Hamburg University
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St. Petersburg, Russia

Strange Particle Production in DIS at HERA

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- 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: Why Strange Particle Production?

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

  → **Strangeness Supression Factor λ_s= P(s)/P(d); P(d) = P(u)**

  → **LEP $\lambda_s = 0.3$; HERA $\lambda_s \approx 0.2$ (K^0, Λ and ϕ(1020))**
- **Are there any differences between strange baryon and anti-baryon production?**

Strange Quark Production in DIS & Fragmentation to Hadrons

Inclusive Deep Inelastic Scattering at HERA:

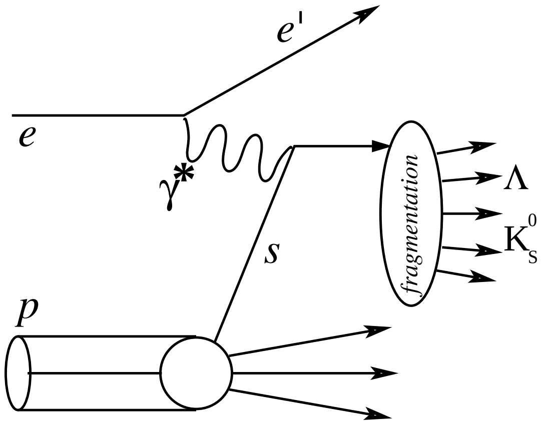
$ep \longrightarrow e'X$

Kinematics of DIS:

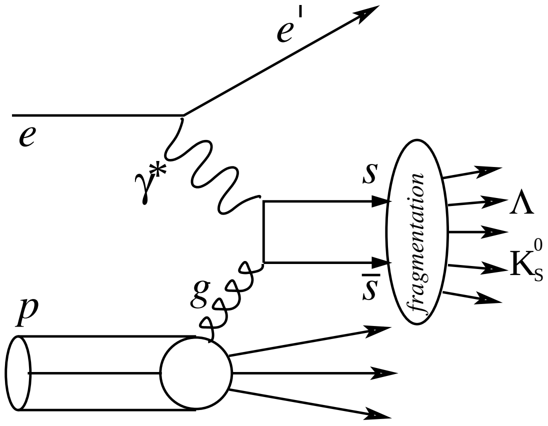
$q = e - e' \qquad Q^2 = -q^2 = sxy$

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

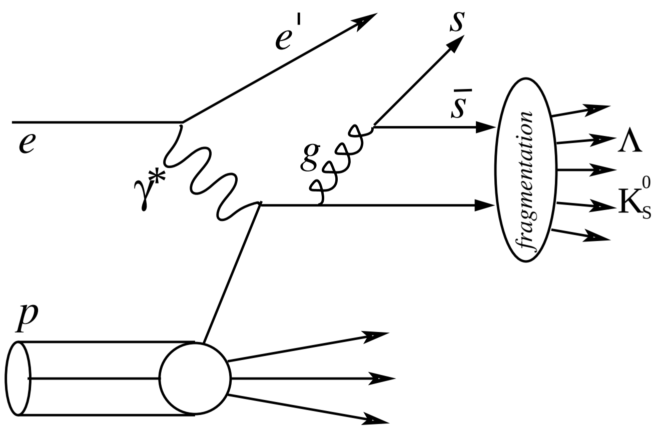
Possible Mechanisms of Strange Quark Production:



Flavour Excitation



Boson-Gluon Fusion



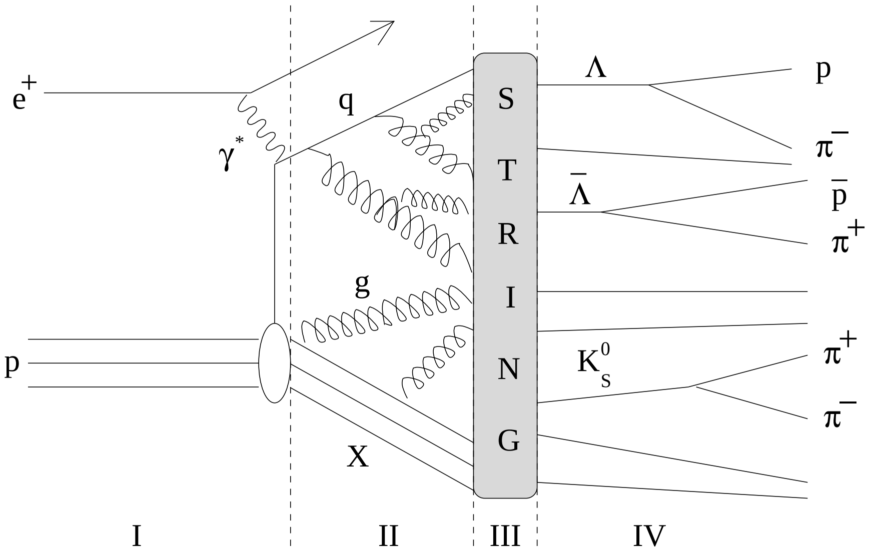
Gluon-Splitting

Models of Fragmentation in Strange DIS

ARIADNE plus JETSET

- QCD cascade as described by the Color Dipole Model (CDM)
- Parton cascade fragments to hadrons as per the Lund String Model
- Final state hadrons (which can be reconstructed)

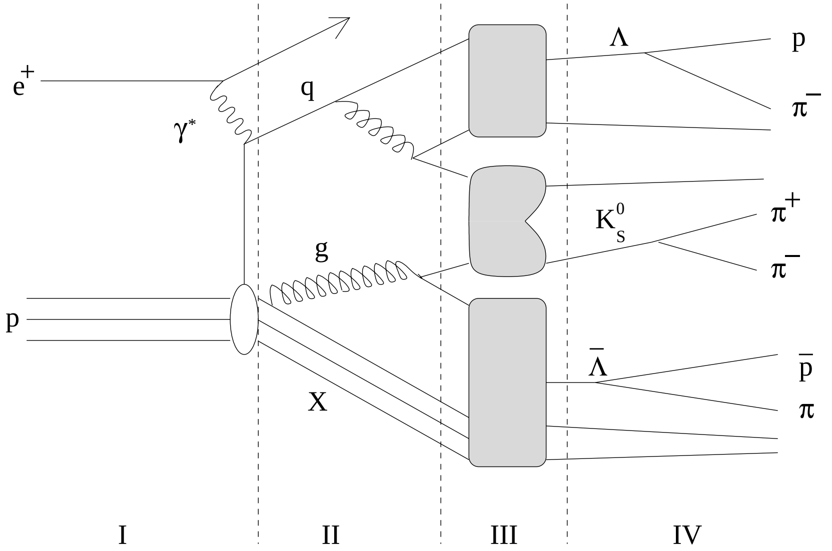
Event Generated by ARIADNE plus JETSET



HERWIG

- $q\bar{q}$ pairs created from break up of colour dipoles
- Parton cascade fragments to hadrons as per Cluster Fragmentation Model
- Final state hadrons (which can be reconstructed)

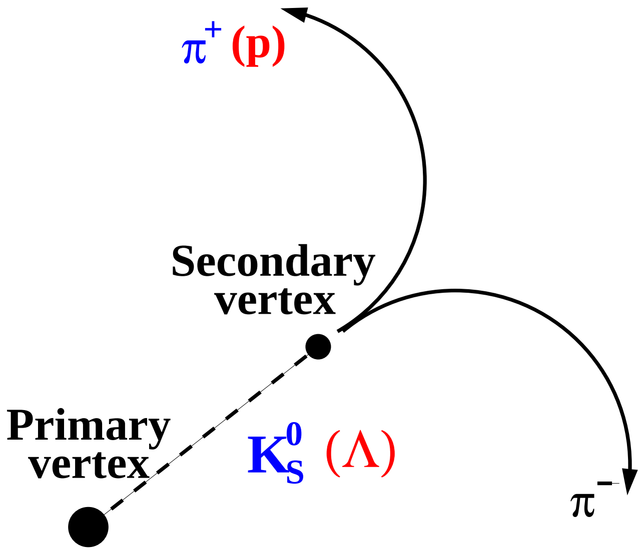
Event Generated by HERWIG



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**

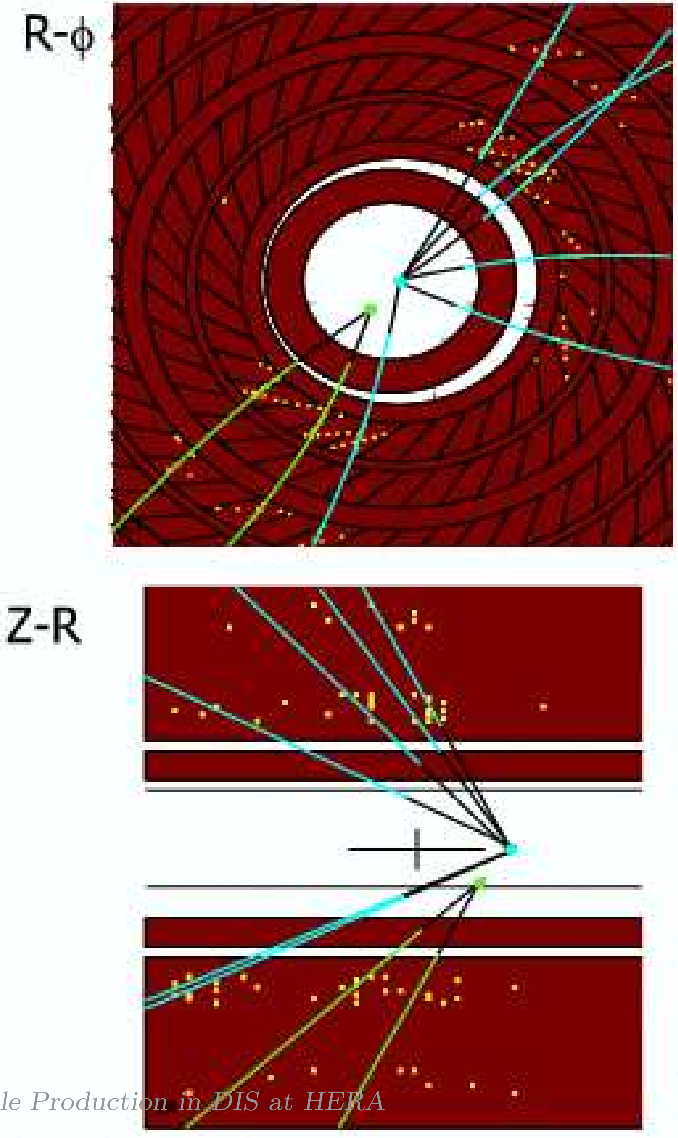
$\Rightarrow \mathcal{L} = 60\ \text{pb}^{-1}$

DIS Kinematic Region:

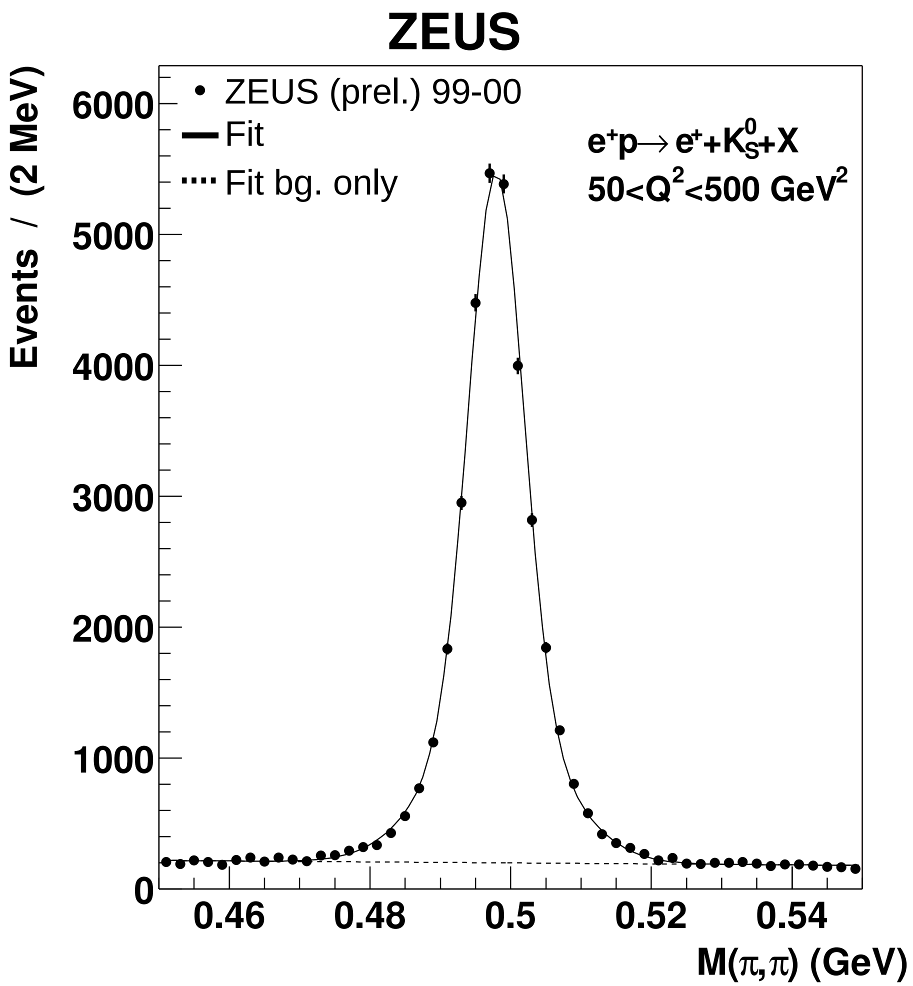
- $50 < Q^2 < 500\ \text{GeV}^2$
- $3 \cdot 10^{-4} < x < 10^{-1}$

K^0_S, Λ Kinematic Region:

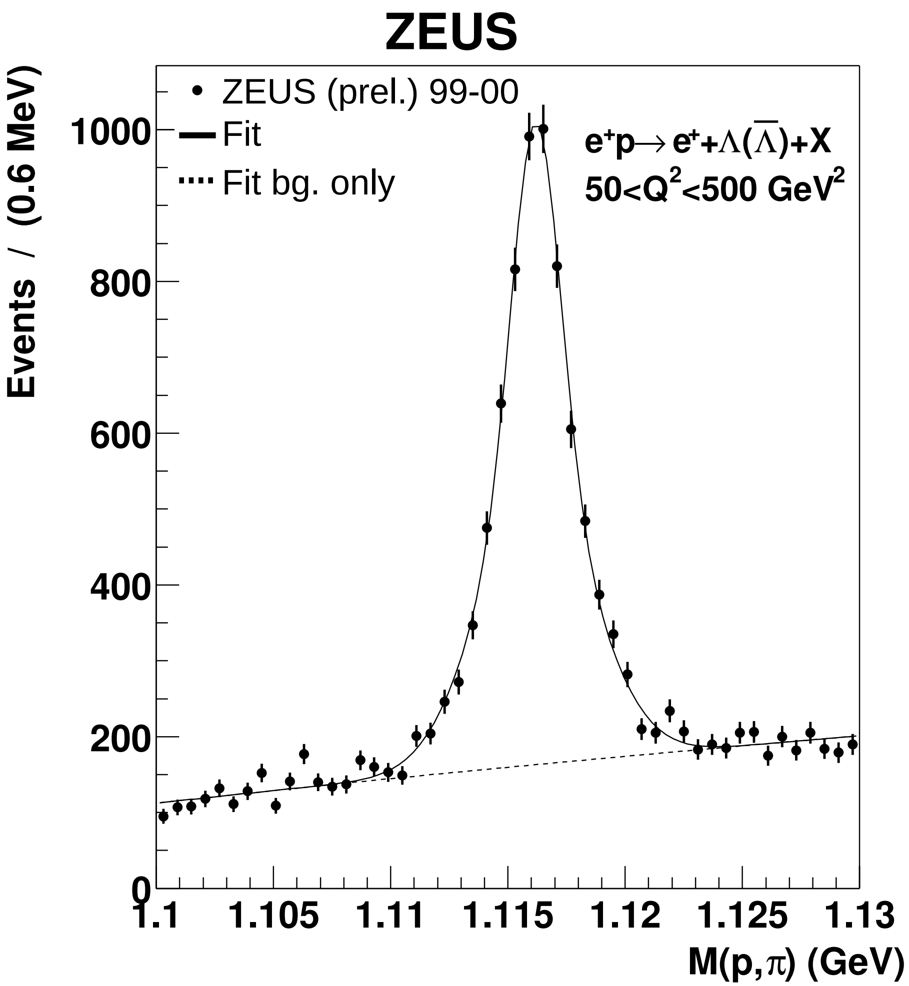
- $0.5 < p_T(K^0_S, \Lambda) < 5.0\ \text{GeV}$
- $|\eta(K^0_S, \Lambda)| < 1.5$



K_S^0, Λ Signal



K_S^0

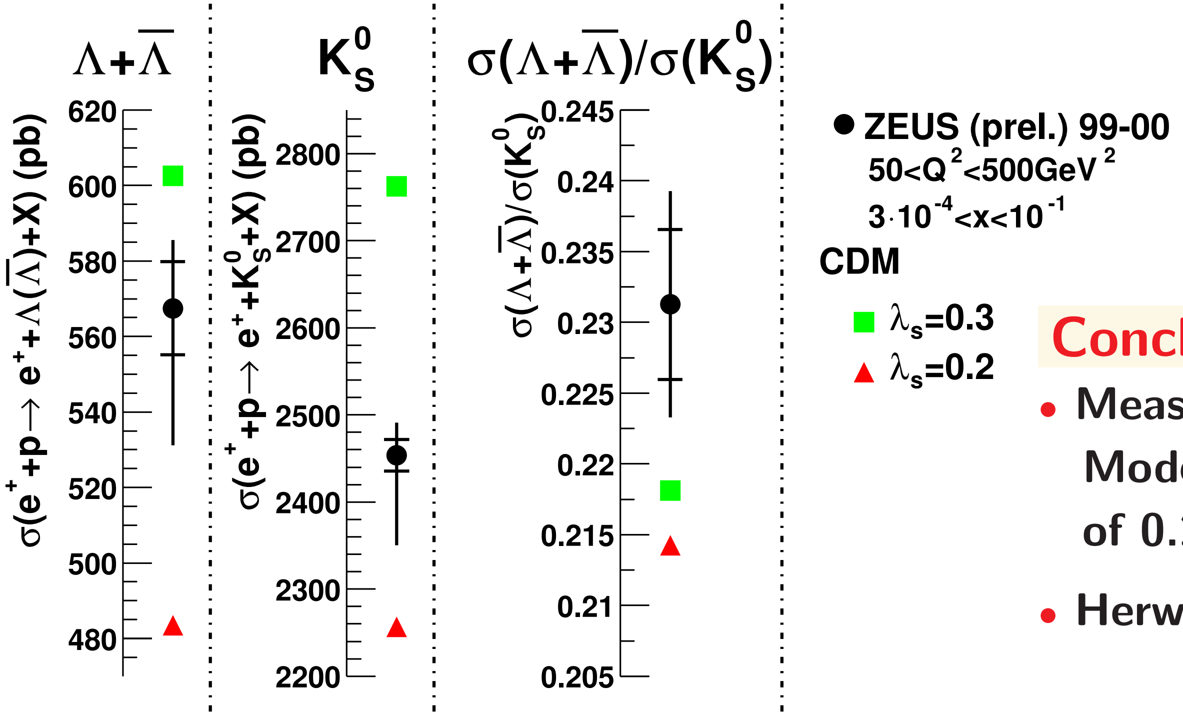


$\Lambda + \bar{\Lambda}$

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

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

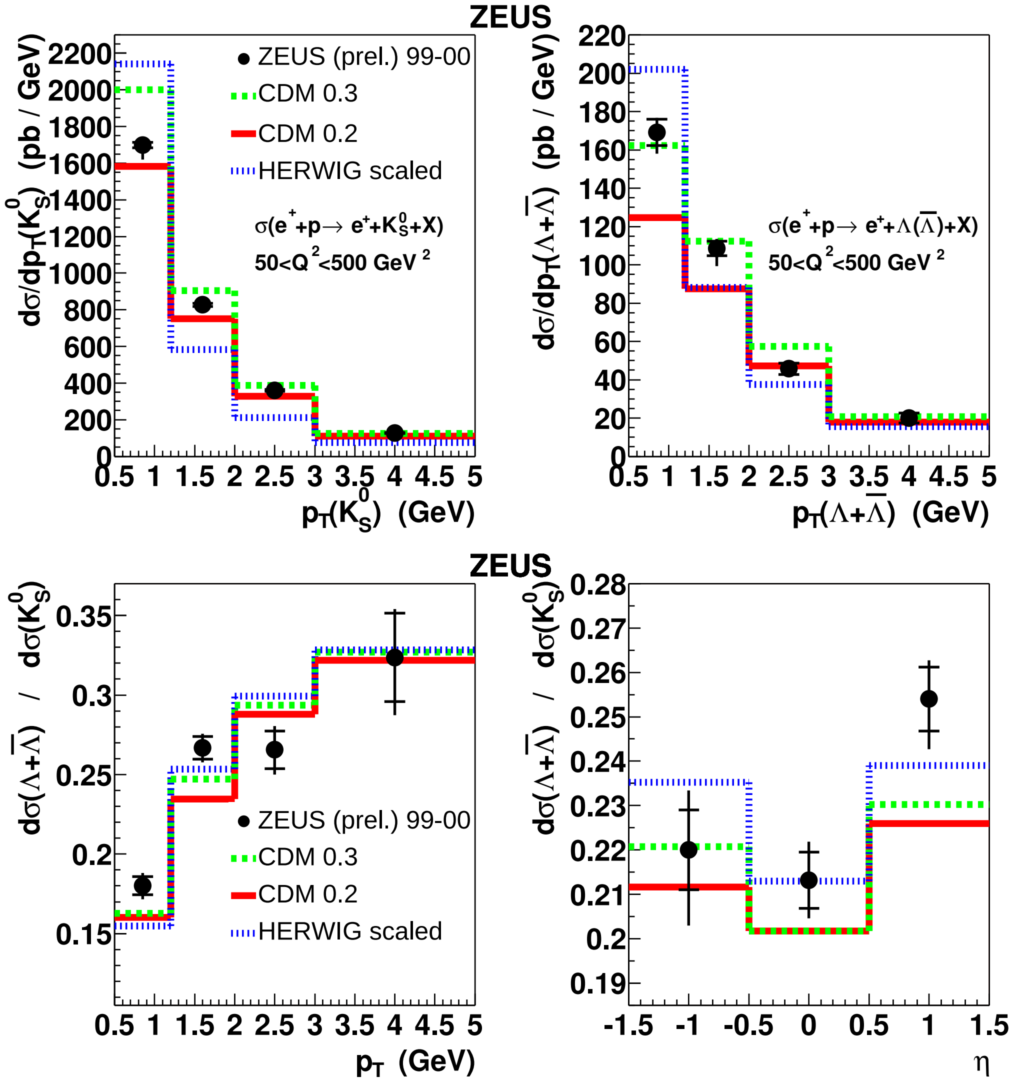
	$\sigma(K_S^0)$ **[pb]**	$\sigma(\Lambda+\bar{\Lambda})$ **[pb]**	$\sigma(\Lambda+\bar{\Lambda})/\sigma(K_S^0)$	$\sigma(\Lambda)$ **[pb]**	$\sigma(\bar{\Lambda})$ **[pb]**	$\sigma(\Lambda)/\sigma(\bar{\Lambda})$
ZEUS (prel.)	$2454 \pm 18^{+32}_{-102}$	$567 \pm 12^{+13}_{-34}$	$0.231 \pm 0.005^{+0.005}_{-0.006}$	$292 \pm 9^{+7}_{-18}$	$279 \pm 9^{+12}_{-18}$	$1.05 \pm 0.05^{+0.05}_{-0.05}$
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**



Conclusion:

- **Measurement falls between Lund String Model strangeness suppression factor, λ_s, of 0.2 and 0.3**
- **Herwig fails to predict total cross sections**

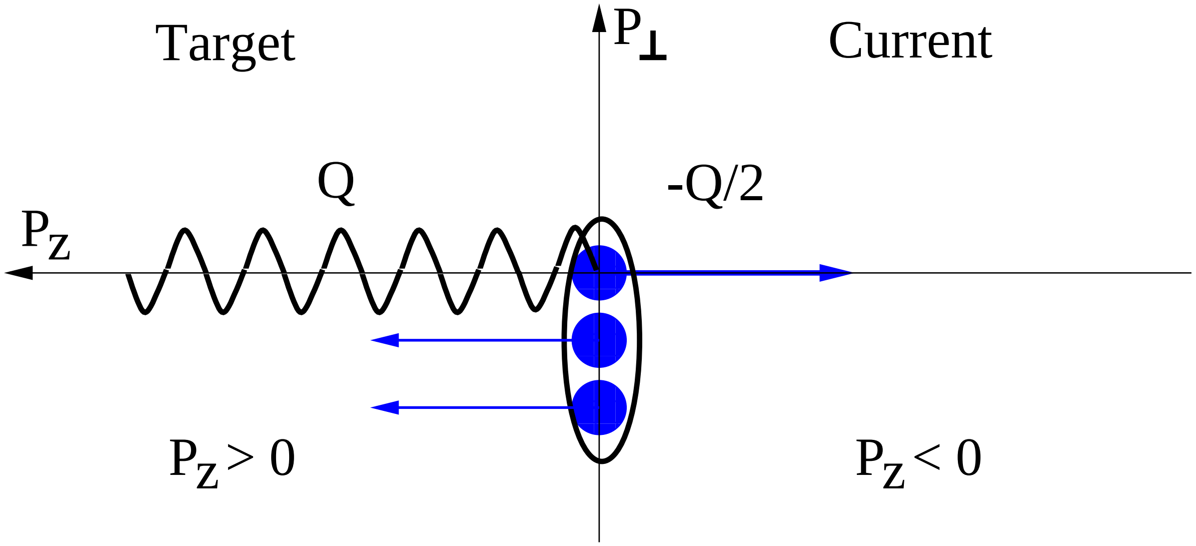
K_S^0 and Λ Cross Sections in bins of p_T & η in Lab Frame



- **HERWIG** fails to reproduce shape of K_S^0 and Λ cross sections in p_T
- Indication of increased baryon to meson production in the forward region and for low p_T 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:** $x_p = 2 \cdot p/Q$ **(**$p = |p|$**)**
- **Target Region (**$p_z > 0$**)**

  Maximum Remnant Momentum:

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

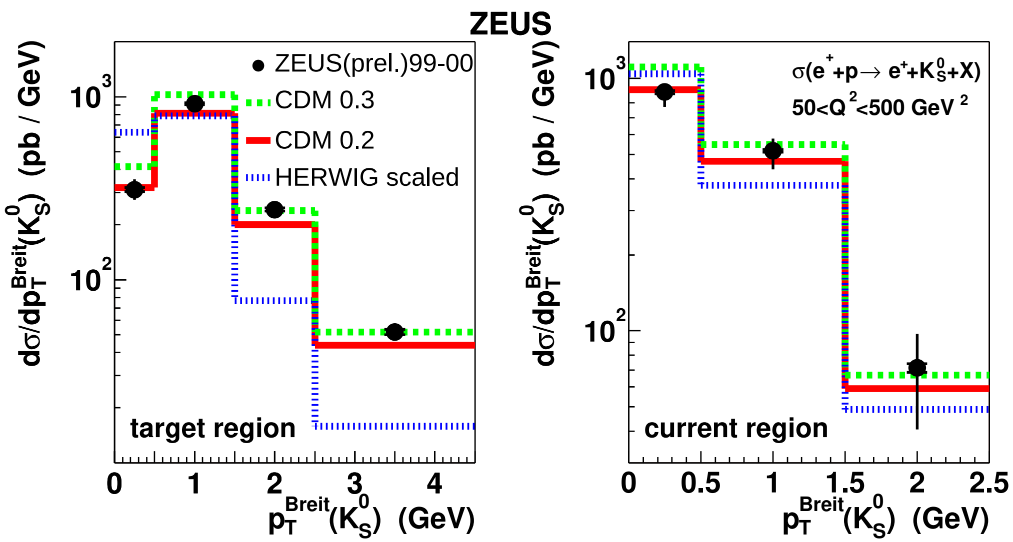
Current Region ($p_z < 0$**)**

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

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

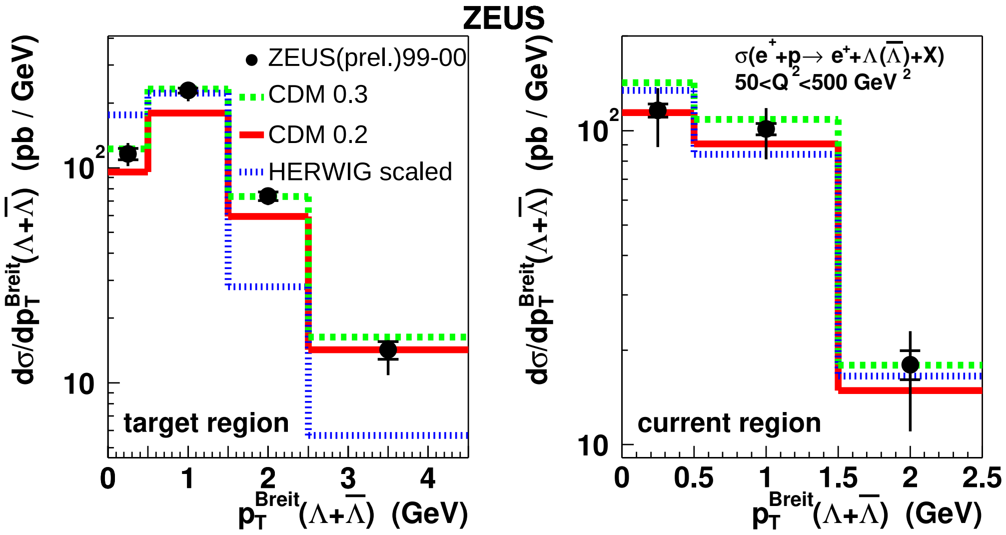
⋆ ep **current region analogous to single hemishpere of** e^+e^- **annihilation**

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



K_S^0:

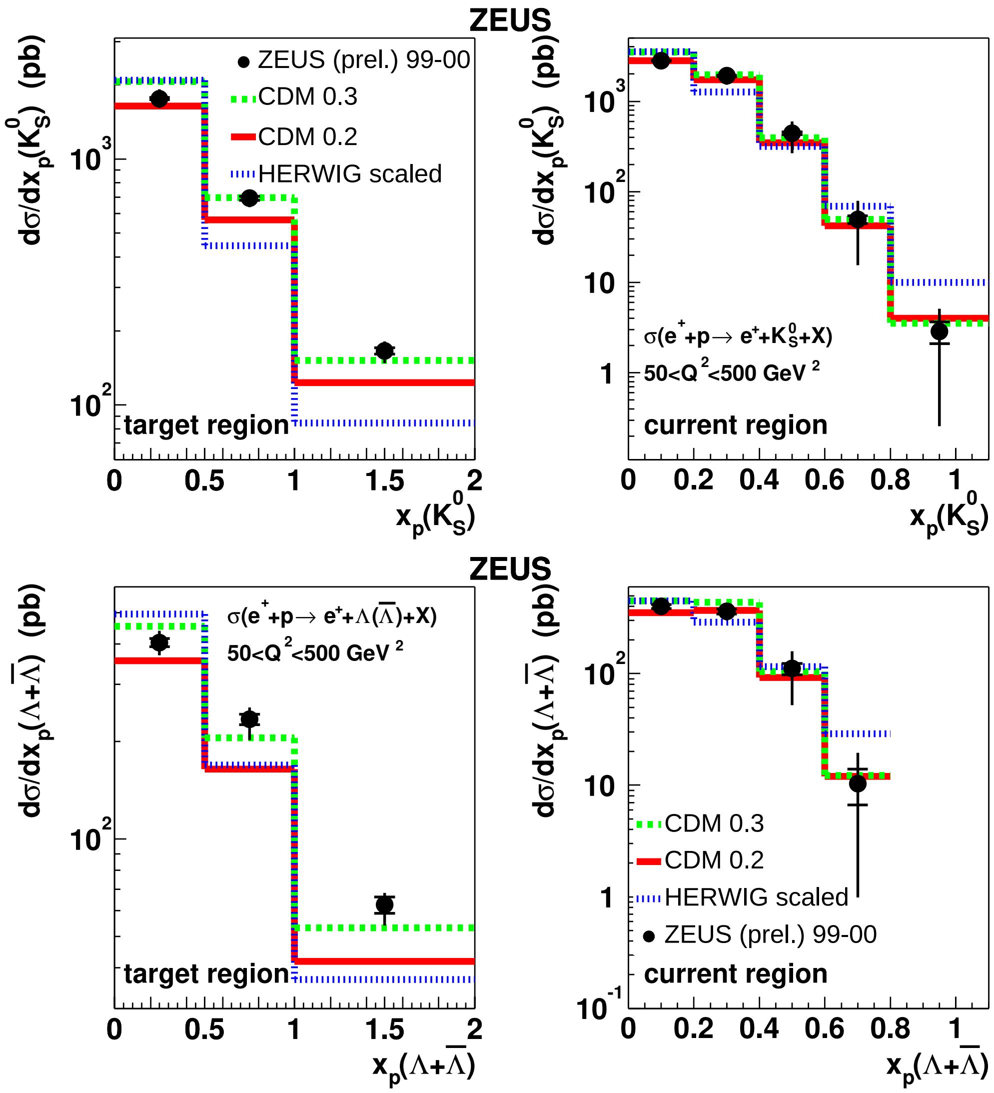
Measurement moves toward CDM $\lambda_s = 0.3$ in target region



Λ:

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

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



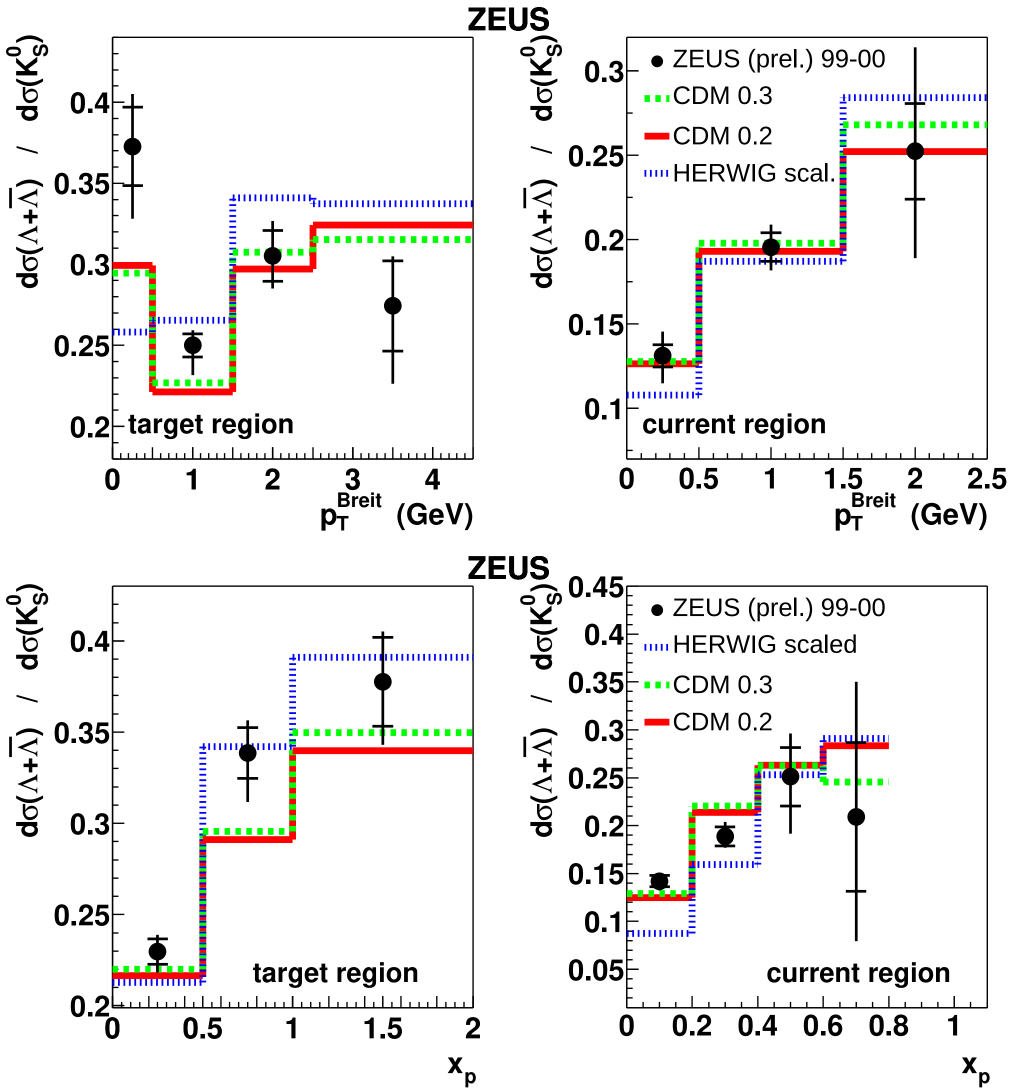
K_S^0, Λ: Same behaviour

- 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_S^0
- Measurement in agreement with CDM $\lambda_s = 0.3$ in target region for Λ, but maybe also different shape

Is 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?

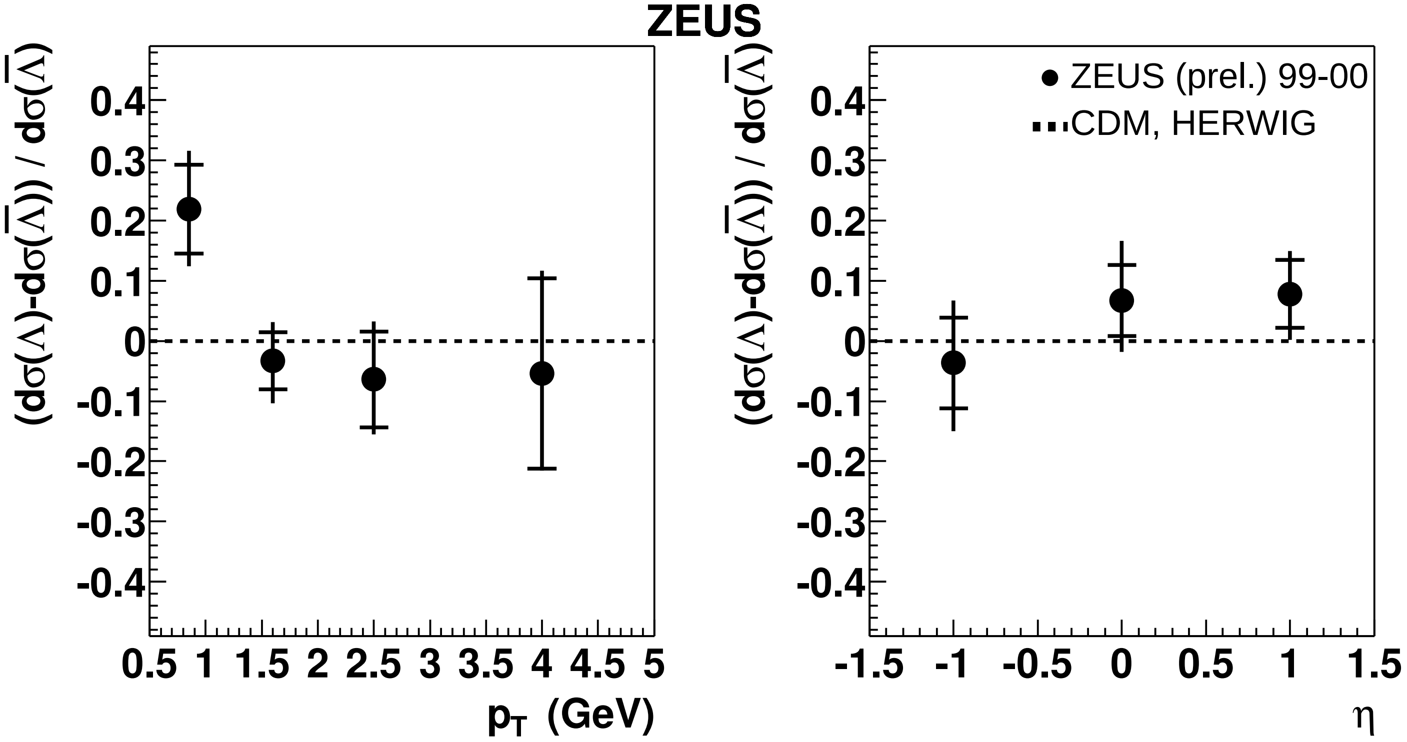
Ratio of Λ to K_S^0 in bins of p_T^{Breit} & x_p



- **Good agreement in current region**
- **Shape of ratio of Λ to K_S^0 production not described for p_T^{Breit} in target region**
- **Shape for x_P described, but overal ratio too low for Lund Model**

Ratio of Λ to $\bar{\Lambda}$

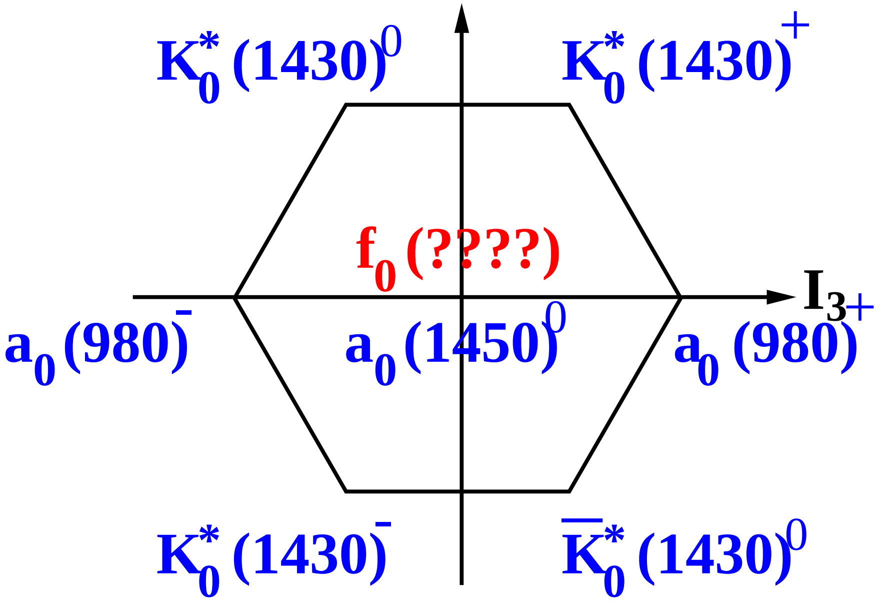
Total: $\sigma(\Lambda)/\sigma(\bar{\Lambda}) = 1.05 \pm 0.05^{+0.005}_{-0.05}$

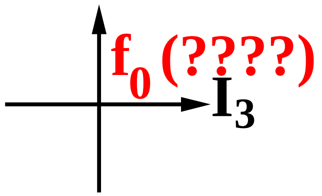


Equal Λ and $\bar{\Lambda}$ production is measured.

$K_S^0 K_S^0$ Final States in DIS: Why?

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





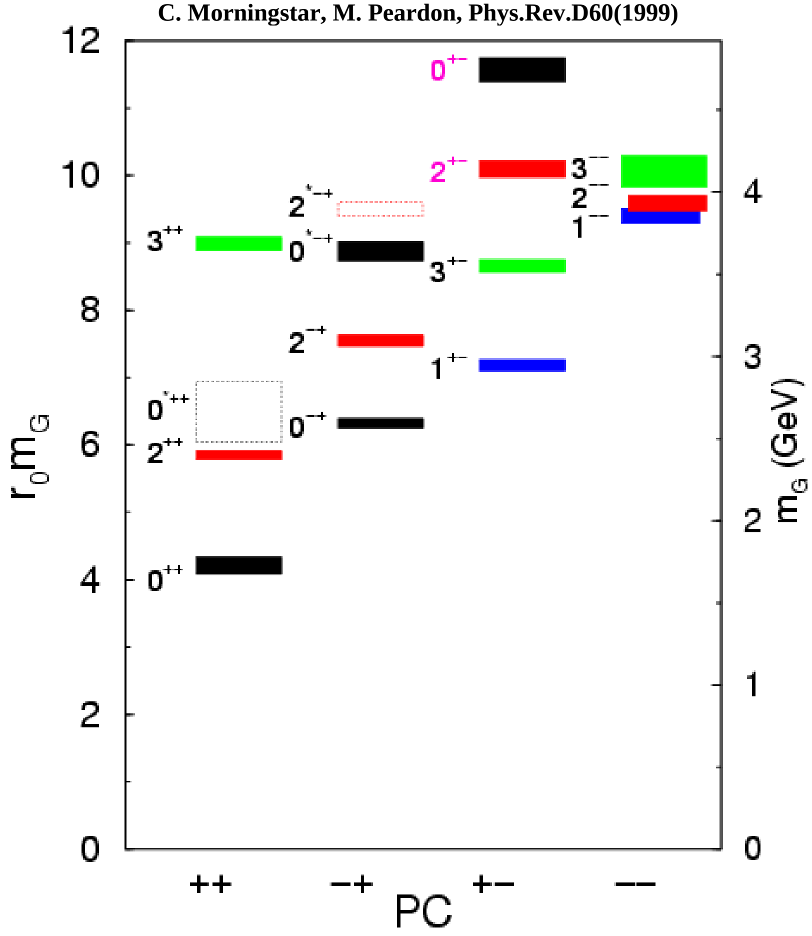
$\Rightarrow$ **Number of (I=0) scalar states observed exceeds the number accomodated by SM: f_0(980), f_0(1370), f_0(1500), f_0(1710)**

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

- $K_S^0 K_S^0$ **Final States ⇒ Radial Excitations or possible candidates for Glueballs?**

Lattice QCD predictions

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



Lightest glueball candidates:

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

⇒ **mass range: 1730 ± 100 MeV**

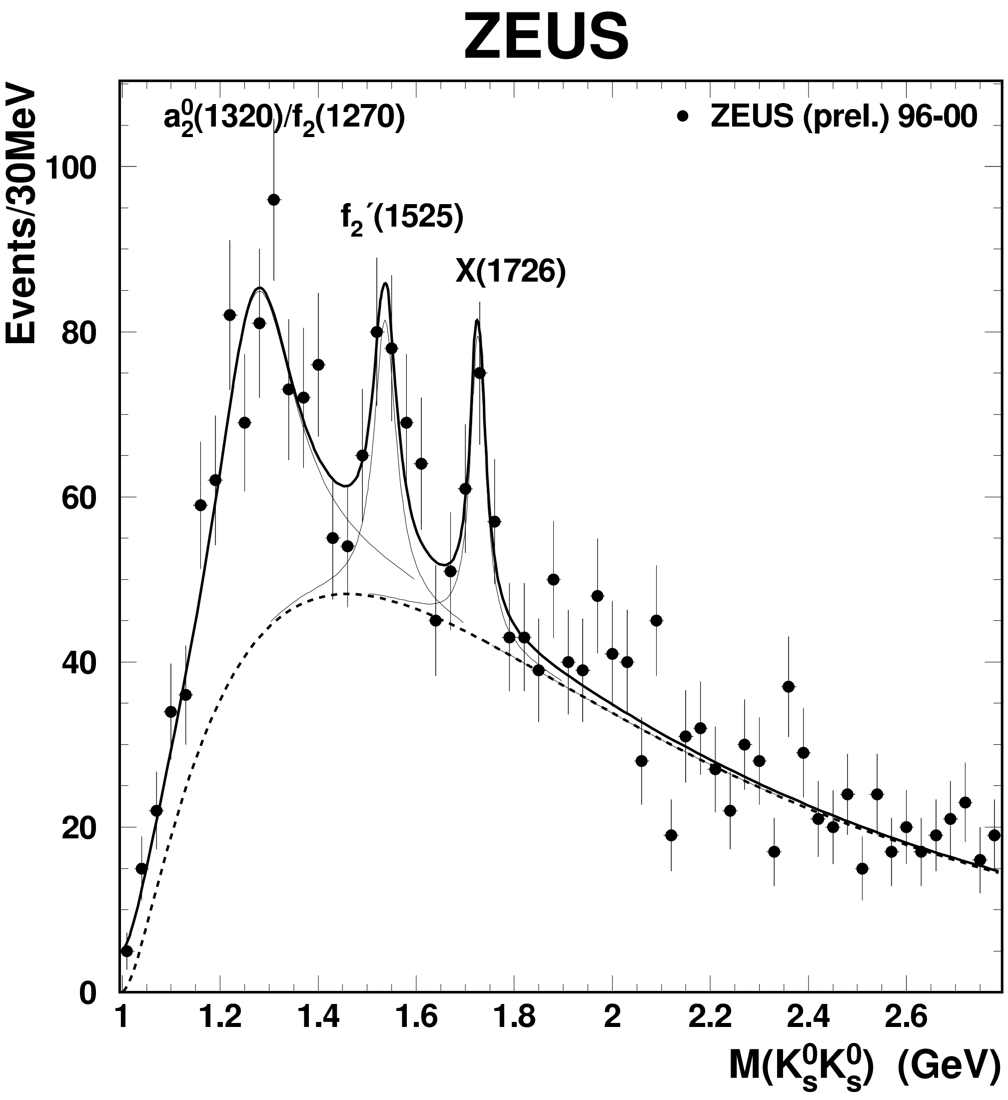
$J^{PC} = 2^{++}$

⇒ **mass range: 2400 ± 120 MeV**

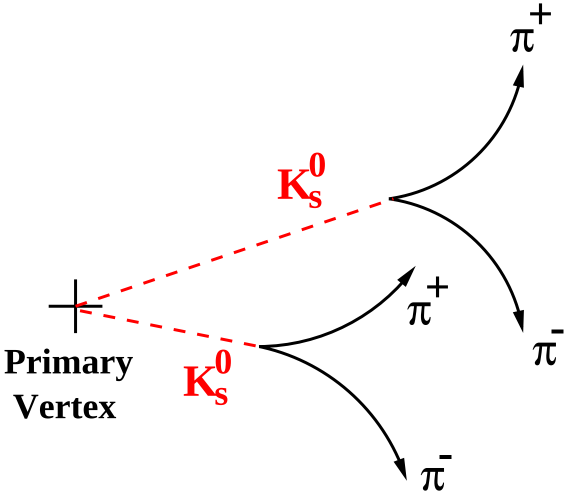
Primary glueball candidate:

f_0**(1710) (WA102 ⇒ J=0)**

$K_S^0 K_S^0$ Final States at HERA



$K_S^0 K_S^0$ 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**$\theta_{K_S^0 K_S^0} <$ **0.92**,

$p_T(K_S^0) > 200$ **MeV**

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

Conclusions

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