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ON SOME RARE WEAK DECAYS OF HYPERONS IN E781

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Abstract

Landsberg L.G. On Some Rare Weak Decays of Hyperons in E781: IHEP Preprint 96-5. – Protvino, 1996. – p. 8, figs. 4, tables 2.

A possibility of precision study of several semileptonic and nonleptonic hyperon decay modes in the E781 joint experiment with the Fermilab Tevatron hyperon beams is considered. The estimation of the expected decay event statistics is carried out. The sensitivity of these measurements would exceed the sensitivity of all previous experiments in this field by two orders of magnitude.

Аннотация

Ландсберг Л.Г. О некоторых слабых распадах гиперонов в эксперименте E781: Препринт ИФВЭ 96-5. – Протвино, 1996. – 8 с., 4 рис., 2 табл.

Рассмотрена возможность прецизионного изучения некоторых полулептонных и нелептонных слабых распадов гиперонов в совместном эксперименте E781 на гиперонных пучках тэватрона Фермилаб. Проведена оценка ожидаемой статистики распадных событий. Чувствительность этих измерений может на два порядка величины превысить чувствительность всех предыдущих экспериментов в этой области.

In the experiments with the SELEX facility (E781 Fermilab) in the hyperon beams of the Tevatron machine a wide research program in the hyperon and charm physics should be carried out [1,2]. The main part of this research program is devoted to the spectroscopy of charmed and strange-charmed baryons and weak decays of these particlees, to the search for charm-strange exotic hadrons and strange pentaquark hyperons with additional $s\bar{s}$ valence quark pairs, to the study of electromagnetic properties of hyperons, as well as several Primakoff production processes in Coulomb field of heavy nuclei [1-5].

The general layout of the SELEX setup for these measurements is presented on Fig.1. The apparatus is a three stage magnetic spectrometer with proportional and drift chambers. It includes also a microstrip vertex detector, trigger hodoscopes H_1 and H_2, three Photon spectrometers, RICH and TRD detectors for particle identification, a neutron calorimeter, a complicated 3 stage trigger logic with fast Primakoff trigger processor, very powerful data acquisition system.

The aim of this paper is to show that in the E781 run with special "$1 \rightarrow 3$ particles" trigger there would be a very good opportunity for a precise study of several weak hyperon decays. This "$1 \rightarrow 3$ particles" trigger was proposed earlier to study the Coulomb production of hyperon resonances and to search for exotic pentaquark baryons ($Y_Q = qqss\bar{s}$) – see details in [5]. The sensitivity of weak decay measurement is estimated to be by 2 orders of magnitude better than in all previous experiments.

The "$1 \rightarrow 3$" trigger uses the increase of multiplicities of charged particles after the secondary decays on the decay base between the setup target and the trigger hodoscopes H_1 and H_2 (around 9 m).

The trigger requirements are as follows:

1. The primary particle is a hyperon (beam TRD identification).

2. After the setup target there is one and only one particle with emission angles $\theta_{x;y} > 10^{-1}$ mrad relative to a primary beam particle (identification is in the interaction counter after the target IC(=1) and in the Primakoff trigger processor – see Fig.2, [6]).

3. There are 3 or 5 particles in H_1 and H_2 (depending of one or two secondary decays before H_1).

4. Some guard anticoincidence counters can be used to reduce the background from secondary interactions (see [5] for more details).

Fig. 1. Layout of the SELEX facility. M_1 – M_3 – magnetic spectrometers; DC – drift chambers, PC – proportional chambers, VEEA-VEEC – drift chamber clusters; Photon 1-3 – multichannel lead glass γ – spectrometers; HOD1 (H_1), HOD2 (H_2) – Trigger hodoscops; TRD – transition radiation detectors.

Fig. 2. The scheme of the Primakoff trigger processor for the selection of the events with one particle after the target with angles Θ_x, $\Theta_y > 10^{-1}$ mrad (relative to the primary particle). MS1-3 — silicon stations (with 50 μm strips); Pb – the Primakoff target. This processor is now under development in PINP [6].

Table 1. Possibility to study several hyperon weak decays in E781 run with trigger "1 particle $\rightarrow$ 3 particles"

Decay mode	BR	World statistics (events)	Number of Σ or Ω decays in the decay region, (sec^{-1})	BR second. decays	ϵ	$\frac{N_{events}}{14\ weeks}$	N events in the experiment
$\Sigma^+ \rightarrow \Lambda e^+ \nu_e$, $\hookrightarrow p\pi^-$	$(0.20 \pm 0.05) \cdot 10^{-4}$	~ 20	$3.3 \cdot 10^3$ (500 GeV/c)	0.64	0.039	250/2 weeks	~ 800
$\Sigma^+ \rightarrow \Lambda e^+ \nu_e$			$2.4 \cdot 10^3$ (250 GeV/c)	0.64	0.12	550/2 weeks	
$\overline{\Sigma^+} \rightarrow \bar{\Lambda} e^- \overline{\nu}_e$, $\hookrightarrow \bar{p}\pi^+$			60 (650 GeV/c)	0.64	0.030	25	~ 75
$\Sigma^- \rightarrow \Lambda e^- \overline{\nu}_e$, $\hookrightarrow p\pi^-$	$(0.574 \pm 0.027) \cdot 10^{-4}$	~ 1850	$0.75 \cdot 10^5$	0.64	0.030	86000	$\sim 2.5 \cdot 10^5$
$\Omega^- \rightarrow \Lambda K^-$, $\hookrightarrow p\pi^-$	0.678 ± 0.007	$\sim 1.4 \cdot 10^4$	22	0.64	0.17	$2.2 \cdot 10^6$	$\sim 5 \cdot 10^6$
$\Omega^- \rightarrow \Lambda \pi^-$, $\hookrightarrow p\pi^-$	$< 1.9 \cdot 10^{-4}$ (90% c.l.)	0	22	0.64	0.17		*)
$\Omega^- \rightarrow \Xi^- \pi^o$, $\hookrightarrow \Lambda\pi^-$, $\hookrightarrow p\pi^-$	0.086 ± 0.004	~ 760	22	0.64	0.016	20000	$\sim 5 \cdot 10^4$
$\Omega^- \rightarrow \Xi^o \pi^-$, $\hookrightarrow \Lambda\pi^o$, $\hookrightarrow p\pi^-$	0.236 ± 0.007	~ 1950	22	0.64	0.011	38000	$\sim 1 \cdot 10^5$
$\Omega^- \rightarrow \Xi^o e^- \overline{\nu}_e$, $\hookrightarrow \Lambda\pi^o$, $\hookrightarrow p\pi^-$	$(5.6 \pm 2.9) \cdot 10^{-3}$	~ 14	22	0.64	0.007	550	$\sim 1.5 \cdot 10^3$

*) The upper limit for $BR(\Omega^- \rightarrow \Lambda\pi^-) < 10^{-6}$ can be obtained.

These requirements may be written as

$$T(1 \to 3) \;=\; [TRD = Y^-] \times [\text{Primakoff processor} = 1 \text{ with} [\theta_{x;y} > 10^{-1} \text{ mrad}] \times$$

$$\times \;\; [H_1 = 3;4;5] \cdot [H_2 = 3,4,5] \cdot [\text{guard anti}]. \qquad (1)$$

The examples of processes which are selected with this $T(1 \to 3)$ trigger are [5]

$$\begin{array}{lll} \Sigma^- + (Z,\ A) \to & \Sigma^*(1385)^- + (Z,\ A), & (2) \\ & \hookrightarrow \Lambda\pi^- & \\ & \quad \hookrightarrow p\pi^- & \end{array}$$

(Coulomb production of $\Sigma^*(1385)^-$ hyperon resonance) and

$$\begin{array}{lll} \Sigma^- + N \to & Y_\phi(ddss\bar{s}) + N & (3) \\ & \hookrightarrow \Xi^- K^o & \\ & \quad \hookrightarrow \pi^+\pi^- & \\ & \hookrightarrow \Lambda\pi^- & \\ & \quad \hookrightarrow p\pi^- & \end{array}$$

(diffractive production of exotic baryon resonances Y_ϕ with additional hidden strangeness). It was shown before [5], that the measurements with $T(1 \to 3)$ can be made in parallel with the main charm trigger run of E781. The rate of $T(1 \to 3)$ is expected to be at the level of (1.5-2)$\cdot 10^2$ sec^{-1} (the total trigger rate for E781 is about 10^4 sec^{-1} due to the charm trigger).

Several decays of beam hyperons on the base of the Primakoff processor device are also partly efficient to produce $T(1 \to 3)$ trigger and can be detected. This is just the case for cascade decays $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$, which produce the main component of this trigger rate. Thus $T(1 \to 3)$ trigger can be used to study several weak decays of Σ, Ξ^- and Ω^- hyperons which were not investigated quite precisely before (see also [7] for the discussion of hyperon weak radiative decay study in E781).

The results of calculations of expected statistics for the study of some Σ and Ω^- hyperon decay modes are presented in Table 1. In these calculations we used the composition of negative and positive hyperon beams from Table 2. The numbers in Table 2 were obtained from the cross section curves on Fig. 3 and 4 which are the results of fitting the main existing data on hyperon yields in different regions of kinematical variables x_F and p_T [8].

In the calculations of the event rates of Table 1 several assumptions were made.

1. The effective decay base for hyperons of a beam in the region of the Primakoff processor is 2 m.

2. The efficiency for detecting different decay modes includes the decay kinematics, geometry of the setup and additional efficiency for the registration of π^o-mesons (with

Table 2. Composition of hyperon beams at the distance of 10 m from the production target

Negative beam		Positive beam			
particles sec^{-1}	p=650 GeV/c	particles sec^{-1}	p=500 GeV/c	p=450 GeV/c	p=250 GeV/c
π^-	$1.0 \cdot 10^6$	p	$2 \cdot 10^6$	$1.7 \cdot 10^6$	10^6
Σ^-	$0.9 \cdot 10^6$	π^+	$1 \cdot 10^5$	$3 \cdot 10^5$	10^6
Ξ^-	$0.8 \cdot 10^4$	Σ^+	$1.3 \cdot 10^4$	$1.5 \cdot 10^4$	$5 \cdot 10^3$
$\overline{\Sigma^+}$	$0.4 \cdot 10^3$	$\overline{\Xi^-}$	1.8	11	49
Ω^-	$1.1 \cdot 10^2$				

Notes to Table 2:
1. The initial proton beam has the momentum $P_p = 800$ GeV/c.
2. Total intensity of the secondary beam is $I = 2 \cdot 10^6$ particles/sec.
3. The data in Table are for the beams produced with $p_T = 0$. For positive beams which can be produced in p_T region of 0.59-1.1 GeV/c the percentage of Σ^+ hyperons can be increased by 25-30% for $p = 500$ GeV/c and by 45% for $p = 250$ GeV/c.

$\epsilon(\pi^o)$=1/3) and/or electrons (with $\epsilon(e)$=1/1.7) which is due to the absorption of photons and electrons in the setup matter.

3. The total flux in the beam is $2 \cdot 10^6$ particles/sec. The effective week is $7.5 \cdot 10^4$ sec. The E781 run includes 3 expositions (14 weeks each) in the negative beam with 650 GeV/c momentum and two short expositions in a positive beam with about 500 GeV/c and 250 GeV/c momenta (2 weeks each). It was assumed that the expositions on positive beams would be with $0.6 < p_T < 1.1$ GeV/c to increase the fluxes of Σ^+ hyperons.

It is clear from Table 1 that the E781 has a possibility to study several quite interesting hyperon decays with the statistics which exceeds the existing data by 2 orders of magnitude. This increase in the sensitivity seems quite important for the future testing of the Cabibbo model for the semileptonic decays of baryons (see [9]), for measuring the asymmetry in the non-leptonic Ω^- hyperon decays and for reducing the upper limits for the anomalous process. The $\Omega^- \to \Lambda\pi^-$ decay with $\Delta S = 2$, a possible influence of the weak current of the second kind on the ratio $\Gamma(\Sigma^+ \to \Lambda e^+\nu_e)/\Gamma(\Sigma^- \to \Lambda e^-\bar{\nu}_e)$[1] and so on may be the examples of such processes.

[1]See Appendix for more details.

Fig. 3. Positive and negative particles invariant cross sections in x_F for P_T=0 (from [8]). Negative beam: ▲ $-\Sigma^-$; □ $-\Xi^-$; ▲ $-\Omega^-$; ★ $-K^-$; ∘ $-(\overline{\Sigma^+})$; ♦ $-\pi^-$ (A); Positive beam: $*$ $-p$; □ $-(\overline{\Xi^-})$; ♦ $-\pi^+$; ★ $-K^+$; ∘ $-\Sigma^+$ (B).

Fig. 4. Positive particles invariant cross section in x_F for $0.59 < P_T < 1.1$ GeV/c (from [8]). $*$ – p; ♦ – π^+; ★ – K^+; • – Σ^+; □ – $\overline{\Xi^-}$.

References

[1] Edelstein R. et al. Fermilab Proposal E781 (1987, revised 1993).

[2] E781 Physical Meetings, Fermilab, 18-19 August, 1993 and Fermilab, 31 July – 1 August, 1995.

[3] Landsberg L.G. et al. — Preprint IHEP 94-19, Protvino, 1994.

[4] Moinester M.A. et al. The Future of High-Sensitivity Charm Experiments. — In: Proc. of the Charm-200 Workshop, Fermilab, June 7-9, 1994, p. 275.

[5] Landsberg L.G., Molchanov V.V. — Preprint IHEP 95-25, Protvino, 1995; Landsberg L.G., Molchanov V.V. Talk on E781 Physical Meeting, Fermilab, 31 July – 1 August, 1995.

[6] Terentiev N.K., Vorobiev A.A. Private communication.

[7] Ramberg E.J., Cooper P. Talk on E781 Physical Meeting, Fermilab, 31 July – 1 August, 1995.

[8] Langland J.L. The PhD Thesis, Univ. of Iowa, August 1995.

[9] Cooper P. Talk on the Strassburg Conference, September 1995.

[10] Heitel P. Z.Phys., 202, 383 (1967).

[11] Montanet L. et al. (PDG).//Phys. Rev., D50, 1173 (1994).

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Appendix

Measurement of the ratio $(\Gamma(\Sigma^- \to \Lambda e^- \bar{\nu}_e)/\Gamma(\Sigma^+ \to \Lambda e^+ \nu_e)$

Let us consider the existing data on the ratio

$$\frac{\Gamma(\Sigma^- \to \Lambda e^- \bar{\nu}_e)}{\Gamma(\Sigma^+ \to \Lambda e^+ \nu_e)} = R \cdot \underbrace{\frac{f(W_-)}{f(W_+)}}_{\substack{phase\ space \\ factor}} \qquad \text{(see [10])}.$$

Phase space for these decays can be evaluated as

$$f(W) = \int_{m_e}^{W} dE_e \cdot \sqrt{E_e^2 - m_e^2} \cdot E_e \cdot (W - E_e)^2 \simeq \frac{W^5}{30} \qquad (\text{for } W/m_e >> 1),$$

where $W = \frac{M(\Sigma)^2 - M(\Lambda)^2 + m_e^2}{2M(\Sigma)}$ is the maximal energy of electrons in $\Sigma \to \Lambda e \nu_e$ decay. From the data of PDG [11]:

$$\left.\begin{array}{l} W_- = 74.39 \pm 0.09 \text{ MeV}; \\ W_+ = 71.40 \pm 0.08 \text{MeV} \end{array}\right\} f(W_-)/f(W_+) = 1.228 \pm 0.009.$$

$$\frac{\Gamma(\Sigma^- \to \Lambda e^- \bar{\nu}_e)}{\Gamma(\Sigma^+ \to \Lambda e^+ \nu_e)} = \frac{BR(\Sigma^-)}{\tau(\Sigma^-)} \Big/ \frac{BR(\Sigma^+)}{\tau(\Sigma^+)} =$$

$$\frac{(5.74 \pm 0.27) \cdot 10^{-5}}{(1.479 \pm 0.011) \cdot 10^{-10}} \Big/ \frac{(2.0 \pm 0.5) \cdot 10^{-5}}{(0.799 \pm 0.004) \cdot 10^{-10}} = 1.54 \pm 0.39$$

and

$$R = \frac{1.54 \pm 0.39}{1.228 \pm 0.009} = 1.25 \pm 0.25.$$

The square of matrix elements ratio $R = 1$ if there are no hadronic weak currents of second kind (antihermitian currents – see [10] for detail). For different models with weak currents of the second kind, the ratio R is rather sensitive to the presence of such currents and can deviate from value 1 by 10-15% or even more. The existing very limited data for $\Sigma^\pm \to \Lambda e^\mp \bar{\nu}_e(\nu_e)$ decays (and first of all for Σ^+ decays) give the value R with large uncertainty and practically do not allow one to obtain the information about the weak hadron currents of the second kind. It is expected that from the future data of E781 (see Table 1) it would be possible to obtain the precision in R around 3÷4% and to provide the meaningful information about the existence of a new type of weak hadron currents.

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