New results on c-baryons and a search for cc-baryons in FOCUS

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1. Cabibbo forbidden decays $\Lambda_c^+ \to \Sigma^+ X$

FOCUS is a high statistic charm photoproduction experiment. A total of about 7 billion triggers have been collected and many results have been published. The knowledge of the single Cabibbo suppressed decay rates of the Λ_c^+ baryon are useful in testing theoretical predictions of the contributions to the inclusive decay amplitudes [1] as well as our theoretical understanding of the Ξ_c^+ lifetime[2].

We measured the single Cabibbo suppressed decays $\Lambda_c^+ \to \Sigma^+(K\pi)^o$; and the Cabibbo allowed decay $\Lambda_c^+ \to \Sigma^+K^+K^-$, together with their branching ratios relative to the normalizing mode $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$, our highest statistic decay containing a Σ hyperon.

The first decay may proceed via a 2-body channel such as $\Sigma^+K^*(892)^o$ as well as via the 3-body channels $\Sigma^+K^-\pi^+$ or $\Sigma^-K^+\pi^-$. The statistics is not sufficient to allow a Dalitz plot analysis; however we see that the 2-body channel is dominant (see fig. 1a). The 2-body decay includes also a $K^-\pi^+$ combination in the final state. The fit to the $M[\Sigma^+(K\pi)^o]$ distribution leads to a signal of (49 ± 10) Λ_c^+ events. Fig.1b shows instead the absence of a signal in $M(\Sigma^-K^+\pi^+)$, a configuration equivalent to $\Sigma^+K^-\pi^+$. The fit returns a yield of (11 ± 10) events). This may justify the suppression of the 3-body channel since no extra pion is necessary to get the $\Sigma^+K^*(892)^o$ state.

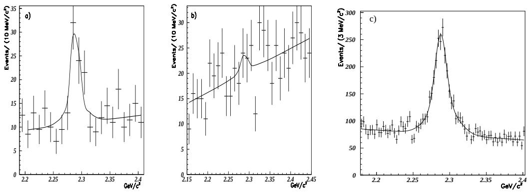

Figure 1. Mass distributions: a- $M(\Sigma^+K^*(892)^o)$ (with $K^*(892)^o \to K^+\pi^-$); b- distributions of $M(\Sigma^-K^+\pi^+)$; c- reference signal $M(\Sigma^+\pi^+\pi^-)$. The distributions are fit with a double Gaussian for the signal plus a linear background.

The normalizing mode (shown in fig. 1c) leads to a signal of (1706 ± 88) Λ_c^+ events.

We get a first measurement of the relative branching ratio $\frac{\Gamma(\Sigma^+K^*[892])}{\Gamma(\Sigma^+\pi^+\pi^-)} = 0.078 \pm .018 \pm .013$ and a first estimate of an upper limit for the relative branching ratio $\frac{\Gamma(\Sigma^-K^+\pi^+)}{\Gamma(\Sigma^+K^*[892])} < 0.35$ (90% confidence level).

2. The $\Lambda_c^+ \to \Sigma^+K^+K^-$ decay.

We also studied the events $\Lambda_c^+ \to \Sigma^+K^+K^-$ as well as the 2-body configurations which may be present. The branching ratios are again related to the normalization channel $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ since the dominant source of systematics is the selection and isolation of the Σ hyperon.

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Table 1
Comparison of the FOCUS results to BELLE and CLEO.

	Efficiency ratio	FOCUS results	BELLE results	CLEO results
$\frac{\Gamma(\Sigma^+ K^*[892])}{\Gamma(\Sigma^+\pi^+\pi^-)}$	0.35	$0.078 \pm .018 \pm .013$	-	-
$\frac{\Gamma(\Sigma^- K^+\pi^+)}{\Gamma[\Sigma^+ K^*(892)]}$	1.49	$< 0.35\%$ CL 90%	-	-
$\frac{\Gamma(\Sigma^+ K^+ K^-)}{\Gamma(\Sigma^+\pi^+\pi^-)}$	0.85	$0.071 \pm .011 \pm .011$	$0.076 \pm .007 \pm .009$	$0.095 \pm 0.017 \pm .019$
$\frac{\Gamma(\Sigma^+\phi^o)}{\Gamma(\Sigma^+\pi^+\pi^-)}$	0.39	$0.087 \pm .006 \pm .011$	$0.085 \pm .012 \pm .012$	$0.093 \pm 0.032 \pm .024$
$\frac{\Gamma[\Xi^{*+}(\Sigma^+ K^-)K^+]}{\Gamma(\Sigma^+\pi^+\pi^-)}$	0.92	$0.022 \pm 0.006 \pm .006$	$0.023 \pm .005 \pm .005$	-
$\frac{\Gamma(\Sigma^+ K^- K^+)_{NR}}{\Gamma(\Sigma^+\pi^+\pi^-)}$	0.44	$< 2.8\%$ CL 90%	$< 1.8\%$ $CL 90\%$	-

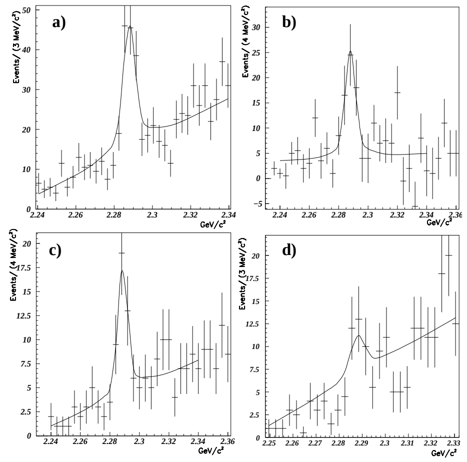

Figure 2. Mass distributions: a- total $M(\Sigma^+ K^+ K^-$; b- side-band subtracted distributions of $M(\Sigma^+\phi)$; c- distribution of $M(\Xi^{*o}[1690] \rightarrow \Sigma^+ K^-)K^+$; d- distribution of $M(\Sigma^+ K^+ K^-)$ for $M(K^+K^-) > 1.03 GeV/c^2$ and $M(\Sigma^+ K^-) > 1.71 GeV/c^2$. The figures show double Gaussian fits plus linear background.

Fig. 2a shows the fit of the $\Sigma^+ K^+ K^-$ mass distribution with a double Gaussian plus a linear background. This yields (103 ± 15) total events and a reelative branching ratio $\frac{\Gamma(\Sigma^+ K^+ K^-)}{\Gamma(\Sigma^+\pi^+\pi^-)} = [7.1 \pm 1.1(stat.) \pm 1.1(syst.)]\%$. However the decay is dominated by the 2-body decays $\Lambda_c^+ \rightarrow \Sigma^+\phi^o$ and $\Lambda_c^+ \rightarrow \Xi^{*o}(1690)K^+$. The $\Sigma^+\phi^o$ mass distribution is shown in fig. 2b. The fit yields (57 ± 10) events after sideband subtraction; the measured relative branching ratio (corrected for unseen decay modes of the ϕ^o) is: $\frac{\Gamma(\Sigma^+\phi^o)}{\Gamma(\Sigma^+\pi^+\pi^-)} = (8.7 \pm 1.6 \pm .6)\%$. The $\Xi^{*o}(1690)K^+$ mass distribution is shown in fig. 2c. The fit yields (34 ± 8) events after sideband subtraction; the measured relative branching ratio (corrected for unseen decay modes of the ϕ^o) is: $\frac{\Gamma[\Xi^+\phi^{*o}(1690)K^+]}{\Gamma(\Sigma^+\pi^+\pi^-)} * BF[\Xi^+\phi^{*o}(1690) \rightarrow \Sigma^+ K^-] = [2.2 \pm .6(stat.) \pm .6(syst.)]\%$.

Our measured branching ratios are compared to Belle[3] and Cleo[4] in Table 1.

3. Other Λ_c^+ decays and the Ω_c^o signal

Rare are meant the decays which violates fundamental laws such as conservation of major quantum numbers, however there exist also *rather unfrequent* if not really *rare* decay channels. FOCUS has preliminarily evidence for two 5-body decays of the Λ_c^+ baryon which have topological similarities so that the selection criteria can be made almost identical. Both decays constitute first evidence, although very preliminary, of unseen channels.

The first decay $\Lambda_c^+ \rightarrow \Sigma^-\pi^- 3\pi^+$ is not yet reported in the Data Particle Book[5]a; preliminary evidence by E687 was presented in 1993 [5]b; only 1 event has been reported in 1992 by ACCMOR[5]c of the decay $\Lambda_c^+ \rightarrow \Sigma^+ 2\pi^- 2\pi^+$. Applying standard cuts and requesting out of target decays to improve geometrical resolution, we selected a sample of (18.6 ± 5.8) events at a measured mass $M = 2281 \pm 4\ MeV/c^2$, as shown in fig. 3a. The result is preliminary, about 3σ above background, but the sample seems rather clean.

The second channel is presented as evidence of an interesting *technical* challenge i.e. the isolation of decays containing a neutron in the final state.

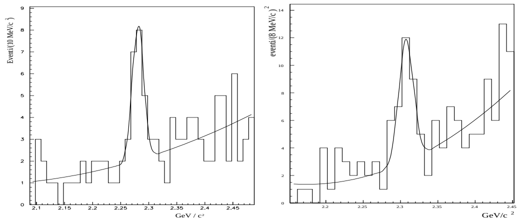

Figure 3. Mass distributions of 5-body decays: *left*) $M(\Sigma^- 3\pi^+\pi^-)$; *right*) $M(nK^-\pi^- 3\pi^+)$. The fits are Gaussians plus 2nd-order polynomial backgrounds.

We detect (see fig. 3b a very preliminary signal of (24 ± 6) events, and a width $\sigma = 11 \pm 3\ MeV/c^2$, at a signal to noise ratio $S/n \approx 5.9$.

Finally, FOCUS is presenting to this Conference[6] a new measurement of the lifetime of the Ω_c^o baryon. The most we can get as a signal, using all the four channels investigated so far, i.e. the channels: $\Omega_c^o \rightarrow \Omega^-\pi^+$, $\Omega_c^o \rightarrow \Omega^-\pi^- 2\pi^+$, $\Omega_c^o \rightarrow \Xi^- K^- 2\pi^+$ and $\Omega_c^o \rightarrow \Sigma^+ 2K^-\pi^+$ is a sample of (115.5 ± 17.8) events above background shown in fig. 4. This evidence will be relevant to the discussion of next Section.

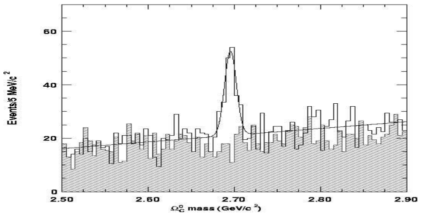

Figure 4. Mass distribution showing the global Ω_c^o signal. The fit is Gaussian plus a linear background; shaded are the side band events.

4. Search for cc-Baryons

SELEX has recently reported evidence for cc-baryon production in h-h collisions at 600 GeV[7].

FOCUS searched for low lying cc-baryons states such as (ccu) Ξ_{cc}^{++} or (ccd) Ξ_{cc}^{+}, since year 2000 as one of the most ambitious targets of our high statistics experiment.

We started with a sample of over 1.1 million golden mode decays of the $D^{o,+}$ mesons (fig. 6a) and about 20,000 $\Lambda_c^+ \rightarrow pK^-\pi^+$ events (fig. 6b). We investigated 14 possible $\Xi_{cc} \rightarrow D^{o,+}Y, 1, 2, 3\pi$ decay modes (where Y stands for a pK system or a Λ^o hyperon) and 7 possible $\Xi_{cc} \rightarrow \Lambda_c^+, K, 1, 2\pi$ decay modes.

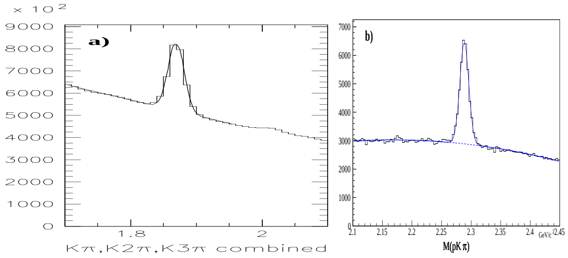

Figure 5. a- Mass distribution of the golden mode decays of the D mesons; b- mass distribution $M(pk^-\pi^+)$ of the Λ_c^+ c-baryon.

The results are shown in fig. 6. To better compare our results the areas of the SELEX signals are shaded in fig. 6. We have no evidence whatsoever for the photoproduction of cc-baryons at about 200 GeV.

While it is up to SELEX to convince the scientific community that their signal is real with a statistical significance safe against variations of the experimental cuts and selection criteria we may ask the question whether or not the two experimental observations can be reconciled.

Let us limit the argument to the decays including a Λ_c^+. The numerical data of the 2 experiments are preliminarily compared in Table 2. Assuming a reasonable Ξ_{cc} lifetime (0.2 ps), a mass of $\approx 3.6 Gev/c^2$ and production characteristics according to PYTHIA, we compare, of the 2 experiments: the number of events and/or their upper limits; the efficiencies relative to the Λ_c^+ and the estimated ratio Ξ_{cc}/Λ_c^+ production to conclude that the 2 results might be compatible if there is a two order of magnitude difference in the production cross section for the 2 experiment. It is photoproduction at 200 GeV against hadroproduction at 600 GeV. Since our analysis is still preliminary, here we can obviously only speculate and argue on a general basis.

It is supported by experimental evidence that multiparticle production proceeds via a 4 step QCD process [8] : 1- a primordial initial strong QCD process leading to a $q - \overline{q}$ pair or a q-g sys-

Table 2
Comparison of FOCUS $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ and $\Xi_{cc}^{++} \to \Lambda_c^+ K^- 2\pi^+$ data samples to SELEX.

Decay mode	$\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$		$\Xi_{cc}^{++} \to \Lambda_c^+ K^- 2\pi^+$	
Experiment	FOCUS	SELEX	FOCUS	SELEX
Ξ_{cc} Events	< 2.21 @ 90% CL	15.8	< 2.21 @ 90% CL	8
Reconstructed Λ_c^+	$19,444 \pm 262$	1650	$19,444 \pm 262$	1650
ϵ_r relative to Λ_c^+	5%	10%	13%	5%
Ξ_{cc}/Λ_c^+ Ratio	$\approx 0.23\%$ @ 90% CL	$\approx 9.6\%$	$\approx 0.09\%$ @ 90%	$\approx 9.7\%$
$\frac{FOCUS}{SELEX}$ Rel. $\Xi_{cc}/\Lambda_c^+ \sigma_{prod}$	> 42 @ 90% CL		> 111 @ 90%	

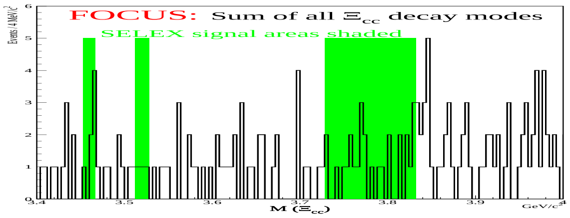

Figure 6. Cumulative mass distribution of 21 possible decays of the Ξ_{cc} baryons. The regions of the SELEX observation is shaded.

tem; 2- a parton shower (a flavor conserving multiplicative cascade process made of (g,gg) $(g, q\overline{q})$ or (q,qg) vertices); 3- a hadronization process in which quarks (antiquarks) and gluons recombines into colorless hadrons (or eventually glueballs); 4- an "old physics" series of strong decays of resonances, weak or electromagnetic decays to end up to final particles directly detected in the apparatus such as γ, e, π, K, p etc. The two experiments differ in the total CMS energy and in step 1. FOCUS starts with a quark-gluon fusion type of process, SELEX starts with a (q,qg) type of process. For the rest the two production processes are identical. Excluding b production and decays, in order to have, after hadronization, a cc-baryon, the minumum we need are 2 steps: a- somewhere, sometime during the parton shower 2 $(g, c\overline{c})$ vertices. The presence of an s quark in the projectile (Σ^+) is irrelevant in this particular QCD step; b- during hadronization the 2 c-quarks must get together to form a cc-baryon rather than a c-baryon plus a D meson, or 2 D mesons and a non-c baryon. In the parton shower process, if there is a two order of magnitude difference in the probability of finding 2 $(g, c\overline{c})$ vertices, there must be an order of magnitude difference for the presence of one $(g, c\overline{c})$ vertex. We presented in fig. 4 a signal of (111.5 ± 7.8) Ω_c^o events. Thus, starting from the same statistical samples, SELEX should observe a sample of *at least* one thousand Ω_c baryons. We can say "at least" because during the hadronization process, the presence of the s-quark indeed helps in forming the (css)-baryon. In SELEX it is enough the presence of *one* $(g, c\overline{c})$ vertex, while two are needed in photoproduction. The observation of a signal of "about" one thousand events should be very easy. We observe one Ω_c^o every 200 Λ_c^+; they should observe a *comparable* number of Λ_c^+ and Ω_c^o. It is up to SELEX to show that this is the case.

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