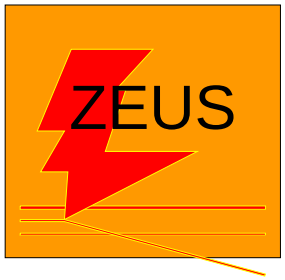


Hamburg University

Low X Workshop 2003

Nafplio, Greece

Strange Particle Production in DIS at HERA

Amita Raval on behalf of the ZEUS Collaboration

- Motivation
- DIS at HERA
- K^0_S, Λ, $\bar{\Lambda}$ Identification & Selection
- Signal & Total Cross Sections
- Differential Cross Sections
- $K^0_S K^0_S$ Final States in DIS
- Conclusions

Motivation

- Strange hadron production, particularly baryons, not well understood in hadronic collisions
- Strange particle measurements at HERA behind those of LEP and heavy flavours at HERA
- Strange particle fragmentation $\Rightarrow$ universal?
  - Improve the understanding of fragmentation?
    $\Rightarrow$ needed for direct measurement of the $s\bar{s}$ sea in the proton
- Disagreement between LEP and HERA measurements concerning fragmentation into strange hadrons:

  $\longrightarrow$ Strangeness Supression Factor λ_s= P(s)/P(d); P(d) = P(u)

  $\longrightarrow$ LEP $\lambda_s = 0.3$; HERA $\lambda_s \approx 0.2$ (K^0, Λ and $\phi(1020)$)
- Baryon and anti-baryon production $\Rightarrow$ different?

Previous Measurements of Strange Particles at HERA

- ***Neutral Strange Particle Production in DIS at HERA*** **by ZEUS; K^0 and Λ rate measurements with 1994 data; published 1995**
- ***Strangeness Production in DIS*** e^+p ***Scattering at HERA*** **by H1; K^0 and Λ rate measurements; published 1996**
- ***Charged Particles and Neutral Kaons in Photoproduced Jets at HERA*** **by ZEUS; K^0 and Λ rate measurements; published 1997**
- ***Photoproduction of*** K^0 ***and*** Λ ***at HERA*** **by H1; K^0 and Λ rate measurements; published 1997**
- ***Study of Inclusive*** ϕ***(1020)-meson production in neutral current DIS at HERA*****; ϕ(1020) Cross Section**
- **(Cross Sections of K^0 and Λ production at HERA have never been published!)**

Strange Quark Production in DIS & Fragmentation to Hadrons

Inclusive Deep Inelastic Scattering at HERA:

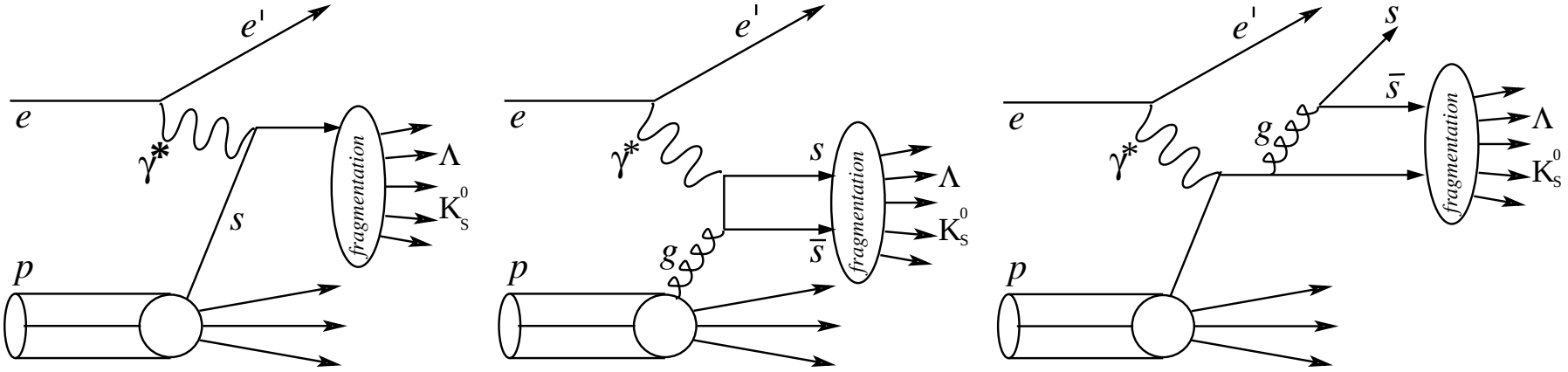
$ep \rightarrow e'X$

Kinematics of DIS:

$q = e - e'$ $\qquad Q^2 = -q^2 = sxy$

$x = \frac{Q^2}{2p \cdot q}$ $\qquad y = \frac{p \cdot q}{p \cdot e}$

Possible Mechanisms of Strange Quark Production:



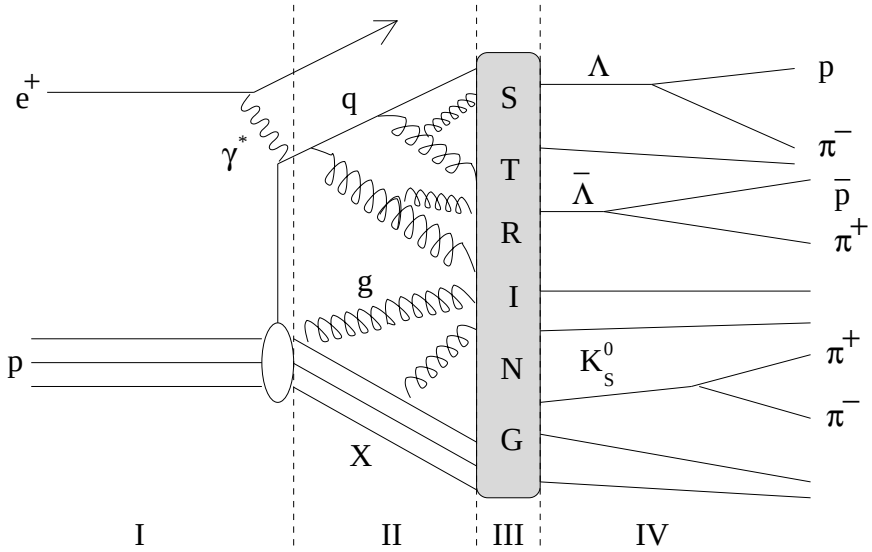
Flavour Excitation **Boson-Gluon Fusion** **Gluon-Splitting**

Models of Fragmentation in Strange DIS

ARIADNE plus JETSET

- QCD cascade as described by the Color Dipole Model (CDM)
- Parton cascade fragmentation to hadrons: Lund String Model
- Final state hadrons $\Rightarrow$ reconstructed

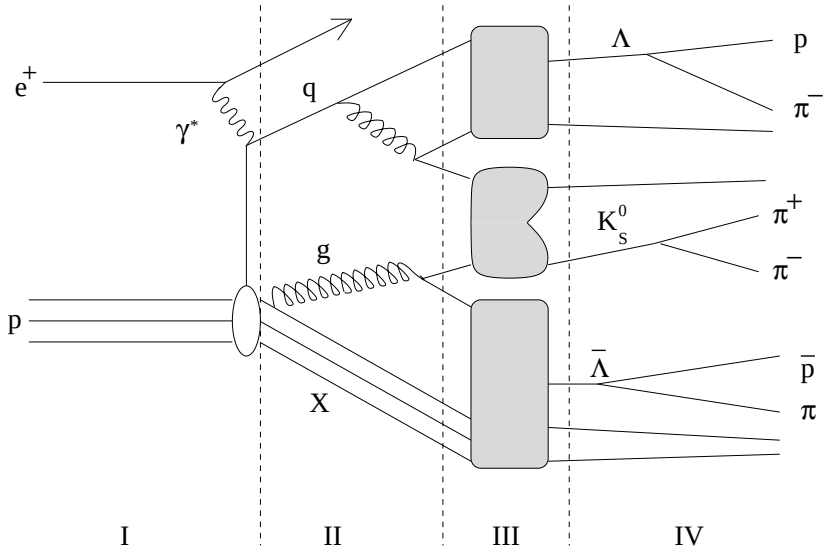
Event Generated by ARIADNE plus JETSET



HERWIG

- $q\bar{q}$ pairs created from break up of colour dipoles
- Parton cascade fragmentation to hadrons: Cluster Fragmentation Model
- Final state hadrons $\Rightarrow$ reconstructed

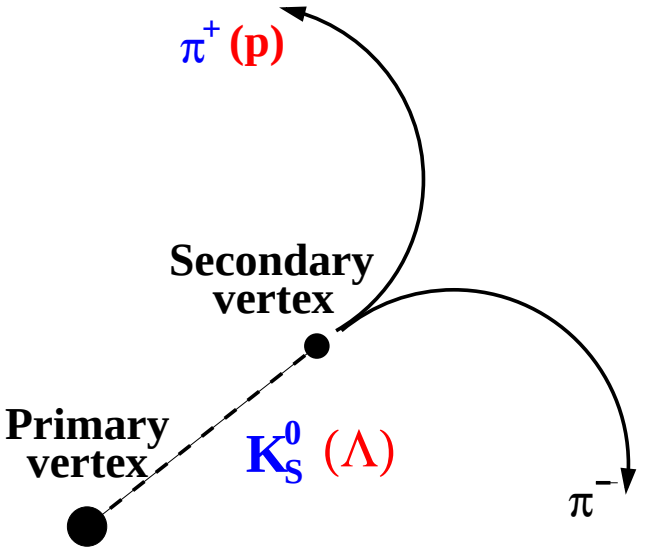
Event Generated by HERWIG



Strange Particle Identification & Selection I

Event Selection Requirments:

- Primary and secondary vertices well separated
- Two secondary vertex tracks with opposite charges



Background:

- Combinatorial
  - ⇒ Removed by background subtraction
- Λ's in K^0_S's
  - ⇒ Removed with an anti-Λ mass cut

K^0_S, Λ Reconstruction:

- Reconstruct two oppositely charged tracks assigned to secondary vertex

Particle	Main Decay	Mass (GeV)	Decay Length (cm)	Lifetime (10^{-8} sec)
K^0_S	$\pi^+\pi^-$	0.497	2.68	0.89
Λ	$p^+\pi^-$	1.112	7.89	2.63

Strange Particle Identification & Selection II

Data Sample:

- e^+ **(27.5 GeV);** p **(920 GeV)**
- **99/00** e^+p ZEUS **data**

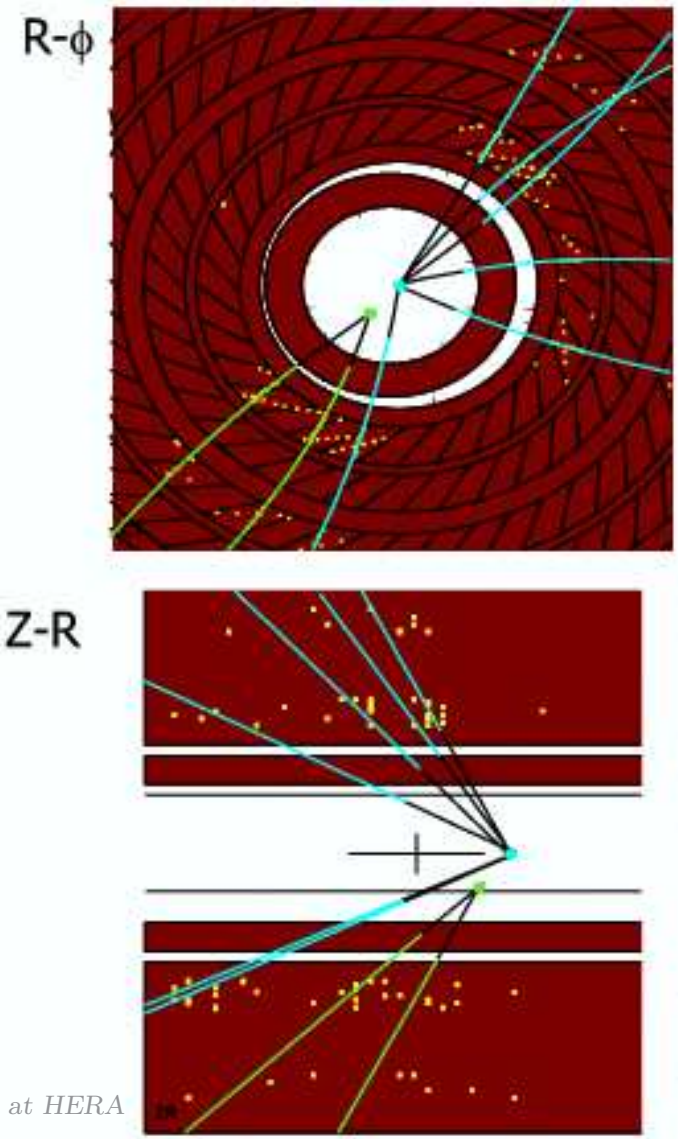
$\Rightarrow \mathcal{L} = 60$ pb^{-1}

DIS Kinematic Region:

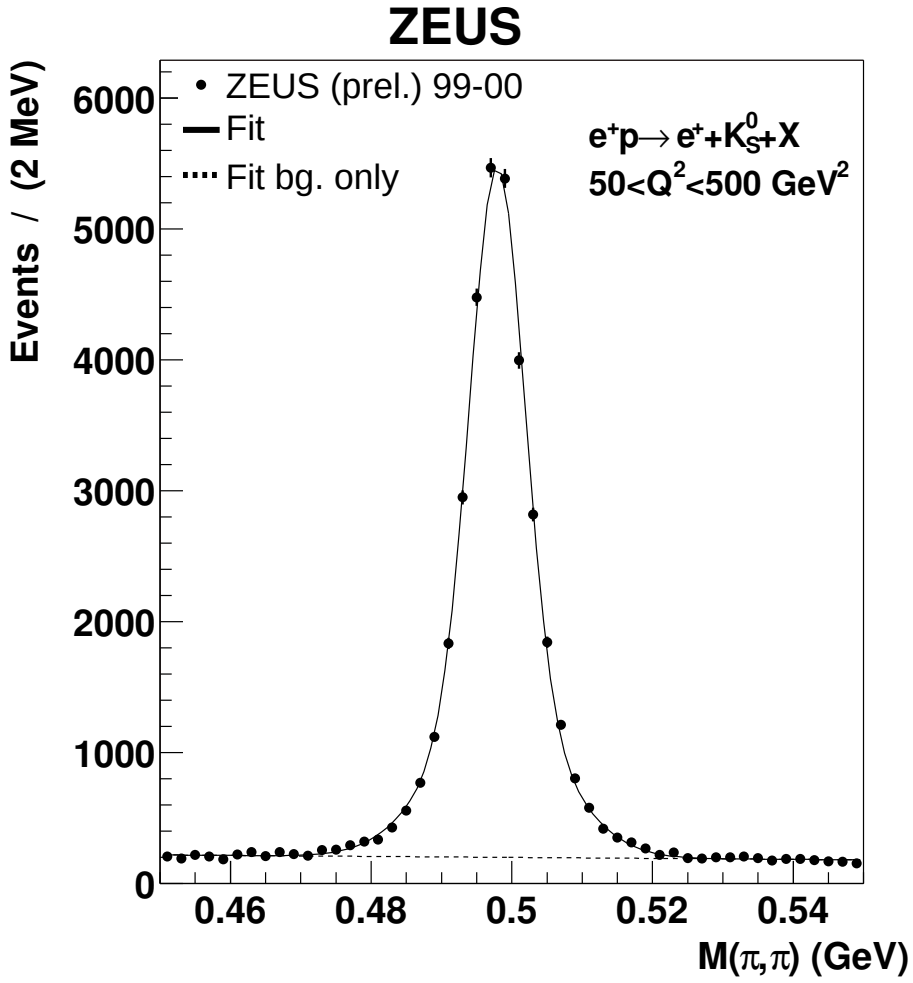
- $50 < Q^2 < 500$ GeV^2
- $3 \cdot 10^{-4} < x < 10^{-1}$

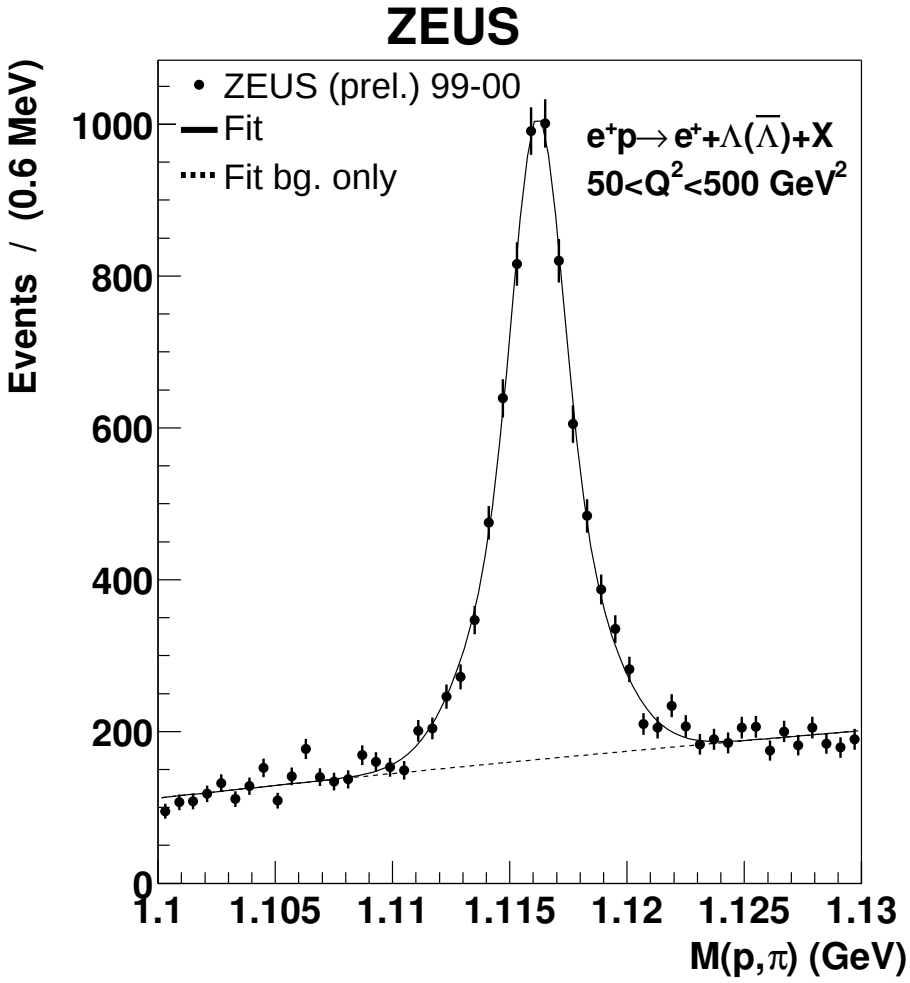
K^0_S, Λ Kinematic Region:

- $0.5 < p_T(K^0_S, \Lambda) < 5.0$ GeV
- $|\eta(K^0_S, \Lambda)| < 1.5$



K^0_S, Λ Signal



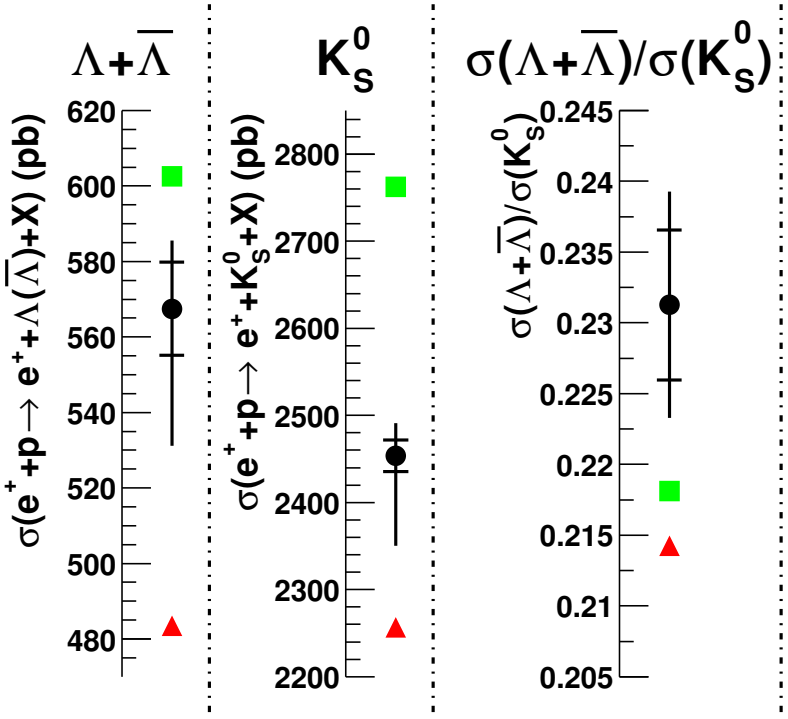


K^0_S $\Lambda + \bar{\Lambda}$

$\Rightarrow$ **Clear Signal, Large Statistics, Low Background**

Total Cross Sections: K^0_S, Λ, $\bar{\Lambda}$

	$\sigma(K^0_S)$ [pb]	$\sigma(\Lambda+\bar{\Lambda})$ [pb]	$\sigma(\Lambda+\bar{\Lambda})/\sigma(K^0_S)$	$\sigma(\Lambda)$ [pb]	$\sigma(\bar{\Lambda})$ [pb]	$\sigma(\Lambda)/\sigma(\bar{\Lambda})$
ZEUS (prel.)	$2454 \pm 18^{+32}_{-102}$	$567 \pm 12^{+13}_{-34}$	$0.231 \pm 0.005^{+0.005}_{-0.006}$	$292 \pm 9^{+7}_{-18}$	$279 \pm 9^{+12}_{-18}$	$1.05 \pm 0.05^{+0.05}_{-0.05}$
CDM: λ_s=0.3	**2762**	**603**	**0.218**	**302**	**301**	**1.00**
CDM: λ_s=0.2	**2257**	**483**	**0.214**	**240**	**243**	**0.99**
HERWIG	**1854**	**1329**	**0.717**	**661**	**668**	**0.99**



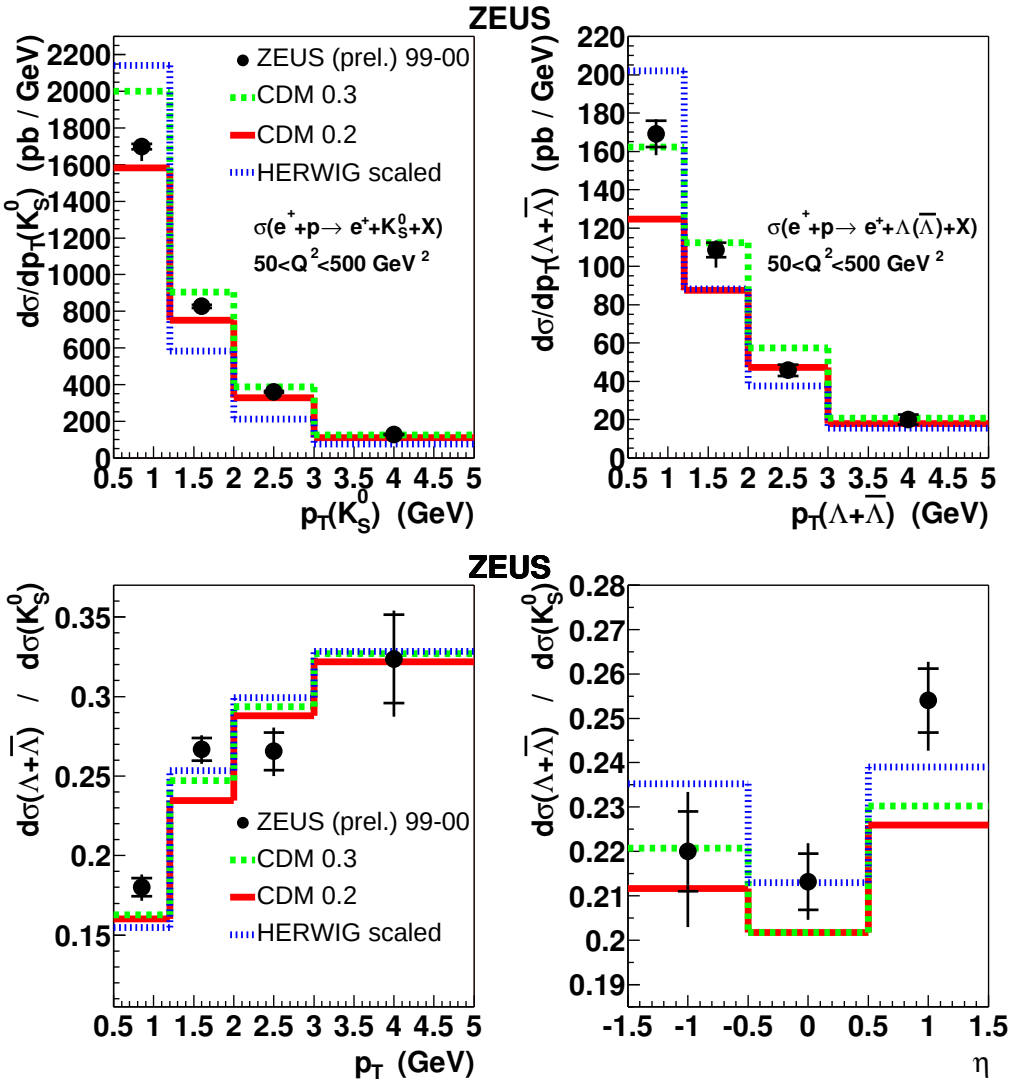
● ZEUS (prel.) 99-00
$50<Q^2<500 GeV^2$
$3\cdot10^{-4}<x<10^{-1}$

CDM
■ λ_s=0.3
▲ λ_s=0.2

Conclusion:

- Measurement between Lund String Model Strangeness Suppression factor, λ_s, of 0.2 and 0.3
- Herwig fails to predict total cross sections

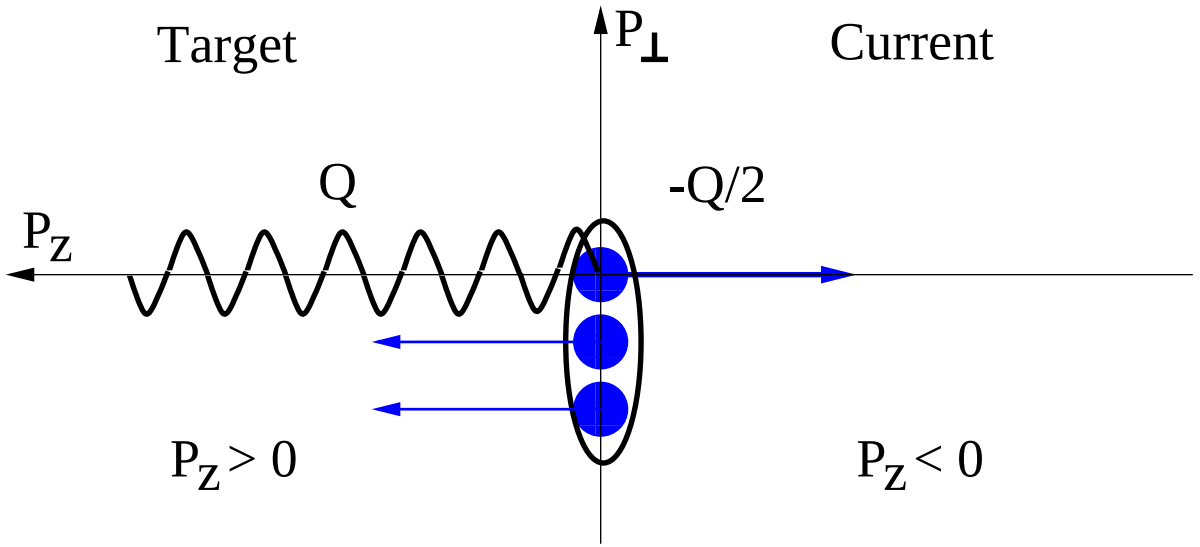
K^0_S and Λ Cross Sections in bins of p_T & η in Lab Frame



- **HERWIG** fails to reproduce shape of K^0_S and Λ cross sections in p_T
- Low p_T and Forward Regions: Indication of increased baryon to meson production compared to MC models
- What is going on in the proton direction?

Investigation in Breit frame necessary!

Breit Frame



- **Separates proton remnant and struck quark**
- **Scaled momentum spectrum:** $x_p = 2 \cdot p/Q \quad (p = |p|)$
- **Target Region** $(p_z > 0)$

  Maximum Remnant Momentum:

  $p = \frac{Q(1-x)}{2x} \Rightarrow x_p^{max} \approx \frac{1-x}{x} >> 1$

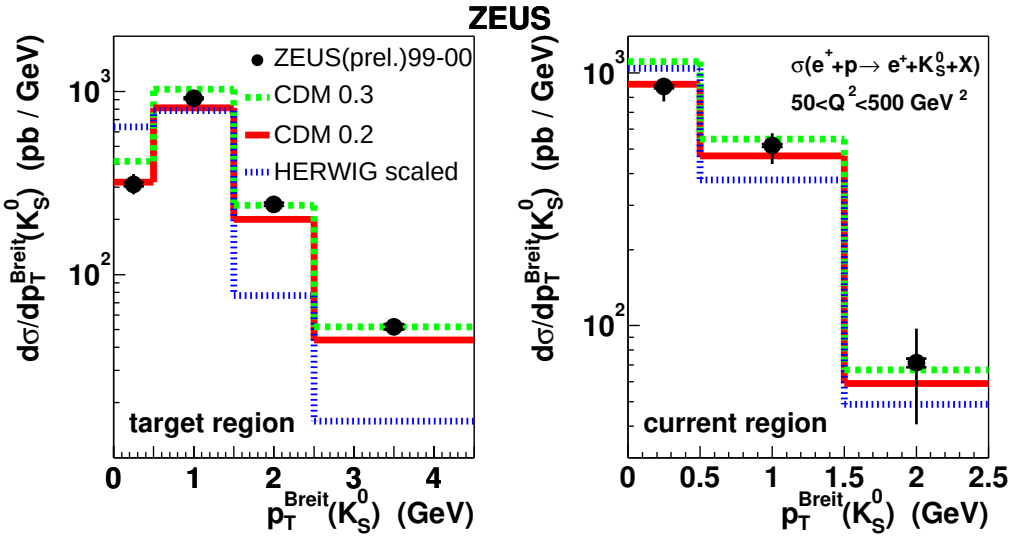
Current Region $(p_z < 0)$

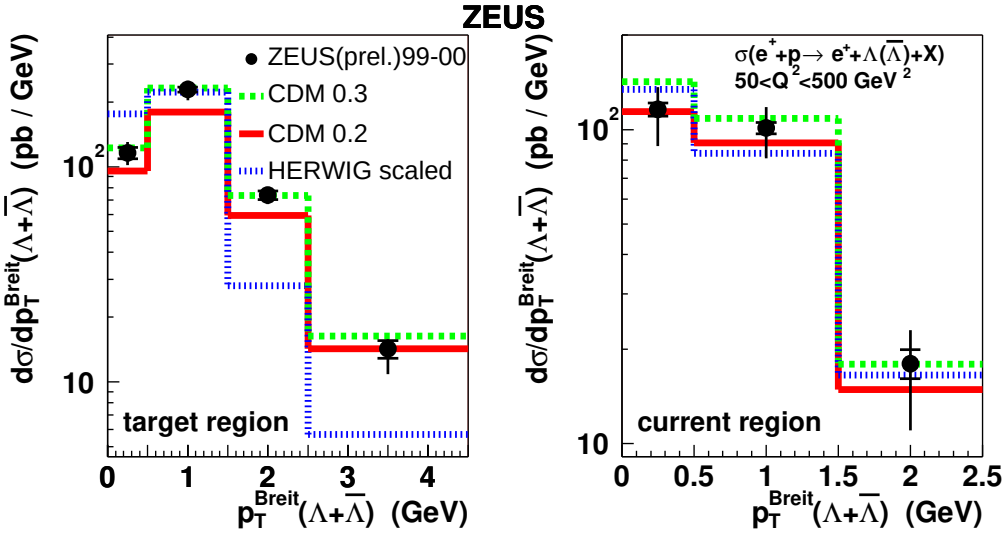
QPM model: $x_p(s) = \frac{2 \cdot p(s)}{Q} = 1$

Higher order QCD: $x_p(s) \leq 1$

$\star$ ep **current region analogous to single hemishpere of** e^+e^- **annihilation**

K^0_S, Λ Cross Sections in bins of $p_T^{\rm Breit}$ in Breit Frame

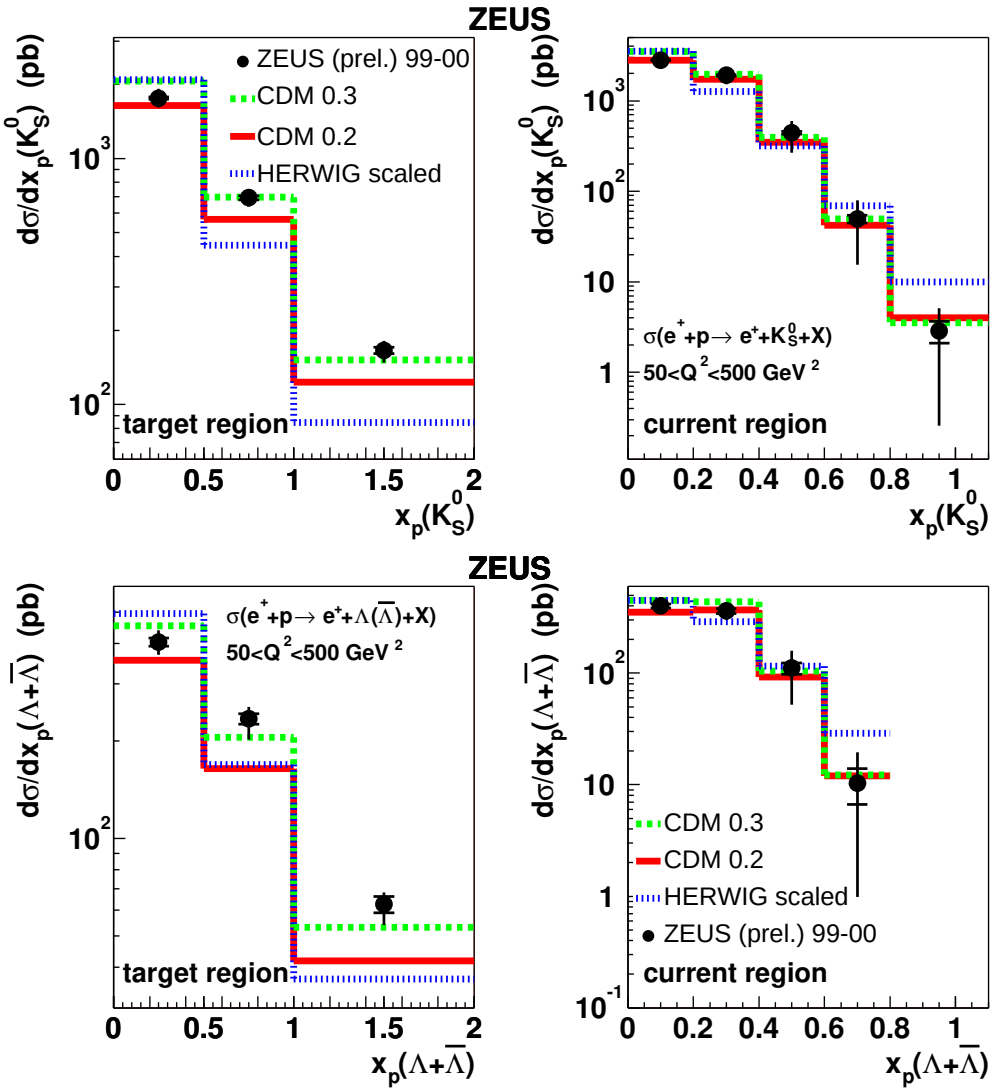




K^0_S:
Measurement moves toward CDM $\lambda_s = 0.3$ in target region

Λ:
Measurement in agreement with CDM $\lambda_s = 0.3$ in target region

K^0_S, Λ Cross Sections in bins of x_p in Breit Frame



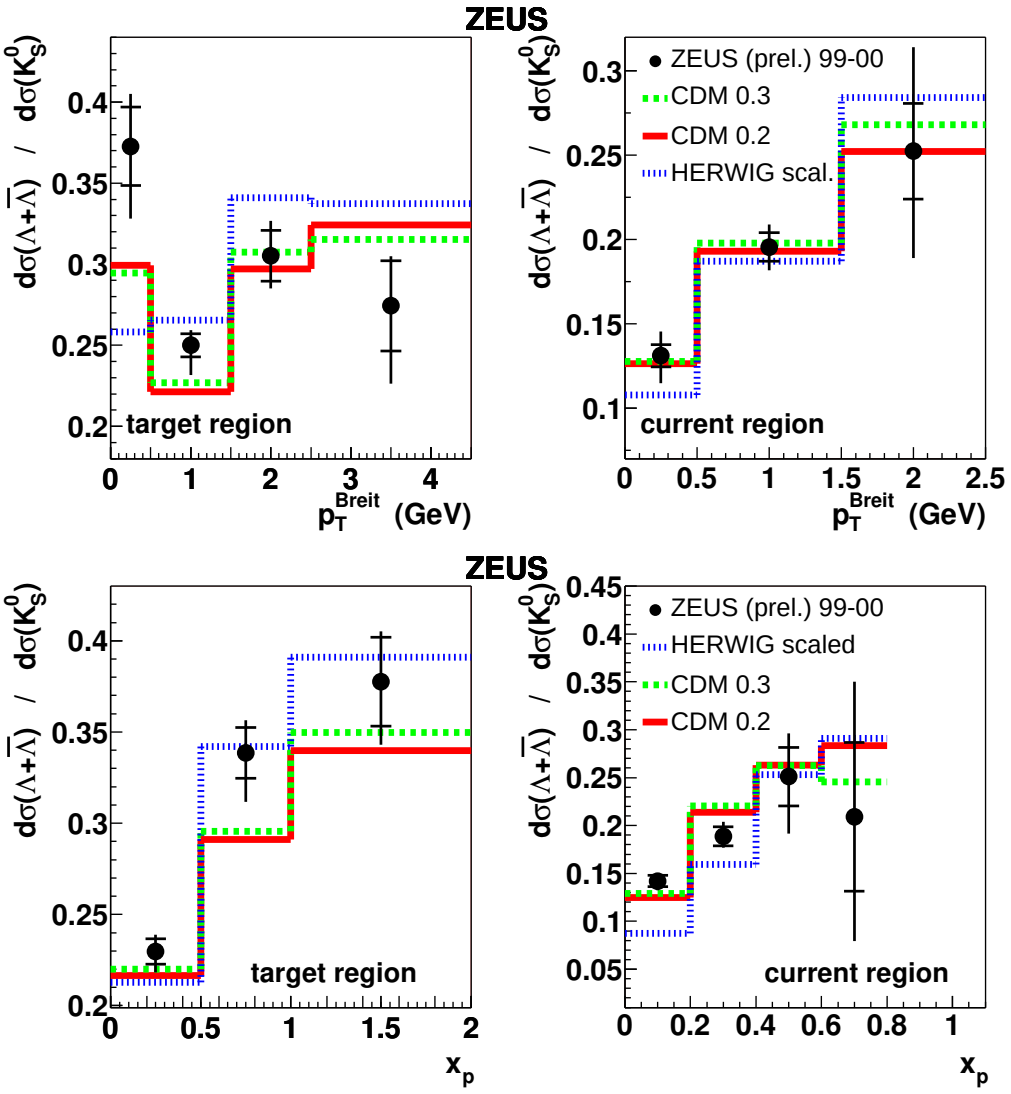
K^0_S, Λ: Same behaviour

- Bigger difference between CDM $\lambda_s = 0.2$ & $\lambda_s = 0.3$ in target region than in current region
- Measurement moves toward CDM $\lambda_s = 0.3$ in target region for K^0_S
- Measurement in agreement with CDM $\lambda_s = 0.3$ in target region for Λ, but maybe also different shape

Strangeness suppression related to gluon density in the proton remnant (target) region?

If the shapes of measurement and prediction differ in target region, would the relative baryon to meson shape be in agreement?

Ratio of Λ to K^0_S in bins of $p_T^{\rm Breit}$ & x_p



p_T

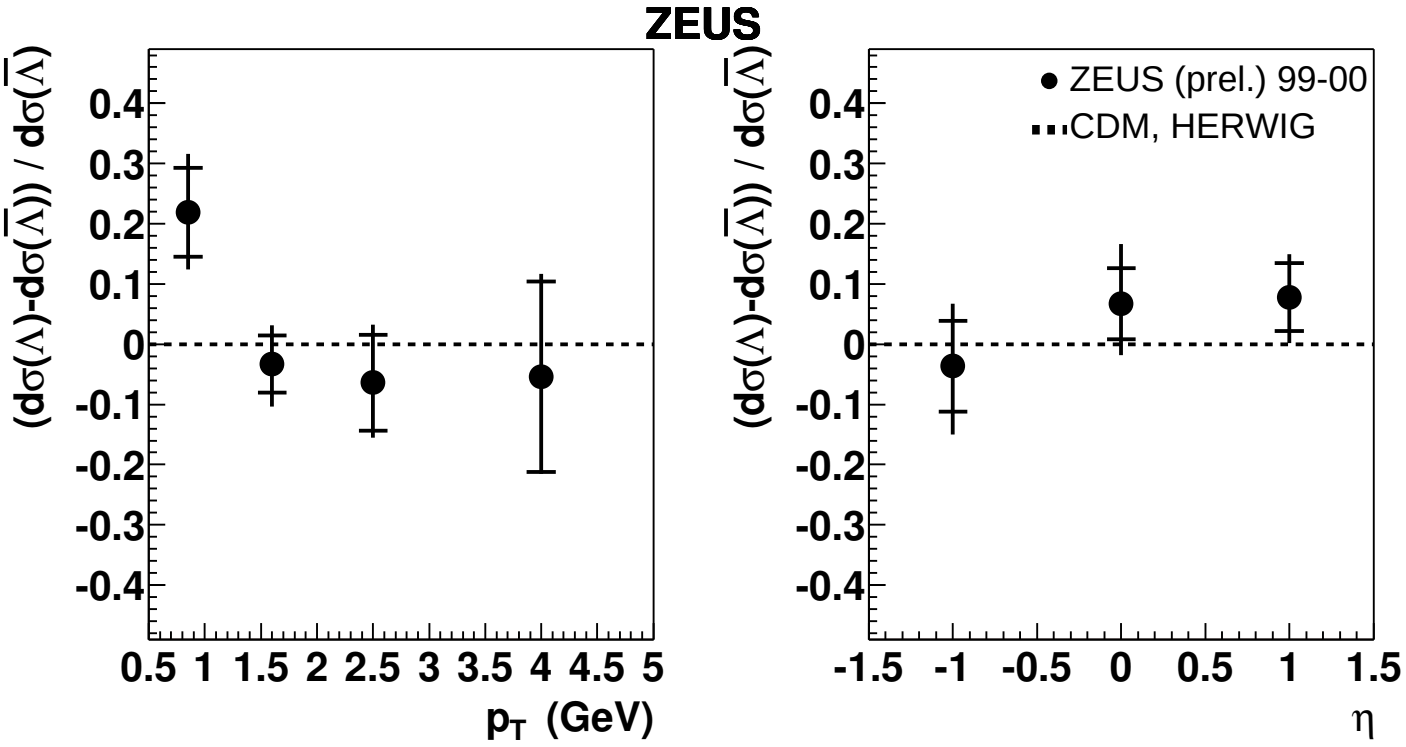
- **Current Region: Good agreement**
- **Target Region: Shape of ratio of Λ to K^0_S production not described for $p_T^{\rm Breit}$**

x_P

- **Current Region: Good agreement**
- **Target Region: Shape described, but overall ratio too low for Lund String Model**

Ratio of Λ to $\bar{\Lambda}$

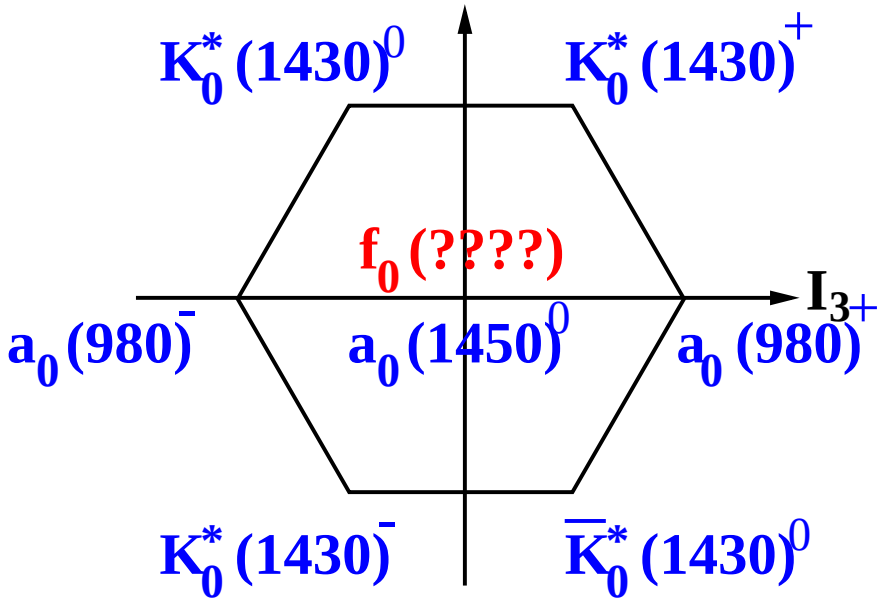
Total: $\sigma(\Lambda)/\sigma(\bar{\Lambda}) = 1.05 \pm 0.05^{+0.005}_{-0.05}$

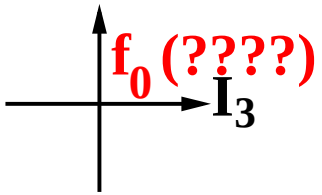


Equal Λ and $\bar{\Lambda}$ production is measured.

$K^0_S K^0_S$ Final States in DIS: Why?

- $K^0_S K^0_S$ **bound states** $\Rightarrow J^{PC}$: 0^{++} **(scalar);** 2^{++} **(tensor) . . .**





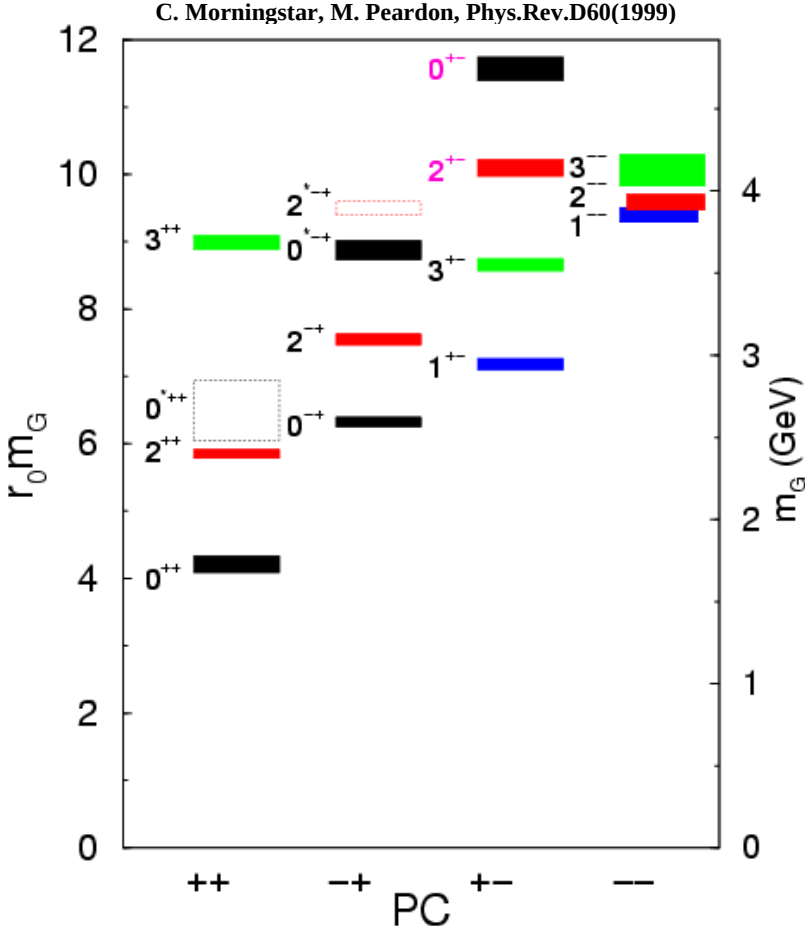
$\Rightarrow$ **Number of (I=0) scalar states observed exceeds the number accomodated by SM:** f_0**(980),** f_0**(1370),** f_0**(1500),** f_0**(1710)**

$K^0_S K^0_S$ Final States in DIS: Why? (contd.)

- $K^0_S K^0_S$ **Final States $\Rightarrow$ Radial Excitations or possible candidates for Glueballs?**

Lattice QCD predictions

C. Morningstar, M. Peardon, Phys.Rev.D60(1999)



Lightest glueball candidates:

$J^{PC} = 0^{++}$

$\Rightarrow$ **mass range: 1730 $\pm$ 100 MeV**

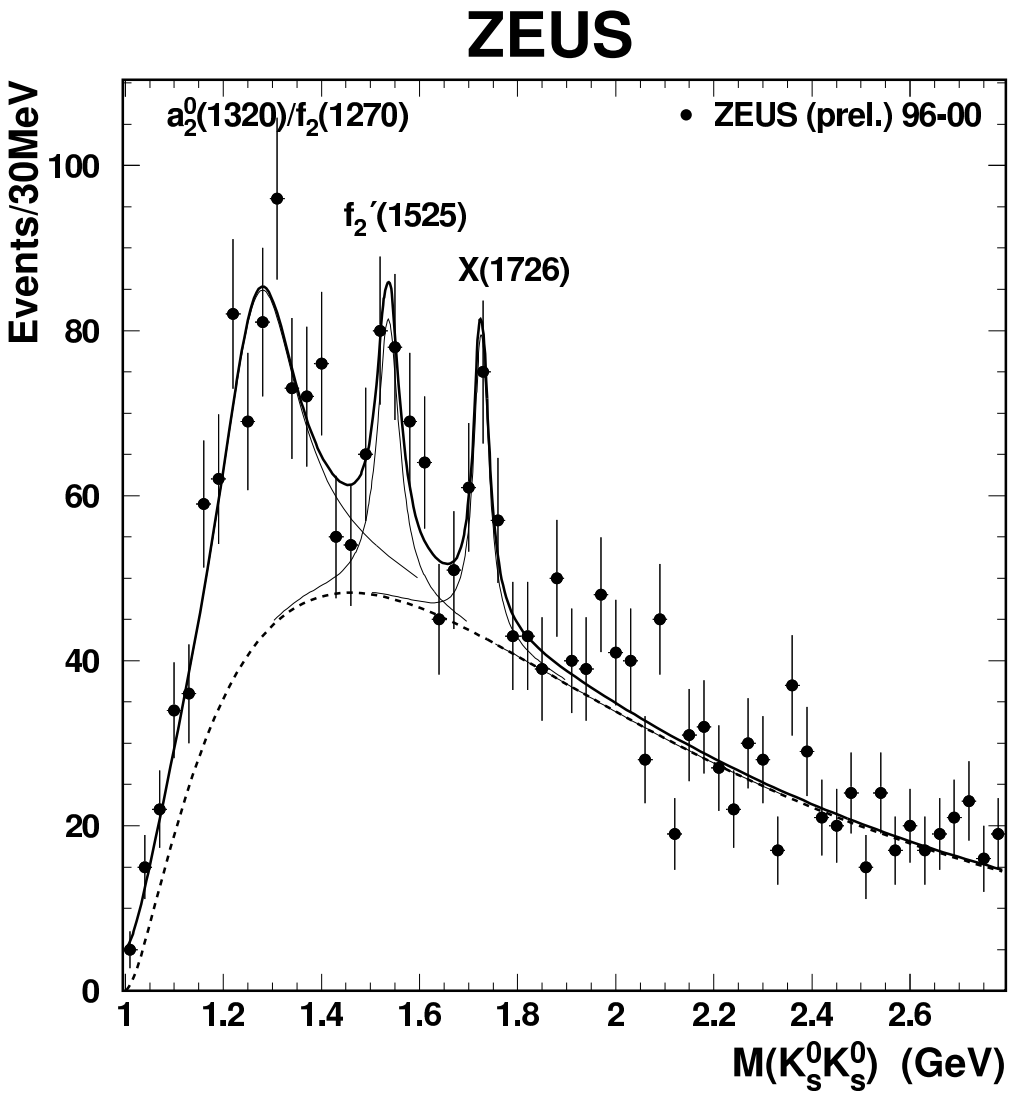
$J^{PC} = 2^{++}$

$\Rightarrow$ **mass range: 2400 $\pm$ 120 MeV**

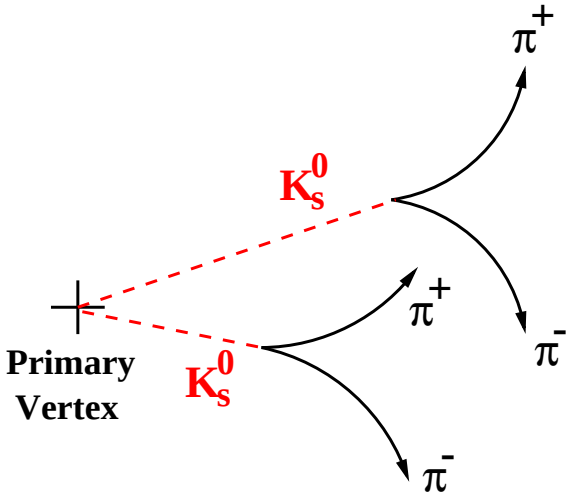
Primary glueball candidate:

f_0**(1710) (WA102 $\Rightarrow$ J=0)**

$K^0_S K^0_S$ Final States at HERA



$K^0_S K^0_S$ Reconstruction



Data Sample

ep ZEUS $\Rightarrow \mathcal{L} = 121\ \mathrm{pb}^{-1}$

Kinematic Region

$E_e > 8.5$ **GeV**, $0.04 \leq y \leq 0.95$,

$Q^2 \gtrsim 4$ **GeV**^{2}, **cos**$\theta_{K^0_S K^0_S} <$ **0.92**,

$p_T(K^0_S) > 200$ **MeV**

First observation, at an ep collider, of $K^0_S K^0_S$ final states: $f_2'(1525), X(1726)$

Conclusions

- **Measurement of total and differential K^0_S, Λ, $\bar{\Lambda}$ Cross Sections with high precision!**
- **Indication of excess of baryon to meson production in forward region**
- **HERWIG does not reproduce the shape of the kinematics of K^0_S and Λ production**
- **CDM with JETSET provides better description than HERWIG, but . . .**
  - **Apparent x_p and p_T^{Breit} dependent strangeness suppression in target region in Breit frame (clear for K^0_S, hint for Λ)**
  - **Ratio of baryon to meson production in p_T^{Breit} possibly not well described**
- **Measurement shows equal production of Λ and $\bar{\Lambda}$**
- **First observation, at an ep collider, of $K^0_S K^0_S$ states at masses of 1525 MeV and 1726 MeV**