Fermilab E299: to be published in
Physical Review Rapid Communications

FERMILAB-PUB-84-142-E
RU-84-28
July, 1984

Search for Long-lived Charge +2 Hadrons

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ABSTRACT

We have searched for the production of long-lived R-Δ^{++} hadrons, which contain a gluino in addition to three up quarks, in pp, $\pi^{+}p$, and $K^{+}p$ interactions at 147 GeV/c. For R-Δ^{++}'s of lifetime greater than 10^{-9} seconds, and laboratory momentum greater than 2 GeV/c, we place 90% confidence level upper limits of 6.1 μb in pp collisions, 4.4 μb in $\pi^{+}p$, and 29 μb in $K^{+}p$.

A well-known feature of supersymmetry is the prediction of gluinos, the spin 1/2 partners of the gluons. New color singlet hadrons must then exist, consisting of bound states of gluinos and quarks. Hadrons containing one gluino are called R-hadrons, and would carry a conserved quantum number called R-parity.[1-3] R-baryons, composed of a gluino and three quarks, would have integer spin. Recently, Farrar has pointed out[4] that the lightest R-baryons may be absolutely stable if the photino is massive. Even is the photino is light, Farrar has shown that if the scalar quark mass is greater than 10^4 GeV, the lightest R-baryons may be essentially stable, with lifetimes in excess of 10^{-6} seconds. Although bag model estimates[4] suggest that the lightest R-baryon may be the flavor singlet, it is worthwhile to consider also the flavor octet and decuplet possibilities. The $R\text{-}\Delta^{++}$ in the decuplet has been estimated[5] to have a mass in the range 1.2 - 1.5 GeV.

We report a search for $R\text{-}\Delta^{++}$ particles produced in existing data on pp, π^+p, and K^+p interactions at 147 GeV/c. Our search is sensitive to an $R\text{-}\Delta^{++}$ of lifetime greater than 10^{-9} seconds, laboratory momentum greater than 2 GeV/c, and mass comparable to or greater than that of the proton. To our knowledge, this is the first experimental search for long-lived R-hadrons. The experiment was carried out at Fermilab, using the 30-inch hydrogen bubble chamber-hybrid spectrometer system[6], exposed to a tagged beam of positive hadrons. Interactions producing only the ordinary, stable hadrons result in events with an even number of charged tracks. However, an event with an R-Δ^{++} would have an odd-prong topology, and therefore we examined that sample for our search. Furthermore, since the ionization produced by a particle is proportional to the square of its electric charge, an R-Δ^{++} would be four times as heavily ionizing as a proton of the same velocity. Therefore, we have a clean experimental signature: an event with an anomalous (odd) number of charged prongs, one of which is anomalously dark.

Farrar has estimated[5] that in the fragmentation region of pp scattering, the ratio of R-Δ^{++} to Σ^{+} production may be of order 1-10%. In our experiment, we have previously measured[7] the cross section for Λ production to be 4.2 ± 0.2 mb, mostly in the fragmentation region. At 19 GeV/c the cross sections for Λ and Σ^{+} have been measured[8] to be $1.86 \pm .06$ mb and $0.625 \pm .06$ mb respectively. If we assume that the Σ^{+}/Λ ratio remains 1/3 at our energy, we predict a Σ^{+} cross section of 1.4 mb in our experiment. Then the predicted R-Δ^{++} cross section would be 14 to 140 μb.

A similar figure is obtained using a second estimate of Farrar, that in the central region of pp collisions the ratio R-$\Delta/\bar{p}$ may be of order 1%. Fits to measured $\bar{p}$ multiplicity have been done by Antonucci et al.,[9] and they have been converted to cross sections by Whitmore.[10] At 147 GeV/c the fit yields a $\bar{p}$ cross section of 1.2 mb. This value seems reasonable, since we have directly measured[7] $\bar{\Lambda}$ production in our experiment to be 0.8 ± 0.2 mb, and at all energies $\bar{p}$ production is known[10] to exceed $\bar{\Lambda}$ production by factors like 2. If $\bar{p}$ production is 1.2 mb, then the R-Δ production is predicted to be 12 μb.

To search for the R-Δ^{++} we have examined a sample of 180,000 frames containing 26,774 events. Table I shows the number of these events for each of the three beam types. For each event, the beam tag was obtained by a Cerenkov counter, described in Ref. 6. All events were scanned and measured, and the measurements were geometrically reconstructed using the program GEOHYB, which combined the bubble chamber film measurement with information from the proportional wire chambers in the hybrid spectrometer system. Kinematic fitting was done using the program SQUAW, to isolate elastic events. Table I gives the numbers of inelastic events for the three beams, and the corresponding μb equivalents, obtained by using our own measurement[6] of the inelastic cross sections.

Two samples of events were considered for the R-Δ^{++} search:

i) 193 events that were originally scanned as odd-prong events.

ii) 231 events that were even-prong, but where one of the tracks was identified as e^+ or e^- from characteristic spiral. This sample was re-examined to allow for the possibility that the e^- may be a delta ray, making the event truly odd-prong. It was found, however, that all of these events were consistent with a

Dalitz pair interpretation, and in any case no anomalously dark track signifying an R-Δ^{++} was observed. This sample will not be discussed further.

The sample of 193 odd-prong events was re-examined carefully on the scan table, with particular attention to all heavily ionizing tracks. It was found that all such tracks had ionization consistent with their measured momenta, on the assumption of a single unit of electric charge, and mass comparable to that of the proton. Even though there were no anomalously ionizing tracks in the odd-prong sample, we still checked to see if the number of observed odd-prong events was reasonable, assuming no R-Δ^{++} production. The 193 odd-prong events were categorized as follows:

a) 64 events had net charge +3. It is likely that one of the tracks underwent a secondary interaction very close to the primary vertex. Such an occurrence would produce an apparent net charge of +3 if the secondary interaction products were included with the rest of the primary interaction prongs. For 9 of the 64 events, a close secondary interaction was detected during the special re-scan. That left 55 events, and we can check whether it is reasonable that there should be 55 events with an unseen secondary interaction. The inelastic interaction length in our liquid is about 830 cm, and our sample consists of 24007 inelastic events. Using an average charged particle multiplicity of 7, we calculate that there would be 55 events in which one track interacted within about 3 mm of the vertex. This calculated confusion distance of 3 mm for visual scanning of events is obviously reasonable.

b) 95 events had net charge +1. Of these, 41 were found to include an identified, slow delta ray, so that they were truly even-prong events. The remaining 54 could be due to three sources.

i) A fast (and therefore unidentified) delta amongst the tracks.

ii) A slow and very short proton hidden amongst the tracks.

iii) Scattering off a neutron in the deuterium contamination of the liquid. This is a small effect, since the contamination is less than .02%.

Our estimates show that these three sources together could account for all 54 events.

c) 17 events were odd-prong, but the net charge could not be determined due to the complexity of the event. Of these 17, two had close secondary interactions, and three had an identified delta.

d) 17 events were truly even-prong; they had been incorrectly categorized on the first scan.

This categorization indicates that the apparently anomalous odd-prong sample can be understood on the basis of ordinary sources, without invoking R-Δ^{++} particles. More importantly, every track in this sample was explicitly checked on the scan table to have ionization consistent with its momentum for a single unit of charge.

Since there were 193 events scanned as odd-prong out of the total sample of 26,774 events, but all of them are understood to be "truly" even-prong, we calculate an efficiency of 99.3% for recognizing an even-prong event as even-prong. We assume that the identification efficiency for odd-prong events is the same, because no distinction was drawn at the scan stage between even and odd topologies.

Since we did not find any R-Δ^{++} candidates, we place 90% confidence level upper limits based on 2.3 events. Using the μb equivalents and an identification efficiency of 99.3%, we obtain the limits given in Table I. They are comparable to the theoretical estimates discussed earlier. It should be noted that this search is sensitive only to an R-Δ^{++} of momentum greater than 2 GeV/c, which would be at least four times minimum ionizing. A 2 GeV/c R-Δ^{++} would have the same radius of curvature as a 1 GeV/c proton, which would be about 1.9 times minimum ionizing. For tracks whose momentum is less than 2 GeV/c, the distinction between protons and doubly charged particles on the basis of curvature and ionization would not be reliable. We also note that a track must be at least 10 cm or so in length for a reliable estimation of curvature and ionization. Our search is therefore sensitive only to R-Δ^{++} of lifetime greater than about 10^{-9} sec.

This work was supported in part by the U.S. Department of Energy, the National Science Foundation, the U.S.-Israel Binational Science Foundation, and the Dutch Society for Fundamental Research of Matter. We gratefully acknowledge the efforts of the 30-inch bubble chamber crew, and the scanning and measuring personnel at the participating institutions. We would also like to thank Glennys Farrar for motivating this work, and for making many helpful suggestions.

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TABLE I

Limits on the Production of Stable R-Δ^{++} Hadrons

	pp	π^+p	K^+p	TOTAL
Total events	13,500	11,772	1502	26,774
Inelastic events	11,950	10,694	1363	24,007
μb/inelastic event	2.65	1.92	12.58	
90% C.L. upper limits (μb)	6.1	4.4	29	