New Measurements of Hyperon Production in the Charmonium Region

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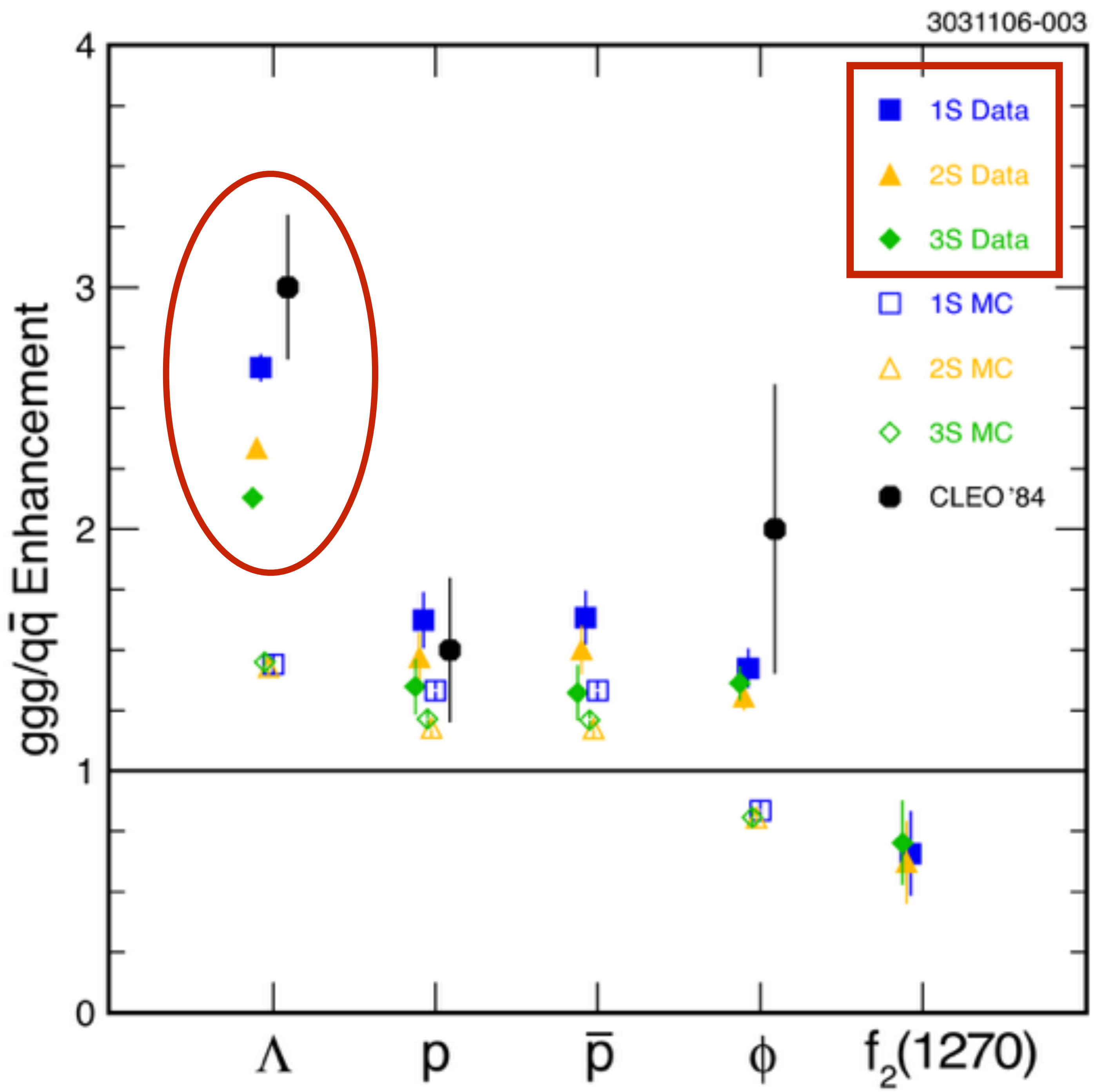
Introduction

- 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 ($|Q^2|$)

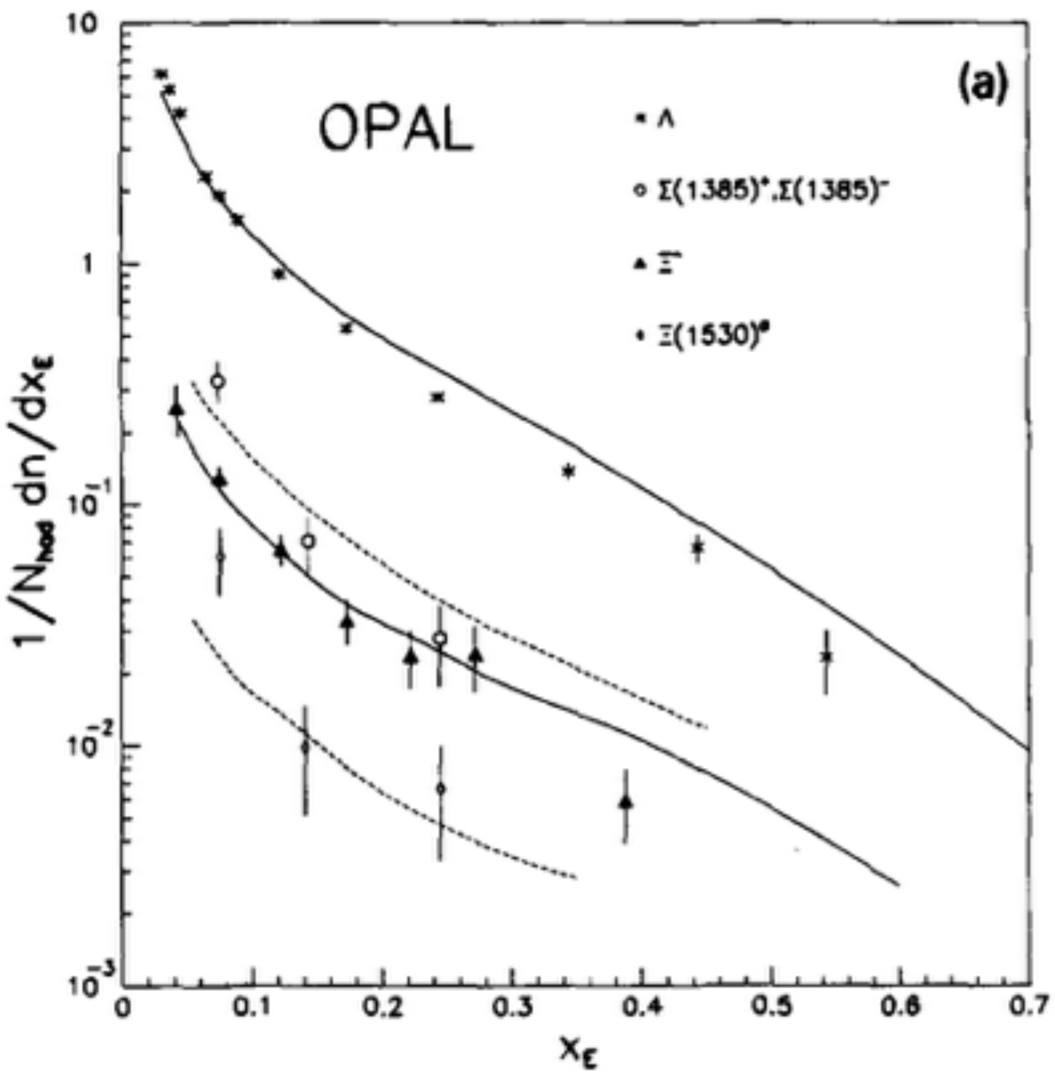
- Hadronization in e^+e^- annihilation is an exceptionally clean laboratory for hyperon production.
  - Long history of studying these processes at Cornell (CLEO), SLAC (HRS,Mark II,TPC), DESY (CELLO,TASSO), LEP (DELPHI,L3,OPAL)
  - Can study the difference between quark-initiated (**$e^+e^- \to q\bar{q}$**) versus gluon-initiated production (e.g, **$e^+e^- \to \Upsilon/\psi \to ggg$**)

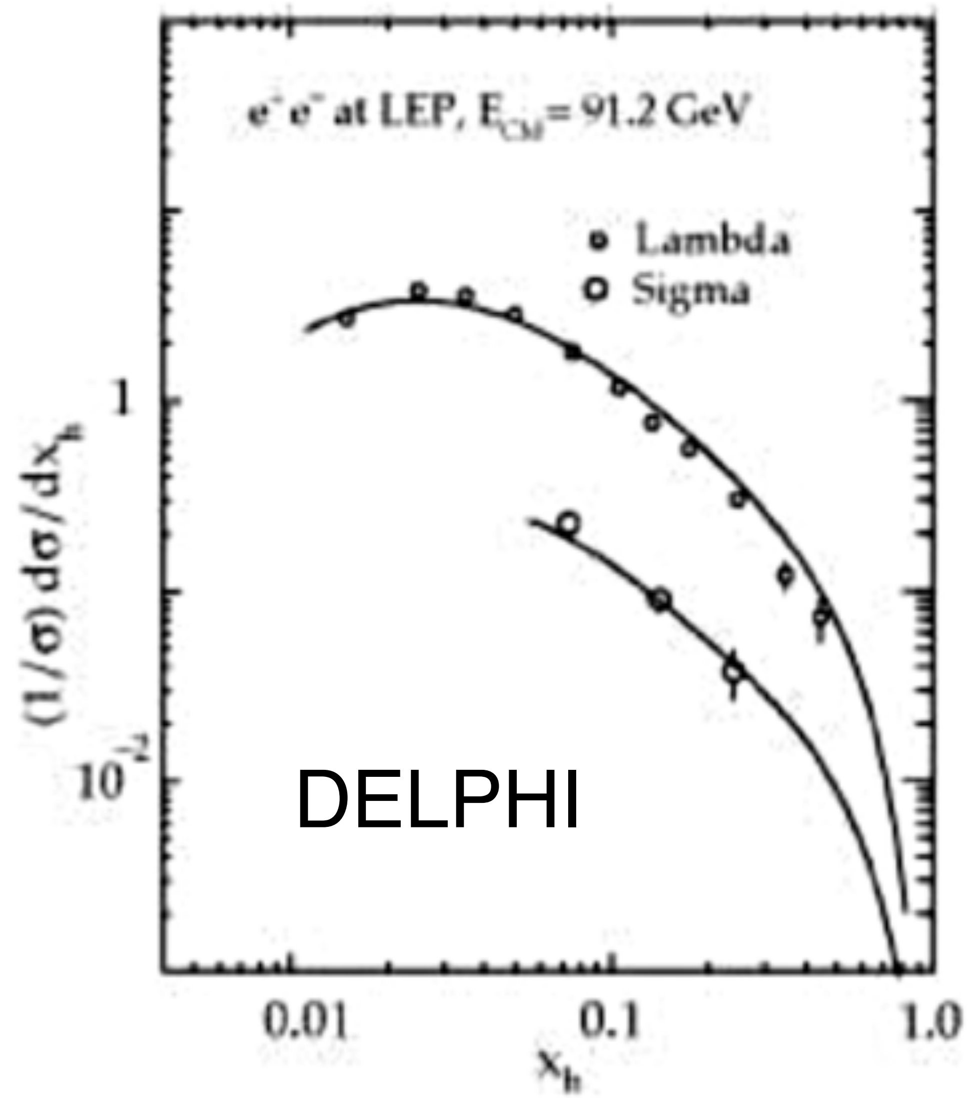
Hyperon Production in e+e- annihilation

- CLEO III measurements of hadron production in **$e^+e^- \to q\bar{q}$** @ **$\sqrt{s} \sim 10$ GeV** and **$\Upsilon(nS) \to ggg$** show enhancement of **Λ** production in **$\Upsilon(nS)$** decay.



Hyperon Production in e+e- annihilation





- Measurements from LEP at the Z^0 peak show:
  - Suppression of Ξ^- (2 s-quark) compared to Λ^0 (1 s-quark)
  - Suppression of I=1 Σ^0 compared to I=0 Λ^0, possible **diquark** effect

Data Sets & Hyperon Reconstruction

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

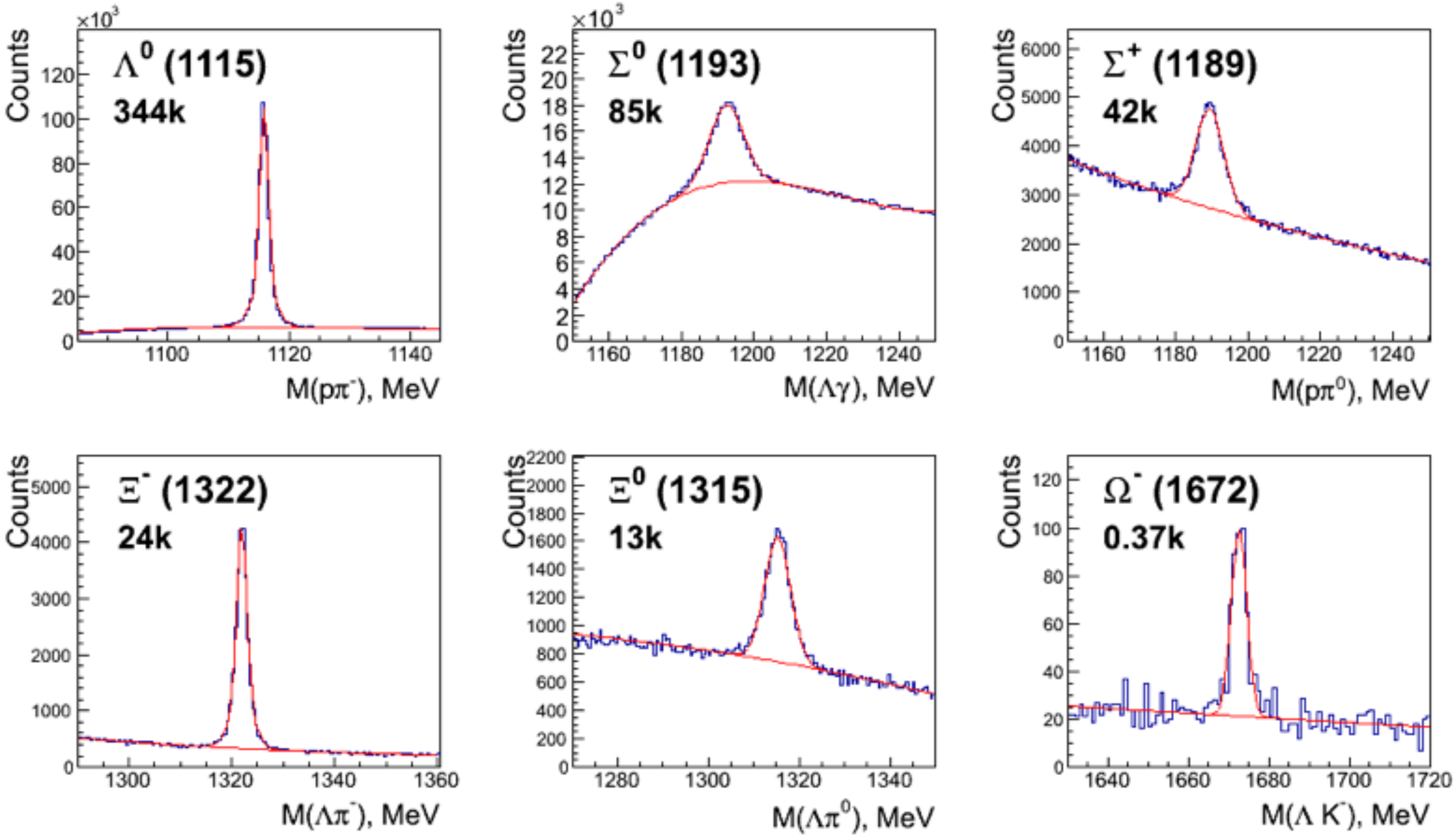
- **$\psi(2^3S_1,3686)$** decays primarily to ggg, lighter charmonia
  - Expect hyperons to be produced primarily via
    $e^+e^- \to (c\bar{c}) \to$ gluons $\to$ hyperon + X
- **$\psi(1^3D_1,3770)$, $\psi(2^3D_1,4160)$** decay primarily to D mesons
  - Expect hyperons to be produced primarily from
    $e^+e^- \to \gamma^* \to q\bar{q} \to$ hyperon + X
- We identify the hyperons by their dominant decays:

$\Lambda^0 \to p\pi^-$ (64 %)　$\Sigma^+ \to p\pi^0$ (52 %)　$\Sigma^0 \to \Lambda^0\gamma$ (100 %)

$\Xi^- \to \Lambda^0\pi^-$ (100 %)　$\Xi^0 \to \Lambda^0\pi^0$ (100 %)　$\Omega^- \to \Lambda^0 K^-$ (68 %)

Inclusive Hyperon Mass Spectra From ψ(2S)

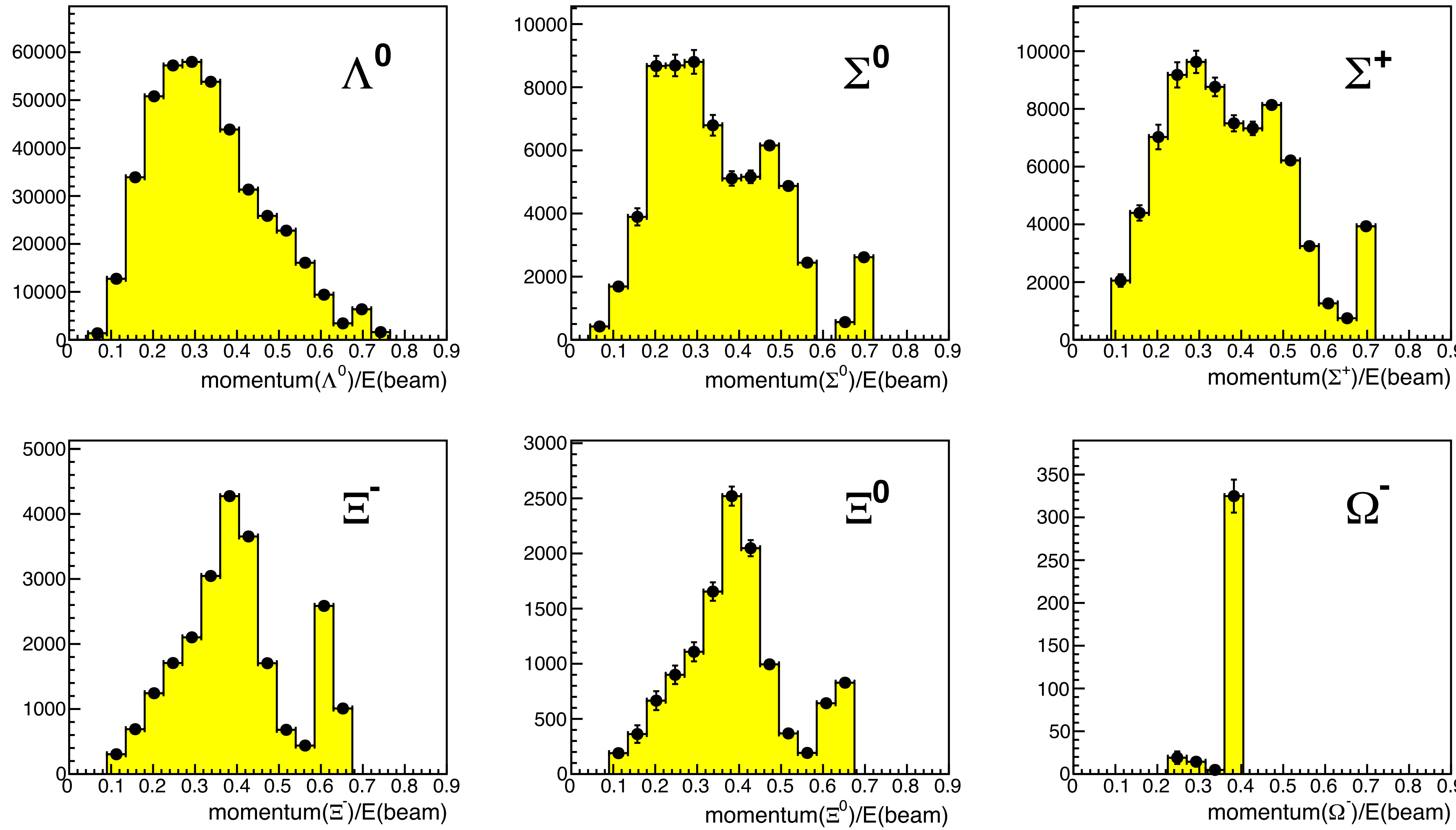
$\psi(2S) \rightarrow B$ or $\bar{B} + X$, (Preliminary, Statistical uncertainties only)



- 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 ψ(2S)

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

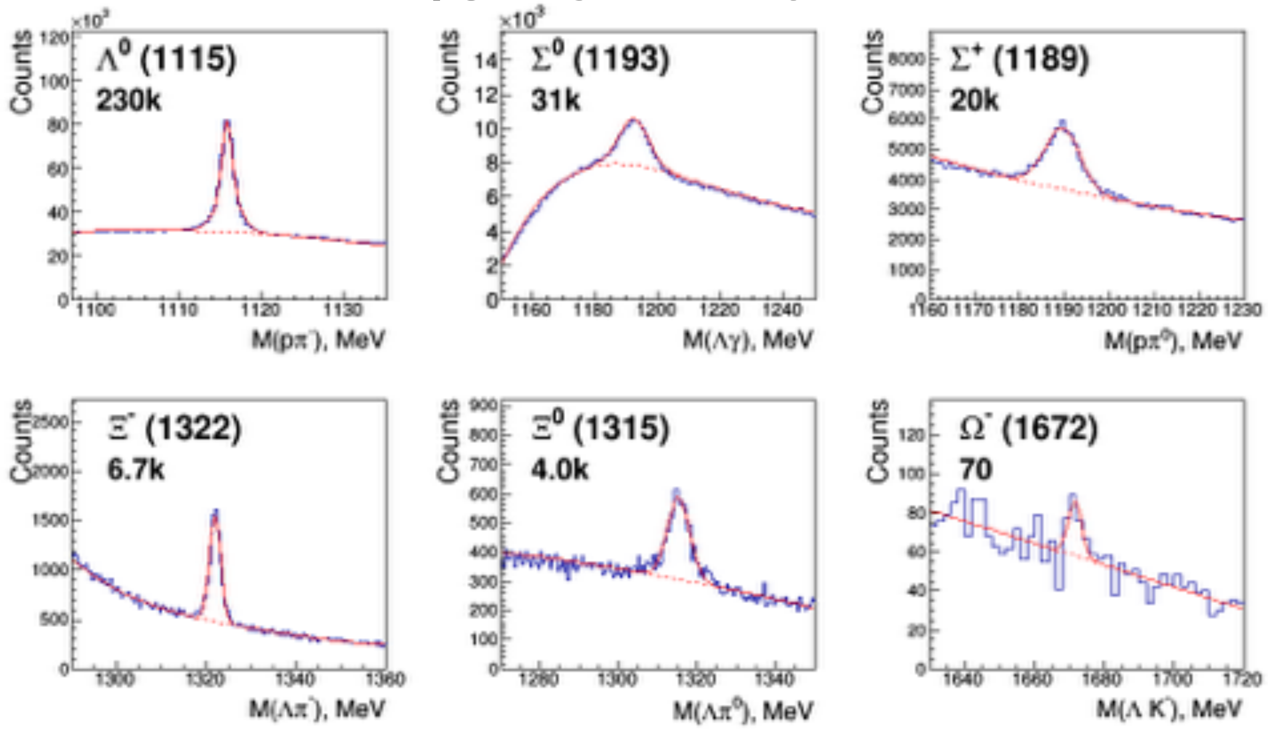


- Pair-production peaks are clearly seen.
- Yields from Σ^0/Σ^+ and Ξ^0/Ξ^- have similar shapes.

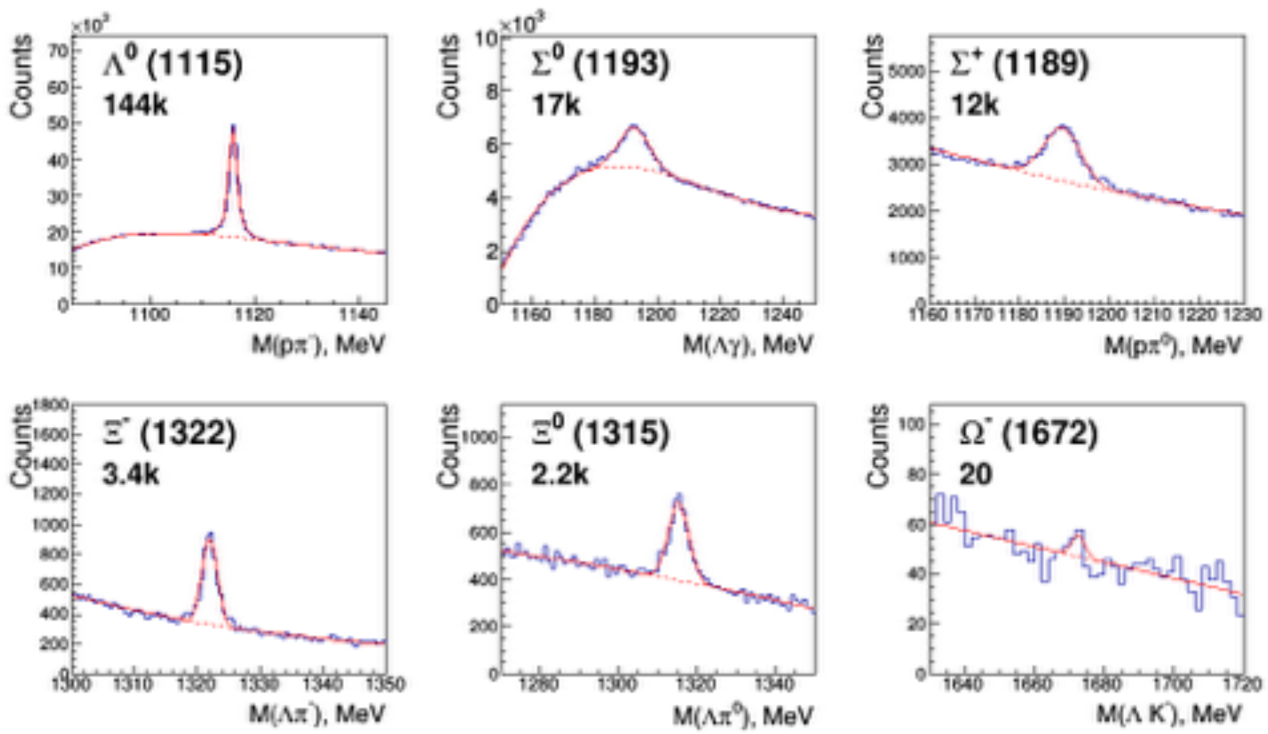
Hyperon Yields From √s = 3772, 4170 MeV

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

√s = 3772 MeV



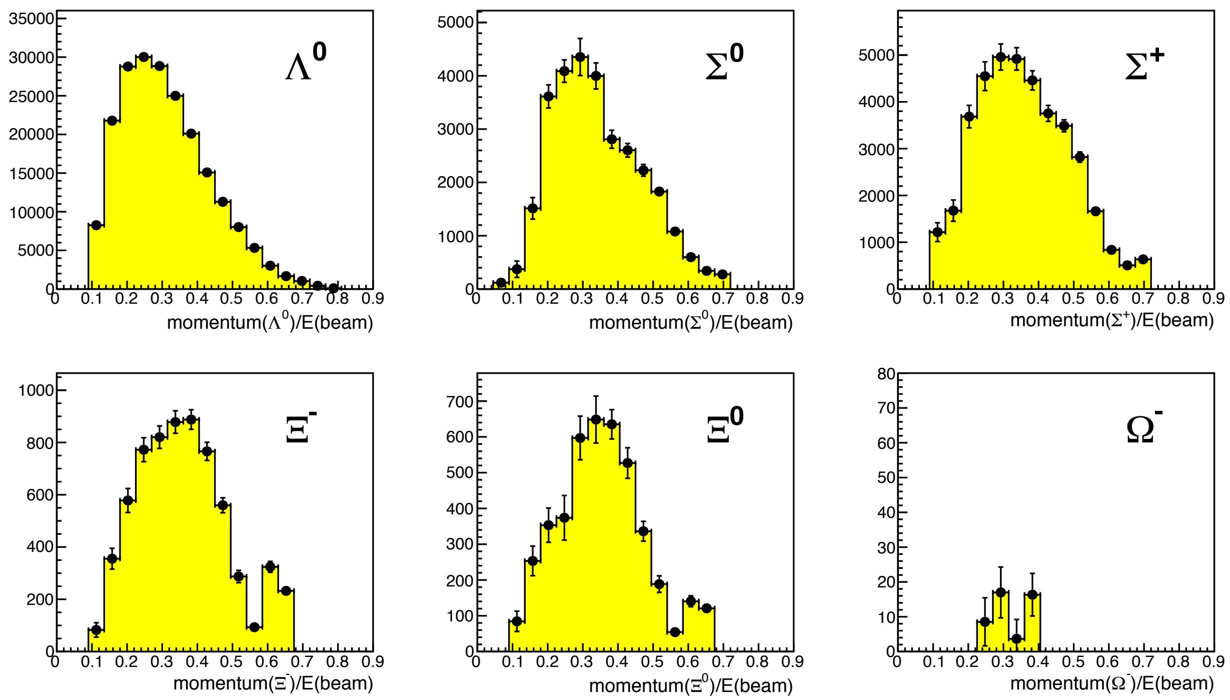
√s = 4170 MeV



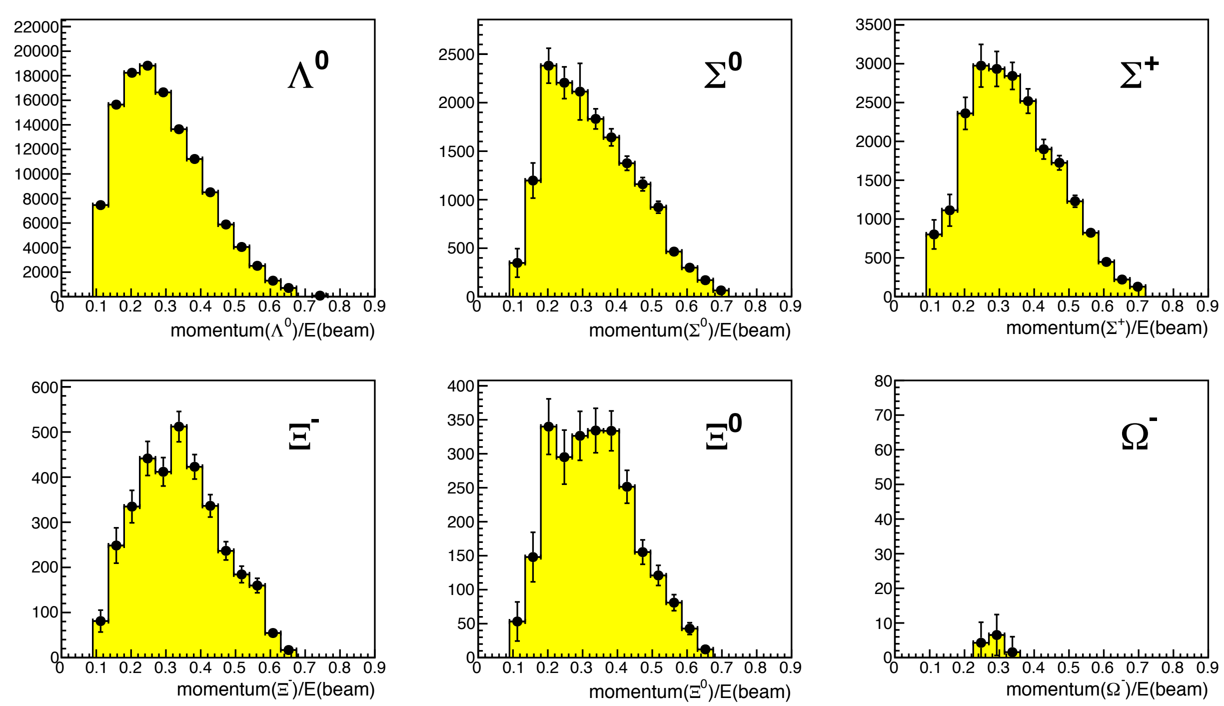
- For data taken above $D\bar{D}$ threshold, strong peaks are seen in each channel, except **Ω^-**.
- 4170 data have yields 1.5—2x less than 3772 data (1.4x smaller luminosity).

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

√s = 3772 MeV



√s = 4170 MeV

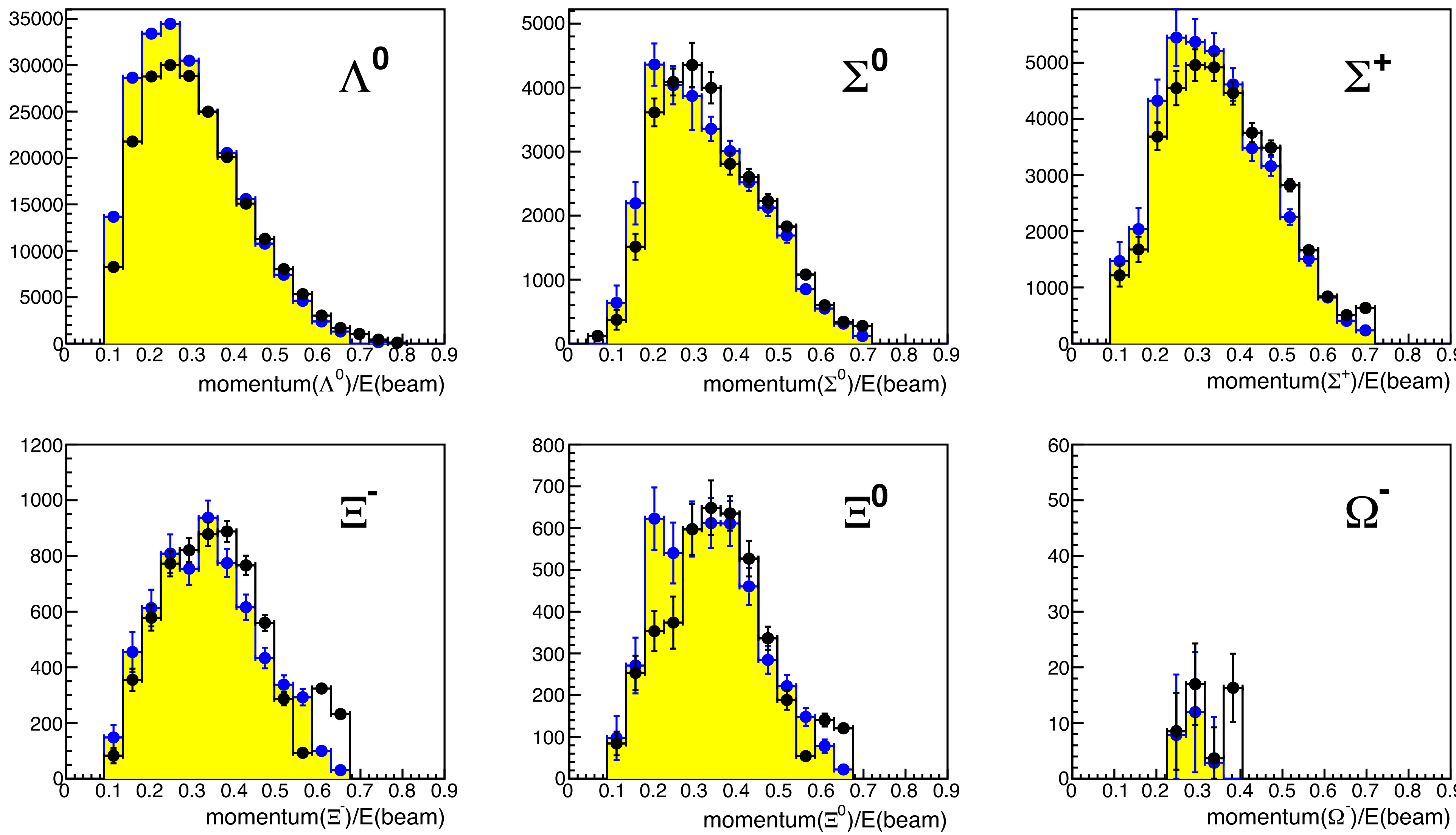


- 3772 data and 4170 data have similar shapes, differ from ψ(2S) data.

Hyperon Yields From √s = 3772, 4170 MeV

e⁺e⁻ → B or B̄ + X, (Preliminary, Statistical uncertainties only)

Open hist: √s=3772 MeV Filled hist: √s=4170 MeV data (1/s² norm.)

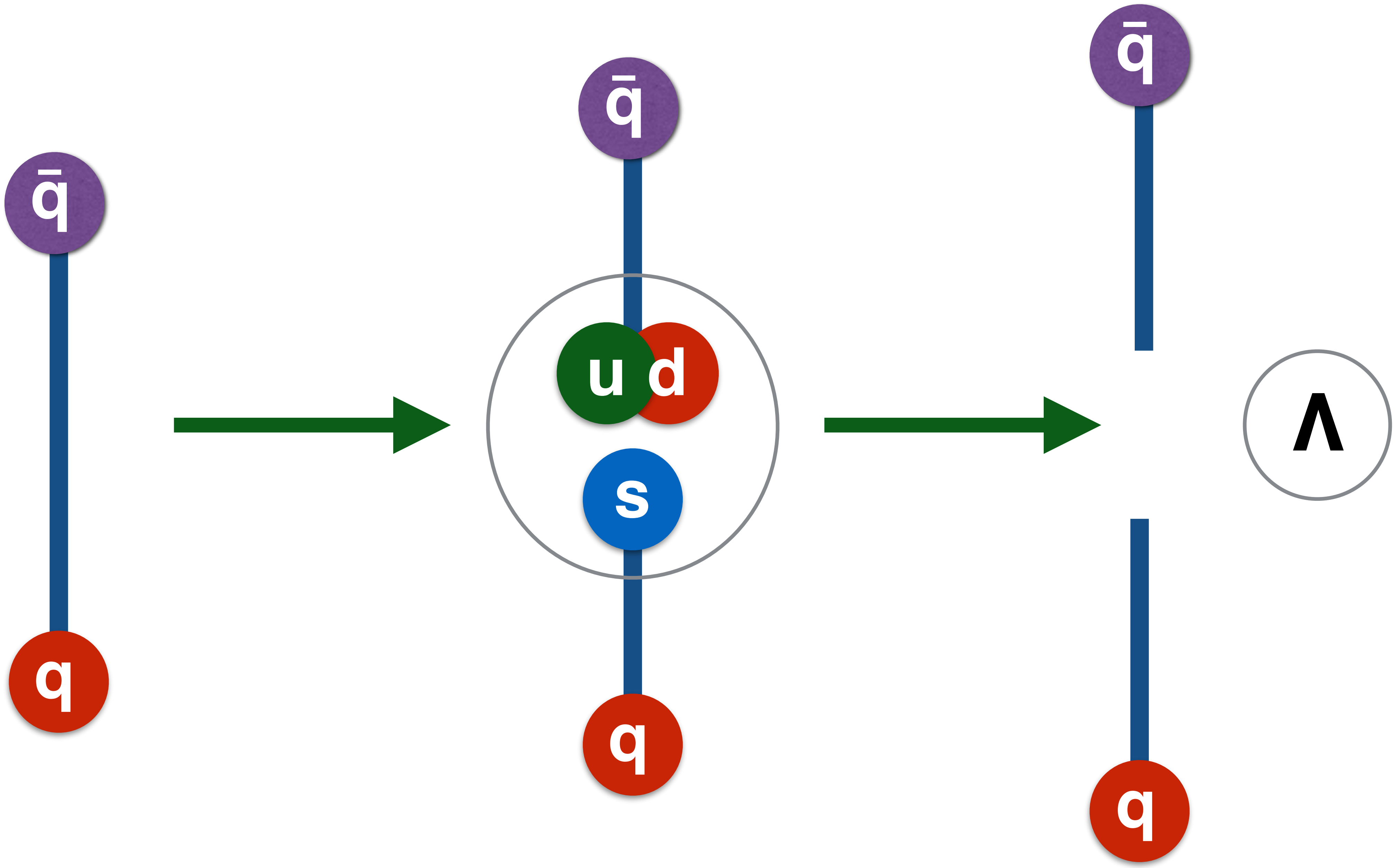


- Yields from both data are consistent after normalizing √s=4170 MeV data by additional factor of $1/s^2$.
- Note that Spacelike proton FF has 1/√s dependence, opposed to expected 1/s dependence

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.

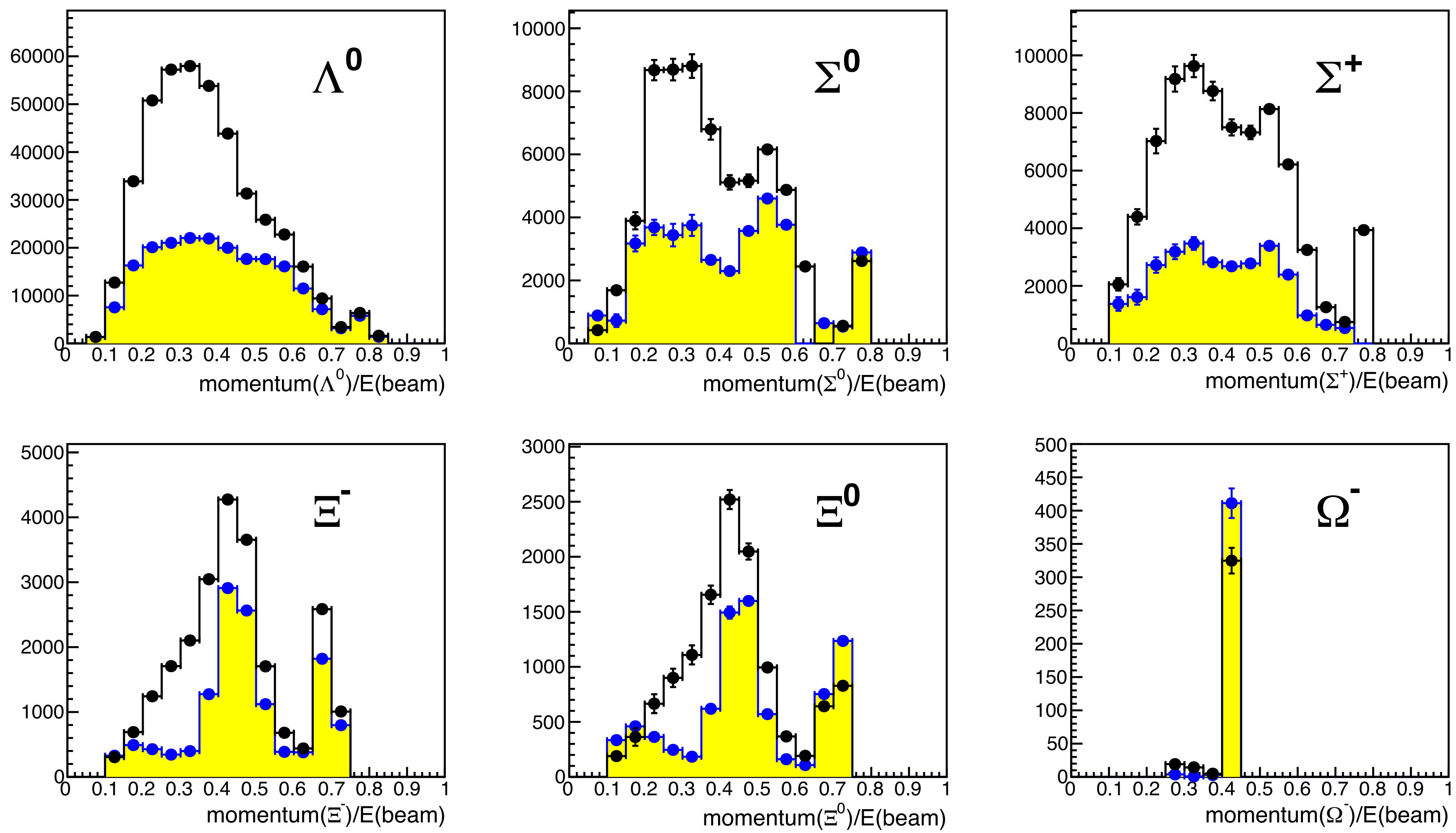
Baryon Production in LUND string model



Hyperon Yields From ψ(2S): Data and MC

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

Open hist: ψ(2S) **DATA** Filled hist: ψ(2S) **MC**

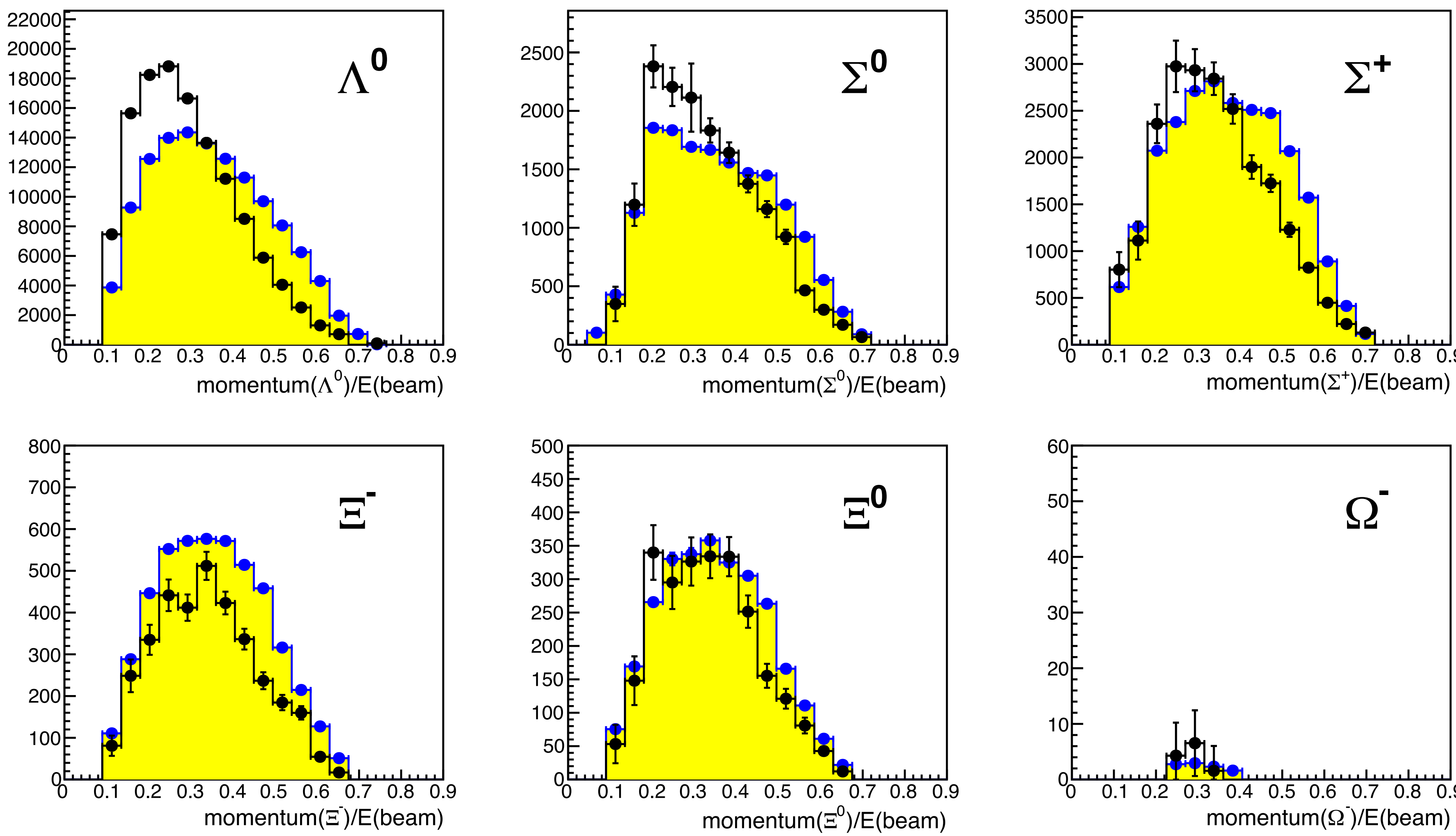


- ψ(2S) MC is mix of LUND and known b.f.'s fixed to PDG.
- MC reproduces some features of data, gives generally poor agreement.

Hyperon Yields From √s = 4170 MeV: Data and MC

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

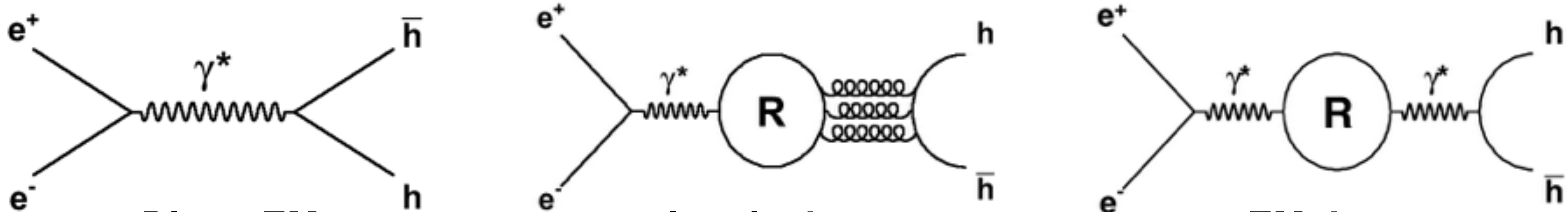
Open hist: 4170 MeV **DATA** Filled hist: 4170 MeV **MC**



- Reasonable agreement between data and MC.
  Data spectra are generally slightly softer than MC data.

Unequal Baryons — Production of Λ^0 Σ^0

- Production of **Λ^0 Σ^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]

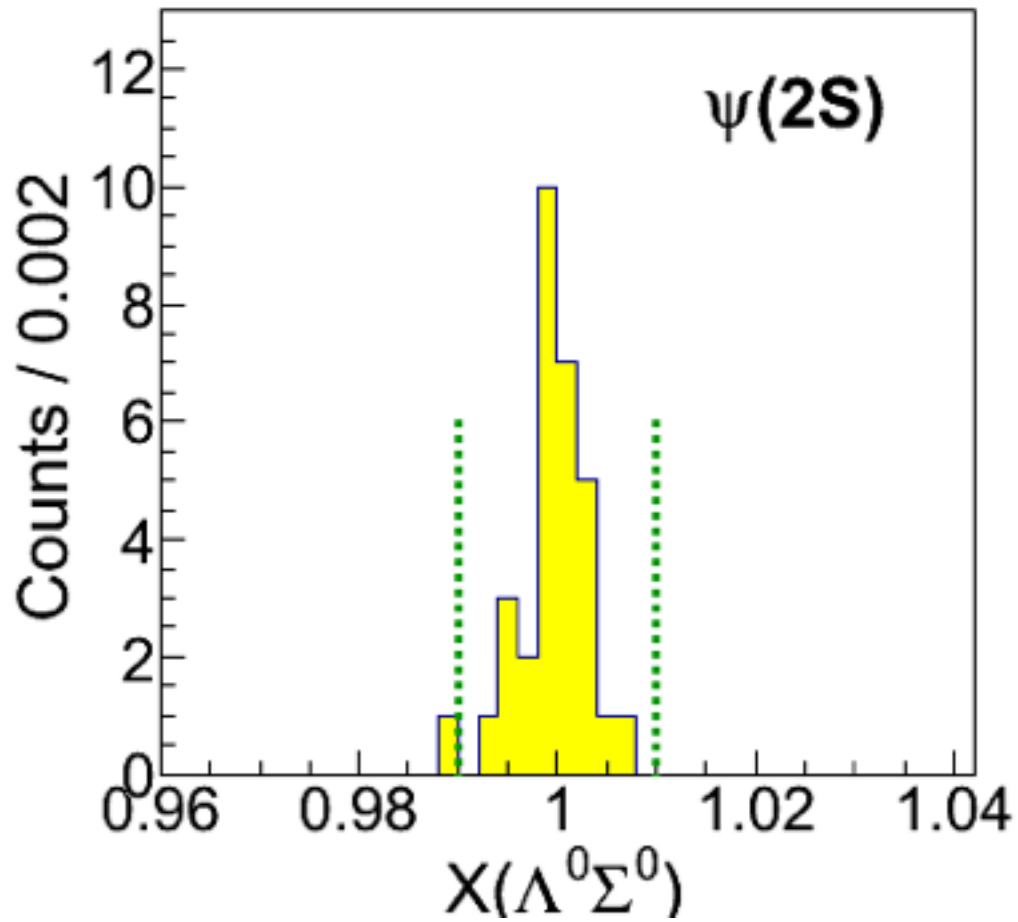


Direct EM production | **gluonic decay of resonance** | **EM decay of resonance**

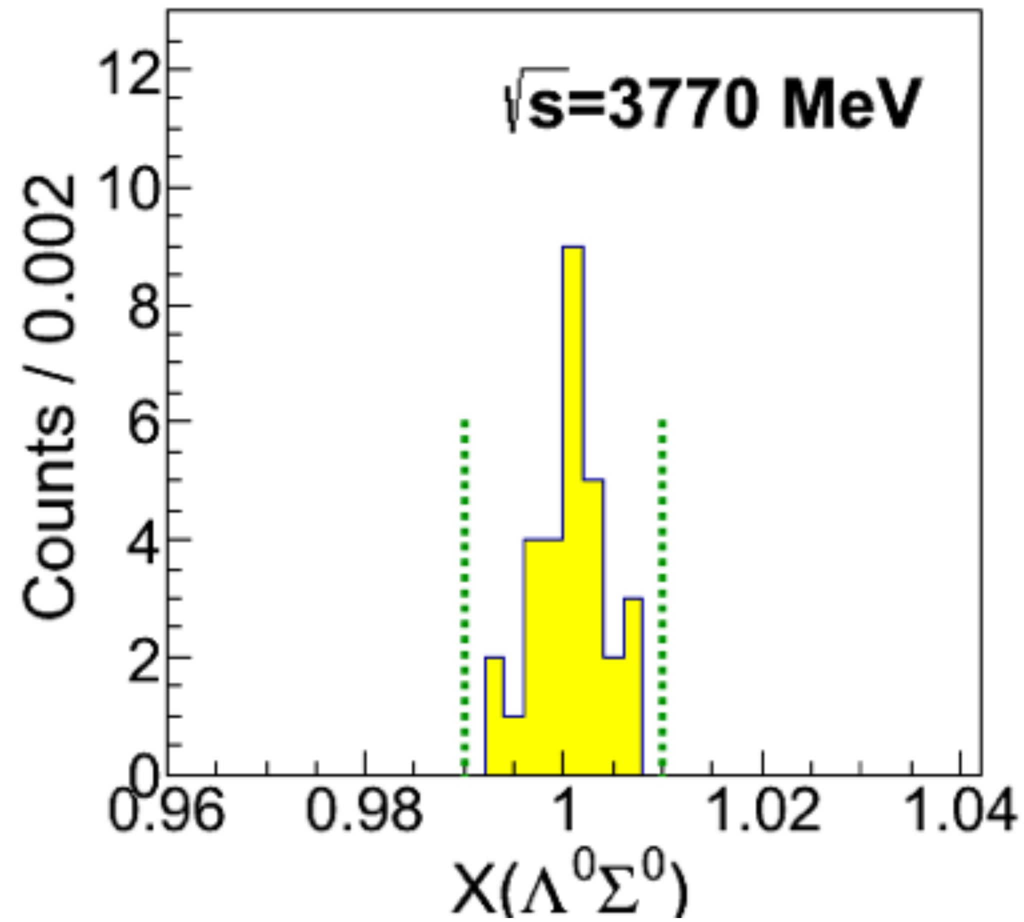
- The **Λ^0** (**I=0**) and **Σ^0** (**I=1**) states have the same uds quark content but opposite isospin.
  - **Λ^0 Σ^0** (**total I=1**) pair production in **e^+e^-** annihilation (**total I=0**) can only proceed through isospin-violating processes.
- In $\psi(2S)$ decay, the strong force conserves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

Unequal Baryons — Production of $\Lambda^0\ \Sigma^0$

$\psi(2S) \to ggg \to \Lambda^0\ \Sigma^0$



$e^+e^- \to q\bar{q} \to \Lambda^0\ \Sigma^0$



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

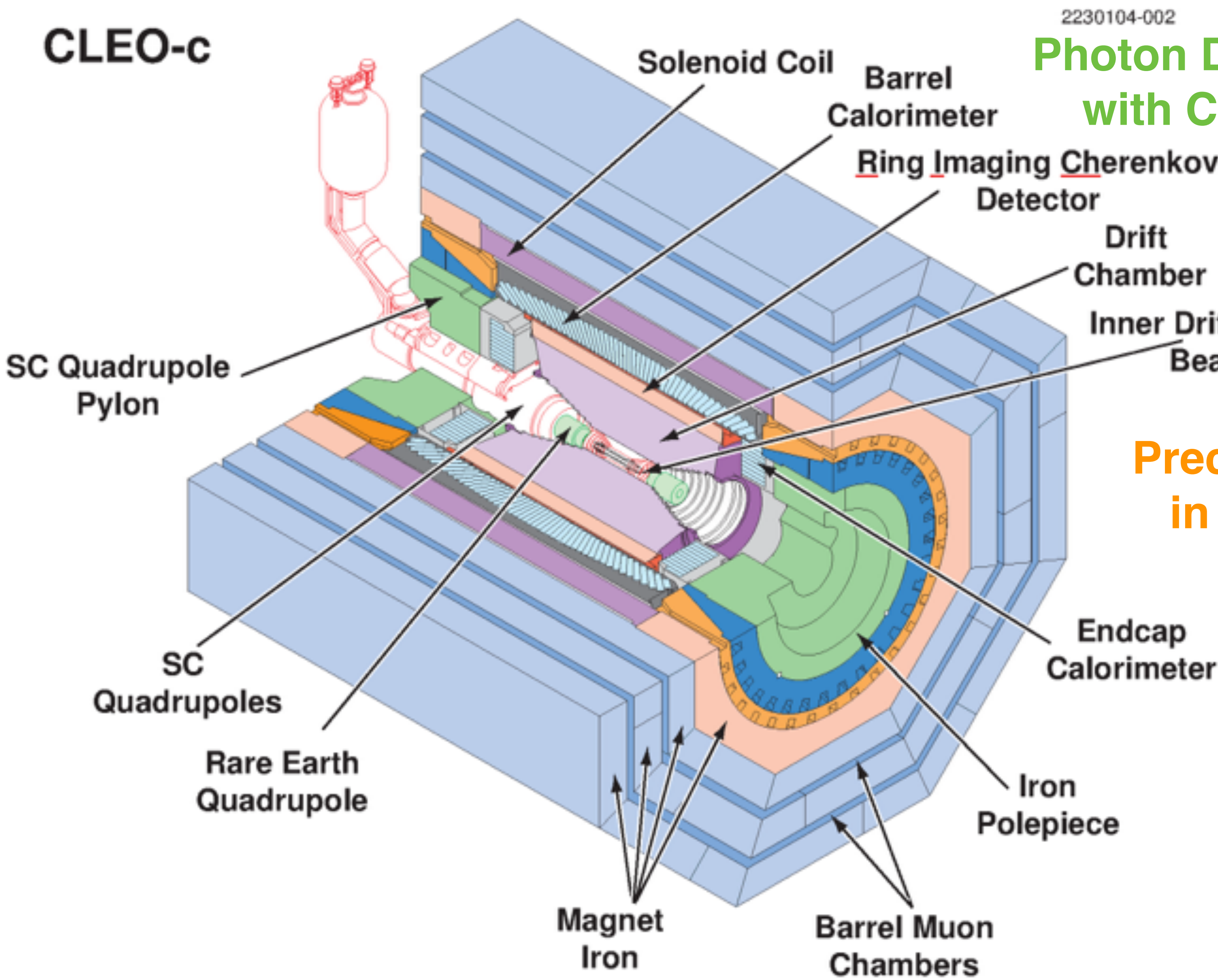
- Form factor @ $|Q^2|$ = 14.2 GeV^2:
  N = 30 ± 5, **$G_M(\Lambda^0\ \Sigma^0)$ = (0.79 ± 0.07(stat)) x 10^{-2}**
  This is consistent with $G_M(\Sigma^0)$ = (0.79 ± 0.07) x 10^{-2}
  and is factor ~0.6 smaller than $G_M(\Lambda^0)$ = (1.31 ± 0.05) x 10^{-2}

Summary

- Detailed study of hyperon production can yield useful insights into their structure.
- We have measured yields of the hyperons Λ^0, Σ^+, Σ^0, Ξ^-, Ξ^0, Ω^- produced in the decay of $\psi(2S)$ and in e^+e^- annihilation at two energy points above $\mathbf{D\bar{D}}$ 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



Photon Detection with Crystal Calorimeter

π/K separation using RICH and DC dE/dx

Precision tracking in 1T B field

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

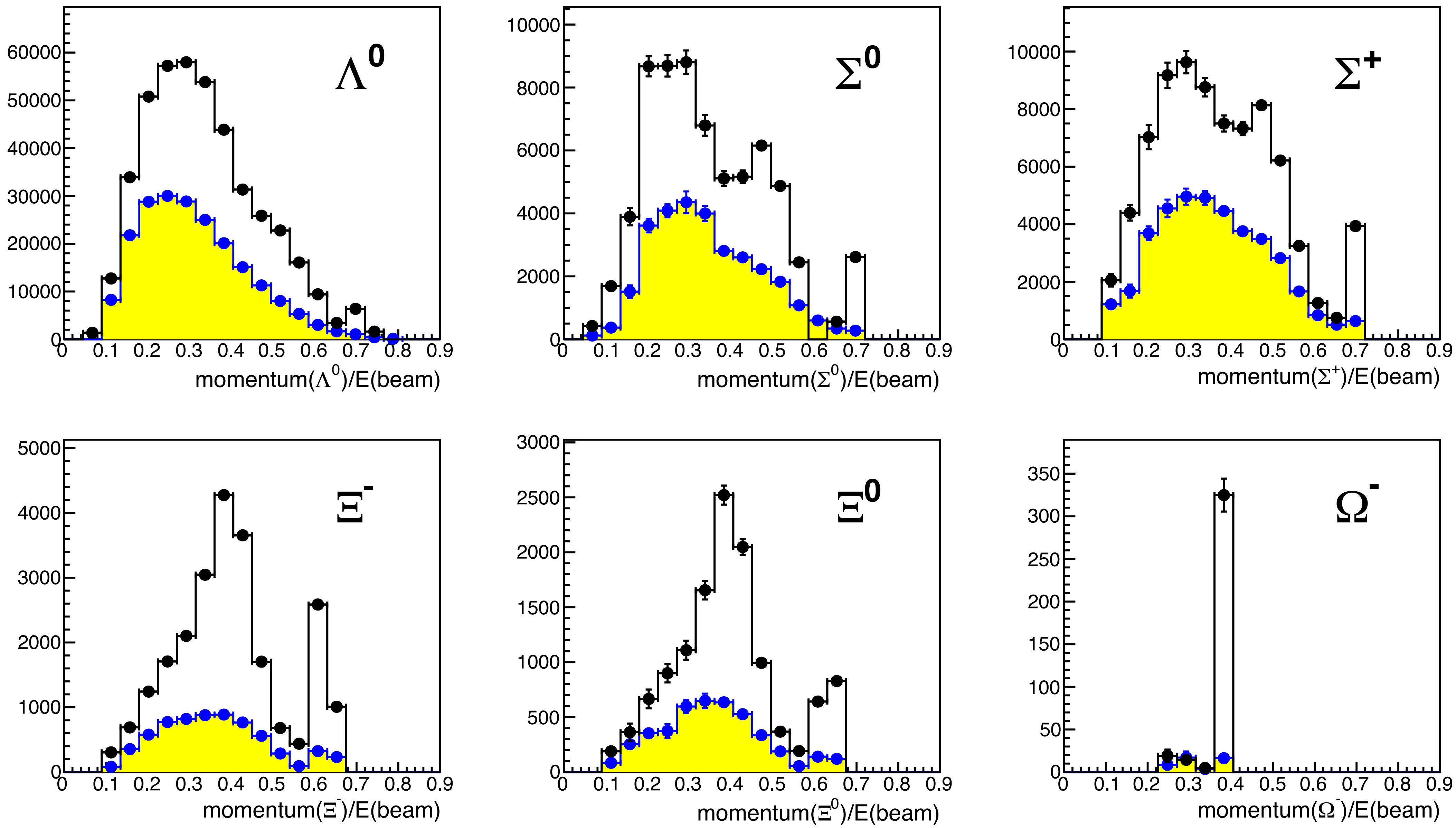
Charged particles:
$\sigma_p/p = 0.6\%$ @ 1 GeV/c

Photons:
$\sigma_E/E = 2.2\%$ @ 1 GeV
$\sigma_p/p = 5\%$ @ 100 MeV

Hyperon Yields From ψ(2S) and √s=3772 MeV

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

Open hist: ψ(2S) data   Filled hist: √s=3772 MeV data (arb. norm.)



- Results from ψ(2S) and √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): PARJ(1) = 0.065 [default = 0.1]
- Strange quark suppression factor P(s)/P(u): PARJ(2) = 0.26 [default = 0.30]
- Strange diquark suppression factor [P(us)/P(ud)]/[P(s)/P(d)]: PARJ(3) = 0.4
- Suppression of spin-1 diquarks relative to spin-0: (1/3)P[ud_1]/P[ud_0]: PARJ(4) = 0.05
- Popcorn production probability: PARJ(5) = 0.5