New Measurements of Hyperon Production in the Charmonium Region

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Introduction

- The study of the production of hadrons gives unique insight into their structure. The strangeness-containing hyperons are especially interesting since they provide a family of states that allow us to study how their properties evolve with:
  - Strange quark content (1–3 strange quarks)
  - Isospin (I=0,1)
  - Momentum transfer (|Q^2|)

- Hadronization in e^+e^- annihilation is an exceptionally clean laboratory for hyperon production.
  - Long history of studying these processes at Cornell (CLEO), SLAC (HRS,Mark II,TPC), DESY (CELLO,TASSO), LEP (DELPHI,L3,OPAL)
  - Can study the difference between quark-initiated (e^+e^- → q̅q) versus gluon-initiated production (e.g, e^+e^- → Y/ψ → ggg)
Hyperon Production in $e^+e^-$ annihilation

- CLEO III measurements of hadron production in $e^+e^- \rightarrow q\bar{q}$ at $\sqrt{s} \sim 10$ GeV and $Y(nS) \rightarrow ggg$ show enhancement of $\Lambda$ production in $Y(nS)$ decay.
Hyperon Production in $e^+e^-$ annihilation

- Measurements from LEP at the $Z^0$ peak show:
  - Suppression of $\Xi^-$ (2 s-quark) compared to $\Lambda^0$ (1 s-quark)
  - Suppression of $I=1 \Sigma^0$ compared to $I=0 \Lambda^0$, possible diquark effect
Data Sets & Hyperon Reconstruction

- We measure $e^+e^- \rightarrow \text{hyperon} + X$ using $e^+e^-$ annihilation data taken with the CLEO-c detector at:
  - $\psi(2S)$ [$\sqrt{s} = 3686$ MeV]: $48 \text{ pb}^{-1}$, 25 M $\psi(2S)$
  - $\psi(3770)$ [$\sqrt{s} = 3772$ MeV]: $805 \text{ pb}^{-1}$
  - $\sqrt{s} = 4170$ MeV: $586 \text{ pb}^{-1}$

- $\psi(2^3S_1,3686)$ decays primarily to $ggg$, lighter charmonia
  - Expect hyperons to be produced primarily via
    $e^+e^- \rightarrow (c\bar{c}) \rightarrow \text{gluons} \rightarrow \text{hyperon} + X$

- $\psi(1^3D_1,3770)$, $\psi(2^3D_1,4160)$ decay primarily to $D$ mesons
  - Expect hyperons to be produced primarily from
    $e^+e^- \rightarrow \gamma^* \rightarrow q\bar{q} \rightarrow \text{hyperon} + X$

- We identify the hyperons by their dominant decays:
  - $\Lambda^0 \rightarrow p\pi^- (64 \%)$
  - $\Sigma^+ \rightarrow p\pi^0 (52 \%)$
  - $\Sigma^0 \rightarrow \Lambda^0 \gamma (100 \%)$
  - $\Xi^- \rightarrow \Lambda^0 \pi^- (100 \%)$
  - $\Xi^0 \rightarrow \Lambda^0 \pi^0 (100 \%)$
  - $\Omega^- \rightarrow \Lambda^0 K^- (68 \%)$
Inclusive Hyperon Mass Spectra From $\psi(2S)$

$\psi(2S) \rightarrow B$ or $\bar{B} + X$,  (Preliminary, Statistical uncertainties only)

- Well reconstructed particles with a vertex displaced from the $e^+e^-$ IP are selected. Strong peaks are seen in each channel.
- We also measure yields as a function of hyperon momentum.
Hyperon Yields From $\psi(2S)$

$\psi(2S) \rightarrow B$ or $\bar{B} + X$,  (Preliminary, Statistical uncertainties only)

- Pair-production peaks are clearly seen.
- Yields from $\Sigma^0/\Sigma^+$ and $\Xi^0/\Xi^-$ have similar shapes.
Hyperon Yields From $\sqrt{s} = 3772, 4170$ MeV

$e^+e^- \rightarrow B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)

- For data taken above $D\bar{D}$ threshold, strong peaks are seen in each channel, except $\Omega^-$. 
- 4170 data have yields 1.5—2x less than 3772 data (1.4x smaller luminosity). 

$\sqrt{s} = 3772$ MeV

$\sqrt{s} = 4170$ MeV
Hyperon Yields From $\sqrt{s} = 3772, 4170$ MeV

$e^+e^- \rightarrow B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)

$\sqrt{s} = 3772$ MeV

$\sqrt{s} = 4170$ MeV

- 3772 data and 4170 data have similar shapes, differ from $\psi(2S)$ data.
Hyperon Yields From $\sqrt{s} = 3772, 4170$ MeV

$e^+e^- \rightarrow B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)

Open hist: $\sqrt{s}=3772$ MeV  Filled hist: $\sqrt{s}=4170$ MeV data ($1/s^2$ norm.)

- Yields from both data are consistent after normalizing $\sqrt{s}=4170$ MeV data by additional factor of $1/s^2$.
- Note that Spacelike proton FF has $1/\sqrt{s}$ dependence, opposed to expected $1/s$ dependence
Theoretical Models

• Hyperon production is generally modeled by the **LUND string model** as implemented in JETSET/PYTHIA.

• To more accurately model string fragmentation at charm energies, we use the **LUNDCHARM** model, which includes **C- and G-parity conservation**.

• Baryon production in the LUND model arises from the combination of a **diquark with a quark**. There are three main parameters that affect this:
  
  • The probability of **qq diquark** to **quark** production
  
  • The probability to produce a strange **su/sd diquark** to a **ud diquark**
  
  • The probability to produce a **spin-1** to a **spin-0 diquark**

• Properly tuning this model requires many careful measurements, but to start we can compare our measurements with predictions obtained from the standard CLEO-c parameters.
Baryon Production in LUND string model

\[ \bar{q} \rightarrow q \bar{q} \rightarrow u \bar{d} \bar{s} \rightarrow \Lambda \]
Hyperon Yields From $\psi(2S)$: Data and MC

$\psi(2S) \rightarrow ggg \rightarrow B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)

Open hist: $\psi(2S)$ DATA    Filled hist: $\psi(2S)$ MC

- $\psi(2S)$ MC is mix of LUND and known b.f.’s fixed to PDG.
- MC reproduces some features of data, gives generally poor agreement.
Hyperon Yields From $\sqrt{s} = 4170$ MeV: Data and MC

$e^+e^- \to q\bar{q} \to B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)

Open hist: 4170 MeV DATA    Filled hist: 4170 MeV MC

- Reasonable agreement between data and MC.
- Data spectra are generally slightly softer than MC data.
Unequal Baryons — Production of $\Lambda^0\Sigma^0$

- Production of $\Lambda^0\Sigma^0$ probes two interesting phenomena: isospin violation in charmonium decays and hyperon transition form factors [see presentation of K. Seth for more details on hyperon pair production]

- The $\Lambda^0$ ($I=0$) and $\Sigma^0$ ($I=1$) states have the same uds quark content but opposite isospin.
  - $\Lambda^0\Sigma^0$ (total $I=1$) pair production in $e^+e^-$ annihilation (total $I=0$) can only proceed through isospin-violating processes.
  - In $\psi(2S)$ decay, the strong force conserves isospin, so the decay must be through a virtual photon: $\psi(2S) \rightarrow \gamma^* \rightarrow \Lambda^0\Sigma^0$
  - In EM production, this process probes the $\Sigma^0 \rightarrow \Lambda^0$ transition form factor.
Unequal Baryons — Production of $\Lambda^0 \Sigma^0$

- $\psi(2S)$: $N = 30 \pm 5$, $Br = (0.12 \pm 0.02\text{(stat)}) \times 10^{-4}$
  This is $20 - 30$ times smaller than $Br(\psi(2S) \rightarrow \Lambda^0 \Lambda^0, \Sigma^0 \Sigma^0)$

- Form factor $|Q^2| = 14.2$ GeV$^2$:
  $N = 30 \pm 5$, $G_M(\Lambda^0 \Sigma^0) = (0.79 \pm 0.07\text{(stat)}) \times 10^{-2}$
  This is consistent with $G_M(\Sigma^0) = (0.79 \pm 0.07) \times 10^{-2}$
  and is factor $\sim 0.6$ smaller than $G_M(\Lambda^0) = (1.31 \pm 0.05) \times 10^{-2}$
Summary

• Detailed study of hyperon production can yield useful insights into their structure.

• We have measured yields of the hyperons $\Lambda^0$, $\Sigma^+$, $\Sigma^0$, $\Xi^-$, $\Xi^0$, $\Omega^-$ produced in the decay of $\psi(2S)$ and in $e^+e^-$ annihilation at two energy points above $D\bar{D}$ threshold, $\sqrt{s} = 3772, 4170$ MeV.

• Detailed studies of efficiencies and MC simulations are being performed.

• These measurements open the door for measurements of other properties of inclusive hyperon production.

• We have measured for the first time $\Lambda^0 \Sigma^0$ production from $\psi(2S)$ and at $\sqrt{s} = 3772$ MeV, probing isospin violating effects in these processes.
Backup Slides
CLEO-c Detector

π/K separation using RICH and DC dE/dx

Photon Detection with Crystal Calorimeter

Precision tracking in 1T B field

Acceptance: $|\cos \theta| < 0.93$

Charged particles: $\sigma_p/p = 0.6\% @ 1 \text{ GeV}/c$

Photons: $\sigma_E/E = 2.2\% @ 1 \text{ GeV}$ $\sigma_p/p = 5\% @ 100 \text{ MeV}$
Hyperon Yields From $\psi(2S)$ and $\sqrt{s}=3772$ MeV

$\psi(2S) \rightarrow B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)
Open hist: $\psi(2S)$ data  Filled hist: $\sqrt{s}=3772$ MeV data (arb. norm.)

- Results from $\psi(2S)$ and $\sqrt{s}=3772$ MeV data have different shapes, as expected from different production process.
CLEO-c MC JETSET Default Parameters

• Diquark suppression factor $P(qq)/P(q)$: $\text{PARJ}(1) = 0.065$ [default = 0.1]

• Strange quark suppression factor $P(s)/P(u)$: $\text{PARJ}(2) = 0.26$ [default = 0.30]

• Strange diquark suppression factor $[P(us)/P(ud)]/[P(s)/P(d)]$: $\text{PARJ}(3) = 0.4$

• Suppression of spin-1 diquarks relative to spin-0: $(1/3)P[ud_1]/P[ud_0]$: $\text{PARJ}(4) = 0.05$

• Popcorn production probability: $\text{PARJ}(5) = 0.5$