ed together; the AND between 9 of these logic blocks constitute the required coincidence.

When a trigger is obtained, the x and y position and time for each hit involved in the trigger are recorded. Time is digitized by scalers running at 1 MHz. It should be noted that time is recorded for each group of 8 planes, even if two successive groups are OR-ed in the trigger logic.

In this way an event will be composed of 9 x and y co-ordinates and of a number of times varying from 9 to 16.

In fig. 3 the acceptance for monopoles is shown as a function of the primary ionization of the traversing particle, expressed in units of the ionization of a minimum particle. For $\beta > 2 \cdot 10^{-4}$ the acceptance depends only on ionization. Full acceptance is reached for $I/I_0 \sim 6 \cdot 10^{-2}$.

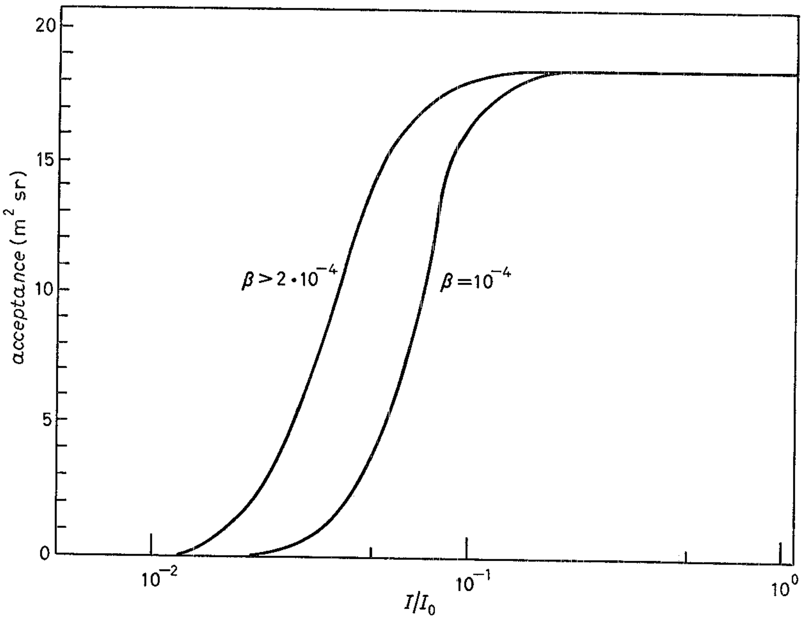

Fig. 3. – Monopole trigger acceptance *vs.* monopole ionization power normalized to the primaries numbers due to a minimum ionizing particle. For β values greater than $2\cdot 10^{-4}$, the efficiency does not depend on the velocity.

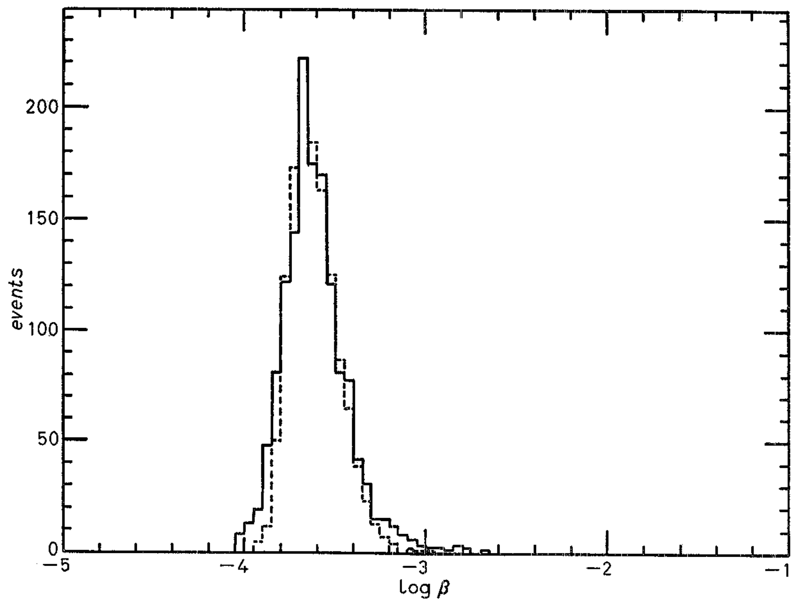

Fig. 4. – β-distribution for the events with a good time alignment, compared with the Monte Carlo results obtained for random coincidences.

The trigger has been working since April 1983, with a counting rate of $\sim 3\cdot10^{-5}$ Hz, consistent with the accidental rate expected from the singles frequencies of the groups of planes defining the trigger.

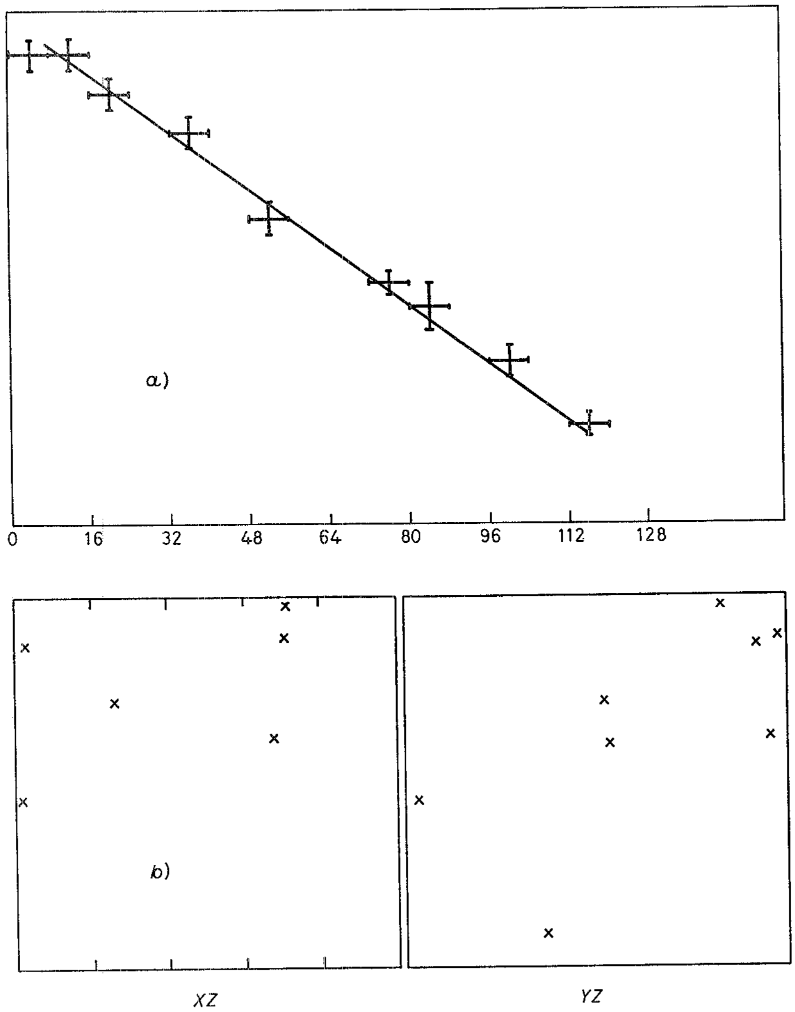

Fig. 5. – *a*) time-alignment and *b*) spatial configuration for one of the events selected as good-χ^2 events. $\beta = 2.0\cdot 10^{-4}$.

The collected events are analysed in two stages. In the first stage the recorded arrival times are linearly fitted *vs.* their position along the vertical direction z, which is known only with the approximation of a group of 8 planes.

They are accepted or rejected according to the χ^2 value of the constant crossing velocity hypothesis. This procedure was applied to a μ sample. The resulting β and χ^2 distributions are in good agreement with those expected for a uniform time distribution 1 μs wide, corresponding to the electronic time resolution.

About 40% of monopole triggers survive this first stage of analysis. This is not surprising since the trigger logic automatically selects events with a

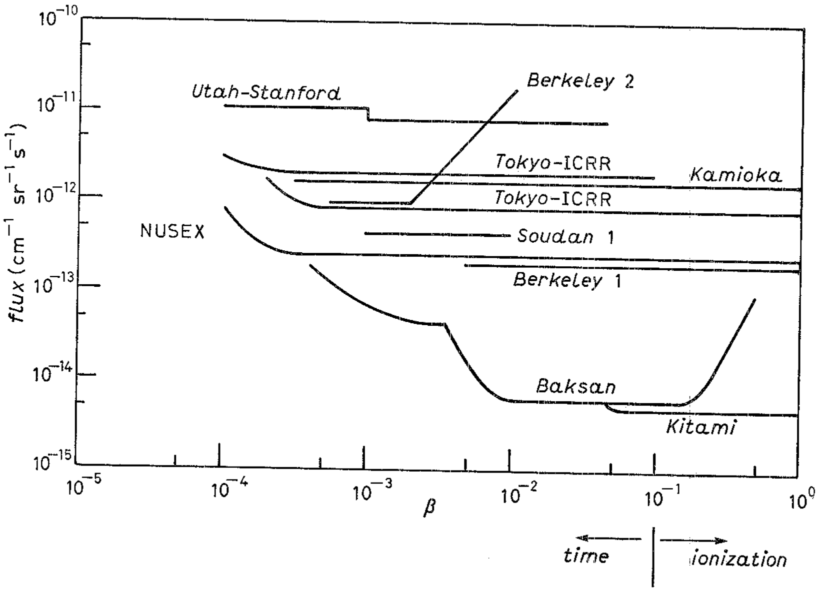

Fig. 6. – Upper limits on the monopole flux by experiments using different techniques: Utah-Stanford (3), scintillators; Tokyo-ICCR (4), scintillators+MWPC; Kamioka (5), scintillators; Berkeley 2 (6), thick plastic scintillators; Soudan I (7), proportional tubes; NUSEX (this work), stream tubes; Berkeley1 (8), CR39-Lexan; Baksan (9), scintillators; Kitami (10), Daicel.

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(3) D. E. Groom, E. C. Loh, H. N. Nelson and D. M. Ritson (Utah-Stanford): *Phys. Rev. Lett.*, **50**, 573 (1893).

(4) F. Kajino, S. Matsuno, Y. K. Yuan and T. Kitamura (Tokyo ICRR): *Phys. Rev. Lett.*, **52**, 1373 (1984).

(5) T. Mashimo, S. Orito, K. Kawagoe, S. Nakamura and M. Nozaki (Kamioka): *Phys. Lett. B*, **128**, 327 (1983).

(6) T. M. Liss, S. P. Ahlen and G. Tarlé (Berkeley 2): *Phys. Rev. D*, **30**, 884 (1984).

(7) J. Bartelt, H. Courant, K. Heller, T. Joyce, M. Marshak, E. Peterson, K. Ruddick, M. Shupe, D. S. Ayres, J. W. Dawson, T. H. Fields, E. N. May and L. E. Price (Soudan I) : *Phys. Rev. Lett.*, **50**, 655 (1983).

(8) K. Kinoshita and P. B. Price (Berkeley 1): *Phys. Rev. D*, **24**, 1707 (1981).

(9) E. N. Alexeyev, M. M. Boliev, A. E. Chudakov and S. P. Mikleyev (Baskan): *XVIII International Cosmic Ray Conference*, edited by N. Durgaprosad, Vol. **5** (Bangalore, 1983), p. 52.

(10) T. Doke, T. Hayashi, R. Hamasaki, T. Akioka, T. Naito, K. Ito T. Yanagimacki, S. Kobayashi, T. Takenaka, M. Ohe, K. Nagata and T. Takahashi (Kitami): *Phys. Lett. B*, **129**, 370 (1983).

reasonable time alignement. Figure 4 shows the β distribution of the « good χ^2 » events, compared to a Monte Carlo calculation performed in the hypothesis that the triggers are random coincidences between the group of planes, and assuming as input the measured counting rate of the planes.

In the second stage of analysis, these events are examined to check their spatial configuration, and to establish if it is compatible with a straight line in both XZ and YZ projections.

Figures 5*a*) and *b*) show a typical good χ^2 event. In fig. 5*a*) the relative time of the hits is plotted *vs.* the tubes planes. The space pattern of hits is drawn in fig. 5*b*).

No event has survived both stages of analysis.

In fig. 6 the upper limit to monopoles flux set from our experiment is presented as a function of β, together with results of a few other experiments [3-10].

This limit, of $2.3 \cdot 10^{-13}\ \text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$ at 90% c.l., corresponding to $\sim 15\,000$ hours live time, deserves a few comments. In the β region extending up to ~ 0.1 it relies on time measurement and space pattern observation, while for $\beta > 0.1$ it relies on ionization. A fast monopole is a highly ionizing particle (at $\beta = 0.1$ it ionizes ~ 50 times a minimum particle). It has been experimentally demonstrated [11] that the streamer tubes respond to high ionization by increasing the hit multiplicity. Thus for $0.1 < \beta \leqslant 1$ the limit corresponds to the absence of events with unusually high multiplicity. For β below 0.1 and down to $\sim 10^{-3}$, there is almost general agreement that the mechanisms by which a monopole loses energy traversing matter are understood [12]. To be conservative, the binary encounter approximation sets a threshold for ionization in argon to $\beta = 2 \cdot 10^{-3}$. At lower velocity, $10^{-4} \leqslant \beta \leqslant 2 \cdot 10^{-3}$, our result should be interpred as meaning that we did not observe any slow particle with ionization as low as a few percent that of a minimum particle.

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(11) C. De Marzo, O. Erriquez, N. Giglietto, F. Posa, M. Attolini, F. Baldetti' G. Giacomelli, F. Grianti, A. Margiotta, P. Serra, B. Barish, C. Lane, G. Liu, P. Musset, G. Poulard, H. Sletten, F. Cecchini, P. Galeotti, M. Dardo, R. Steinberg, G. Battistoni, H. Bilokon, C. Bloise, P. Campana, V. Chiarella, A. Ciocio, A. Grillo, E. Iarocci, A. Marini, A. Rindi, F. Ronga, L. Satta, M. Spinetti, L, Trasatti, V. Valente, S. Ahlen, B. Brabson, R. Crittenden, R. Heinz, S. Mufson, H. Ogran, J. Musser, J Stone, L. Sulak, G. Tarlé, C. Angelini, A. Baldini, C. Bemporad, A. Cnops, V. Flaminio, G. Giannini, R. Pazzi, B. Saitta, G. Auriemma, M. De Vincenzi, E. Lamanna, G. Martellotti, S. Petrera, L. Petrillo, P. Pistilli G. Rosa, A. Sciubba, M. Severi, R. Webb, M. Arneodo, G. Borreani, P. Giubellino, F. Marchetto, A. Marzari, S. Palestrini, L. Ramello, S. Torres and P. Trower: MACRO proposal (1984).

(12) S. P. Ahlen and K. Kinoshita: *Phys. Rev. D*, **26**, 2347 (1982); S. D. Drell, N. M. Kroll, M. T. Mueller, S. J. Parke and M. A. Ruderman: *Phys. Rev. Lett.*, **50**, 644 (1983).

● RIASSUNTO

Da circa due anni è operativo sull'apparato NUSEX, installato nel tunnel del Monte Bianco, un trigger dedicato alla ricerca dei monopoli previsti dalle teorie di grande unificazione. L'identificazione dei monopoli è basata sul tempo di volo e sulla localizzazione nello spazio degli impulsi coinvolti nel trigger. Il limite superiore fino ad oggi raggiunto per il flusso di monopoli è $2.3\cdot 10^{-13}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$ (90% c.l.).

Предел на поток монополей в NUSEX эксперименте под Мон Бланом.

Резюме (*). — Триггерная схема, предназначенная для поиска сверхтяжелых монополей, действует в течение почти двух лет в установке NUSEX, расположенной в туннеле под Мон Бланом. Идентификация монополей основана на времени пролета, а локализация в пространстве осуществляется с помощью импульсов в триггерной схеме. Настоящий верхний предел на поток монополей составляет $2.3\cdot 10^{-13}$ см$^{-2}$ с$^{-1}$ ср$^{-1}$ (к 90% вероятностью).

(*) *Переведено редакцией.*

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Marzo-Aprile 1986
Il Nuovo Cimento
Serie 1, Vol. 9 C, pag. 551-558