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INSTITUTO DE FÍSICA
CAIXA POSTAL 20516
01452-990 SÃO PAULO - SP
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NEW UPPER LIMIT FOR THE BRANCHING RATIO OF THE $\Omega^- \rightarrow \Xi^- \gamma$ RADIATIVE DECAY

I.F. Albuquerque(1), N.F. Bondar(3), R. Carrigan Jr.(2), D. Chen(9), P.S. Cooper(2), Dai Lisheng(4), A.S. Denisov(3), A.V. Dobrovolsky(3), T. Dubbs(7), A.M.F. Endler(11), C.O. Escobar(1), M. Foucher(13), V.L. Golovtsov(3), H. Gottschalk(2), P. Gouffon(1), V.T. Grachev(3), A.V. Khanzadeev(3), M.A. Kubantsev(8), N.P. Kuropatkin(3), J. Lach(2), Lang Pengfei(4), Li Chengze(4), Li Yunshan(4), M. Luksys(10), J.R.P. Mahon(1), E. McCliment(7), A.Morelos(2), C. Newsom(7), M.C. Pommot Maia(12), V.M. Samsonov(3), V.A. Schegelsky(3), Shi Huanzhang(4), V.J. Smith(5), Tang Fukun(4), N.K. Terentyev(3), S. Timm(6), I.I. Tkatch(3), L.N. Uvarov(3), A.A. Vorobyov(3), Yan Jie(4), Zao Wenheng(4), Zheng Shuchen(4), Zhong Yuanyuan(4), E761 Collaboration

(1)Universidade de São Paulo, São Paulo, Brazil; (2)Fermi National Accelerator Laboratory, Batavia, IL 60510; (3)Petersburg Nuclear Physics Institute, Gatchina, Russia; (4)Institute of High Energy Physics, Beijing, PRC; (5)H.H. Wills Physics Laboratory, University of Bristol, UK; (6)Carnegie Mellon University, Pittsburgh, PA 15213; (7)University of Iowa, Iowa City, IA 52242; (8)Institute of Theoretical and Experimental Physics, Moscow, Russia; (9)State University of New York at Albany, Albany, NY 12222; (10)Universidade Federal da Paraiba, Paraiba, Brazil; (11)Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil; (12)Conselho Nacional de Pesquisas CNPq, Rio de Janeiro, Brazil; (13)J.W. Gibbs Laboratory, Yale University, New Haven, CT 06511

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New Upper Limit for the Branching Ratio of the $\Omega^- \to \Xi^- \gamma$ Radiative Decay.

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Yan Jie(4), Zhao Wenheng(4), Zheng Shuchen(4), Zhong Yuanyuan(4)

(E761 Collaboration)

(1) *Universidade de Sao Paulo, Sao Paulo, Brazil*
(2) *Fermi National Accelerator Laboratory, Batavia, IL 60510*
(3) *Petersburg Nuclear Physics Institute, Gatchina, Russia*
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(5) *H.H. Wills Physics Laboratory, University of Bristol, UK*
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(8) *Institute of Theoretical and Experimental Physics, Moscow, Russia*
(9) *State University of New York at Albany, Albany, NY 12222*
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(12) *Conselho Nacional de Pesquisas CNPq, Rio de Janeiro, Brazil*
(13) *J.W. Gibbs Laboratory, Yale University, New Haven, CT 06511*

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Abstract

We have searched for the rare hyperon radiative decay $\Omega^- \to \Xi^- \gamma$, using the Fermilab Proton Center 375 GeV/c charged hyperon beam. Our measurement of the Ω^- beam fraction at 13.6 m from production is $(4.8 \pm 0.4) \times 10^{-5}$. No signal was found and we determine a new upper limit of 4.6×10^{-4} at 90% CL for the $\Omega^- \to \Xi^- \gamma$ branching ratio.

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Among the six hyperon radiative decays with $\Delta S = 1$, the $\Omega^- \to \Xi^- \gamma$ presents a special challenge to both experimentalists and theorists. This is because of the low flux of Ω^- when compared to other hyperons and the theoretical expectation of having the smallest branching ratio of all the hyperon radiative decays [1]. To the theorist the challenge is that this is the only such decay involving a transition from an SU(3) decuplet to an octet with the inherent complications of a spin 3/2 system. It has been conjectured [2,3] that this decay is a good testing ground for penguin diagrams whose magnitude remains uncertain.

The unitarity lower bound for the branching ratio [1] of the $\Omega^- \to \Xi^- \gamma$ is 0.8×10^{-5}. An estimate [1] of the real part of the amplitude leads to a branching ratio of (1.0-1.5) $\times 10^{-5}$. The only previous experimental information [4] for this decay is an upper limit of 2.2×10^{-3}.

The E761 experiment was performed at the Fermilab Proton Center beam line during the 1990 fixed target run. The main goals of the experiment were to determine the asymmetry parameter and the branching ratio for the weak hyperon radiative decays $\Sigma^+ \to p\gamma$ [5] and $\Xi^- \to \Sigma^- \gamma$ [6]. The 800 GeV/c proton beam from the Tevatron impinged on a 1 interaction length Cu target to produce a 375 GeV/c charged hyperon beam. This target was placed at the beginning of the channel inside the Hyperon Magnet (Fig. 1).

The spectrometer was divided into three main systems in order to measure the trajectory and momentum of the hyperon, the baryon and the photon energy. The hyperon spectrometer consisted of 3 stations of silicon strip detectors (SSD) with 50 μm pitch and one dipole magnet with a field integral of 4.3 T·m. The resolutions (σ) obtained, for this part of the spectrometer, were $\Delta p/\mathrm{p} = 0.7$ % , 12 μrad and 5 μrad for momentum, horizontal and vertical angles respectively.

The 12 m long decay region (Fig. 1) starting at 14 m from the target was filled with helium gas. The baryon spectrometer consisted of 4 stations of multiwire proportional chambers (MWPC) and 2 dipole magnets (a total of 5.3 T·m). A third magnet (2.6 T·m) was situated downstream of the last MWPC in order to deflect low momentum baryons which were part of the background to another decay analysed by E761, the $\Xi^- \to \Sigma^- \gamma$ [6]. The resolutions of the baryon spectrometer were Δp/p = 0.6%, 21 μrad and 12 μrad for momentum, horizontal and vertical angles respectively.

The photon spectrometer had two steel plates [8] and a photon calorimeter which consisted of lead glass and bismuth germanate (BGO) blocks. The steel plate converted the photon, whose energy was measured in the calorimeter (ΔE/E $\sim 30\%/\sqrt{E(GeV)}$ plus a 3% constant term added in quadrature). This system had a square hole in its center to allow the baryon through. A more detailed description of the E761 apparatus can be found in references [5,7] [9]. The trigger required a beam particle through a coincidence of scintillation counters, a photon conversion in one of the steel plates and a high momentum baryon. The latter was defined by scintillation counters. Undecayed beam particles were rejected by counter V1 and low momentum baryons by V2 (see fig. 1). We collected 2.8 $\times 10^8$ events with this trigger.

The data analysed here were selected after requiring good quality hyperon and baryon track reconstruction, as well as a decay vertex in the decay region. We measured the missing neutral mass squared ($M^2_{x^0}$) under the hypothesis that the hyperon was an Ω^- and the baryon a Ξ^-.

The backgrounds consisted of the decays $\overline{\Sigma}^- \to \overline{p}\pi^0$, $K^- \to \pi^- \pi^0$ and $\Omega^- \to \Xi^- \pi^0$. These occur at a much higher rate than the $\Omega^- \to \Xi^- \gamma$ decay and have a π^0 in the final state which could satisfy the trigger. The first two can be separated using as kinematical variables the ratio between the baryon and hyperon momentum and the angle between their trajectories. The other source of background, $\Omega^- \to \Xi^- \pi^0$, is harder to separate due to the small mass difference of the π^0 and γ compared to the momentum of the Ω^-.

In order to separate $\Omega^- \to \Xi^- \gamma$ from $\Omega^- \to \Xi^- \pi^0$, we use information from the photon calorimeter. The reconstruction of the hyperon and baryon momenta and tracks allows us to determine the position where the neutral particle would hit the photon calorimeter. The single gamma from the $\Omega^- \to \Xi^- \gamma$ has its energy concentrated around the extrapolated neutral trajectory while the two gammas coming from the π^0 decay deposit their energy over a larger region. The energy of the single γ is measured by the sum of the energy on the block which is hit by the extrapolated neutral trajectory plus the energy in the neighboring blocks. Thus the separation between these two kinds of events is performed with a cut on the ratio between this energy and the total energy in the photon calorimeter. We require this ratio to be greater than 0.95.

Care must be taken when one of the γ's coming from the π^0 decay goes through the hole of the photon calorimeter. To eliminate these events, we require the minimum value for the ratio between the total energy in the photon calorimeter and the missing momentum (momentum of the hyperon minus the momentum of the baryon) to be 0.80.

A further source of background is beam particle interactions. In order to decrease their number, we required that the decay vertex occurred between 1 to 8 meters from the start of the the decay region, where the material in the beam is minimized. We also found that the horizontal projection of the angle between the hyperon and baryon trajectories (T_{X_B}) is smaller for interactions than for decays. The requirement that $T_{X_B} > 2.4 \times 10^{-3}$mrad lowered the background by almost a factor of 2.

Figure 2 plots $M^2_{\pi^0}$, under the hypothesis $\Omega^- \rightarrow \Xi^- X$, with all the data that survived the cuts described above. Note the clear signal for the $\Omega^- \rightarrow \Xi^- \pi^0$ but no signal for the $\Omega^- \rightarrow \Xi^- \gamma$. The solid line corresponds to the fitted exponential background plus a gaussian at the π^0 peak.

Two steps are then taken, one to confirm that there is no signal for the $\Omega^- \rightarrow \Xi^- \gamma$ and the other to obtain an upper limit with 90% CL. The first consists of adjusting a gaussian centered to the left of the π^0 peak (see Fig. 2), by an amount equal to the π^0 mass squared and with the same width [10] as the $\Omega^- \rightarrow \Xi^- \pi^0$ peak. The amplitude of such a fit is negative which assures us that there is no signal around the gamma mass squared. The second step, in order to obtain the number of events that gives us 90% CL, is to force the amplitude of the gaussian to change in such a way that the χ^2 of the fit will increase by 1.64 units. The result of this procedure is a total of 9 events.

The normalization needed for extracting an upper limit for the branching ratio is provided by the Ω^- fraction in our secondary beam. This was determined by the analysis of the decays $\Omega^- \rightarrow \Lambda^0 K^-$ [11] and $\Omega^- \rightarrow \Xi^- \pi^0$. Both analyses agree and the results are dominated by statistical errors. Their average gives an Ω^- fraction of $(4.8 \pm 0.4) \times 10^{-5}$ in the E761 hyperon beam, at 13.6 meters from the target. The average transverse momentum of production is 0.66 GeV/c while the average X_F is 0.47.

The upper limit for the branching ratio is given by:

$$BR < \frac{N_\gamma}{\varepsilon_\gamma \times f_{\Omega^-} \times N_{bp}} \tag{1}$$

where N_γ is the number of $\Omega^- \rightarrow \Xi^- \gamma$ at 90% CL, ε_γ is the efficiency for this decay, f_{Ω^-} is the fraction of Ω's in the hyperon beam and N_{bp} is the number of particles in the hyperon beam. ε_γ includes geometrical acceptance, trigger and cuts efficiencies. It was determined by Monte Carlo studies which used the same experimental apparatus and the same trigger and cuts (except those related to the photon calorimeter) as the data analysed. The efficiency of the cuts related to the photon calorimeter was determined through studies using samples of single photons obtained from the $\Sigma^+ \rightarrow p\gamma$ analysis. Table 1 lists the values used in Equation 1.

We obtain as a final result the following upper limit at 90% CL:

$$BR(\Omega^- \rightarrow \Xi^- \gamma) < 4.6 \times 10^{-4} \tag{2}$$

This result is smaller than the previous upper limit [4] by a factor of 4.8. It confirms the indication [6] that radiative decays of hyperons which do not contain a valence u quark have low branching ratios. We note that this new measurement is still more than an order of magnitude above the unitarity lower bound [1].

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[a] Supported by FAPESP, Brazil

[b] Present address Fermilab

[c] Present address Department of Physics, University of Maryland, College Park, MD 20747.

[d] Partially supported by FAPESP and CNPq, Brazil

[e] Partially supported by CONACyT, Mexico. Present address Universidad Autonoma de San Luis Potosi, San Luis Potosi, Mexico

[f] Present address Department of Physics, Stanford University, Stanford, CA 94309

[g] Present address Department of Physics, University of California, Santa Cruz, CA

[h] Present address Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

[i] Present address COPPE, Universidade Federal do Rio de Janeiro, Brazil

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[8] In the analysis of other decays studied by E761 a transition radiation detector (TRD) was used and the steel plates were then needed. The TRD information was not used in this analysis.

[9] Differences between the geometry for the $\Sigma^+ \to p\gamma$ decay [5] and the one for the negative hyperons [6], are described in [5,6]

[10] Monte Carlo studies show that the widths of the $\Omega^- \to \Xi^- \pi^0$ and the $\Omega^- \to \Xi^- \gamma$ distributions are the same.

[11] To study this decay, we removed the photon calorimeter and modified the trigger, to require a single beam particle and a hit (from the K^- in the V1 counter (fig. 1).

FIGURES

FIG. 1. Plan view of the E761 apparatus in the Fermilab Proton Center charged hyperon beamline.

FIG. 2. Distribution of $M^2_{\pi^0}$ for the hypothesis $\Omega^- \to \Xi^- X$. The arrow indicates the π^0 squared mass. No signal appears on the gamma squared mass.

TABLES

TABLE I. Parameters used for branching ratio upper limit in Equation 1.

N_γ	9 (90% CL)
ϵ_γ	0.78 ± 0.02 %
f_{Ω^-}	$(4.8 \pm 0.3) \times 10^{-5}$
N_{bp}	5.21×10^{10}
BR $<$	4.6×10^{-4} (90% CL)

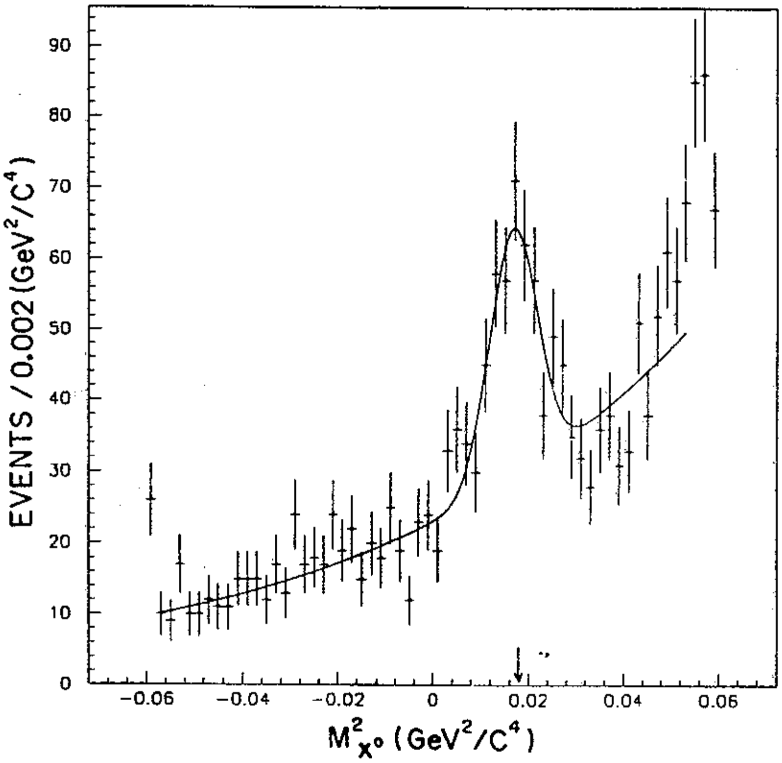

FIGURE 2

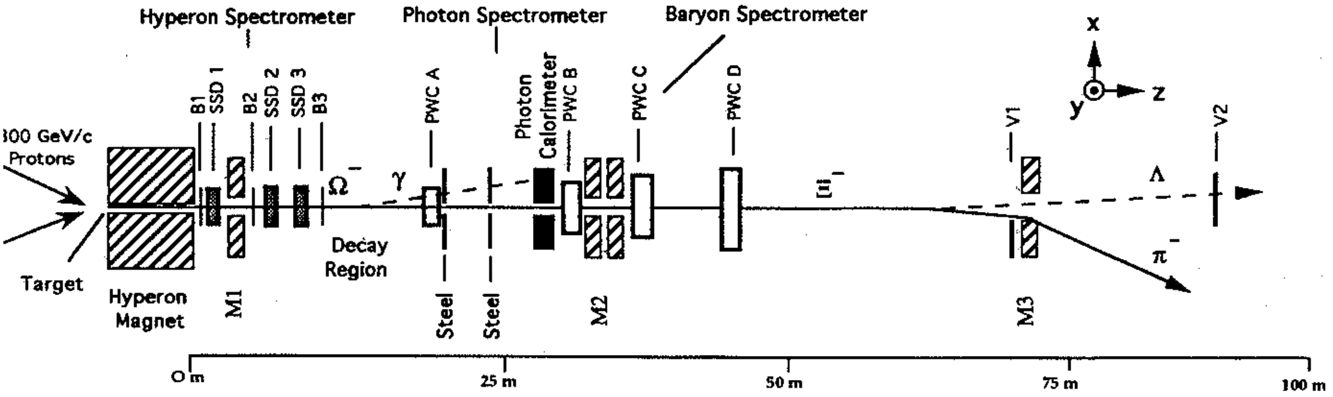

Figure 1