Frascati Physics Series Vol. nnn (2001), pp. 000-000
Heavy Quarks at Fixed Target - Rio de Janeiro, Oct. 9-19, 2000

UASLP–IF–00–05
Fermilab–Conf–00/309–E

RECENT RESULTS ON CHARM AND HYPERON PHYSICS FROM SELEX

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ABSTRACT

The SELEX experiment (Fermilab E781) is a 3-stage magnetic spectrometer for the study of charm hadroproduction at large x_F using 600 GeV/c Σ^-, π^-, and p beams. New precise measurements of the Λ_c, D^0, and D_s lifetimes are presented. Results on Λ_c and D_s production for $x_F > 0.2$ are reported as well. The spectrometer was also used for hyperon physics, where we will show measurements of the Σ^- charge radius, the polarization of inclusive produced Λs, and the polarization of beam Σ^+.

1 The SELEX Experiment

The SELEX experiment at Fermilab is a 3-stage magnetic spectrometer [1]. The negative beam (600 GeV/c) had about equal fluxes of π^- and Σ^-. The positive beam (540 GeV/c) was 92 % protons. The primary and secondary vertex resolution for typical charm events is $\sigma_p = 270\,\mu$m and $\sigma_s = 560\,\mu$m, respectively. The momentum resolution for charged tracks is $\delta p/p \approx 0.5\,\%$ at $100 - 300$ GeV/c. A RICH detector [2] labelled all particles above 25 GeV/c with high efficiency, greatly reducing background in charm analyses.

Our charm analysis, a vertex driven analysis with definite RICH identification for all kaon and proton candidates required: (i) a good secondary vertex ($\chi^2/dof < 5$); (ii) a longitudinal separation (L) between the vertices bigger than $8\,\sigma$, were σ is defined as $\sigma^2 = \sigma_p^2 + \sigma_s^2$; (iii) the reconstructed momentum vector of the charm track to point back towards the primary vertex within errors; (iv) K, p identified by the RICH with $\mathcal{L}(K) > \mathcal{L}(\pi)$, $\mathcal{L}(p) > \mathcal{L}(\pi)$; (v) no secondary vertices inside downstream material.

The mass resolution, measured via the width of $D^0 \to K^\pm\pi^\mp$ and $D^0 \to K^\pm\pi^\mp\pi^+\pi^-$, is constant ($\sim 9\,\mathrm{MeV}/c^2$) over the whole momentum range of interest.

The geometrical acceptance and detection efficiency is identical for particle and anti-particle to $< 3\,\%$, still high at large x_F, and is flat in p_T.

2 Weak Decays of Charm

2.1 Motivation

Charm lifetime measurements test models based on $1/M_Q$ QCD expansions and evaluate corrections from non-spectator W-annihilation and Pauli interference to perturbative QCD matrix elements. The lifetime hierarchy for the charm system presents a challenge to HQET and pQCD methodologies due to the low charm quark mass.

2.2 SELEX Lifetime Analysis Method

SELEX charm signals are extracted by the sideband subtraction method with a fixed signal region ($\pm 2.5\,\sigma_M$, i.e. $20\,\mathrm{MeV}/c^2$) centered on the charm mass. Sidebands of equal width are defined above and below the charm mass region. The background under the charm peak is the average of the two sideband regions.

π and K misidentification causes mixing of charm signals. In SELEX this is significant only for the D_s peak, due to the excellent particle identification. For both D_s modes kaon momenta are $\leq 160\,\mathrm{Gev}/c$ to reduce misidentification. Any $KK\pi$ event having a pseudo-$D^{\pm}$ mass in the interval $(1867 \pm 20)\,\mathrm{Mev}/c^2$ is removed to eliminate an artificial lengthening of the D_s lifetime, even though some of these are real D_s events.

Due to the excellent proper time resolution of $\approx 20\,\mathrm{fs}$, we make a binned maximum likelihood fit simultaneously to signal and sideband regions in reduced proper time $t^* = M(L - 8\sigma)/pc$.

The acceptance correction functions were established using data only, which greatly reduces systematic effects. Overall systematics errors were studied with different decays modes and by comparing the results with events from different production targets. The D^0 and D^+ lifetimes were measured mostly to validate the other measurements, presenting the largest acceptance correction.

2.3 Results for Λ_c^+, D^0, D^+, D_s

The results presented here for the lifetimes of Λ_c^+, D^0, and D^+ are submitted for publication [3], the results for D_s are still preliminary. A summary is presented in table 1. A summary of recent lifetime measurements for Λ_c, D^0, and D_s is shown in fig. 1. As can be seen, the SELEX result for the Λ_c^+ lifetime has a smaller error than the PDG2000 average. The result for D^0 and D_s is comparable with previous measurements, but we are looking forward to the new results from FOCUS. For the ratio of the lifetimes of D_s and D^0, the preliminary SELEX result gives $\tau_{D_s}/\tau_{D^0} = 1.166 \pm 0.065$, about 3 standard deviations away from 1. Taking into account all recent measurements, the

Table 1: *SELEX charm lifetime measurements. The results for D_s are preliminary.*

	Lifetime	Stat. Err.	Sys. Err.
$\boldsymbol{\Lambda_c^+ \to pK^-\pi^+}$	**198.1 fs**	**7.0 fs**	**5.6 fs**
$D^0 \to K\pi$	416 fs	8 fs	–
$D^0 \to K\pi\pi\pi$	402 fs	10.5 fs	–
$\boldsymbol{D^0}$	**407.9 fs**	**6.0 fs**	**4.3 fs**
$\boldsymbol{D^\pm \to K\pi\pi}$	**1070 fs**	**36 fs**	–
$D_s \to \phi\pi$	474 fs	22 fs	–
$D_s \to K^\star K$	478 fs	33 fs	–
$\boldsymbol{D_s}$	**475.6 fs**	**17.5 fs**	**4.4 fs**

result is $\tau_{D_s}/\tau_{D^0} = 1.21 \pm 0.02$, which support the necessity [23] of the W-annihilation diagrams in weak decays.

3 Hadroproduction of Charm

3.1 Motivation

Charm Hadroproduction is a major challenge to factorized perturbative QCD analysis. The quark level processes are charm–anticharm symmetric, and next to leading order terms only introduce a small asymmetry. In contrast, some experiments observed large production asymmetries in some cases.

Two basic models exist which try to explain these asymmetries: the color drag model, sometimes also called "leading particle effect" [24], and the intrinsic charm model [25]. The models differ in the predicted behavior of the asymmetries as functions of x_F and p_T. SELEX, with its 3 different hadron beams (Σ^-, π^-, p), has the unique opportunity to add experimental data to this problem.

3.2 SELEX Features

As mentioned before, SELEX has (by design) a high acceptance at large x_F, the acceptance is constant over a wide range of p_T, and is identical for particle and anti-particle to better than 3 % in any bin. For the asymmetry data, no acceptance correction has been applied.

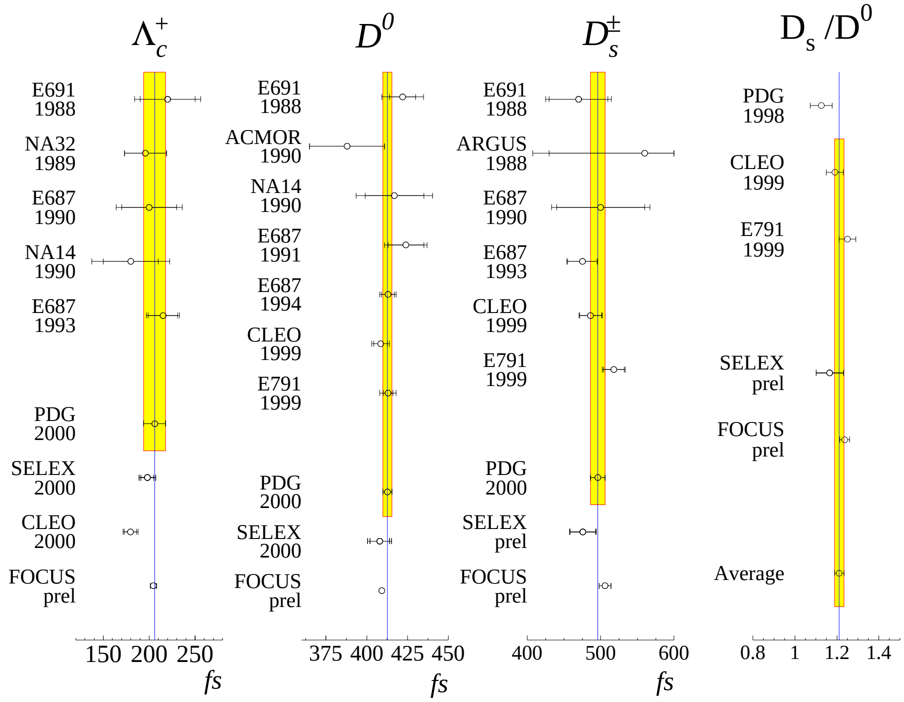

Figure 1: *Summary of recent lifetime measurements for Λ_c, D^0, and D_s. Also shown are results for the ratio of D_s to D^0 lifetimes. Lifetime results are taken from references [3] to [22].*

3.3 Production of Λ_c by Σ^-, π^-, and p

SELEX measured the differential production cross sections of Λ_c^+ and Λ_c^- with the 3 different beams as a function of x_F and p_T. The preliminary results for a fit to $d\sigma/dx_F \sim (1-x_F)^n$ are shown in table 2. In general, we observe a very hard production characteristic for all beam particles. There is a striking contrast in Λ_c^- production between π^- beam and the baryon beams. In addition, we see a structure at large x_F in the Σ^- data which suggests, together with the other observations, Pythia–style color drag.

For the production behavior of Λ_c^+ in p_T, we observe the same Gaussian slope for $p_T < 4\,\mathrm{GeV}/c$ for all 3 beam particles. At higher p_T, in the Σ^- data we observe a deviation from the Gaussian behavior.

The production asymmetry results are consistent with other measure-

Table 2: *Preliminary results for a fit to the differential cross section* $d\sigma/dx_F \sim (1-x_F)^n$ *for* Λ_c^+ *and* Λ_c^- *for different beams.*

Beam	Particle	n
Σ^-	Λ_c^+	2.45 ± 0.18
Σ^-	Λ_c^-	6.8 ± 1.1
π^-	Λ_c^+	2.65 ± 0.44
π^-	Λ_c^-	2.2 ± 0.8
p	Λ_c^+	2.22 ± 0.33
p	Λ_c^-	9 ± 7

ments [26, 27], but, especially in the higher x_F values and for the Σ^- beam, of higher statistics.

3.4 Production of D_s by Σ^- and π^-

We observe a large difference in the Σ^- data for the production of D_s^- ($n = 3.8 \pm 0.4$) and D_s^+ ($n = 7.1 \pm 0.9$), with an integrated asymmetry (defined as $A \equiv (N_{D_s^-} - N_{D_s^+})/(N_{D_s^-} + N_{D_s^+})$) of $A = 0.57 \pm 0.07$ ($x_F > 0.2$). For the π^- data, we obtain $A = -0.08 \pm 0.08$. This favors again the color–drag picture of production.

3.5 Production of D^0 by Σ^-, π^-, p

We measured the x_F distribution of the D^0 and $\overline{D^0}$ production. The preliminary results are shown in table 3.

Table 3: *Preliminary results for a fit to the differential cross section* $d\sigma/dx_F \sim (1-x_F)^n$ *for* D^0, $\overline{D^0}$ *and* D^+, D^- *for different beams.*

Beam	Particle	n
Σ^-	D^0	6.20 ± 0.27
Σ^-	$\overline{D^0}$	7.30 ± 0.26
π^-	D^0	3.65 ± 0.35
π^-	$\overline{D^0}$	5.04 ± 0.44
p	D^0	5.88 ± 0.46
p	$\overline{D^0}$	7.30 ± 0.26

Beam	Particle	n
Σ^-	D^+	4.95 ± 0.23
Σ^-	D^-	4.67 ± 0.22
π^-	D^+	2.46 ± 0.31
π^-	D^-	3.58 ± 0.34
p	D^+	4.42 ± 0.42
p	D^-	4.74 ± 0.40

A comparison of π^- data from E791 [28] for $d\sigma/dx_F$ for the sum of of $D^0+\overline{D^0}$ shows good agreement with exception at the highest x_F values, where we do not observe a change in the $(1-x_F)^n$ behavior.

3.6 Production of $D^\pm$ by Σ^-, π^-, p

The preliminary results for the x_F behavior of $D^\pm$ production by the 3 different beams are shown in table 3. For the $D^\pm$ production asymmetry $A \equiv (N_{D^+} - N_{D^-})/(N_{D^+}+N_{D^-})$ as a function of x_F we observe a nearly constant, slightly negative value of A. For the π^- data at higher x_F we observe A consistent with 0, which is, due to the large errors, not totally inconsistent with previous results [29, 30], but indicates some problem in one of the measurements.

3.7 Summary of Hadroproduction Results

As a conclusion we like to mention that our data in general show a strong sensitivity to shared valence quarks. In contrary, they provide little support for the "intrinsic charm" model.

4 Hyperon Physics

4.1 Σ^- Radius Measurement

The measurement of the Σ^- electromagnetic charge radius was performed in parallel with our charm data taking. A special trigger (and a subsequent analysis) selected events with two and only two outgoing tracks, one of them an electron, which were supposed to come from a beam particle scattered on a target electron. The differential cross section for this process is given by

$$\frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2\hbar^2}{Q^4}\left(1-\frac{Q^2}{Q^2_{\max}}\right)\cdot F^2(G_E, G_M, Q^2) \tag{1}$$

and

$$G_E(Q^2) = \frac{1}{\kappa-1}G_M(Q^2) = \left(1+\frac{1}{12}Q^2 <r^2_{ch}>\right)^{-2} \tag{2}$$

where Q denotes the momentum transfer in the reaction and $Q_{\max}$ its kinematically allowed maximum. Via approximating the electric and magnetic form factors G_E and G_M with the dipole approximation (eq. 2), the mean squared charge radius $<r^2_{ch}>$ can be extracted by a fit to the slope of the Q^2 distribution.

We applied this method to Σ^-, π^-, and p as beam particle, the latter two to validate the method. The preliminary results are shown in table 4. As can

Table 4: *Preliminary results for the mean squared charge radius* $<r^2_{ch}>$ *for different particles compared to previous measurements.*

	SELEX $<r^2>$ [fm^2]	$<r^2>$ [fm^2]
Σ^-	$0.61 \pm 0.12 \pm 0.09$	0.91 ± 0.51 [31]
p	$0.69 \pm 0.06 \pm 0.06$	0.72 ± 0.01 [32]
π^-	$0.42 \pm 0.06 \pm 0.08$	0.44 ± 0.01 [33]

be seen, the Σ^- result is the first measurement (after the feasibility has been demonstrated [31]) of this type. Our results for p and π^- are consistent with other, high statistics, measurement.

We extracted also the strong interaction radius of the Σ^- from data of our total cross section measurement [34] and obtain a consistent result.

4.2 Λ^0 inclusive polarization

SELEX made a new measurement of the polarization of inclusive Λ^0s produced by Σ^-, extending to higher x_F than a previous measurement [35]. The preliminary results shows an opposite sign, compared to the previous measurement. A detailed comparison of the analysis is currently in progress.

4.3 Σ^+ polarization

During a dedicated running period, SELEX took data to measure the polarization of Σ^+s produced by protons with a momentum of $800\,\mathrm{GeV}/c$. This measurement was performed at several points in x_F and p_T, and for copper and beryllium targets, extending previous measurements [36], but with lower statistics. Even though the errors are large, our date indicate a slightly higher polarization when the Σ^+ are produced in a Beryllium target.

5 Conclusion

SELEX submitted the most precise measurement of the Λ_c lifetime for publication: $\tau(\Lambda_c) = (198.1 \pm 7.0 \pm 5.1)\,\mathrm{fs}$. A preliminary result for the D_s lifetime

$\tau(D_s^\pm) = (475.6 \pm 17.5 \pm 4.4)$ fs will be submitted soon. The analysis method was validated in both cases by measuring the D^0 and D^+ lifetimes.

SELEX has new results on hadroproduction of Λ_c, D_s, D^0, and $D^\pm$ with Σ^-, π^- and p beams.

In the hyperon sector, SELEX has new results on the electromagnetic charge radius of the Σ^-, the polarization of inclusive Λ^0 produced by Σ^-, and the polarization of Σ^+ produced by protons.

We are starting now a second pass over all data. We improved significantly our efficiency to reconstruct hyperons, which should help us in accessing other charm states, especially charm strange baryons.

6 Acknowledgement

The authors are indebted to the staff of Fermi National Accelerator Laboratory and for invaluable technical support from the staffs of collaborating institutions. This project was supported in part by Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Consejo Nacional de Ciencia y Tecnología (CONACyT), Conselho Nacional de Desenvolvimento Científico e Tecnológico, Fondo de Apoyo a la Investigación (UASLP), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), the Israel Science Foundation founded by the Israel Academy of Sciences and Humanities, Istituto Nazionale di Fisica Nucleare (INFN), the International Science Foundation (ISF), the National Science Foundation (Phy #9602178), NATO (grant CR6.941058-1360/94), the Russian Academy of Science, the Russian Ministry of Science and Technology, the Turkish Scientific and Technological Research Board (TÜBİTAK), the U.S. Department of Energy (DOE grant DE-FG02-91ER40664 and DOE contract number DE-AC02-76CHO3000), and the U.S.-Israel Binational Science Foundation (BSF).

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