

SEARCH FOR PROTON DECAY IN SOUDAN 2

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ABSTRACT

The search for proton decay in the Soudan 2 detector is reported. Soudan 2 is a one-kiloton iron tracking detector which is searching for proton decay in the Soudan mine in Minnesota. Through August 1996, Soudan 2 has a 3.3 kiloton-year fiducial exposures, divided into 6 data sets. Preliminary limits on the decay mode $p \rightarrow \nu K^+$, a description of the analysis progress on multihadronic final states, and our tentative estimate of nuclear corrections are presented.

INTRODUCTION

Nucleon decay continues to be an unverified prediction of most Grand Unified Theories. The Soudan 2 iron calorimeter was designed to search for such decays in a way complementary to water Cherenkov detectors, particularly for multiparticle final states. Search for proton decay into multiparticle final states is complicated by two factors: 1) hadronic intranuclear rescattering can alter the observed topology from the proton decay product final state, through absorption and inelastic scattering, and 2) pion scattering and absorption in the detector makes the range to energy conversion less reliable than for muon tracks and electron showers. These effects are quantitatively similar but quantitatively different for each experiment.

SEARCH FOR THE DECAY $p \rightarrow \nu K^+$

After proton decay into νK^+ , most Kaons will decay at rest into a muon of 236 MeV/c momentum and an invisible neutrino. In Soudan 2 we can identify such events with a visible K and muon track. Using Monte Carlo events with the right reconstructed topology, a requirement of a visible Kaon track, and a muon with range corresponding to a momentum between 170 and 260 MeV/c, we find an efficiency times branching ratio of 9.1% within the fiducial volume. In 3.3 fiducial kiloton-years of data, there are no events, leading to a nucleon decay limit in this mode $\tau/B > 3.7 \times 10^{31} \text{ yr}$.

MERCEDES EVENTS

One major advantage of a tracking calorimeter over the water cherenkov detectors is the vertex resolution of $\pm 1 \text{ cm}$. For example, this allows the separation of an event with three or more charged particles coming from a single vertex from one in which a single track scatters multiple times. We define a class of events called "mercedes events" which have three or more charged tracks coming from a single vertex. A list of proton and neutron decay modes which would lead to such events is given in Table 1. An example of a Monte Carlo of the decay mode $p \rightarrow \mu^+ \mu^+ \mu^-$ is shown in Figure 1.

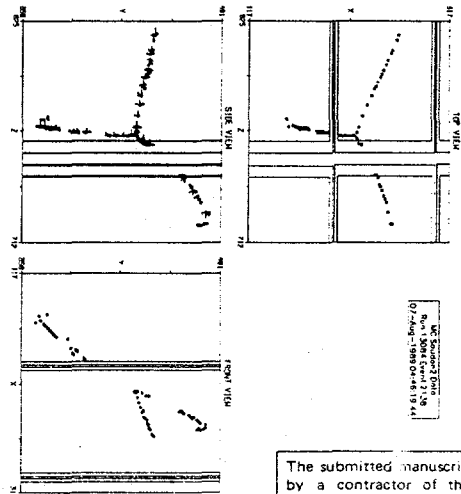


Fig. 1: Monte Carlo simulation of $p \rightarrow \mu^+ \mu^+ \mu^-$. 3 views in Soudan are shown. The scale is cm.

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INTRANUCLEAR EFFECTS

A significant number of pions which are created by proton decay are not expected to get out of the nucleus due to intranuclear scattering. Our Monte Carlo takes into account the rescattering of pions within the nucleus using data obtained by comparison of bubble chamber ν interactions on deuterium and neon (Merenyi, 1992). We have studied the result of this model on the decay mode $p \rightarrow \mu^+ \pi^+ \pi^-$. We find that 42% of the π 's are absorbed, 28% suffer inelastic scattering, 8% charge exchange and only 19% exit the nucleus with their original momentum. These fractions depend on both the target nucleus and the pion momentum. The comparison of proton decay results from experiment to experiment should be done with a similar intranuclear model or with such effects removed. The results of our intranuclear Monte Carlo on the "mercedes" modes are shown in Table 1. The quoted efficiency is solely the fraction of events in which the proton decay remnants emerge from the nucleus with their original momentum. Most of this "inefficiency" will be reflected as observed proton decay events with less particles and momentum in the final state than would be the case for a free nucleon decay.

In an analysis of 3.3 kton-year of Soudan 2 data, there are 12 mercedes events. Most of them have far too much energy to be a nucleon decay candidate. They are consistent with neutrino multiparticle production. We are concentrating on finding a set of cuts for each decay mode with high efficiency. When that analysis is complete, we will apply the cuts to the 12 data events to determine whether we have any candidates. We expect that most limits on the decay modes in Table 1 will be made with no candidate events.

SEARCH FOR THE OTHER DECAY MODES

In addition to the modes discussed above, Soudan 2 has undertaken searches for the decay modes νK_S^0 , $e^+ K_S^0$, $\mu^+ K_S^0$, $\nu \eta$, $\nu \pi^+$, $\nu \pi^0$, $\nu e^+ e^-$ and $e^+ \pi^0$.

REFERENCES

- M. Barnett et al., Phys. Rev. D54, 1 (1996).
- R. Merenyi et al., Phys. Rev. D45,743 (1992).

mode	Branching fraction	PDG limit	ϵ_{nuc}
$e^+\rho^0$	1.0	$7.5 \times 10^{31} \text{ yr}$	0.07
$\mu^+\rho^0$	1.0	11.0	0.07
$e^-\pi^+\pi^+$	1.0	3.0	0.07
$\mu^-\pi^+\pi^+$	1.0	1.7	0.07
$e^+\pi^-\pi^+$	1.0	2.1	0.07
$\mu^+\pi^-\pi^+$	1.0	1.7	0.07
$e^+e^+e^-$	1.0	51.0	1.0
$\mu^+\mu^+\mu^-$	1.0	19.0	1.0
$e^+\mu^+\mu^-$	1.0	8.1	1.0
$\mu^+e^+e^-$	1.0	9.1	1.0
$\mu^-\pi^+K^+$	1.0	0.5	0.26
$e^-\pi^+K^+$	1.0	2.0	0.26
$\mu^+\pi^-K^+$	1.0	x	0.26
$e^+\pi^-K^+$	1.0	x	0.26
$\mu^+\pi^+K^-$	1.0	x	0.26
$e^+\pi^+K^-$	1.0	x	0.26
$\nu\pi^+\pi^+\pi^-$	1.0	x	0.02
$\nu\mu\mu\pi$	1.0	x	0.26
$\nu ee\pi$	1.0	x	0.26
$\nu\mu e\pi$	1.0	x	0.26
$e^+\eta$	0.28	12.0	0.07
e^+K_S	0.69	7.6	1.0
$\mu^+\eta$	0.28	6.9	0.07
μ^+K_S	0.69	6.4	1.0
$\bar{\nu}K^+$	0.06	10.0	1.0
e^-K^+	0.06	3.2	1.0
μ^-K^+	0.06	5.7	1.0
e^+K^-	0.06	0.1	1.0
μ^+K^-	0.06	0.1	1.0
$\nu K^{*0} \rightarrow \pi^+ K_S$	0.46	2.0	1.0
$\mu^+\omega$	0.89	5.7	0.07
$e^+\omega$	0.89	4.5	0.07
$\mu\pi\pi\pi$	1.0	x	0.02
$e\pi\pi\pi$	1.0	x	0.02
$\nu 4\pi$	1.0	x	0.005
$e\mu\mu\pi$	1.0	x	0.26
$ee e\pi$	1.0	x	0.26
$\mu\mu\mu\pi$	1.0	x	0.26
$ee\mu\pi$	1.0	x	0.26
$\nu e\mu\pi\pi$	1.0	x	0.07

Table 1: Calculation of nuclear efficiencies for proton decay modes with 3 (top) or 4 (bottom) charged tracks from a vertex. Particle Data Group (Barnett, 1996) limits are shown where they exist.