Strange particle production at HERA

Stewart Boogert, Oxford University & ZEUS collaboration
DIS2002, Krakow - Poland

Talk outline

K_S^0 and Λ production in dijet photoproduction

Introduction

Photoproduction at HERA

K_S^0 and Λ identification

Measurement definition

K_S^0 production cross sections

Λ and $\bar{\Lambda}$ production cross sections

ϕ(1020) production in DIS

Mechanisms of phi production

Differential cross sections

Hard QCD contributions

ϕ(1020) in the Breit frame

Conclusions

Introduction

- After pions strange particles are the most copiously produced hadrons at HERA
  - Strange hadron production, particularly baryons, is not known to be well described by leading order Monte Carlo simulations
  - Is strange particle fragmentation universal? Is the production of strange particles correct in the current generations of Monte Carlo generators, e.g. HERWIG and PYTHIA?
  - String models: Strangeness suppression factor $\lambda_S = p_s / p_{u,d}$
  - Are there any differences between strange hadron and anti-hadron production?
  - Strange particle production measurements at HERA lags behind those of LEP and heavy flavours at HERA
- Requiring a strange containing particle enhances the contribution from strange from the proton (or photon).
  - Possibilities of constraining strange sea of the proton (ϕ mesons in DIS)

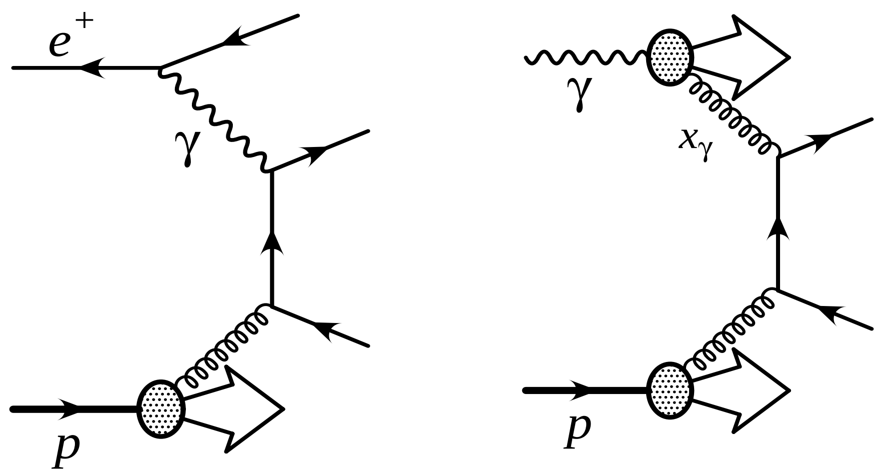
Photoproduction at HERA

- Deep inelastic scattering kinematics

$$q = k - k' \qquad Q^2 = -q^2$$

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

- Photoproduction kinematics
  - Q^2 can no longer used to define the scale of the hard scatter instead the transverse energy of the jets is used
- Direct : photon couples directly to the hard sub-process
- Resolved : photon acts an extended source of partons



- Definition of x_γ^{obs} $$x_\gamma^{obs} = \frac{\sum_{jet} E_T^{jet} e^{-\eta^{jet}}}{2yE_e}$$

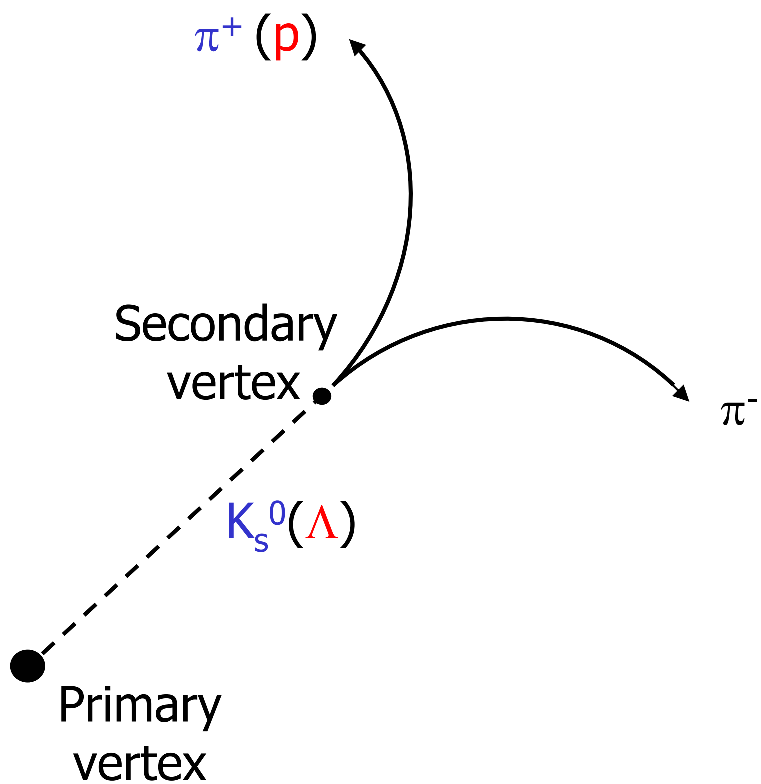
Strange particle identification

- Strange selection
  - Identify events with a well separated secondary vertex
  - Pair of tracks with opposite charge.

Particle	Mass/ GeV	Lifetime/ 10^{-8} s	**Decay length/ cm**	J^P	Main decay
K_S	0.497	0.89	**2.68**	0^-	$\pi^+\pi^-$
Λ	1.112	2.63	**7.89**	$½^+$	$p^+\pi^-$

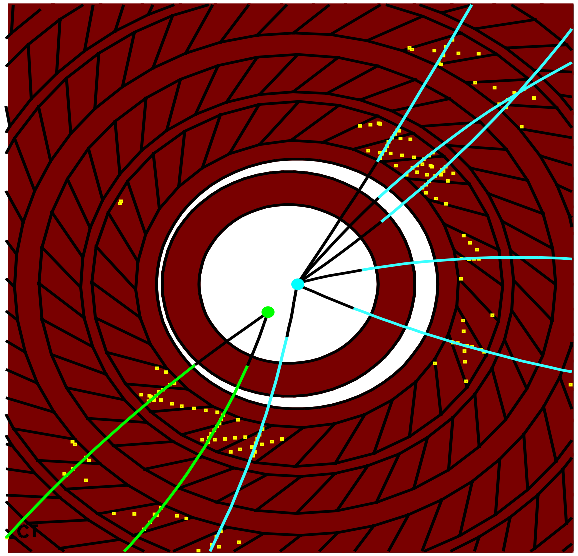
- Backgrounds
  - Photon conversions
    $\Rightarrow$ easily removed with a mass cut
  - Combinatorial
    $\Rightarrow$ background subtract

- $\Lambda/\bar{\Lambda}$ separation
  - Assume highest momentum track is the proton
    - $+ve \Rightarrow \Lambda$
    - $-ve \Rightarrow \bar{\Lambda}$

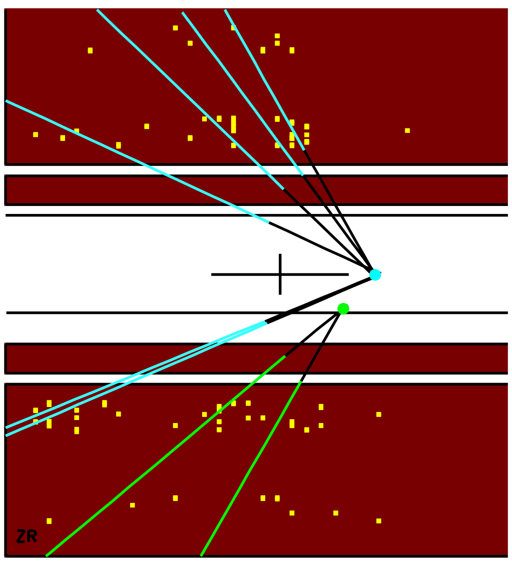


Measurement definition

R-ϕ

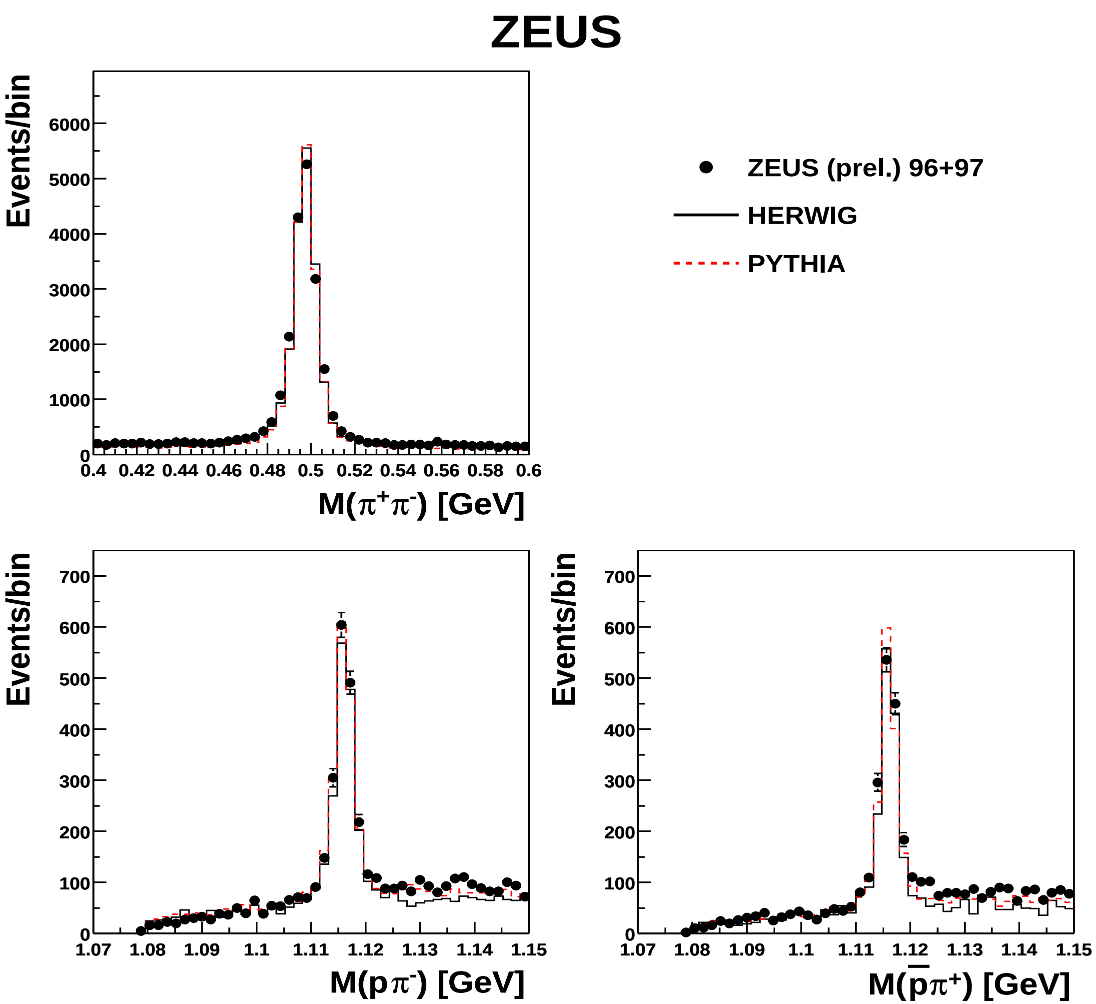


Z-R



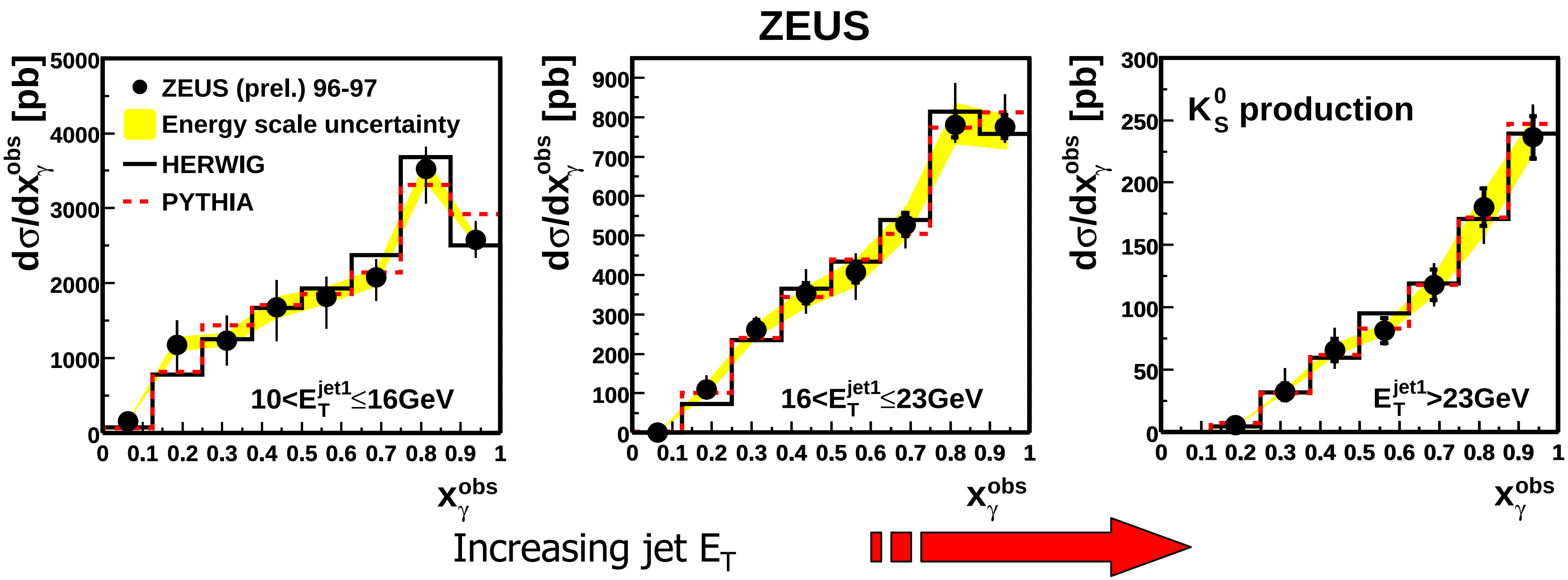
- Photoproduction
  - $Q^2 < 1$ GeV^2 $\langle Q^2 \rangle \sim 3.10^{-4}$ GeV^2
  - $0.2 < y < 0.8$
- Dijet (defined using K_T algorithm)
  - E_T(jet 1, 2) > 10, 9 GeV
  - $|\eta(\text{jet})| < 2$
- Strange particle kinematic region
  - p_T(hadron) > 0.3 GeV
  - $|\eta(\text{hadron})| < 1.5$
- Measure differentially in jet transverse energy
  - K_S: E_T(jet 1) > 10, 16, 23 GeV
  - Λ : E_T(jet 1) > 10, 18 GeV

Strange particle signals



- Clear signals for K_S, Λ and $\overline{\Lambda}$
- K_S
  - Large statistics
  - Low background
  - K_S signal and background reasonably described by Monte Carlo models
- Λ ($\overline{\Lambda}$)
  - Clean low background signal, but significantly lower statistics than K_S
  - Background is not so well described by Monte Carlo models at high mass

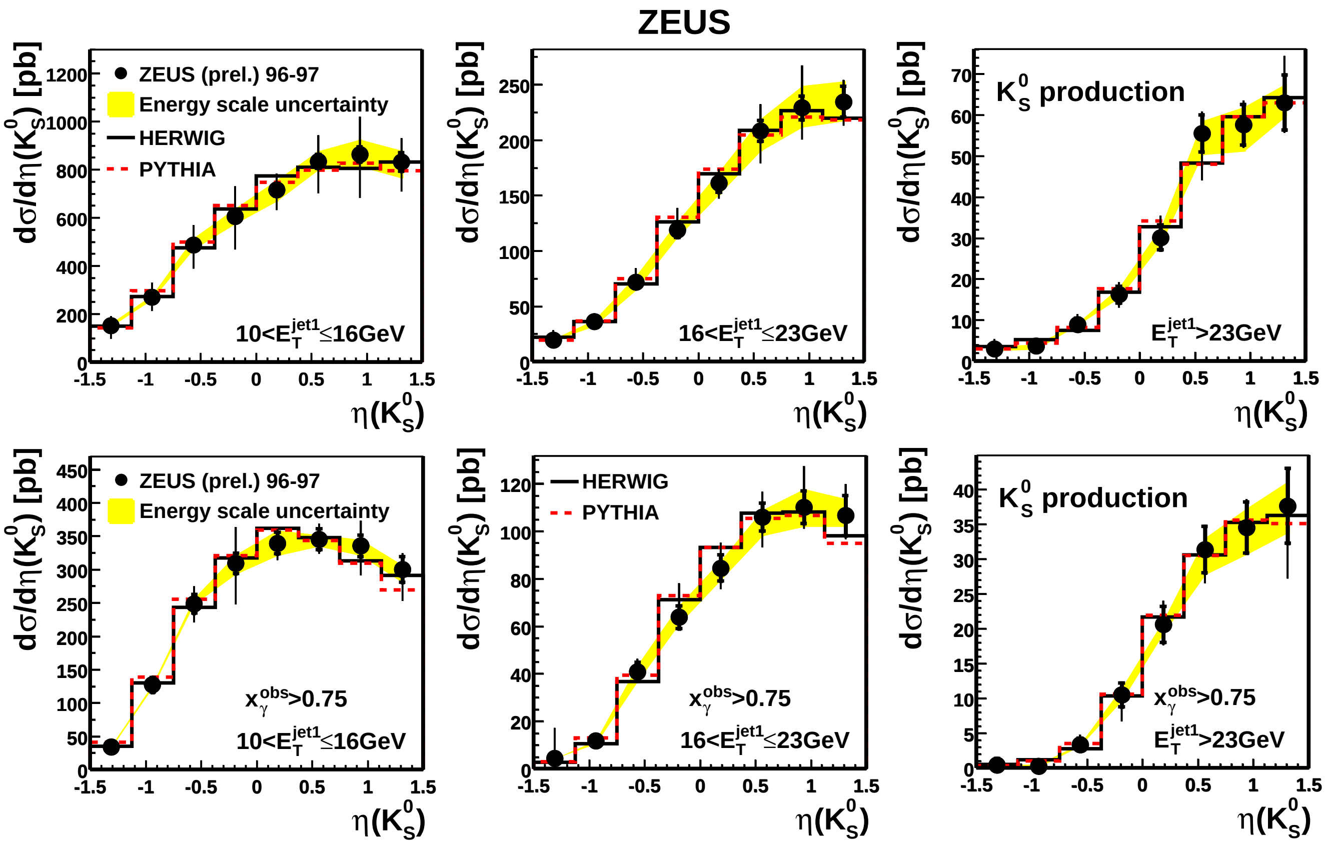
K_s^0 production



- K_S^0 differential cross sections in good shape agreement with both HERWIG and PYTHIA Monte Carlo generators:
  - As a function of jet transverse energy

- Familiar direct enhancement at higher jet energies

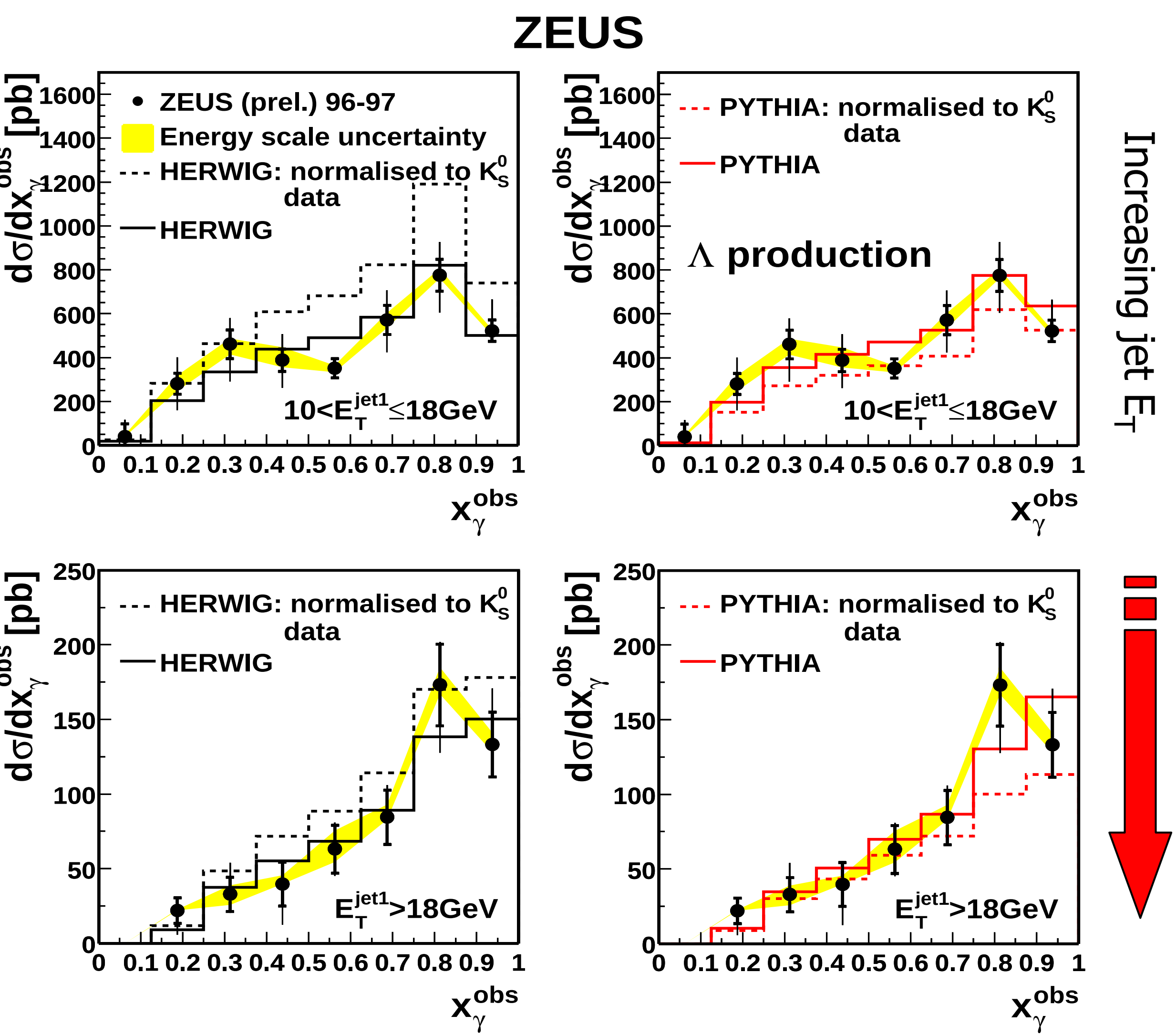
K_S^0 production (cont)



Increasing jet E_T

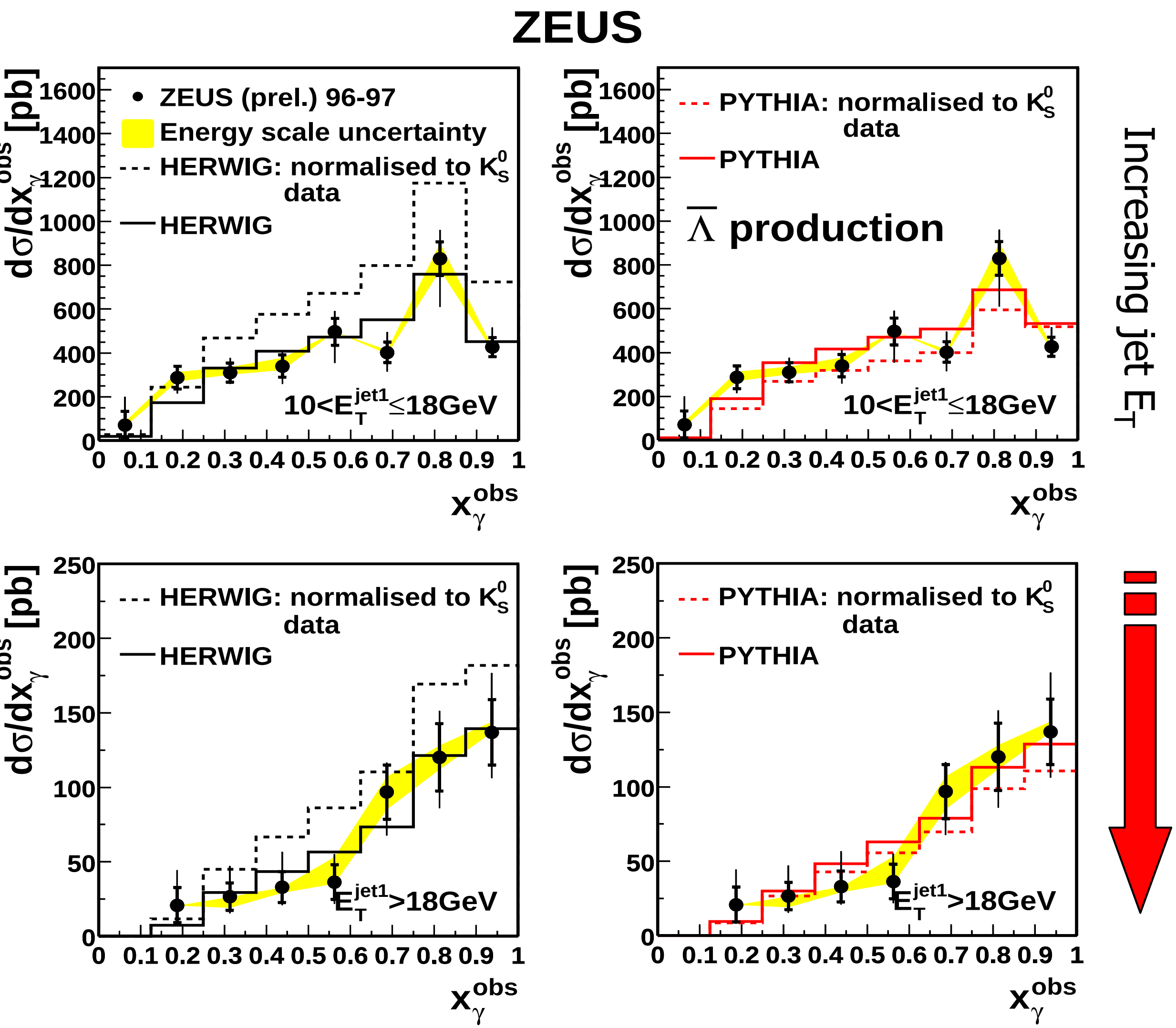
- $K_S{}^0$ production tends to follow the event energy flow, kaons being aligned with the jets.
  - As the jet energy is increased the kaon production tends to more forward (proton beam direction)
- Shape difference at high η between all $x_\gamma{}^{obs}$ and $x_\gamma{}^{obs}$ > 0.75 at lower jet E_T

Λ production



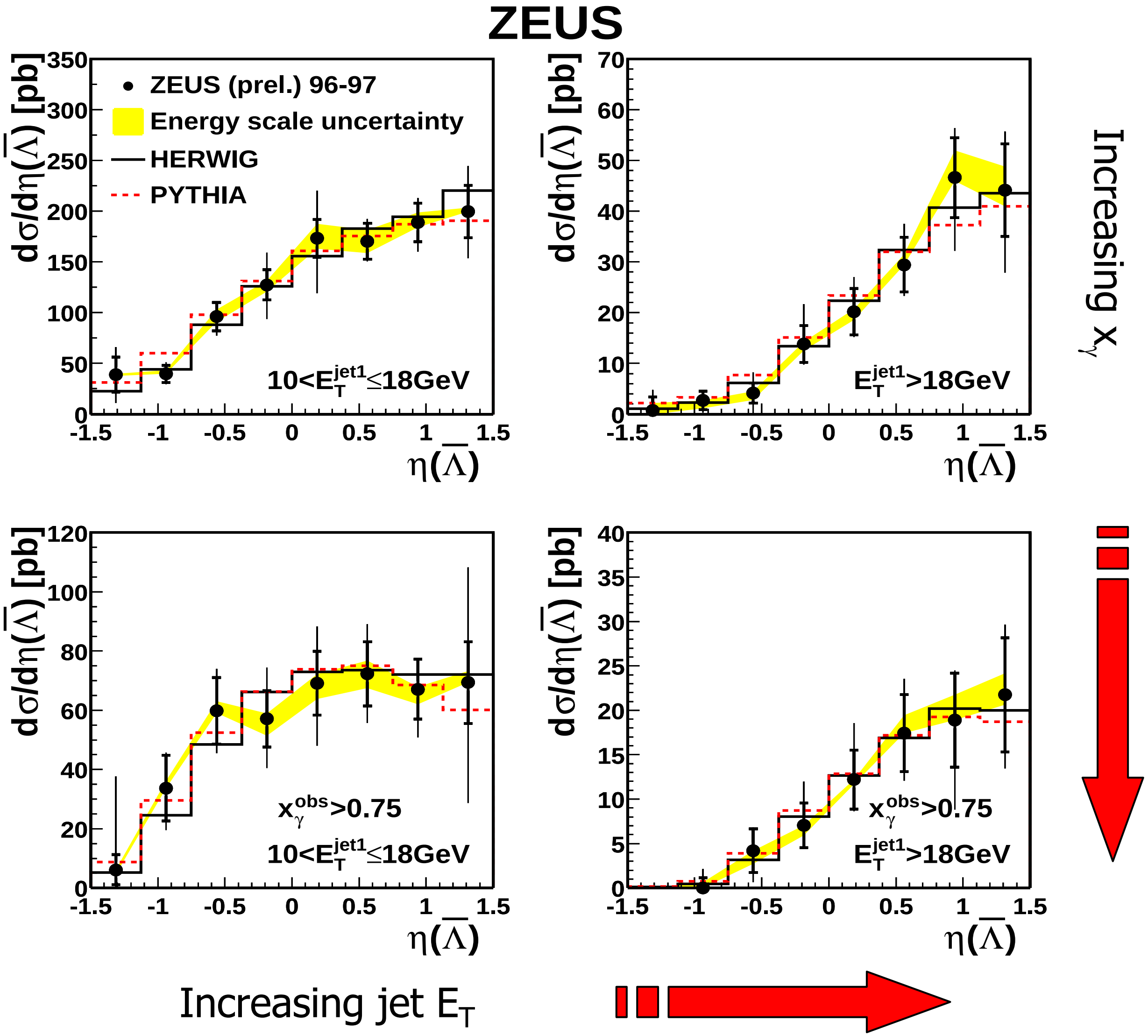
- Good agreement in shape between cross section and Monte Carlo (solid lines) normalised to data
- Fixing the normalisation of the Monte Carlo to the K_S^0 cross section (dashed lines)
  - HERWIG overestimates the measured cross section relative to K_S
  - PYTHIA slightly underestimates relative to K_S
- This effect persists at higher jet energies

$\bar{\Lambda}$ production



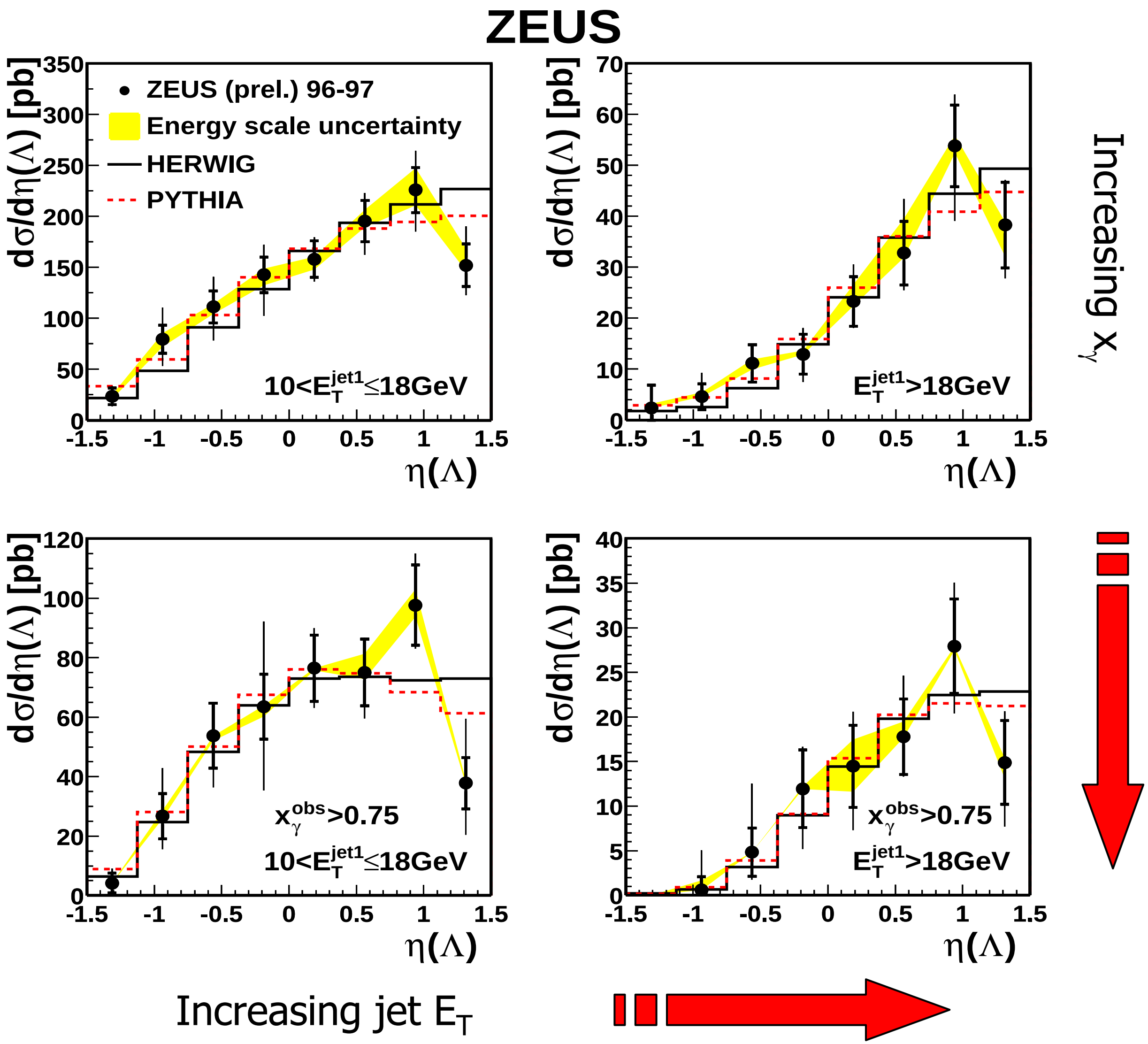
- Similar picture for the $\bar{\Lambda}$.
  - Good shape agreement between data and Monte Carlo prediction
  - HERWIG overestimates the measured cross section relative to K_S
  - PYTHIA slightly underestimates relative to K_S
- $\bar{\Lambda}$ cross section slightly lower than Λ

$\bar{\Lambda}$ production (cont)



- $\bar{\Lambda}$ production differential $\eta(\bar{\Lambda})$ cross section
  - Good shape agreement between cross section and Monte Carlo predictions.
  - Qualitatively same variation in the cross section as with K_S^0

Λ production (cont)



- Λ production differential $\eta(\Lambda)$ cross section
  - Small difference between measured Λ cross section and $\overline{\Lambda}$, possible statistical fluctuation?
  - Difference present at high jet transverse energy and at high x_γ^{obs}
- Overall data agrees well with MC predictions

ϕ(1020) production in DIS

- Motivation
  - Valence content of proton well established. |P> = |UUD>
  - Does the proton have a large strange (primordial) component?

- EMC data ('88) on polarised DIS
  - Net helicity of strange quarks at Q^2=5 GeV

  $\Delta s(Q^2) = s^+ - \bar{s}^- = -0.11 \pm 0.01$
  - Theoretical problem is that hard gluons cannot induce sea polarisation perturbatively for massless quarks

- NuTeV ('99) ν DIS
  - $\nu + N \rightarrow \mu + \text{charm} + X$
  - $W + s \rightarrow c$ ($\cos^2\theta_c$)

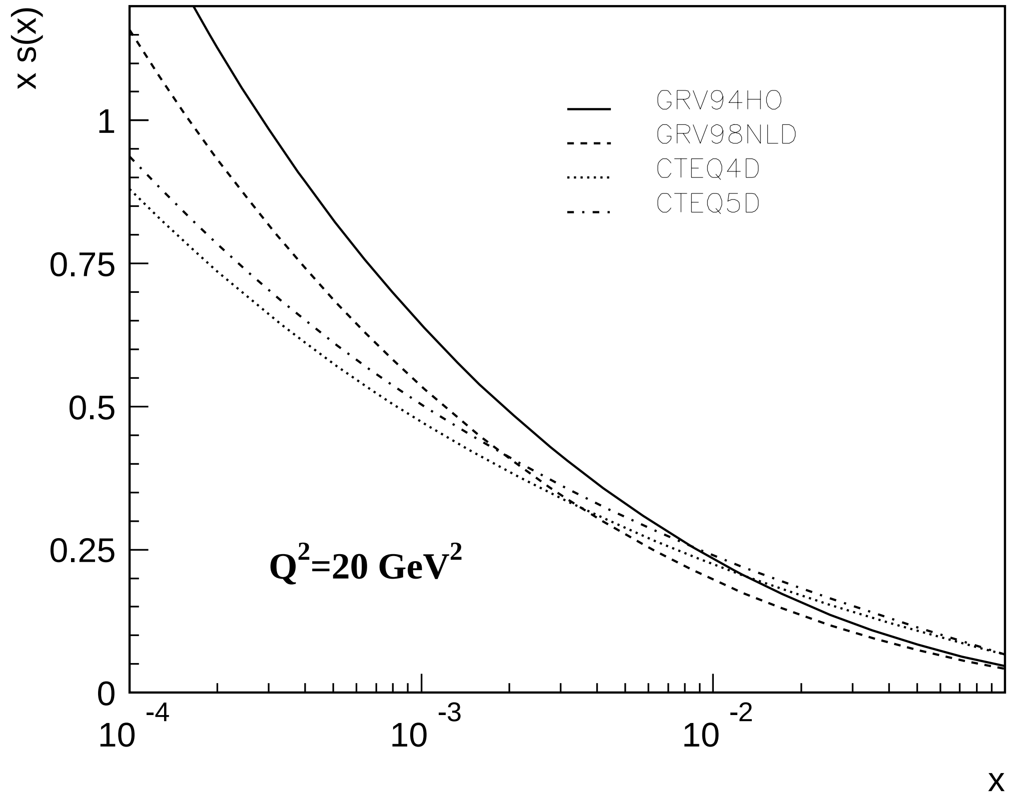
- Measure strange particles in neutral current DIS to constrain strange sea
  - K_S and Λ measured previously by ZEUS and H1
  - ϕ(1020) nearly pure $s\bar{s}$ state
  - Not significantly produced by resonance decays
  - First measurement at HERA

Strange content of the proton

- s-quark distributions
  - CTEQ/MRS:
  $xs = Ax^{-\lambda}(1-x)^{\eta}p(x,s)$ at $Q^2=Q^2 \sim 1$ GeV^2
  - GRV:
  $xs = x\bar{s} = 0$ at $Q^2=\mu^2 \sim 0.4$ GeV^2

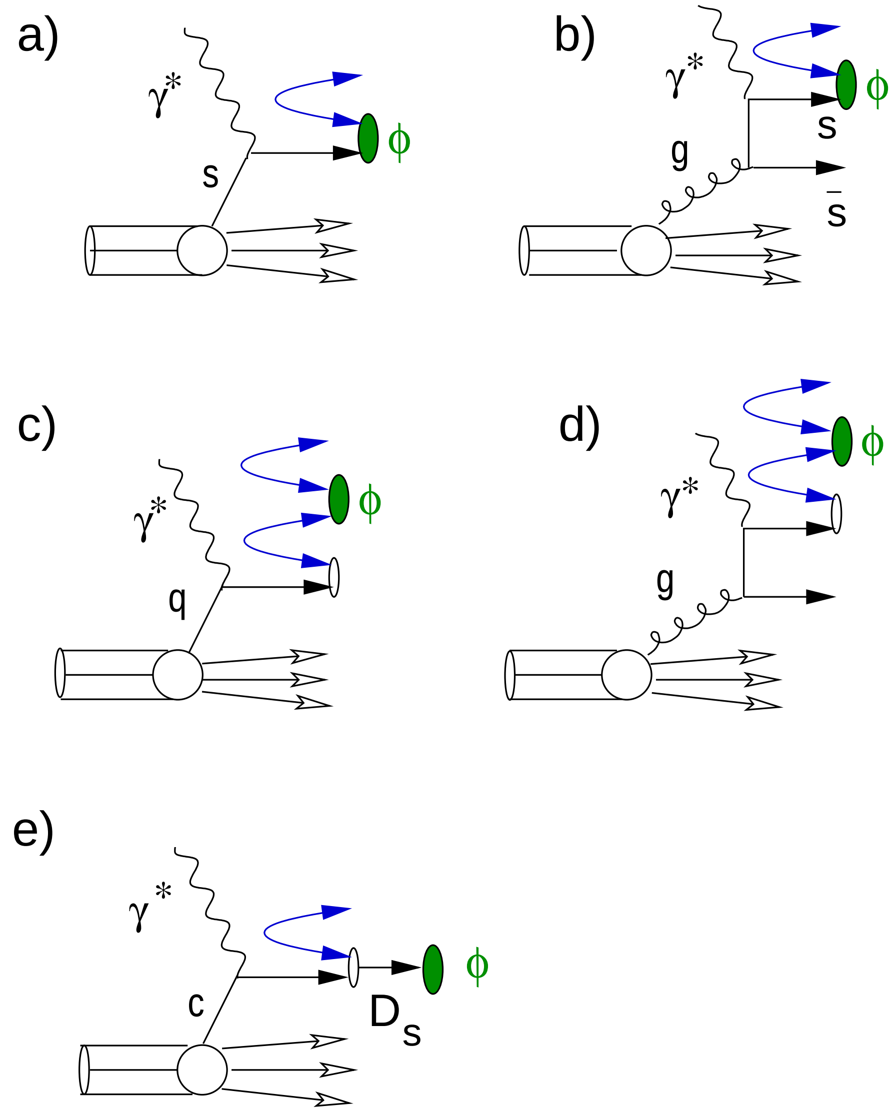
- GRV model for $s(x,Q^2)$
  - strange generated radiatively
  - lower bound for strange sea

- GRV stronger rise as x decreases than CTEQ.



ϕ(1020) production mechanisms

- Main sources of ϕ(1020)
  - Hard QCD processes
    - Quark parton model (QPM), QCD Compton (QCDC) (dependent on strange sea)
    - Boson gluon fusion (BGF) (dependent on gluon content)
- Only soft QCD (parton shower) and hadronization
- Heavy flavour and cascade decays
  - less significant for ϕ than for K and Λ
- Direct interaction of γ^* with strange sea
  - leading mesons with large $P_T(\phi)$
  - In Breit frame $x_P = 2p^{Breit}/Q \approx 1$



ϕ meson selection

- $\phi(1020)$
  - Nearly pure $s\bar{s}$ state.
  - Simple decay chain
    $\phi \to K^+K^-$ (BR = 49.2±0.7%)
  - decays on primary vertex

- Reconstruct 2 opposite charge tracks assigned to primary vertex
  - Large combinatorial background from primary vertex tracks.

- Data sample
  - e^+(27.5 GeV) + p(820 GeV)
  - 1995-1997 ZEUS data, luminosity 45.0±0.7 pb^{-1}

- DIS event selection
  - $10<Q^2<100$ GeV^2
  - $0.04<y<0.95$

- ϕ daughter kinematic region
  - $p_T(K) > 0.2$ GeV
  - $|\eta(K)|<1.75$

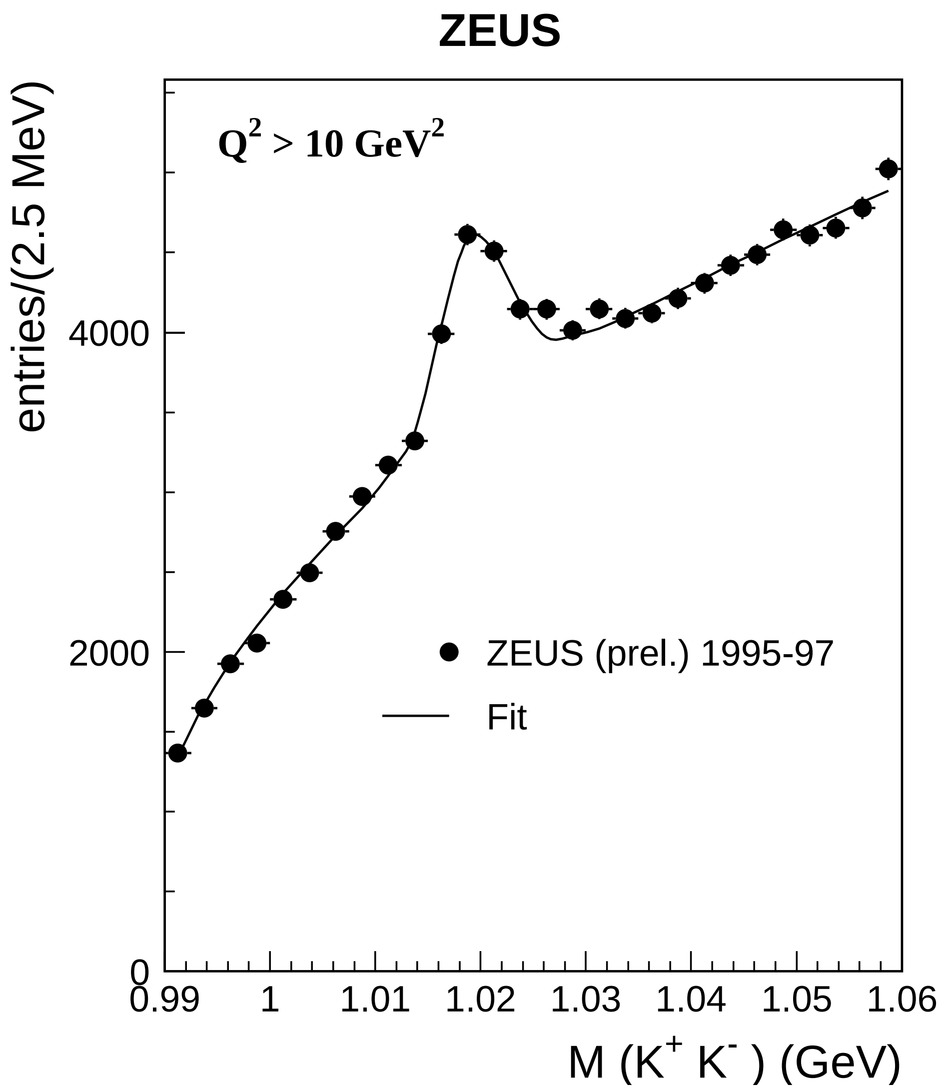
- ϕ kinematic region
  - $p_T(\phi) > 1.7$
  - $-1.7<\eta(K)<1.6$

Mass distribution for K^+K^-

- Mass distribution $M(K^+K^-)$ for $Q^2>10$ GeV
  - $0.99<M(K^+K^-)<1.06$ GeV
  - Large background from other primary vertex tracks
  - Clear $\phi(1020)$ signal

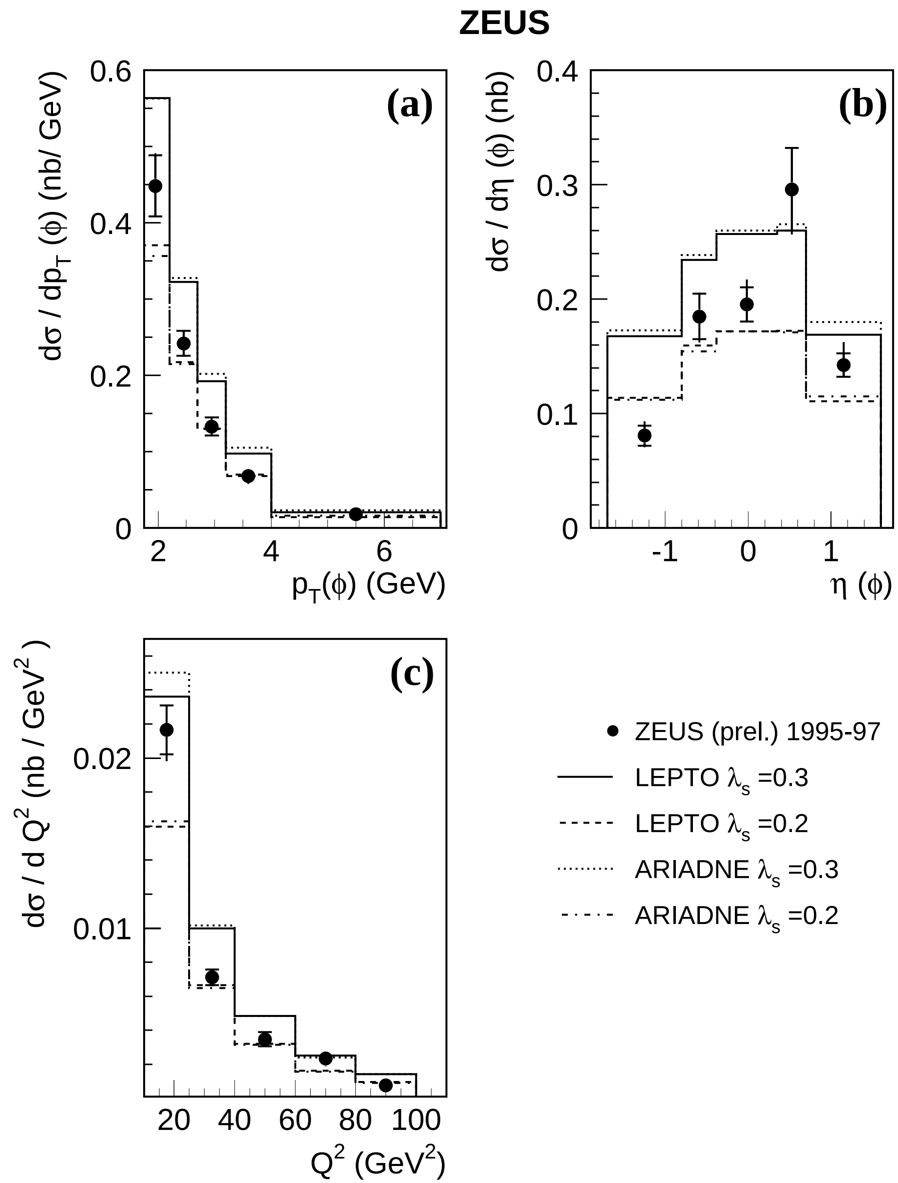
- Signal and background fit
  $F(M)=\text{BreitWigner}\otimes\text{Gaussian}+a(M-2M_K)^b$

- Fit peak value consistent with PDG value of 1019.417 ± 0.014 MeV



Differential cross sections

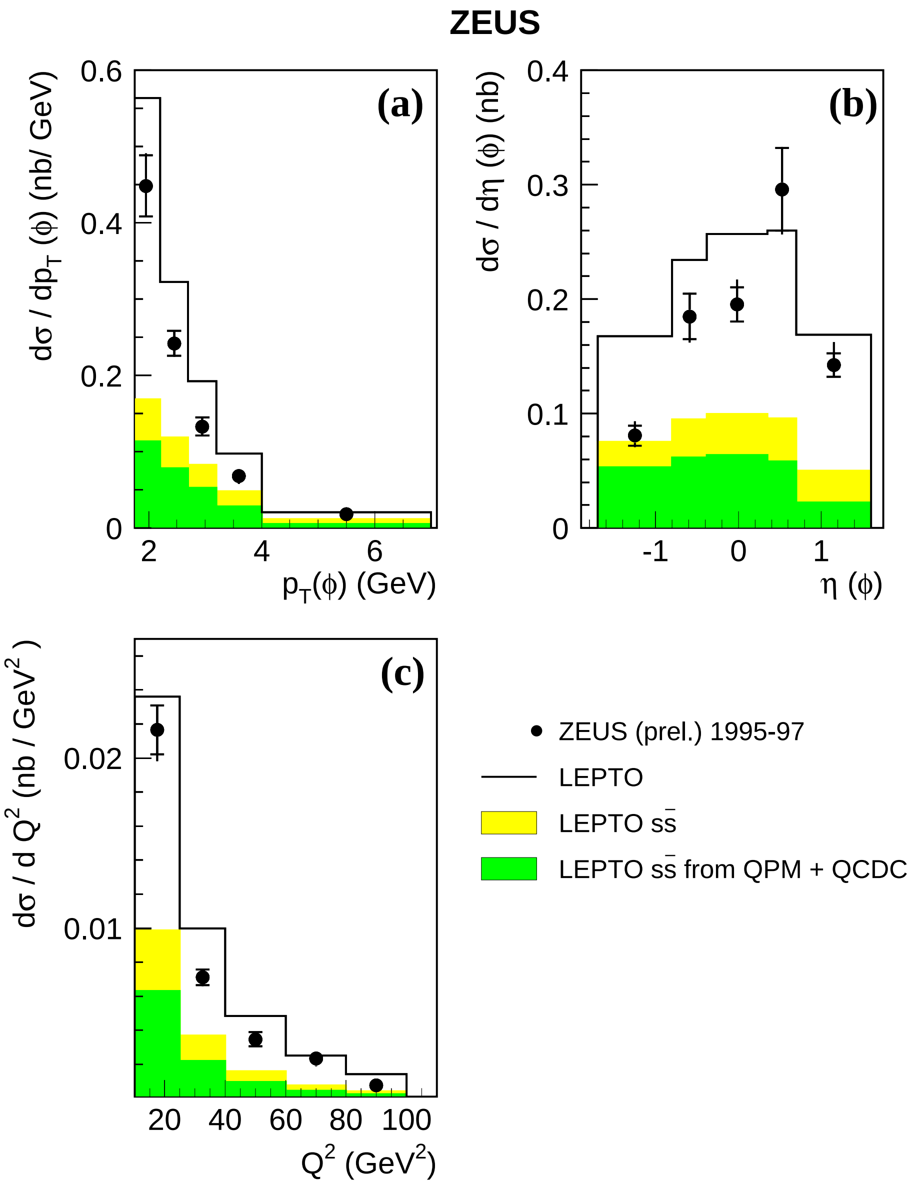
- Differential cross sections as functions of $p_T(\phi)$, $\eta(\phi)$ and Q^2
  - Compared with LEPTO & ARIADNE using CTEQ5D (λ_s=0.3 and 0.2)
- Reasonable shape agreement with predictions from Monte Carlo
  - λ_s=0.3 (LEP default) overestimates measured cross section
  - Better normalisation with λ_s=0.2; favoured by previous ZEUS and H1 measurements with K_S and Λ



Hard QCD contributions

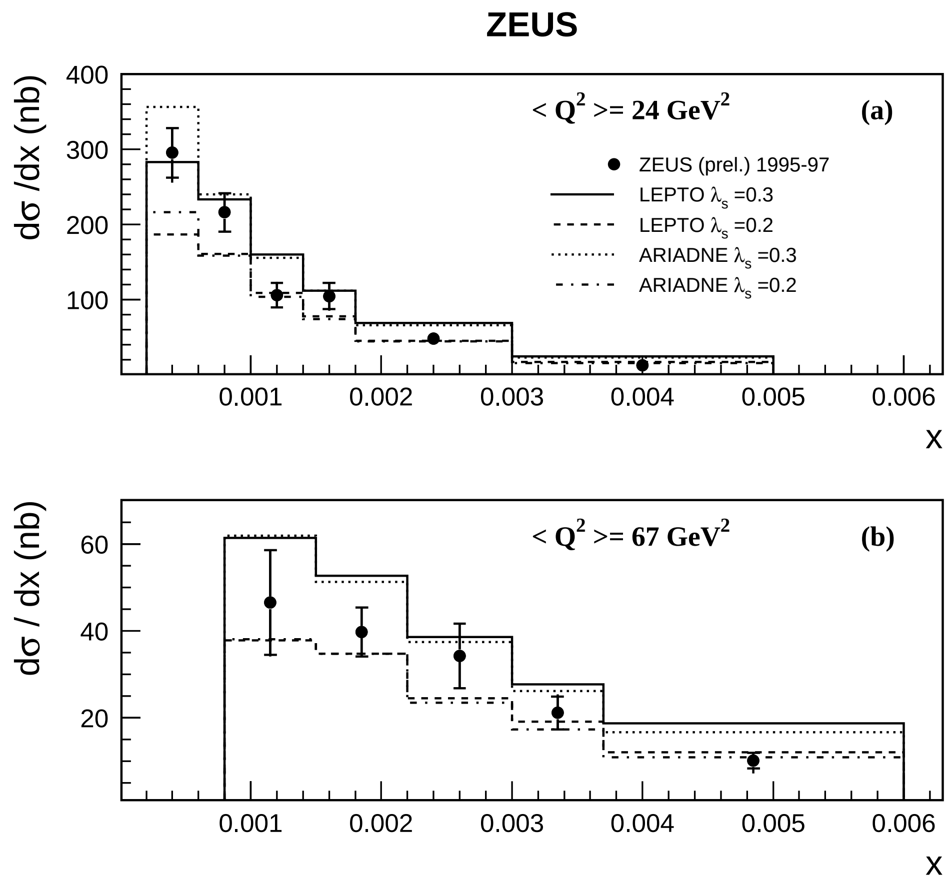
- cross sections as functions of $p_T(\phi)$, $\eta(\phi)$ and Q^2 compared with LEPTO (λ_s=0.3 and CTEQ5D)
  - $s\bar{s}$ pairs from QPM and QCDC (green shaded band)
  - $s\bar{s}$ pairs from BGF (yellow shaded band)

- Relative contribution from hard QCD increases with $p_T(\phi)$



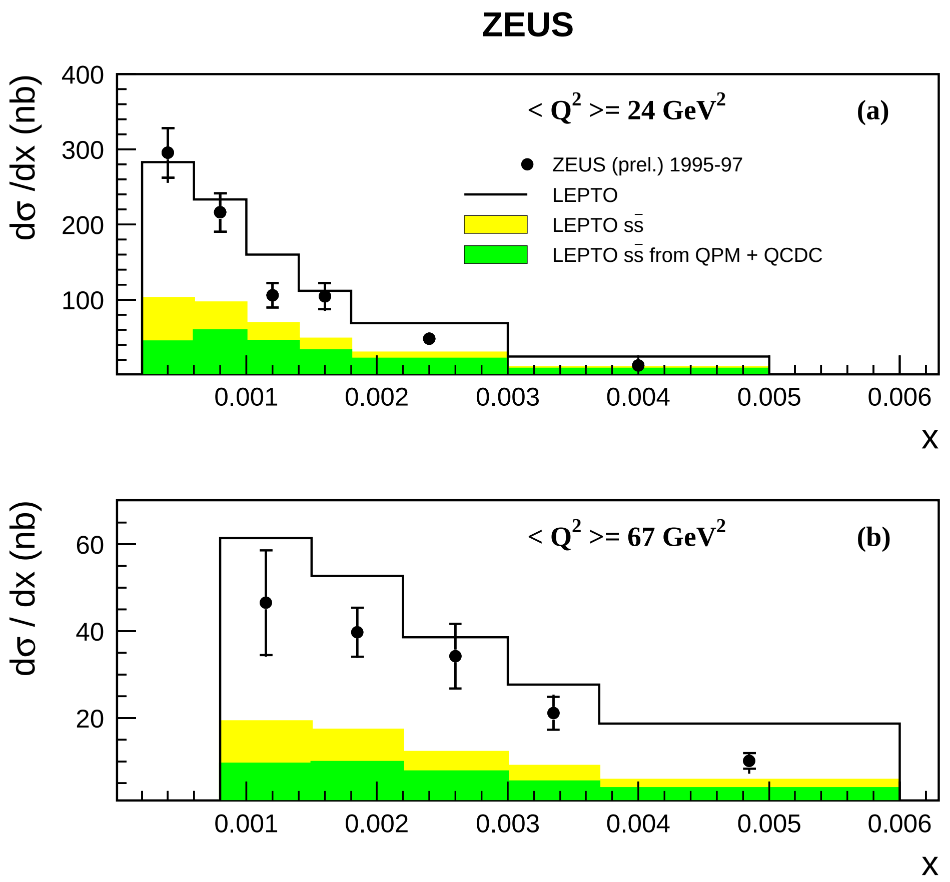
Differential cross sections

- Bjorken-x is sensible parameter to investigate the strange sea
  - sea quark density rises with diminishing x
  - BGF contribution also increases towards lower x as σ(BGF) ~ g(x)
  - Favours lower value of λ_s
  - λ_s=0.2 underestimates the measured cross section for x<0.001

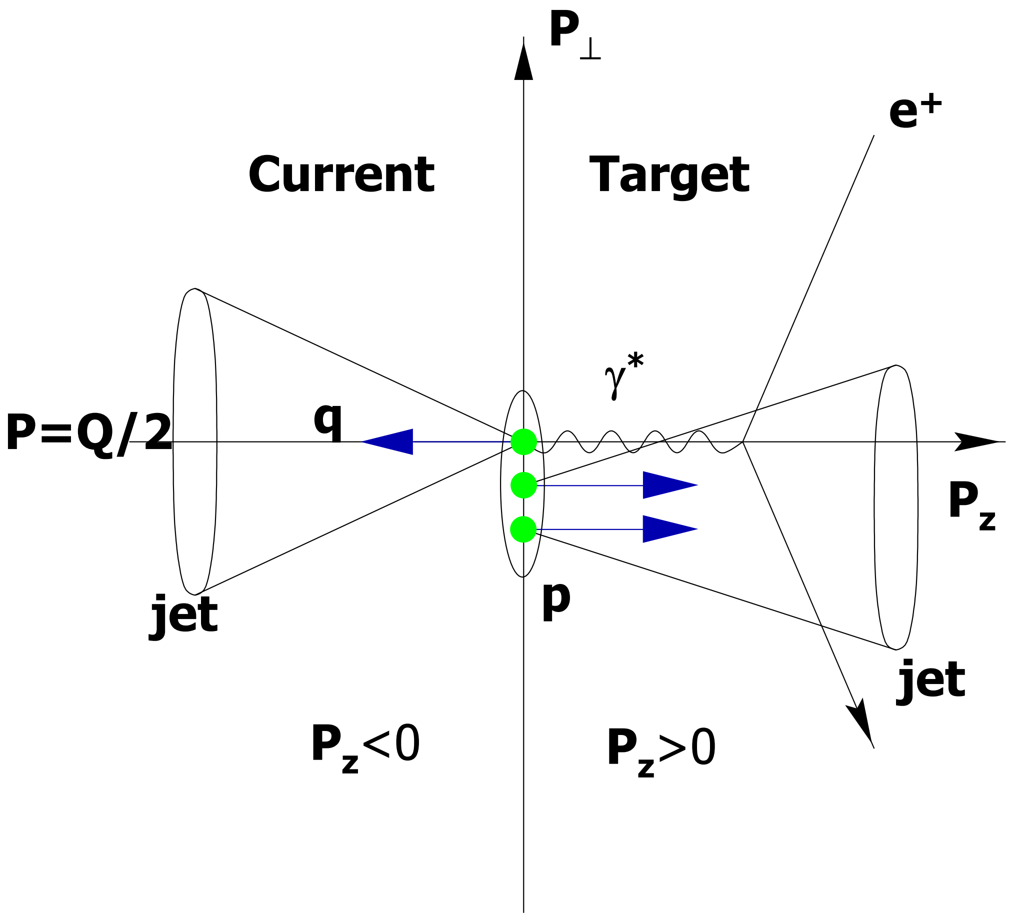


Hard QCD contributions

- Same measured cross sections as previously
  - Both QPM and QCDC contributions rise with decreasing Bjorken x



Breit frame



- Breit frame is natural way to separate the radiation of struck quark and the proton remnant
- Scaled momentum

  x_p=2p/Q (p=|**p**|)
- Current region (p_Z<0)
  - QPM model

    x_p(s)=2p(s)/Q = 1
  - First and higher order QCD

    $x_p(s)\neq 1$
- Target region
  - Maximum remnant momentum

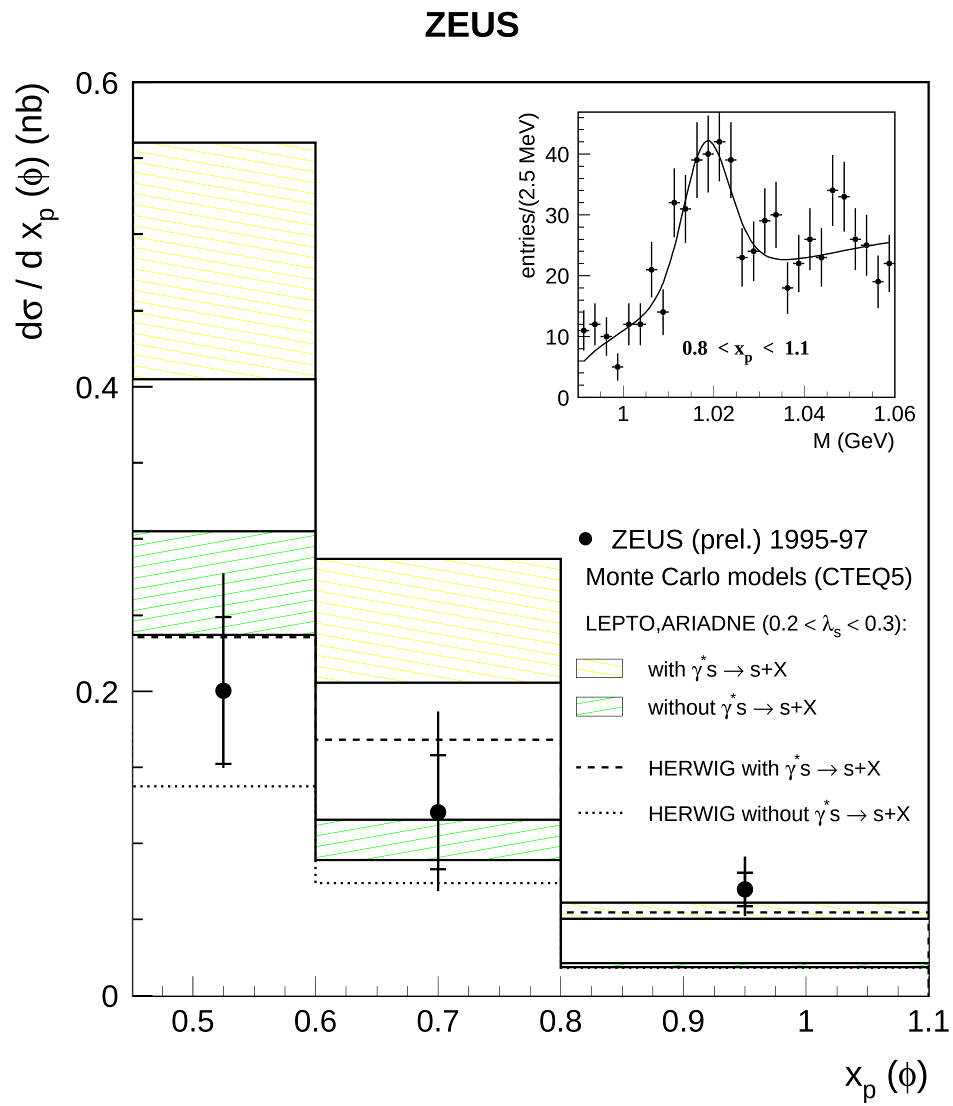
    Q(1-x)/2x

  $\Rightarrow$ $x_p^{max} \approx (1-x)/x >> 1$

ϕ(1020) in the Breit-Frame

- ϕ cross section as function of scaled momentum (x_p)
  - Monte Carlo uncertainties (including variation in λ_S) indicated by shaded bands
  - Monte Carlo uncertainties x_P>0.8 are small
  - Inset $M(K^+K^-)$ distribution for $0.8<x_p(\phi)<1.1$, with clear and well reconstructed signal

- **Contribution from hard QCD processes dominant at x_P>0.8 and in reasonable agreement with data using CTEQ5D parton densities**



Conclusions and summary

- cross sections for K_S and Λ production have been measured over a wider kinematic region and more differentially than previously possible

- Overall, differential K_S and Λ production cross sections are in reasonable shape agreement with HERWIG and PYTHIA Monte Carlo simulations

- Monte Carlo predictions for Lambdas relative to the kaon production disagree with measured cross section
  - HERWIG prediction cross section is larger relative to Kaon production
  - PYTHIA predicted cross section is slightly smaller to Kaon production

Conclusion and summary

- Inclusive $\phi(1020)$ meson cross sections have been measured for neutral current DIS with $10<Q^2<100$ GeV^2
- The Monte Carlo predictions with $\lambda_S = 0.3$ overestimate the measured cross sections
- ZEUS measurements favour a lower value of $\lambda_S \sim 0.2$
- The Monte Carlo predicted cross sections differ in shape from measurements and overestimate at low $p_T(\phi)$, Q^2 and x
- The measurements in the laboratory frame indicate a need for adjustment of the strange suppression factor

- In the current region of the Breit frame for $x_P(\phi)>0.8$ the measured cross section *clearly* indicate the contribution from the strange sea
  - Given current statistics the cross section is consistent with prediction using CTEQ5D