Polarization and Asymmetries in Neutral Strange Particle Production

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On behalf of the ZEUS Collaboration

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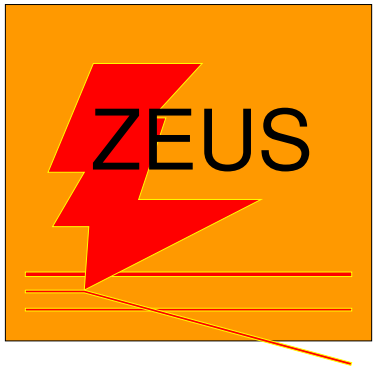


- Introduction
  - Polarization
  - Baryon Asymmetry
  - Baryon - Meson Ratio
- Event and Particle Selection
- Results and Discussion
- Conclusion

Introduction

- Investigate Λ, $\bar{\Lambda}$ and K^0_s produced in eP HERA collisions at ZEUS
  - Low mass $\Rightarrow$ High statistics
  - Weak decay $\Rightarrow$ Clean signal
  - Baryons, antibaryons and mesons

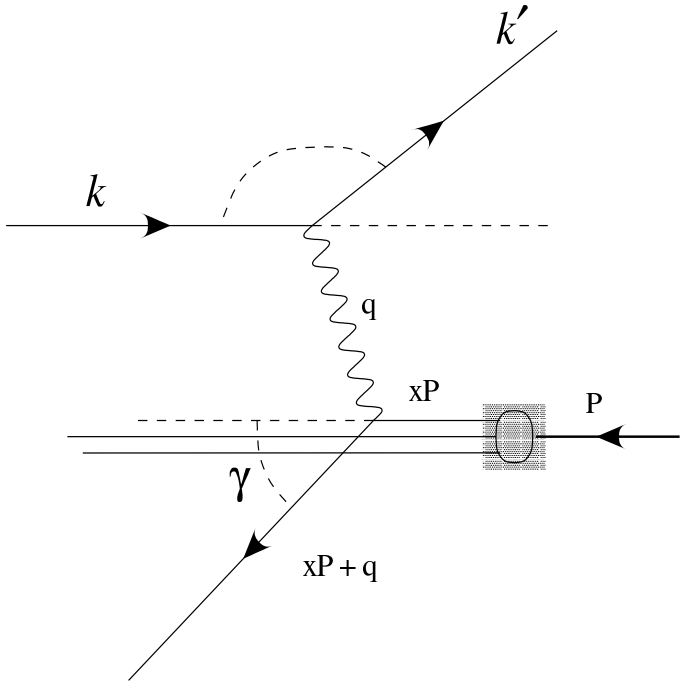
- Hadron Production
  - When is a baryon produced, and when is a meson produced?
  - $\Rightarrow$ Measure $(\Lambda + \bar{\Lambda})/K^0_s$

- Baryon number
  - Does the initial baryon number transfer to the Λ system?
  - $\Rightarrow$ Measure $(\Lambda - \bar{\Lambda})/(\Lambda + \bar{\Lambda})$

- Strange Quarks
  - Where does the strange quark come from?
  - $\Rightarrow$ Measure polarization

Event Kinematics and Particle Selection

- ZEUS 1996-2000 data
  - 121 pb^{-1}
  - $E_e = 27.5$ GeV
  - $E_P = 820$ GeV (1996-1997)
  - $E_P = 920$ GeV (1998-2000)
- Event Selection
  - Standard DIS events
  - $Q^2 > 25 GeV^2$
  - $0.02 < y < 0.95$
- Particle Selection
  - Secondary Vertex
  - $0.6 < P_T(\Lambda, K_s^0) < 2.5$
  - $|\eta(\Lambda, K_s^0)| < 1.2$



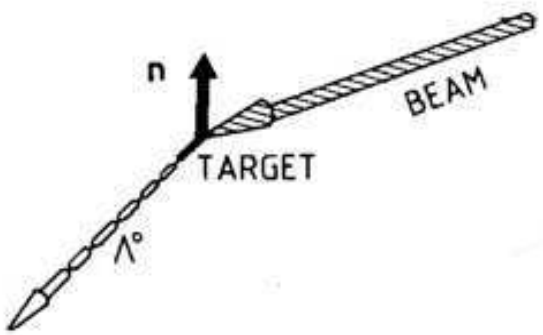
- ZEUS Variables
  - $Q^2 \equiv -q^2$ (4-Momentum Transfer)
  - $x \equiv Q^2/2p.q$ (Bjorken Scaling Variable)
  - $y \equiv p.q/p.k$ (Inelasticity)
  - $\eta \equiv -\ln(\tan\frac{\theta}{2})$ (Pseudorapidity)

Event Simulation

- Data is corrected with and compared to Ariadne Monte Carlo
  - LO Matrix Elements for Initial Event
  - Colour Dipole Model for QCD Cascade
  - Hadronization using Lund String Model
- Good description of data at detector level by Monte Carlo

Why measure polarization?

- Polarization: Preference of Λ spin for a particular direction
  - Transverse: With respect to $\hat{n} = \hat{p}_{beam} \times \hat{p}_{\Lambda}$. ($\hat{p}_{beam}$ is the direction of the electron beam)
  - Longitudinal: With respect to $\hat{p}_{\Lambda}$



- Expect polarization mostly carried by strange quark
- DeGrand and Miettinen model: Transverse Λ polarization arises from acceleration of strange quark via Thomas precession
- Expect no longitudinal polarization for HERA-I (possibly non-zero for HERA-II due to polarized electron beam)
- Where does the s quark come from?

How to measure polarization

- To measure polarization:
  - Look at the proton angular distribution in rest frame of Λ

    $\frac{1}{N}\frac{dN}{d\Omega} = \frac{1}{4\pi}[1 + \alpha P^{\Lambda} cos\theta]$ $\quad$ $\frac{1}{N}\frac{dN}{d\Omega} = \frac{1}{4\pi}[1 - \alpha P^{\bar{\Lambda}} cos\theta]$
  - $\alpha = 0.642 \pm 0.013$; decay asymmetry parameter - Phys Rev D66,010001 (2002)
  - P^{Λ} is the polarization
  - θ is the angle between:
    - Proton direction and $\hat{n} = \hat{p}_{beam} \times \hat{p}_{\Lambda}$ (Transverse polarization)
    - Proton direction and $\hat{p}_{\Lambda}$ (Longitudinal polarization)
- Plot $\frac{dN}{dcos\theta}$ vs $cos\theta \Rightarrow$ polarization from gradient

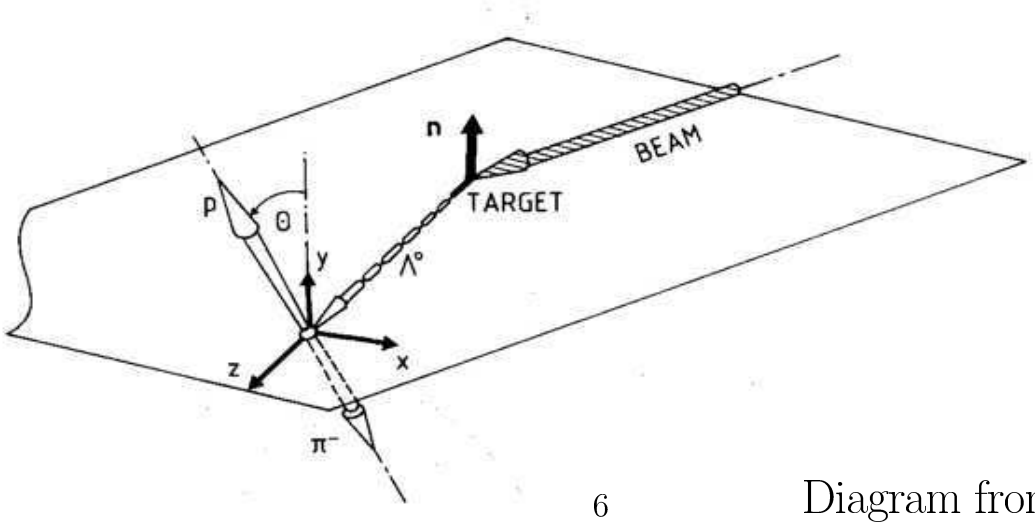
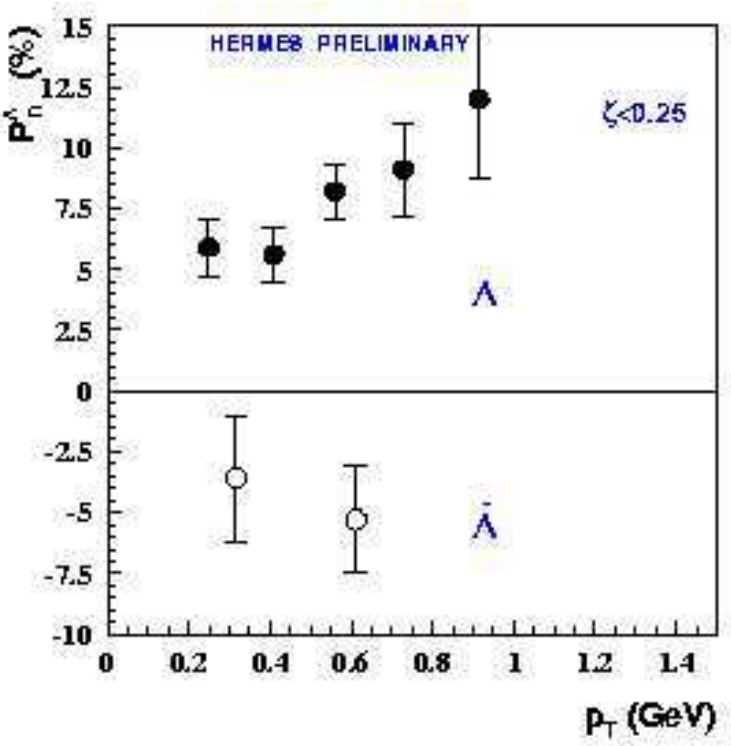


Diagram from A.D.Panagiotou

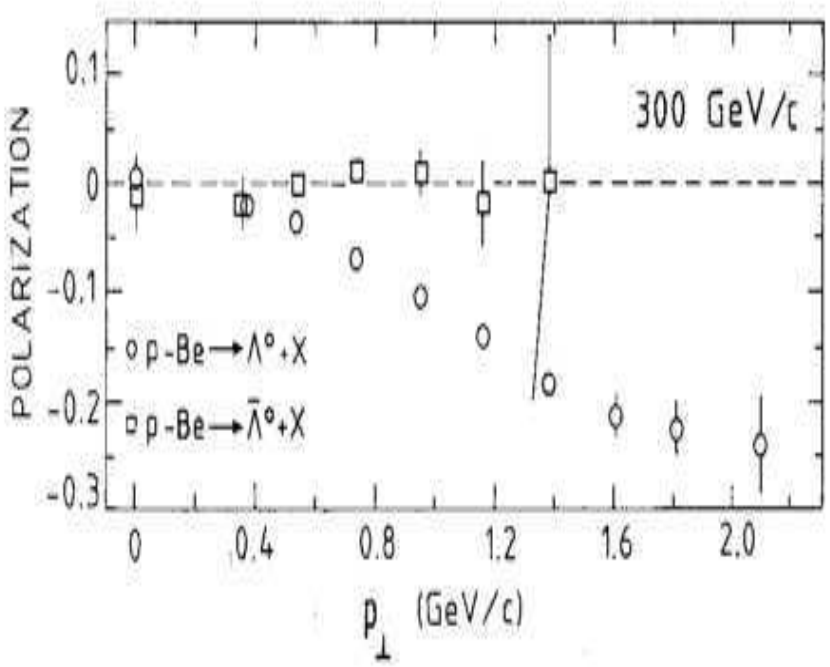
What do other experiments see?

- HERMES result:
  - Positive Λ polarization
  - Negative $\bar{\Lambda}$ polarization
- Interpreted as $s(\bar{s})$ quark from resolved γ



- O. Grebenyuk (HERMES), DIS2002

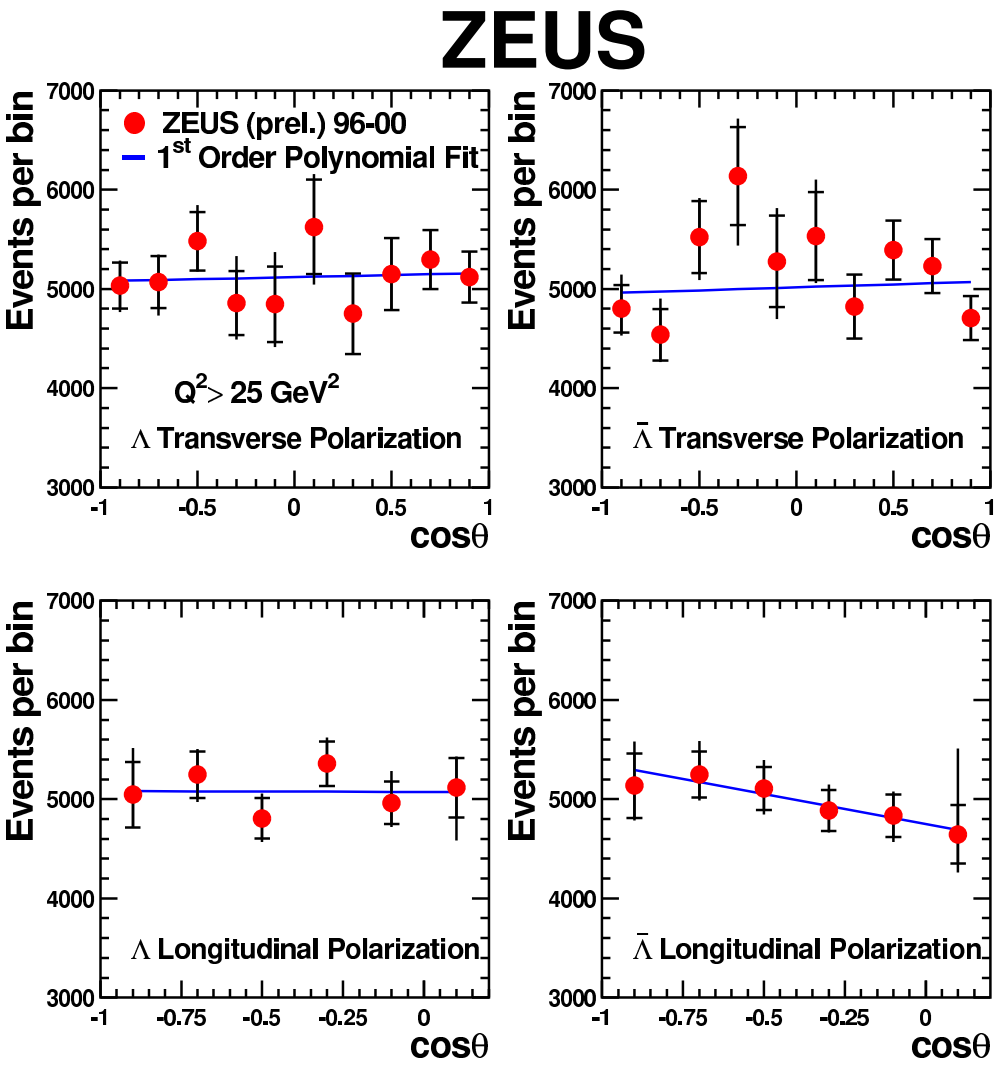
- P-Be scattering:
  - Negative Λ polarization
  - No $\bar{\Lambda}$ polarization
- Interpreted as fast (ud) diquark picking up slow s quark

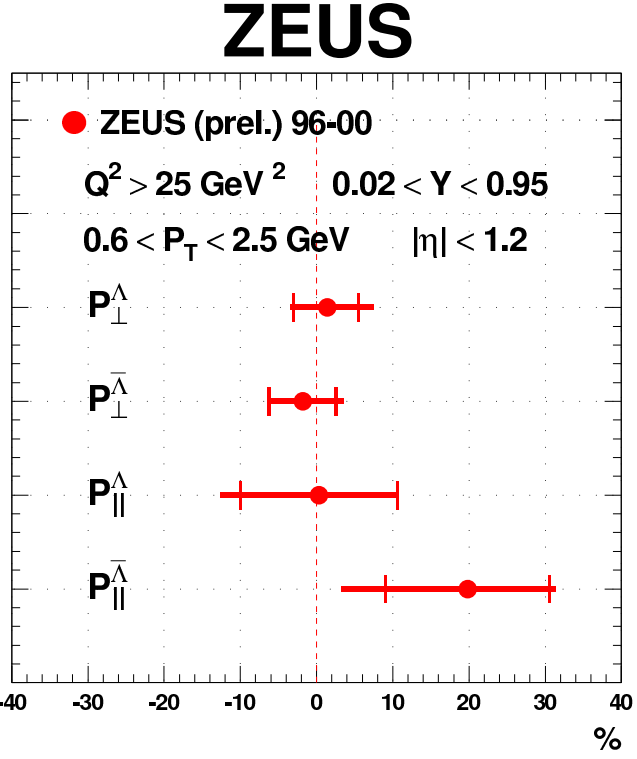


- K. Heller, PRL 41(1978) 607

- Transverse polarization comes from precession of s-quark spin

Polarization measurements - Λ and $\bar{\Lambda}$





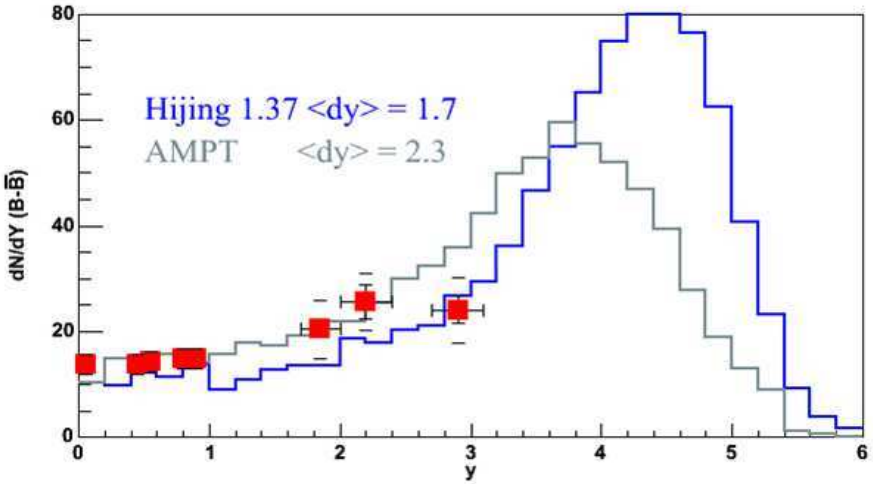
	Transverse (%)	Longitudinal (%)
Λ	$+1.4 \pm 4.5^{+4.1}_{-1.9}$	$+0.3 \pm 10.3^{+0.1}_{-7.8}$
$\bar{\Lambda}$	$-1.8 \pm 4.4^{+3.1}_{-1.3}$	$+19.8 \pm 10.8^{+4.2}_{-12.6}$

- Polarization always consistent with zero
  - s-quarks do not come predominantly from any particular direction
  - Potential to measure polarization transfer from electron beam to Λ in HERA-II

Baryon Number Conservation

- How can baryon number travel through rapidity?
  - Rescattering of valence quarks?
  - Gluonic junctions?

- Heavy Ion Data (Au-Au at RHIC):



- F. Videbaek (BNL), ICPAQGP 2005
- How does baryon number travel through rapidity in Au-Au collisions?

Baryon - meson ratio

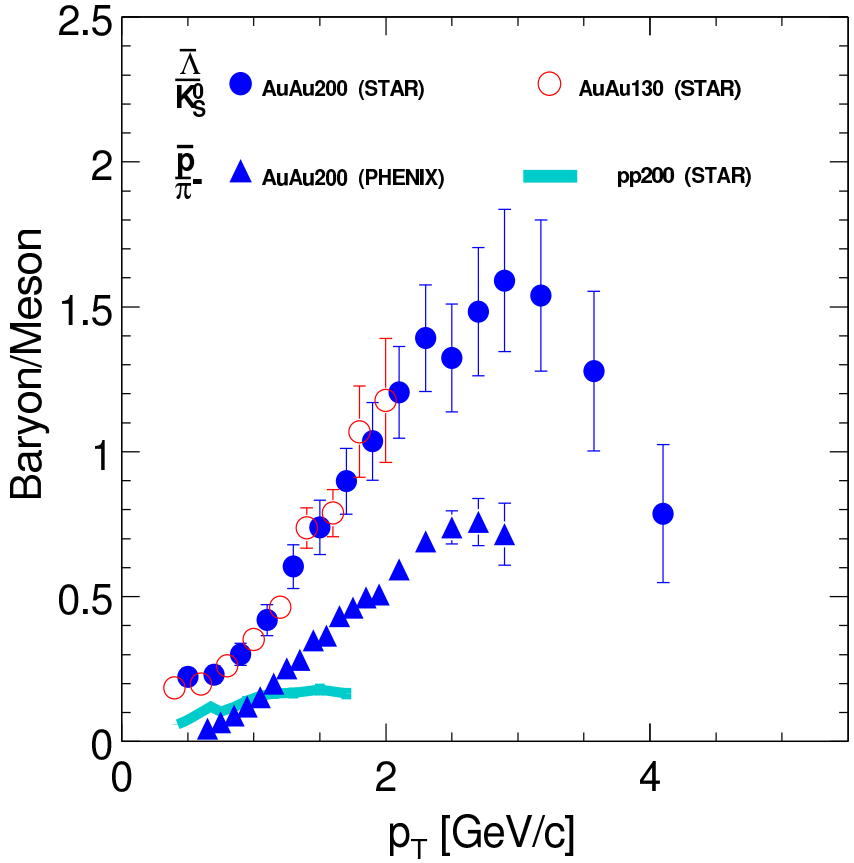
- When is a baryon produced?
- When is a meson produced?
  - What is the physics that affects hadron production?

- Baryon to meson ratio in e^+e^-:
  - Phys Rev D66,010001 (2002)

$\sqrt{s}$ (GeV)	≈ 10	29-35	91	130-200
$\frac{(\Lambda+\bar{\Lambda})}{K^0_s}$	0.18 ± 0.02	0.28 ± 0.02	0.38 ± 0.01	0.37 ± 0.04

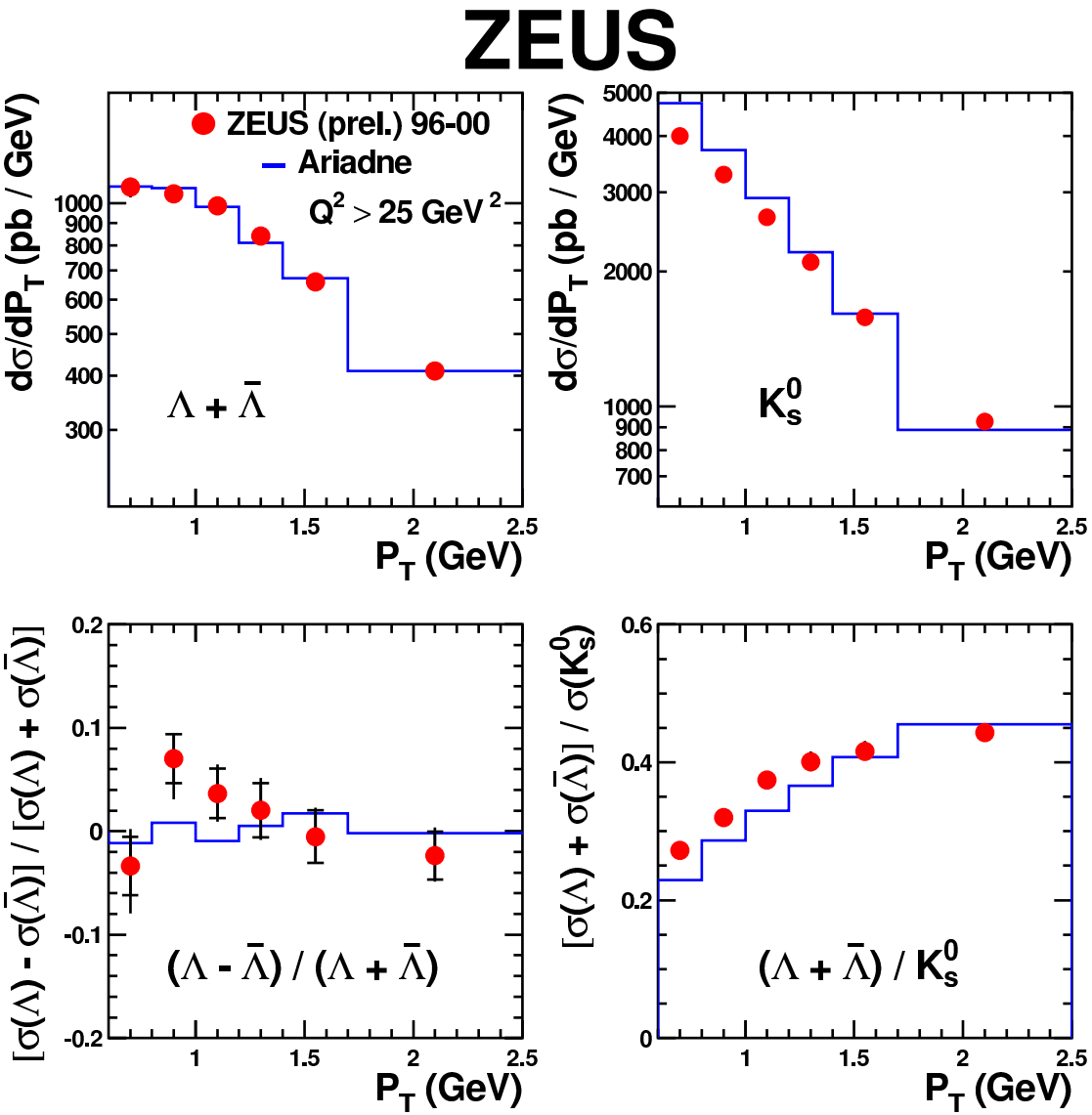
- Generally smaller than in Heavy Ion collisions

- Heavy Ion Data:



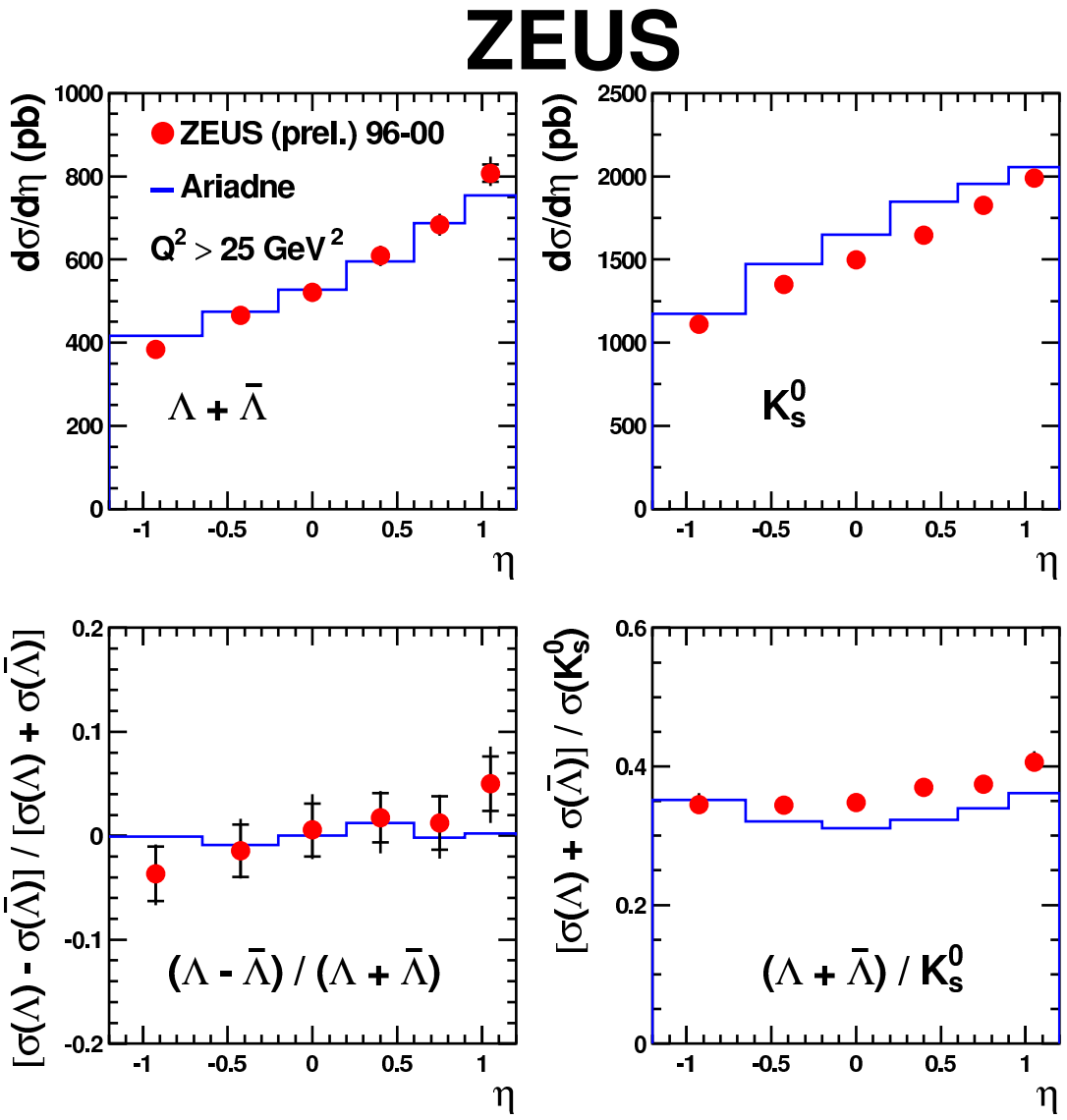
- Heavy Ion Experiments see huge variation (hep-ph/0501187)
- Baryon/meson ratio > 1 !

Cross-sections, baryon asymmetry, baryon-meson ratio - P_T



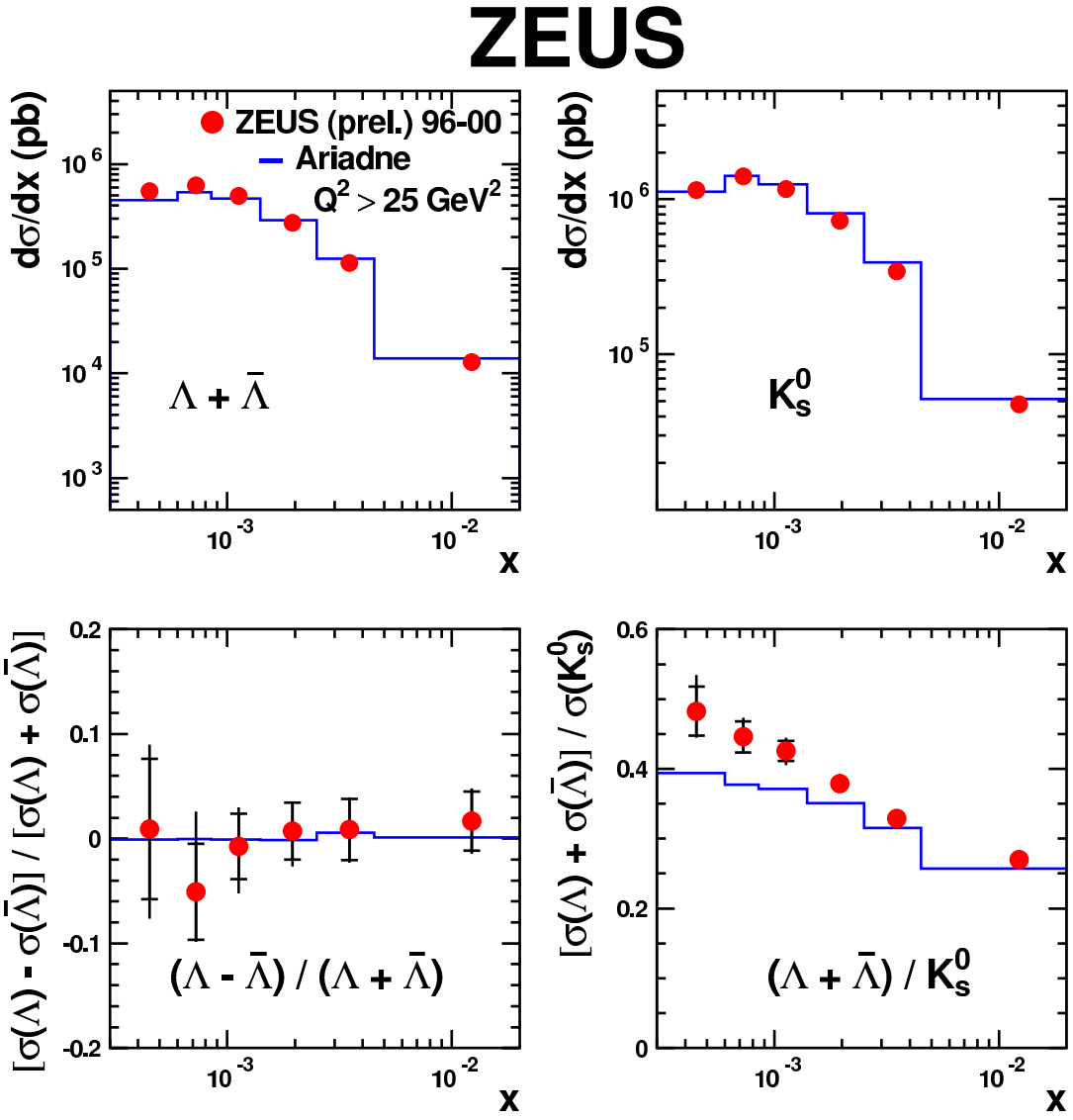
- Fair agreement with Ariadne Cross-sections
  - Excess of Ariadne over Data for K^0_s production
- No signifi cant$\Lambda - \bar{\Lambda}$ asymmetry
  - Slight excess of Λ at low P_T?
- Fair agreement with Ariadne Λ to K^0_s ratio
  - Data gives higher baryon to meson ratio at low P_T

Cross-sections, baryon asymmetry, baryon-meson ratio - η



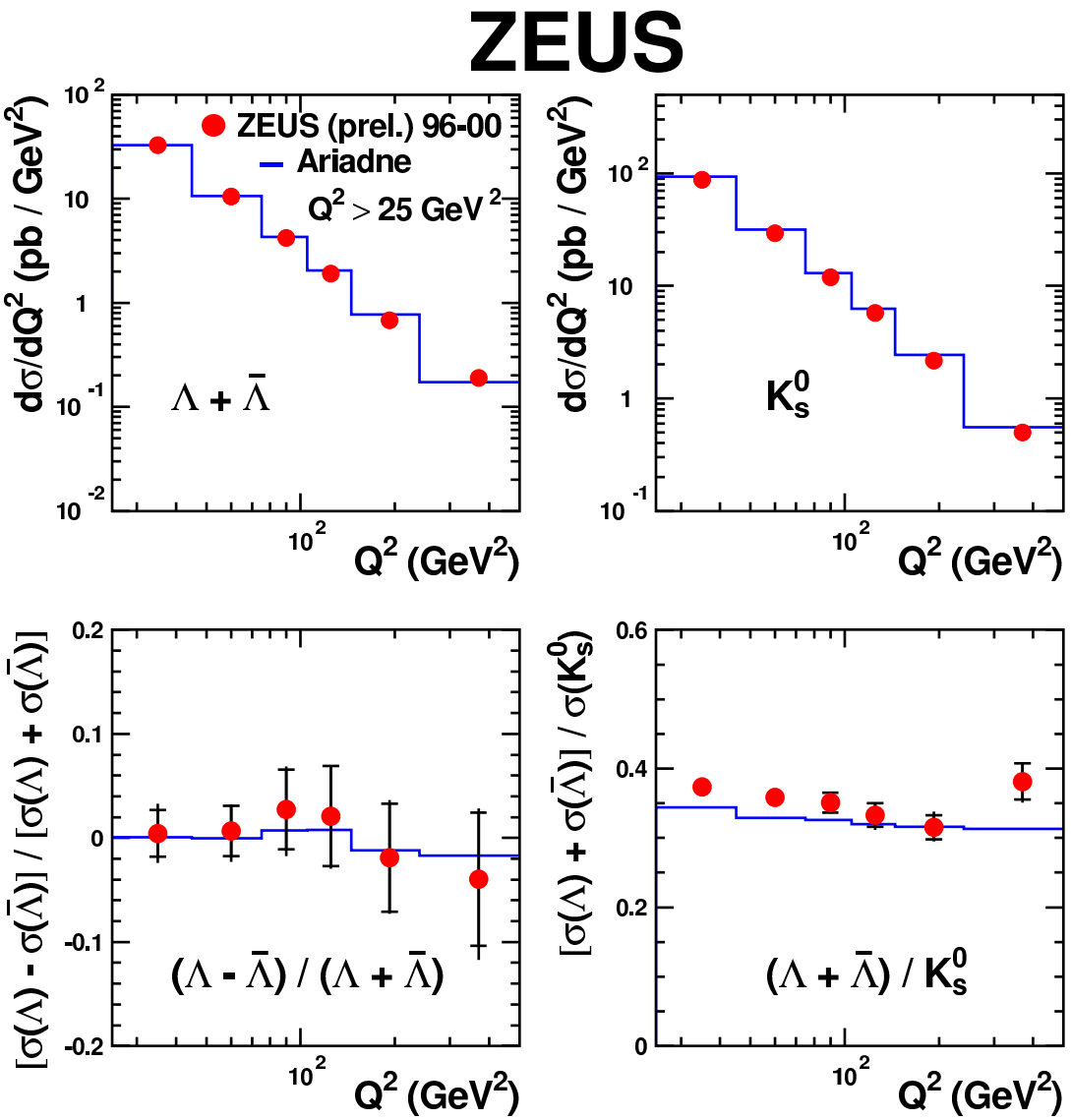
- Fair agreement with Ariadne Cross-sections
  - Excess of Ariadne over Data for K^0_s production
- No signifi cant$\Lambda - \bar{\Lambda}$ asymmetry
  - Increasing $\Lambda - \bar{\Lambda}$ asymmetry as η increases?
  - Baryon number travelling through η?
- Fair agreement with Ariadne Λ to K^0_s ratio
  - Data baryon to meson ratio not symmetric about $\eta = 0$

Cross-sections, baryon asymmetry, baryon-meson ratio - x



- Fair agreement with Ariadne Cross-sections
- No signifi cant $\Lambda - \bar{\Lambda}$ asymmetry
- Similar trend for Data and Ariadne Λ to K^0_s ratio
  - Steeply rising baryon to meson ratio as x decreases
  - Not modelled suffi ciently by Ariadne
  - What physics causes this?
  - Different probabilities for gluons and quarks to fragment to baryons?

Cross-sections, baryon asymmetry, baryon-meson ratio - Q^2



- Fair agreement with Ariadne Cross-sections
- No signifi cant $\Lambda - \bar{\Lambda}$ asymmetry
- Not perfect agreement with Ariadne Λ to K^0_s ratio

Conclusions

- K^0_s,Λ,$\bar{\Lambda}$ Cross-sections, baryon asymmetry, baryon-meson ratio and polarization measured in DIS events at ZEUS with $Q^2 > 25GeV^2$
  - Transverse Λ polarization consistent with zero
    - Strange quarks do not come from predominantly one direction
  - Longitudinal Λ polarization consistent with zero
    - Measure of sensitivity for HERA-II Λ production
  - No Λ - $\bar{\Lambda}$ asymmetry found
    - Begin to limit baryon number transport models
      - Gluonic Junction model predicts $\sim +3.5\%$ asymmetry for $x \sim 0.5 \times 10^{-3}$ (Kopeliovich, Povh, Z.Phys.C 75, 693, 1997)
  - $\Lambda - K^0_s$ ratio measured
    - Mechanism for baryon production at ZEUS is somewhere between that for e^+e^- and Heavy Ion collisions
    - Ratio rises stongly with decreasing Bjorken-x - moving more towards the mechanism in Heavy Ion collisions?