Strange particle production and pentaquark search at HERA

Chuanlei Liu[a*]

[a]Department of Physics, McGill University
3600 rue University, Montreal, QC, Canada H3A 2T8

Recent results on strange hadron production and pentaquark searches at HERA are reviewed. The differential K^0_S cross sections have been measured and compared with theoretical predictions. Neither Λ-to-$\bar{\Lambda}$ production asymmetry nor $\Lambda(\bar{\Lambda})$ transverse polarization was found to be different from zero. An enhanced $\Lambda + \bar{\Lambda}$ baryon production relative to K^0_S meson was observed in photoproduction process, which is not predicted by PYTHIA Monte Carlo (MC) model. Pentaquark searches have been performed by both the H1 and ZEUS collaborations and the results are presented in this report.

1. INTRODUCTION

HERA provides electron-proton (ep) collisions with a center-of-mass energy of above 300 GeV. There are two different kinematic regimes available according to the magnitude of Q^2, 4-momentum transfer squared from the electron to the exchanged boson. These are deep inelastic scattering (DIS) process, corresponding to Q^2 greater than 1 GeV^2, and photoproduction process in which Q^2 is negligibly small.

2. INCLUSIVE STRANGE HADRON PRODUCTION

The inclusive production of the neutral strange hadrons, Λ, $\bar{\Lambda}$ and K^0_S, has been measured with a data sample of 121 pb^{-1} collected with the ZEUS experiment at HERA. The measurement provides an invaluable way to test phenomenological models and to understand the hadronization process in high energy ep collisions.

The measurement has been done in three different kinematic regions: photoproduction, low-Q^2 ($5 < Q^2 < 25\,\mathrm{GeV}^2$) DIS and high-$Q^2$ ($Q^2 > 25\,\mathrm{GeV}^2$) DIS. In photoproduction, the presence of two jets, each of which has at least 5 GeV transverse energy, was additionally required. The reconstructed strange hadrons were constrained by $0.6 < p_\mathrm{T} < 2.5\,\mathrm{GeV}$ and $|\eta| < 1.2$.

2.1. Differential K^0_S cross sections

Figure 1 shows the differential K^0_S cross sections as a function of transverse momentum and pseudorapidity in two DIS regions discussed above. The ARIADNE MC with a strangeness suppression factor (λ_s) 0.3 describes the data reasonably well. However, some phase spaces exist where this MC is not sufficient to describe the data. For example, at low p_T region in high-Q^2 sample the ARIADNE MC with a λ_s value of 0.22 is preferred while a λ_s value larger than 0.3 is suggested to be suitable at large p_T region for low-Q^2 sample. This might be an indication that varying parameter λ_s only is not sufficiently enough to reproduce the data in detail simultaneously, provided there are several other parameters exist to control the strangeness production in MC models. Figure 1 also shows that the LEPTO MC fails to reproduce K^0_S production.

2.2. Λ-to-$\bar{\Lambda}$ production asymmetry

Baryon to anti-baryon production asymmetry has been determined by measuring Λ-to-$\bar{\Lambda}$ production asymmetry, $(N_\Lambda - N_{\bar{\Lambda}})/(N_\Lambda + N_{\bar{\Lambda}})$. In all three different kinematic regions of interest, no significant asymmetry was observed. The average asymmetries in photoproduction, low-Q^2 and high-Q^2 samples were measured to be $-0.07 \pm 0.6^{+1.0}_{-1.0}\%$, $+1.2 \pm 1.6^{+0.7}_{-2.1}\%$ and $+0.3 \pm 1.3^{+0.5}_{-0.8}\%$, respectively. No asymmetry is predicted either by

*The talk is given on behalf of the H1 and the ZEUS collaborations at HERA

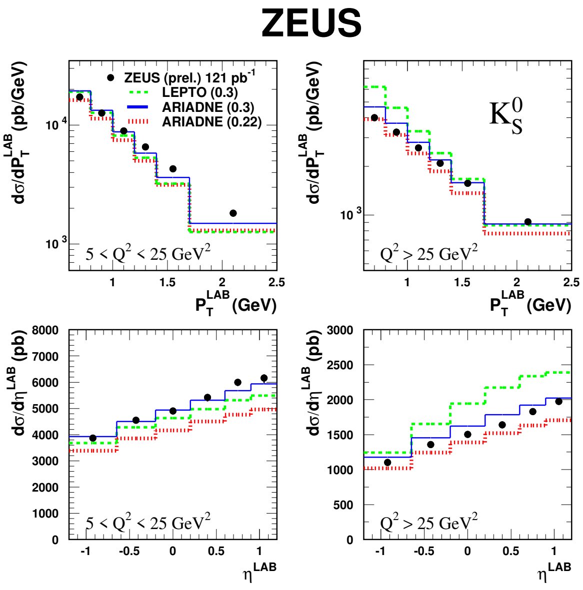

Figure 1. Differential K_S^0 cross sections as a function of p_{T} and η in DIS process.

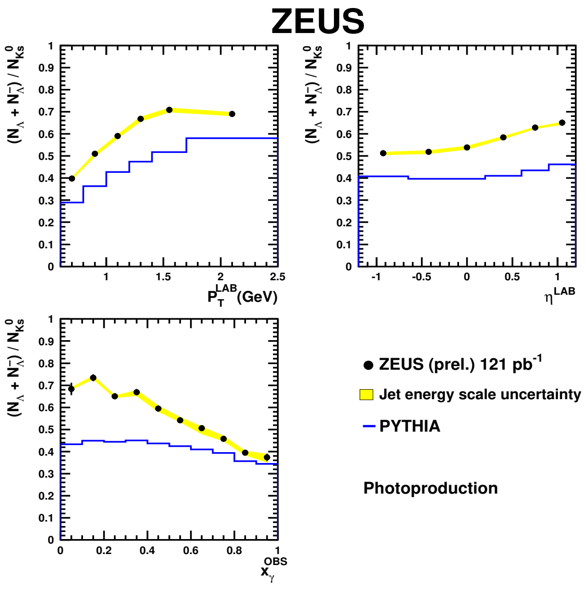

Figure 2. The differential Λ to K_S^0 production ratios in photoproduction.

all MCs used.

The zero asymmetry implies that the Λ and $\bar{\Lambda}$ should be produced according to the same mechanism in the considered phase spaces in *ep* collisions. In these regions, the influence on the baryon production due the appearance of the incident proton should be small. Otherwise one may expect a visible baryon to antibaryon production asymmetry.

2.3. Λ-to-K_S^0 production ratio

The relative yield of strange baryons and mesons has been measured by studying the Λ-to-K_S^0 production ratio, $\mathcal{R} = (N_\Lambda + N_{\bar{\Lambda}})/N_{K_S^0}$. The measured $\mathcal{R}$ in DIS varies from 0.3 to 0.5 and is reasonably described by the ARIADNE MC. In photoproduction, however, the PYTHIA MC largely underestimates $\mathcal{R}$: the $\mathcal{R}$ averages 0.58 in data while 0.41 in PYTHIA. The excess of $\mathcal{R}$ in data can be clearly seen in Figure 2.

The main discrepancy in $\mathcal{R}$ takes place at small x_γ^{OBS} region where the resolved photoproduction is expected to be dominated. Here x_γ^{OBS} is interpreted as the fraction of the photon energy transferred to the dijet system. In order to investigate this effect further, a division of whole photoproduction sample was made. Two different topological subsamples, fireball-enriched and fireball-depleted, are obtained. The fireball-enriched events are selected by requiring the highest E_T^{jet} jet carries at most 30% of total event E_T while the fireball-depleted events are the rest. The fireball-enriched event selected this way is expected to have largely isotropic E_T^{jet} distribution while the fireball-depleted event has a clear jet structure.

The differential $\mathcal{R}$ for both subsamples is shown in Figure 3. The large enhanced $\mathcal{R}$ in data over the PYTHIA was observed in the fireball-enriched subsample. The RHIC experiments [1] have also reported a large enhancement of baryon to meson ratio at a moderate p_{T}. The physics behind this effect is still under investigation. One possible interpretation is the overlap of parton wave functions in 3-dimension at RHIC is much larger than that in 1-dimension distribution in e^+e^-, or *ep* DIS cases. The consequent correlations be-

Table 1
The Λ, $\bar{\Lambda}$ and K_S^0 transverse polarizations in *ep* collisions

Polarization	Photoproduction	Low Q^2 DIS	High Q^2 DIS
Λ (%)	$-2.4 \pm 2.2(stat.)$	$-4.0 \pm 5.3(stat.)^{+4.7}_{-4.0}(syst.)$	$-1.3 \pm 4.3(stat.)^{+4.0}_{-0.8}(syst.)$
$\bar{\Lambda}$ (%)	$-5.8 \pm 2.2(stat.)$	$-8.5 \pm 5.5(stat.)^{+4.7}_{-2.1}(syst.)$	$-2.2 \pm 4.2(stat.)^{+2.4}_{-1.3}(syst.)$
K_S^0 (%)	$-0.5 \pm 2.2(stat.)$	$-0.05 \pm 1.5(stat.)$	$-1.5 \pm 1.1(stat.)$

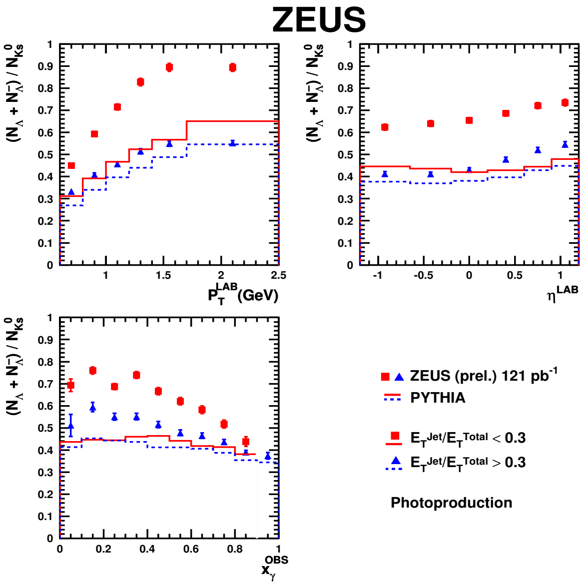

Figure 3. The differential Λ-to-K_S^0 production ratios in the fireball-enriched and fireball-depleted subsamples.

cause of the overlap of parton showers provide a large phase space for more Λ production relative to K_S^0 meson. Therefore a larger $\mathcal{R}$ could be the case. Based on this assumption, the insufficient description of $\mathcal{R}$ by the PYTHIA can be understood. Since the multiple interaction mechanism introduced to PYTHIA creates 'independent' partons only and the fragmentation of these partons are locally. The correlation between different parton showers is therefore not included. Hence a smaller $\mathcal{R}$ value compared to the data is expected in PYTHIA.

2.4. $\Lambda(\bar{\Lambda})$ polarization

The measured $\Lambda(\bar{\Lambda})$ transverse polarization was consistent with zero and the results are presented in Table 1 in three different kinematic regions of interest. The results reported here suggest that no preferential frame exists for $\Lambda(\bar{\Lambda})$ production. The K_S^0 transverse polarization given here is just for a cross check of the analysis procedure and a systematical uncertainty reference for Λ polarization.

3. PENTAQUARK SEARCH AT HERA

Search for pentaquarks has been a hot topic over the past few years. Many efforts have been made to search for such kind of narrow resonances in different types of experiments. The current observations can not confirm the existence of such states yet. Search for strange and charm pentaquarks has been done at HERA as well [2–6].

3.1. Strange pentaquark search

Search for strange pentaquark Θ^+ in the decay channel $\Theta^+ \rightarrow K_S^0 p$ has been done by ZEUS experiment [2] and the result is given in Figure 4. A visible Θ^+ signal was observed. The total number of Θ^+ candidates is fitted to be 221 ± 48. The Θ^+ mass position is determined to be $1521.5 \pm 1.5^{+2.8}_{-1.7}$ MeV and the width of the signal, 6.1 ± 1.6 MeV, is consistent with the detector resolution.

The analysis has been repeated similarly by H1 collaboration [3]. However no signal was observed around 1520 MeV. The upper limit of Θ^+ cross section in this decay channel was determined to be $30 \sim 90$ pb by H1. This value does not exclude the ZEUS observation and is consistent with the Θ^+ cross section measured by ZEUS ($125 \pm 27^{+36}_{-28}$ pb).

Further studies on Θ^+ production property in ZEUS show that Θ^+ is produced predominantly

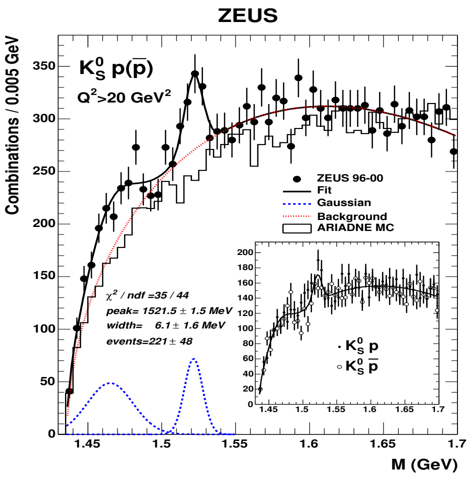

Figure 4. The $K^0_S p$ invariant mass spectrum for strange pentaquark search in ZEUS.

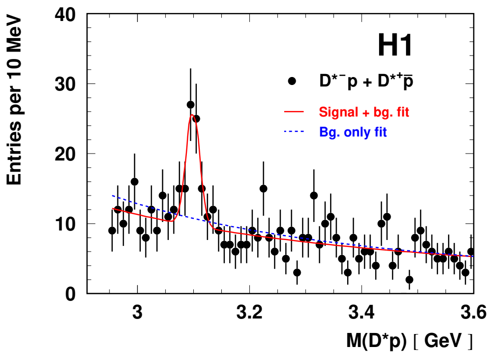

Figure 5. The D^*p invariant mass spectrum for charm pentaquark search in H1.

in the forward region (the proton beam direction in ZEUS), which could indicate that the production mechanism of Θ^+ can be influenced by the proton remnant [4].

3.2. Charm pentaquark search

An observation of a charm exotic narrow resonance at 3100 MeV was reported by H1 [5]. Such a signal could correspond to the pentaquark exotic state $\Theta_c(uudd\bar{c})$. The signal can be seen clearly in both DIS and photoproduction processes. As an example, the observed signal in DIS is shown in Figure 5. The mass position for this state is measured to be $3099 \pm 3 \pm 5$ MeV and the width is about 12 ± 3 MeV. However the H1 observation was not confirmed by ZEUS measurement [6] in which the kinematic region was constrained as close as to that in H1 case. The higher statistic HERA II data is expected to clarify the pentaquark subject.

4. SUMMARY

Inclusive strange particle production has been measured at HERA. The Ariadne describes the data well. The Λ and $\bar{\Lambda}$ production is consistent to be equal. The enhancement of Λ-to-K^0_S ratio was observed in photoproduction and the Pythia can not account for the excess. No $\Lambda(\bar{\Lambda})$ transverse polarization was measured.

Search for strange and charm pentaquarks have been performed at HERA. An exotic strange pentaquark candidate of Θ^+ has been observed in ZEUS and its cross section was determined. However H1 did not observe such a signal in a similar analysis. A positive result on charm pentaquark search was reported by H1, but the observation has not confirmed yet by ZEUS. Further studies using HERA II data are needed to clarify the issue.

REFERENCES

1. PHENIX Collab. S. Adler et al., Phys. Rev. **C69** (2004) 034909
2. ZEUS Collab., S. Chekanov et al., Phys. Lett. **B591** (2004) 7
3. H1 collab., A. Aktas et al., Phys. Lett. **B639** (2006) 202
4. S. Chekanov, Eur. Phys. J. **C44** (2005) 367
5. H1 collab., A. Aktas et al., Phys. Lett. **B588** (2004) 17
6. ZEUS Collab., S. Chekanov et al., Z. Phys. J. **C38**, (2004) 29