# MEASUREMENT OF BRANCHING RATIO FOR RADIATIVE DECAY $\Xi^- \to \Sigma^-\gamma$ (E761 experiment, FNAL)

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

1) *Fermi National Accelerator Laboratory, Batavia, Illinois USA*
2) *Institute of High Energy Physics, Beijing, People's Republic of China*
3) *Institute of Theoretical and Experimental Physics, Moscow, Russia*
4) *Carnegie Mellon University, Pittsburgh, Pennsylvania USA*
5) *University Of Iowa, Iowa City, Iowa USA*
6) *Universidade de Sao Paulo, Sao Paulo, Brazil*
7) *J.W.Gibbs Laboratory, Yale University, New Haven, Connecticut USA*
8) *Universidade Federal da Paraiba, Paraiba, Brazil*
9) *Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
10) *Conselho Nacional de Pesquisas, Rio de Janeiro, Brazil*
11) *State University of New York at Albany, Albany, New York USA*
12) *H.H.Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom*

The decay $\Xi^- \to \Sigma^-\gamma$ is of particular interest among radiative decays of hyperons. The only previous measurement of the branching ratio for the $\Xi^- \to \Sigma^-\gamma$ decay gave the result

$$BR(\Xi^- \to \Sigma^-\gamma/\Xi^- \to \Lambda^0\pi^-) = (2.3 \pm 1.0) \cdot 10^{-4}$$

from a sample of 11 candidate events [1]. Within the quark framework this value is significantly larger than expected from single quark transition and it exceeds predictions based on penguin diagrams by more than two orders of magnitude. Two-quark transitions, which are thought to be a dominant process in other radiative decays, should not contribute to the $\Xi^- \to \Sigma^-\gamma$ decay amplitude since there is no valence $u$ quark to absorb the exchanged $W^{\pm}$. The above experimental value is consistent with the unitarity lower bound of $1.0 \cdot 10^{-4}$.

The measurements were performed as part of Fermilab experiment E761 whose primary goal was to measure the asymmetry parameter in the weak radiative decay $\Sigma^+ \to p\gamma$ [2]. The configuration of the apparatus is shown in Fig.1. The $\Xi^-$ hyperons were produced ($\approx$1000 per sec) by the Tevatron's 800 GeV protons incident on a 1.0 interaction length $Cu$ target at the entrance of hyperon magnet M1. The secondary beam was found to contain approximately 1% of $\Xi^-$ with the dominant component being $\pi^-$. The incident proton beam could be steered horizontally to reverse the targeting angle which in turn reversed the vertical polarization vector of the produced $\Xi^-$. Three spectrometers were used, one each for the incident hyperon, the decay baryon and the photon. The hyperon and baryon spectrometers

had respective momentum resolutions ($\sigma$) of 0.8% and 1.7% at $p = 375$ GeV/c. The photon spectrometer was used to determine position and energy of the photon. At the upstream end of the photon spectrometer there were two steel plates (each 1.44 radiation length thick) to convert photons. Each plate was followed by two PWC (X + Y) planes and two planes (X + Y) of transition radiation detectors (TRD) to determine the position of the produced shower. A segmented lead glass/BGO photon calorimeter was used to measure shower energy and its segmentation allowed for position measurement as well. Downstream of the baryon spectrometer a single dipole magnet M4 was used to separate neutrons and $\pi^-$ that result from the decay sequence $\Xi^- \to \Sigma^-\gamma$, $\Sigma^- \to n\pi^-$. Hyperons candidates were selected from the 180 kHz beam by trigger requiring a single charged particle and at least one photon produced a shower in one of the steel plates. The final trigger rate was typically 1.0% of the beam rate. The geometrical acceptance of the apparatus and trigger for the $\Xi^- \to \Sigma^-\gamma$ decay was about 4%.

Data were collected over a five week period during the Fermilab 1990 fixed target run. A total of $2.8 \cdot 10^8$ triggers were recorded with approximately equal samples taken at horizontal targeting angles near $\pm 1.8$ mrad. All events were first analyzed for single track in the hyperon and baryon spectrometers, and a series of kinematic and fit quality cuts were applied. The $9.5 \cdot 10^6$ selected events were well separated from the dominant decay channels of $\Sigma^-$, $\Xi^-$ and $\Omega^-$. However, the decays $\Sigma^- \to \bar{p}\pi^0$ and $K^- \to \pi^-\pi^0$ completely mask any signal from $\Xi^- \to \Sigma^-\gamma$ without further selection.

We extracted the $\Xi^- \to \Sigma^-\gamma$ radiative decay signal from the background in two stages. The first stage exploited the decay of the $\Sigma^-$ daughter, $\Sigma^- \to n\pi^-$. Offline we extrapolated the trajectory of the baryon track into the scintillator NV (Fig.1). If the baryon was indeed a $\Sigma^-$ it would decay, and the resulting neutron would not produce a signal in the NV counter while the $\pi^-$ would be swept away from the NV counter by the magnet M4. On the other hand, if the downstream baryon candidate (residual undecayed beam, $\bar{p}$ from $\overline{\Sigma^-} \to \bar{p}\pi^0$ or a high momentum pion from $K^-$ decay) did not decay it would produce a signal in NV. A position cut requiring the extrapolated baryon track to pass through the NV counter significantly reduced the background for selected events with no NV signal.

The second stage of the background elimination made use of the segmentation of the lead glass/BGO calorimeter. The high energy component of a shower from a single photon conversion is deposited along or near the original photon's path determined from the measured hyperon and baryon tracks, whereas showers developed from background $\pi^0$ decays produce a broader pattern of energy deposition. We required this energy fraction to be greater than 85% of the total energy of the photon calorimeter. The result, shown in Fig.2a, clearly exhibits a peak at the photon mass based on the $\Xi^- \to \Sigma^-\gamma$ hypothesis. An alternative algorithm based on extrapolating the photon trajectory through the TRD [2] was also used, which yielded the result shown in Fig.2b. This result exhibits a cleaner signal but with fewer events in the signal peak.

The branching ratio for the $\Xi^- \to \Sigma^-\gamma$ decay is determined by comparing this decay mode with a sample of the dominant decay mode $\Xi^- \to \Lambda^0\pi^-$. The latter was obtained from a prescaled fraction of beam tracks collected with the regular trigger events. The branching ratio is given by

$$BR\left(\frac{\Xi^- \to \Sigma^-\gamma}{\Xi^- \to \Lambda^0\pi^-}\right) = (N_\gamma/\varepsilon_\gamma)(\varepsilon_\Lambda/N_\Lambda)(1/F)$$

where $N_\gamma$ is the number of observed signal events obtained from the fits shown in Fig.2

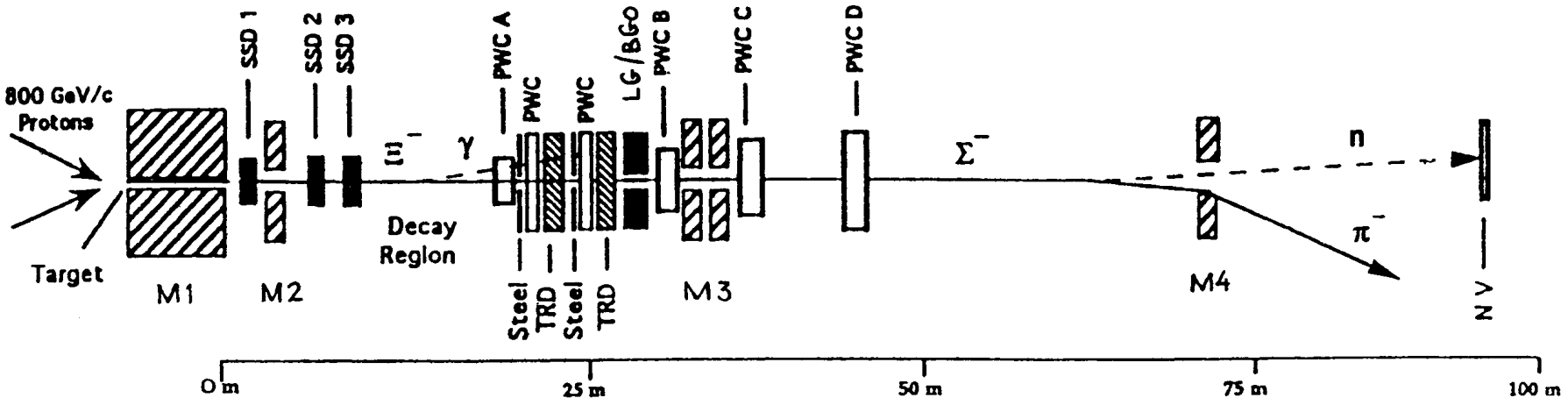


**Fig.1.** Plan view of the E761 apparatus in the Fermilab Proton Center charged hyperon beamline:

| | |
|---|---|
| Hyperon magnet | — M1 |
| Hyperon spectrometer | — M2 magnet, silicon strip detectors SSD1-3 |
| Baryon spectrometer | — M3 magnets, multiwire proportional chambers PWC A—D |
| Photon spectrometer | — Steel plates, PWC, TRD, photon calorimeter LG/BGO |
| Separating magnet | — M4 |
| Neutron veto counter | — NV |

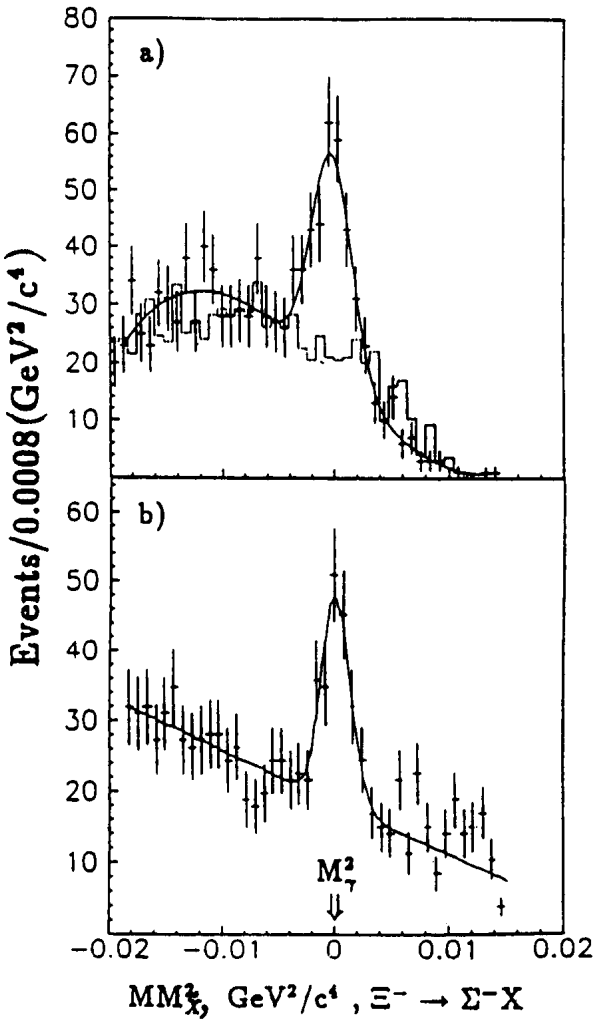


**Fig.2.** Distribution of missing mass squared for the hypothesis $\Xi^- \to \Sigma^- X^0$:
a) For photon calorimeter analysis with energy fraction >85%. Dashed line is Monte Carlo events for $\overline{\Sigma}^- \to \overline{p}\pi^0$ background. Solid line is best fit to signal plus background data.
b) For TRD analysis

($N_\gamma = 211$), $N_\Lambda$ is the number of events seen in the $\Xi^- \to \Lambda^0\pi^-$ normalization mode, $\epsilon_\gamma$ and $\epsilon_\Lambda$ are the determined from Monte Carlo detection efficiencies including trigger, acceptance and cuts, and F is the prescale factor for the normalization signal. The analysis including the lead glass data yields a result for the $\Xi^- \to \Sigma^-\gamma$ branching ratio:

$$BR\left(\frac{\Xi^- \to \Sigma^-\gamma}{\Xi^- \to \Lambda^0\pi^-}\right) = (1.22 \pm 0.23 \pm 0.06) \cdot 10^{-4} \quad (1)$$

The first error is statistical and the second systematic. Similar results were obtained using the TRD analysis :

$$BR = (1.44 \pm 0.37) \cdot 10^{-4} \quad (2)$$

but with larger statistical errors.

The above result (1) obtained from a sample of 211 events [3] is in agreement with the previous measured value [1]. We confirm, with significantly improved precision, that the

$\Xi^- \to \Sigma^-\gamma$ branching ratio is an order of magnitude smaller than those of the other measured hyperon radiative decays, and it is very close to the unitarity lower bound of $1.0 \cdot 10^{-4}$.

Despite the small number of $\Xi^- \to \Sigma^-\gamma$ events, we attempted to obtain the asymmetry parameter ($\alpha_\gamma$) for this decay. We estimate a $-11.0\%$ polarization for the $\Xi^-$. The asymmetry parameter for $\Xi^- \to \Sigma^-\gamma$ is found to be $\alpha_\gamma = 1.0 \pm 1.3$ [3] where the error is statistical only. This result gives weak evidence (63% probability) that the sign of the asymmetry parameter is positive.

REFERENCES


1. *Biagi S.F. et al.* // Z.Phys., 1985. V.C28. P.495.
2. *Foucher M. et al.* // Phys.Rev.Lett., 1992. V.68. P.3004.
   *Bondar N.F. et al.* // LNPI Research Report 1990-1991. St.Petersburg, 1992. P.22.
3. *Dubbs T. et al.* // Phys.Rev.Lett., 1994. V.72. P.808.