Chapter 8

Other Physics Opportunities

8.1 Proton Decay Search

8.1.1 Physical Motivations

The search for the proton decay is really a very exciting item, and up to now it was performed using two different experimental techniques, tracking calorimeters [1] and Cerenkov detectors [2], both of them installed in underground laboratories.

The idea that ordinary matter could be unstable arises in a natural way from the Grand Unified Theories (GUT) of the fundamental interactions, where quarks and leptons belong to the same multiplet and there are new very massive gauge bosons which can mediate the interactions between them. The proton lifetime can be easily obtained as a function of the masses of the new gauge bosons and by knowing some details of the interactions (i.e. Λ_{QCD}, the number of Higgs Bosons in the theory, relativistic corrections, and so on), and can be expressed in the following way:[3]

$$\tau \simeq \frac{1}{\alpha_{GUT}^2} \left(\frac{h}{2\pi c} \right)^2 \frac{M_x^4}{m_p^5} \tag{8.1}$$

If the simplest Grand Unification scheme, known as minimal $SU(5)$,is chosen one obtains the following estimation for the preferred channel $p \to e^+\pi^0$ ($B.R. \simeq 36 \div 38\%$):

$$\tau \left(p \to e^+\pi^0 \right) \simeq 10^{31 \pm 1} \tag{8.2}$$

This value seems to be ruled out by the experimental results obtained by mean of the Cerenkov detectors (IMB [4], Kamiokande [5]), where this decay channel may be identified with high efficiency: in this case Cherenkov detectors are favored with respect to calorimeters, because using this technique it is easy to reach large values of the active mass.

The interest in proton decay remains however fashionable because of several suggestions coming from supersymmetric theories, which bring the idea that the proton could decay following other channels, commonly known as exotic channels. In addition, it is interesting to underline that these channels can be seen with difficulty by the Cerenkov detectors, because the decay products have a low β value and a topological configuration not easily separated from the background. For example, in a very simple supersymmetric scheme, the prevision for the the two more usual channels, $p \to \overline{\nu} K^+$ and $p \to \mu^+ K^0$ is $\tau \simeq 10^{31}\ years$.[6]

Looking for these decay channels, calorimetric detectors are favored, and identification can be performed following the decay products of the K mesons. Unfortunately, in many calorimetric detectors and for the majority of the decay channel, it is not possible to measure the direction of the detected particles, even if correctly tracked, because the detectors are not fast enough. The possibility of measuring the directionality of each detected particle is very important in order to restrict the possible interpretation of the full event, in terms of proton decay or in terms of any other physical sources (atmospheric neutrino interaction, neutrons produced by scattering in the rock surrounding the laboratory, radioactivity, and so on), that with respect to this analysis must be obviously classified as background. For example, the famous candidate propose by the NUSEX collaboration [7] has two different interpretations, as a p-decay or as a ν interaction, simply obtained changing the sign of the direction of some detected particles. Within this scheme, useful to underline the experimental conditions into which we are planning to work, the two different event interpretations give a total value of the impulse of the order of 0.8 Gev/c in a case of a neutrino interaction and of $\simeq$ 0.4 Gev/c in the case of a proton decay. Incidentally, the total impulse of each proton decay event is not exactly zero, because of effects due to the Fermi motion and to the binding energy.

An apparatus like $NO\!E$ in the ideal configuration of maximum granularity (see sect. 3.4.1), reading the single fiber of 2 mm, may be used for this search. In fact in addition to an excellent tracking capability, it is able to furnish, through the time development of the events, also the direction of the detected particles: in this way one can add to many advantages of the calorimeters a

Detector	$p \to e^+\pi^0$	$p \to \overline{\nu}K^+$	$p \to \mu^+K^0$
IMB [4]	3.1 10^{32}	1.9 10^{31}	1. 10^{31}
KAMIOKANDE [5]	2.6 10^{32}	1.2 10^{32}	1. 10^{32}
NUSEX [7]	0.8 10^{31}	1.4 10^{31}	0.9 10^{31}
FREJUS [8]	3.5 10^{31}	2.2 10^{31}	2.2 10^{31}

Table 8.1: Experimental lower limits on the proton lifetime, obtained with the two techniques that we have briefly discussed in the text, for the standard channel $p \to e^+\pi^0$ and the supersymmetric channels $p \to \overline{\nu}K^+$ and $p \to \mu^+K^0$. Each lifetime is expressed in year. It is very important to stress that the masses and the lifetimes are very different in each case: $\simeq 4\ Kton \times year$ for IMB and KAMIOKANDE, 1.3 $Kton \times year$ for the FREJUS detector and only $\simeq 0.21\ Kton \times year$ in the case of NUSEX.

new possibility, typical of a Cerenkov detectors.

The experimental limits obtained with the two techniques that we have briefly discussed, are reported in table 8.1.1 for some of the more representative "standard" and supersymmetric decay channels. The lower bound on the proton lifetime is obtained assuming no candidates during all the lifetime of each experiment: this analysis strategy requires an excellent understanding of the detector efficiency, after having applied all the cuts required to identify a proton decay event and to separate it from each source of background. At the same level it is also required a good knowledge and a quantitative estimation of the background itself, for each configuration that, within the applied cuts, can simulate a proton decay event.

8.1.2 Data Selection and NOE Sensitivity

A detailed Monte Carlo analysis, using a GEANT based package for the simulation of the detector response, and taking into account the contribution of the Fermi motion and of the binding energy is in progress. In this section the main characteristics of the search to evaluate the most significative tags of a proton decay event are shown together with the performances required to the detector and the cut that we must apply to reject the background.

A sample of the quoted decay channels was simulated and a visual scanning was performed to make the following considerations. A pictorial representation of these events, is reported in fig. 8.1. The first channel is a

standard one ($p \to e^+\pi^0$) and the second one is a supersymmetric channels ($p \to \overline{\nu}K^+$; $p \to \mu^+K^0$). From the analysis of these plots it is obvious that the finest possible readout, in order to have an accuracy high enough to track each particle, is required.

In this kind of experiments the signal for which one looks for is obviously a little one: for a lifetime of the order of $\tau \simeq 10^{31}y$, one expects six nucleon decays per year with a mass of 100 tons. Each source of background must be taken into account and rejected. Three different physical processes have been considered:

- Natural radioactivity.

  As discussed in the section devoted to the description of the detector, the radioactivity level of the experimental setup is extremely low. In addition, a particle produced in a radioactive decay has no energy enough to cross at least two planes of streamer tubes or RPC.

- Neutral particles produced by interaction of muons with the rock.

  Neutral particles produced by cosmic muons in the rock surrounding the laboratory, can enter the apparatus without firing a veto system, and so they can simulate a fully contained event. This effect really exist, but it is lower than the following one.

- Neutrinos interacting in the apparatus.

  This is the main source of background, because the rate of events is of the order of 0.3 events per year per ton, as discussed in detail in the previous chapter, devoted to the study of atmospheric neutrinos. The background can be however radically reduced using the criteria described below. It is worth noting that the collaborations IMB and Frejus, for examples, showed that the rate of contamination can be reduced for more than a factor 10^{-3}, up to $0.1 \div 0.14$ background events per year per Kton [9].

By studying the detector response to these decay channels, some specificities of the collected signals have been identifyied, suggesting some selection criteria, which can be used to reject the background:

- At least two planes of streamer tube or RPC.

  This kind of data selection assures us a good trigger efficiency and eliminates the natural radioactivity. The percentage ϵ_{tr} of p-decay

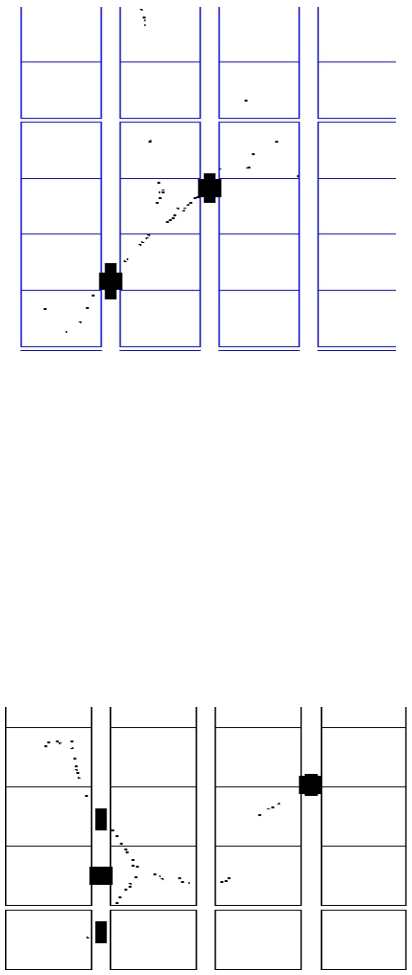

Figure 8.1: A representation of how we can reveal a proton decay in the NOE detector, for three different channels, $p \to e^+\pi^0$ (up) and $p \to \mu^+ K^0$ (down) as discussed in the text. The ideal single fiber readout is assumed.

events surviving this cut is in the range 50 $\div$ 80 %, depending on the decay channel.

- Reconstructed energy between E_{min} and E_{max}, both depending from the selected decay channel.

  The distribution of the reconstructed energy, as shown in Chapter **??**, for the three channels under discussion, indicates that a very efficient cut on the detected energy can be put. If necessary, soft cuts during the first step of the analysis, and a more specific cut when the event is analyzed assuming a specific decay channels, could be used. The signal surving this cut, i.e. the energy cut efficiency ϵ_E is of the order of 60%.

- Topological and timing structure of the event.

  This is a very important point, because it allows to reject a large amount of the background, using the information coming from the geometrical structure of the event and from its time development. The bottom line is to use:

  1. The geometrical extension of the events (not only contained events, but also events confined in a well defined volume).
  2. The algebric sum of all the detected impulse.
  3. The angular distribution of the found tracks (looking for asymmetries to identify induced ν events)

The possibity to translate the ideal intrinsic granularity of the N^OE detector into a realistic high granularity readout as described in sect. 3.4.1, is under study.

8.2 Neutrinos from AGNs

Since 1977 [10] Active Glactic Nuclei has been recognized as a possible source of Ultra High Energy neutrinos. Models in use are based on two fundamental assumptions, first hadrons have a great importance for trasporting energy in the A.G.N. and are accelerated in the accretion disk around the black hole by a first order Fermi mechanism; second, due to the extremely high density of photon, expecially in the U.V. region, p-γ interactions are the most important one for proton energy loss. Decay of charged pions, produced in the p-γ interactions, and the subsequent decay of muons produce neutrinos of extremely

high energy. As a conseguence of the original p-γ interactions electromagnetic cascades are produced. An essential ingredient of the A.G.N. models is that the X-ray spectrum is produced at the end of the electromagnetic cascade, so a link beetwen neutrino flux and X-ray spectrum is obtainable. In the models of Protheroe & Szabo [11][12] the following approximate formula is obtained:

$$F_\nu E_\nu \simeq 0.25 F_X exp(-20\frac{E_\nu}{E_{p_{max}}}) E_\nu^{-2},$$

where F_X is the X-ray flux ($erg\ cm^{-2}s^{-1}$), $E_{p_{max}}$ is the maximum proton energy inside the shock and F_ν is in ($cm^{-2}s^{-1}TeV^{-1}$). Stecker et al. [12] integrated the neutrino fluxes from single generic A.G.N. to obtain a diffuse flux from all cosmological A.G.N.. In the hypotesis that neutrinos and X-ray background have a common source it is possible to obtain the diffuse neutrino flux in the same way as the calculation of the X-ray bacgkround. The diffuse extragalictic neutrino flux dominates over the atmospheric flux at energies going from $10^4\ GeV$ to $10^5\ GeV$ depending on the model. The calculation of muon flux at the detector can be performed in the usual way (see Chapter 7):

$$N_\mu(E > E_\mu) = \sum_{\nu_\mu, \overline{\nu}_\mu} \int dE'_\mu \int dE_\nu \cdot R(E_\mu, E'_\mu) \cdot \frac{d\sigma_{\nu\overline{\nu}}}{dE'_\mu} \cdot \Phi(E_\nu, \theta) \cdot exp(\frac{-2R_o cos(\theta)}{\lambda(E_\nu)}) \tag{8.3}$$

where R_o is the Earth radius and $\lambda(E_\nu)$ is the mean free path of neutrinos with energy E_ν. Has to be noted that the previous formula contains absorption of neutrinos in the Earth, absorption becames important for $\sigma(E_\nu) \simeq 10^{-33}\ cm^{-2}$ that means $E_\nu \simeq 10^7\ GeV$. In fig. 8.2 [15] integral flux of muons for different models is shown, compared with the flux of atmospheric neutrinos. In this figure the only experimental limits is also shown. The limit has been obtained with the Frejus detector [16] and corresponds to a flux of $\simeq 2^{-3} m^{-2} yr^{-1} sr^{-1}$ for $E_\mu > 2\ TeV$ at $\theta \simeq 0$ where there is no absorption.

It is clear that it is necessary to have a detector with high acceptance but is also important to have an evaluation of the muon energy. The $N^O E$ detector have an acceptance of about $10^3\ m^3 sr$ for an isotrophic upward going flux, and a good calorimetric feature, also for muons with very high energy; an important characteristic of the $N^O E$ detector is also the T.o.F. measurement, necessary to distinguish upward going muons.

In tab. 8.2 the number of expected events for different models is shown.

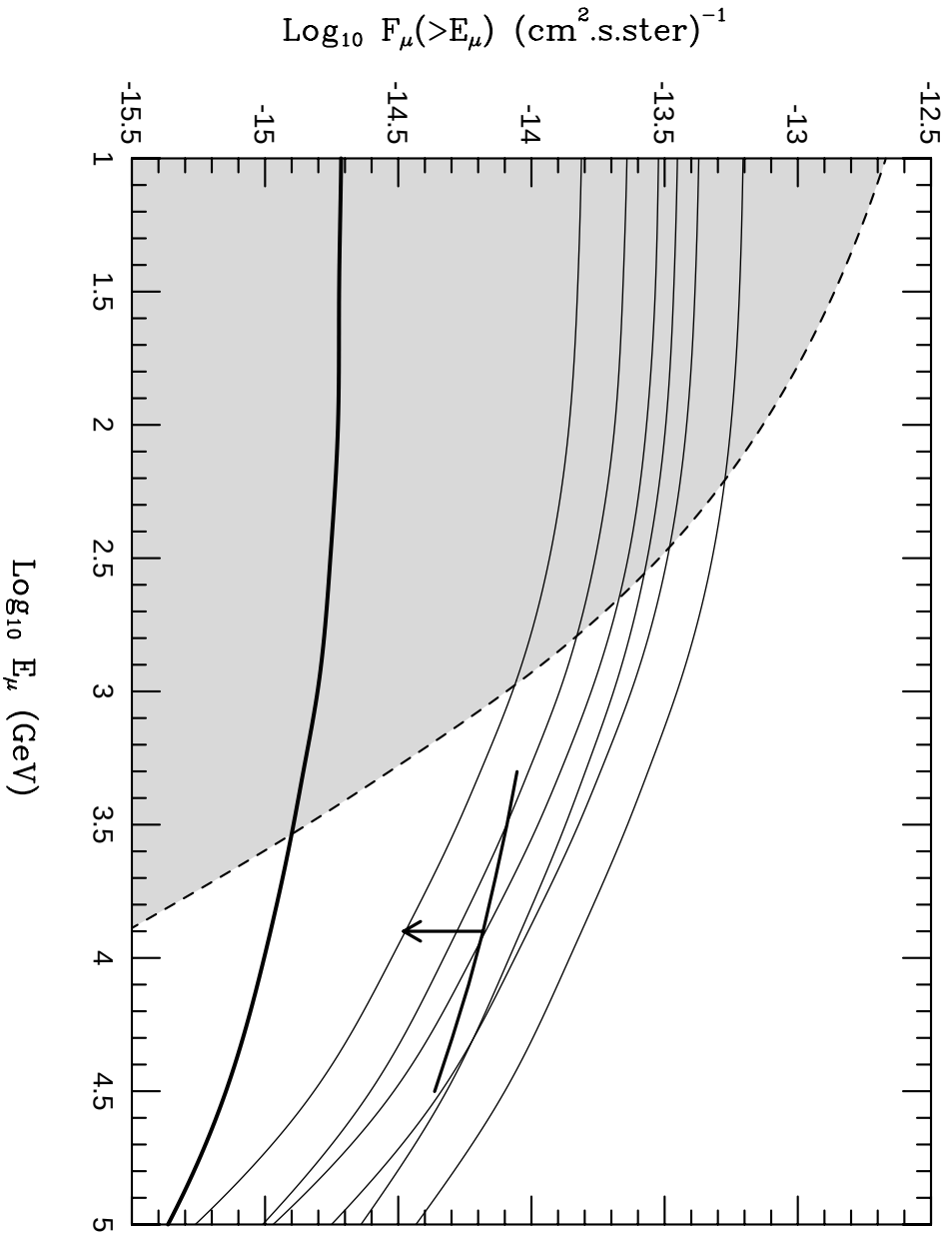

Figure 8.2: Integrated flux of muons for different models of A.G.N. and for atmospheric neutrinos (shaded region). Frejus limit is also shown.

Model and E_{th}	Events
[11] $100GeV$	14
[11] $1TeV$	3
[12] $1TeV$	1
Atmospheric $1TeV$	3

Table 8.2: Number of events per year expected for different models and different energy thresholds. The only requirement is a track length greater than 2 m

The capability of the detector to estimate the energy of the muons with $E > 1TeV$ is under study with a detailed Monte Carlo, however in few years it should be possible to lower the limit obtained by Frejus experiment and eventually it will be possible to evaluate the shape of the integral spectrum.

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