# Light Mesons and Strange Particle Production at HERA

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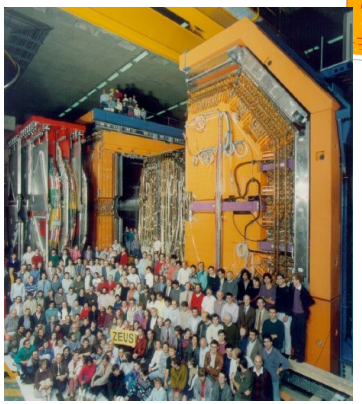
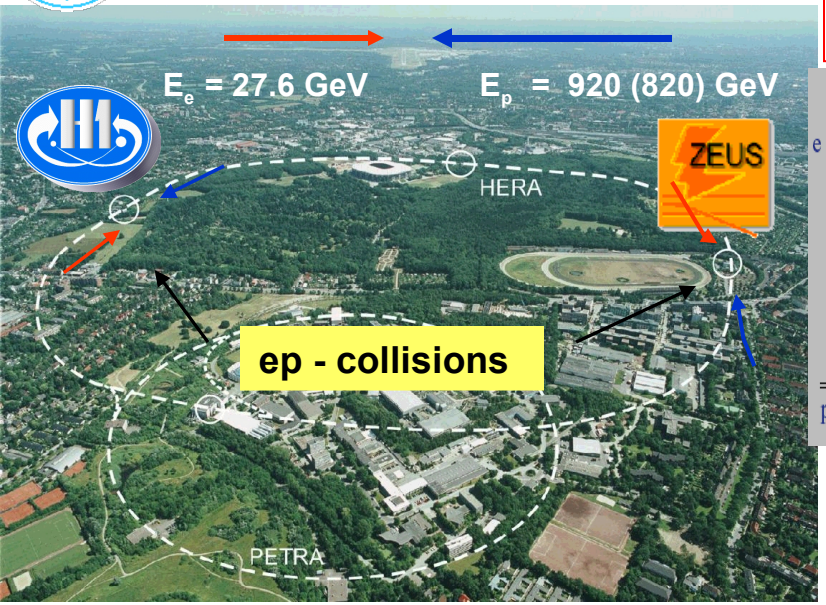
on behalf of the ZEUS and H1 Collaborations

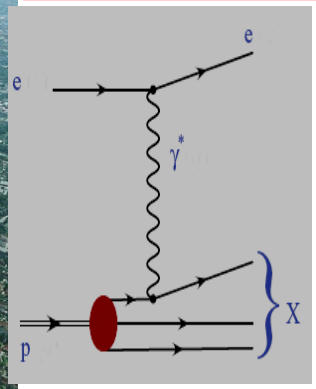
- Inclusive photoproduction of $\rho^0(770)$, $K^{*0}(892)$ and $\phi(1020)$
- Strangeness production in DIS at low and high $Q^2$
- Scaled momentum distribution for $K^0$ and $\Lambda$ particles in DIS
- Summary



# HERA - Hamburg




ep collisions: hard and soft processes
→ $\gamma^* p \rightarrow$ hadrons




**s** : e-p c.m. energy , $\sqrt{s} \approx$ **300 – 318 GeV**
**$Q^2$** : = - $q^2$ , 4-momentum transfer squared
**x** : fraction of p momentum carried by quark
**y** : inelasticity parameter
**W** : $\gamma$-p c.m. energy

$\gamma^*$ virtuality $Q^2$:
$Q^2$ (GeV$^2$) > 0 deep inelastic scattering (DIS)
$Q^2$ (GeV$^2$) ≈ 0 : (quasi) photoproduction

Hadronisation studies : non-perturbative process

Data:

- identified hadrons and resonances
- inclusive multihadron production

H1 and ZEUS experiments:
total integrated luminosity ~ 0.5 fb$^{-1}$
pro experiment

Theoretical description:

- NLO QCD
- Monte Carlo - (LO) QCD based models:

ARIADNE + JETSET
LEPTO + JETSET

# Inclusive photoproduction of $\rho^0$ (770) , $K^{*0}$ (892), $\phi$(1020) mesons at HERA

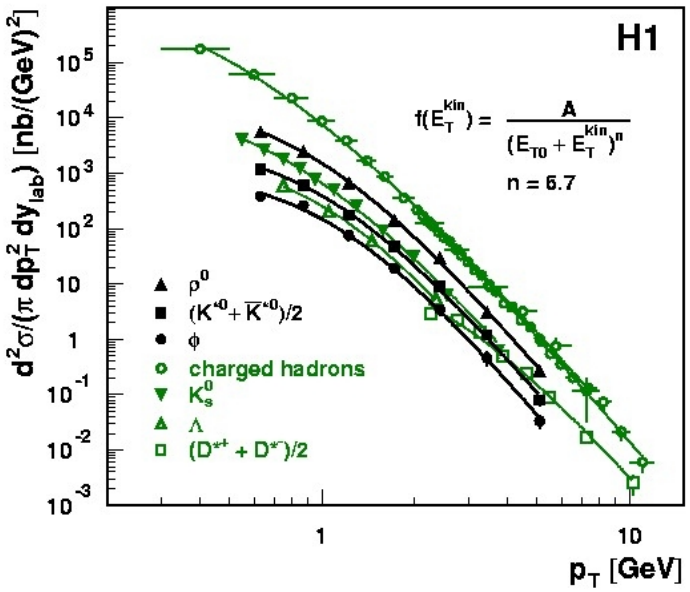
The inclusive differential cross sections as function of transverse momentum can be parametrized as power law distribution:

$$1/\pi\, d^2\sigma^{\gamma p} / dp^2_T dy_{lab} = A / (E_{T0} + E^{kin}_T)^n$$

H1: Phys.Lett. B 673 (2009) 119

More details:
see A. Rostovtsev talk (399)
at this conference
(Thursday 22 July )

Comparison $\rho^0$ , $K^{*0}$, $\phi$ mesons with other paricles:




The measured cross sections are well described by the power law distribution with the same n = 6.7.

Resonances with different masses, lifetimes and strangeness content are produced with about similar average transverse kinetic energy

→ support to thermodynamic picture of hadronic productions.

# $K^0_S$ and $\Lambda$ production at low and high $Q^2$

Strange hadrons production, particularly baryons, is not well understood. Recent results from H1 and ZEUS extend knowledge on the fragmentation/ hadronisation process for strange particles production.

- H1: $K^0_S$, $\Lambda$, $2 < Q^2 < 100$ GeV$^2$, HERA I ; Phys. J. C (2009) 61, 185 : Strangeness production at low $Q^2$ in deep-inelastic ep scattering at HERA
- H1 : $K^0_S$, $145 < Q^2 < 20000$ GeV$^2$, HERA II ; Preliminary results, H1-prelim-10-031
- ZEUS : $K^0_S$, $\Lambda$, $10 < Q^2 < 40000$ GeV$^2$, HERA II; Preliminary results , ZEUS-prel-10-013

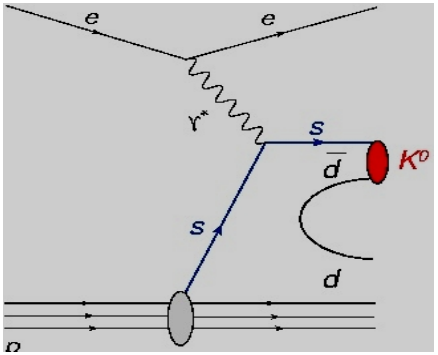
**Goals:**

LAB and the Breit frame measurements

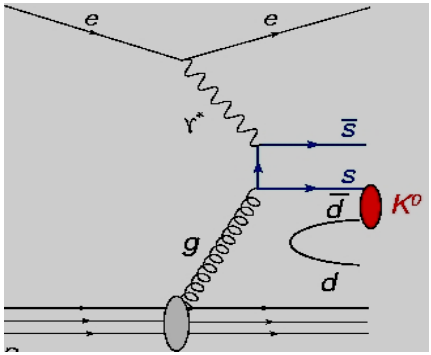
- Test of models of fragmentation/hadronisation
- Test of $\lambda_s$ universality (strangeness suppression factor)
- Fragmentation properties of $K^0_S$ and $\Lambda$ from scaled momentum distributions
- Test NLO QCD calculations and universality of factorization theorem

# Main mechanisms of strange quark production

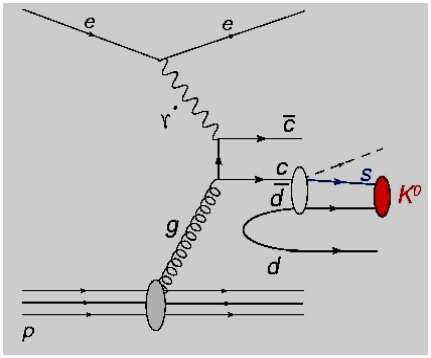
QPM, hard scattering of sea quark



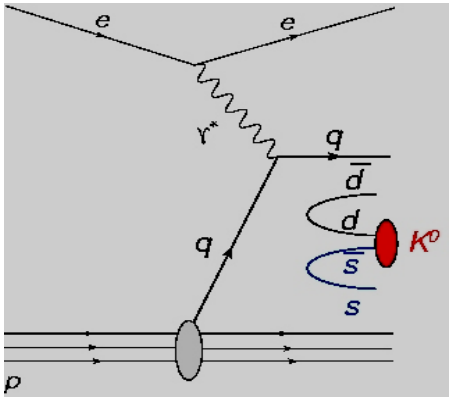

Boson-gluon fusion




Heavy quark decay

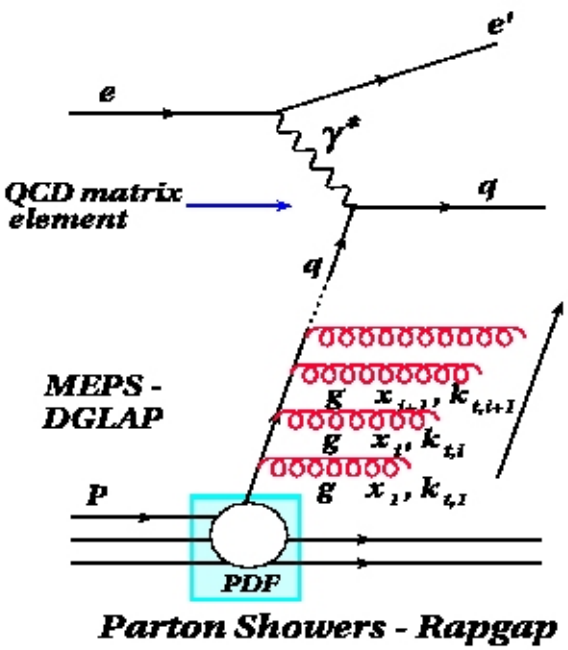



Hadronisation

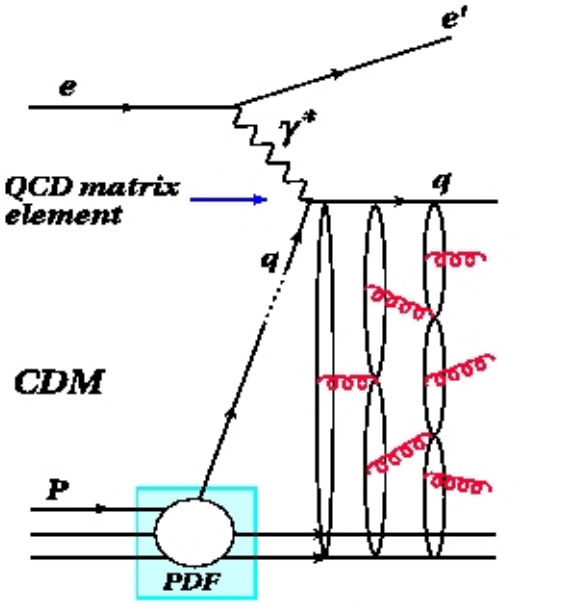



Next step : fragmentation to hadrons – non perturbative process is described by Lund string fragmentation model incorporated in Jetset Monte Calo

# Simulation programs




Parton Showers - Rapgap




Color Dipole Model - Django

MEPS

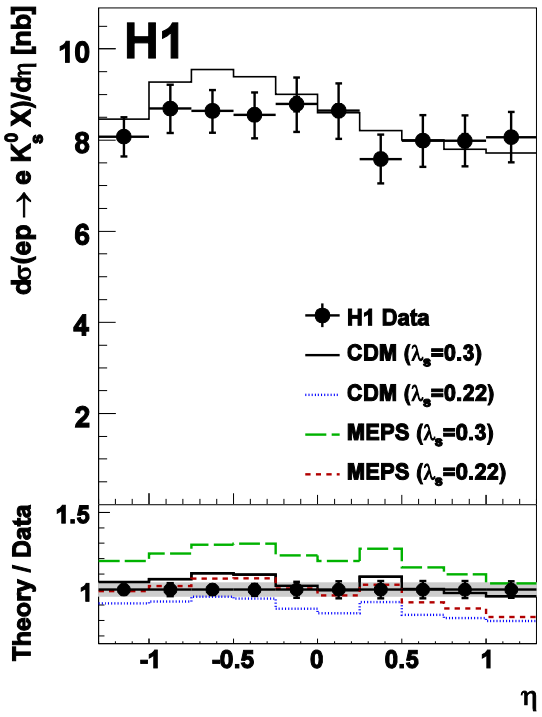
CDM

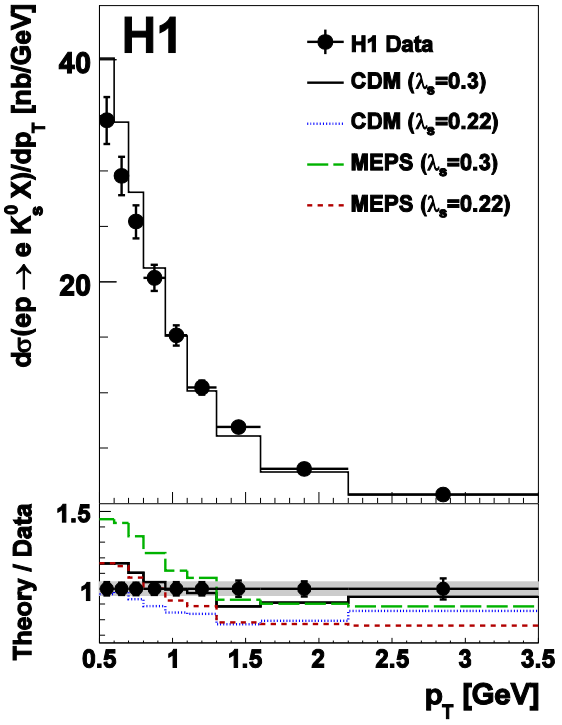
plus Lund colour string model for hadronisation (JETSET)

In comparison of the measuremets with MC predictions:
the values of strangeness suppression factor $\lambda_s$ ($\lambda_s$ = P(s)/P(q) ; q = u,d):
0.22, 0.286 and 0.3 were used in MC.
Other JETSET parameters used by ALEPH at LEP were taken as default:
($\lambda_{qq}$ = 0.108 : $\lambda_{qq}$ =P(qq)/P(q), $\lambda_{sq}$ = 0.690 : $\lambda_{sq}$ = (P(sq)/P(qq))/$\lambda_s$ )

# $K^0_s$ production at low $Q^2$

Laboratory frame (LAB): Differential cross sections -$\eta$ and $p_T$ distributions



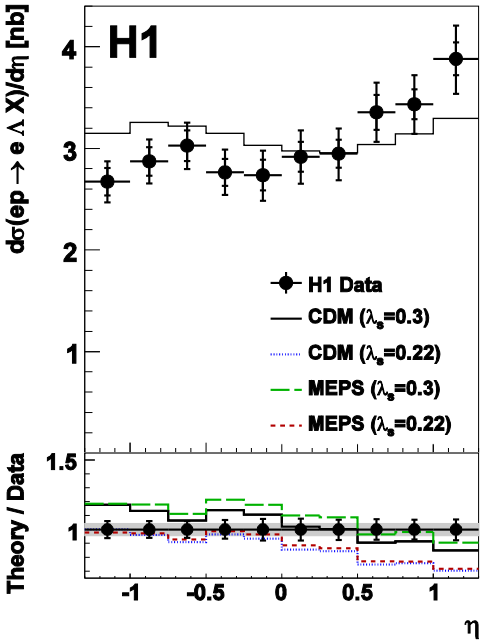



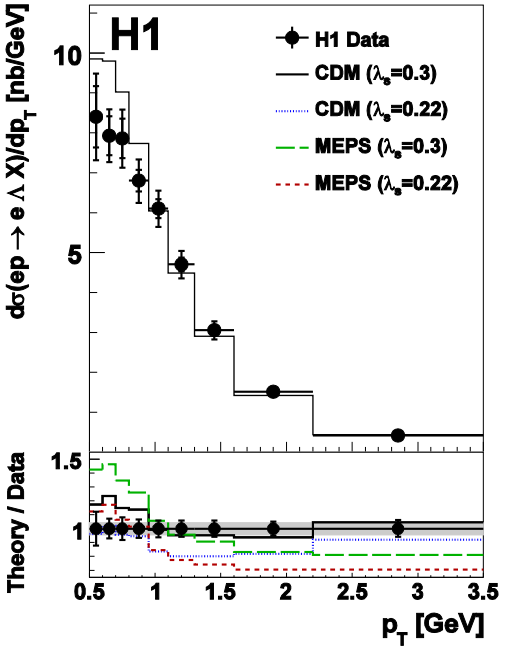

Flat $K^0_s$ production along $\eta$

MC predictions cannot describe the $p_T$ distribution in the whole region. CDM with $\lambda_s$ = 0.3 gives better description of the data but it overestimates the data in small $p_T$ region.

# $\Lambda$ production at low $Q^2$

LAB: Differential cross sections – $\eta$ and $p_T$ distributions



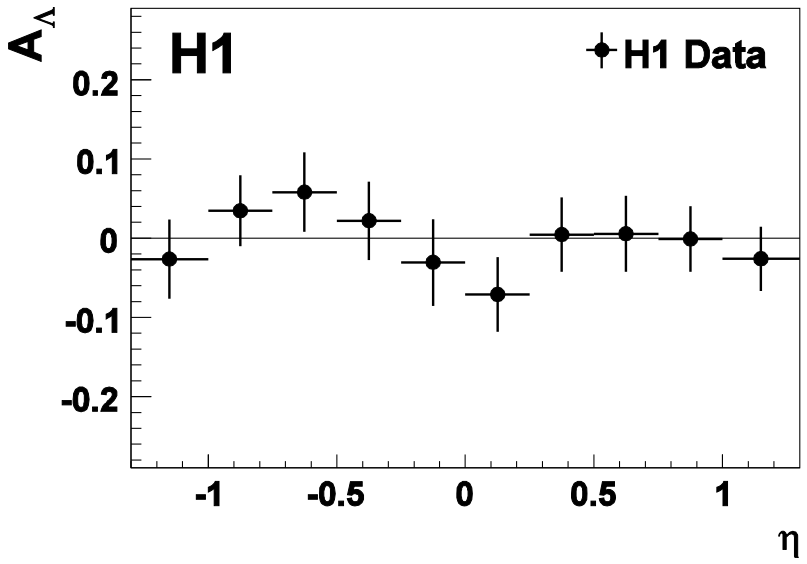



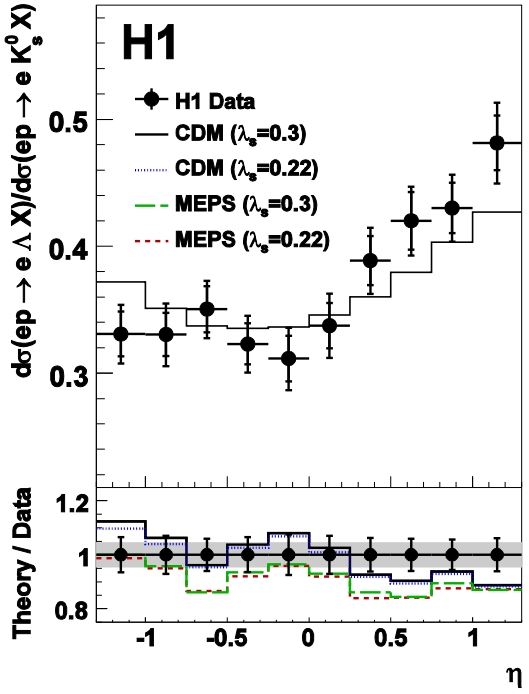

- Both MC predictions with different values of $\lambda_s$ parameter used: $\lambda_s$ = 0.22 or 0.3 cannot describe the data
- A rise in a forward direction is observed in the data

$\Lambda$ $p_T$ distribution is not described by CDM with $\lambda_s$ = 0.3:
CDM overestimates the data in low $p_T$ region

# Low $Q^2$ : $\Lambda$ - $\bar{\Lambda}$ asymmetry and ratio $\Lambda$ / $K^0_s$

LAB:




Within the experimental uncertainties no baryon antibaryon asymmetry was found
→ No evidence for a transfer of the baryon number from the proton beam to the final state strange particles

- The ratio is almost not sensitive to changes in $\lambda_s$
- The CDM and MEPS predictions underestimate the ratio.
- At large, positive η, a rise is observed in the data

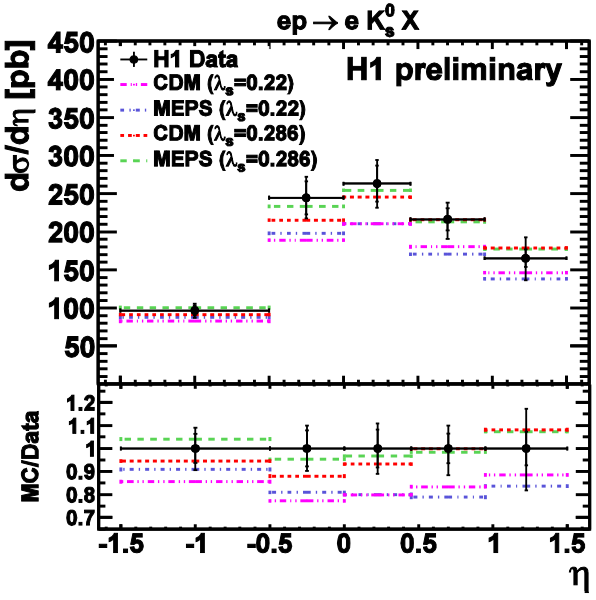
# $K^0_S$ production at high $Q^2$

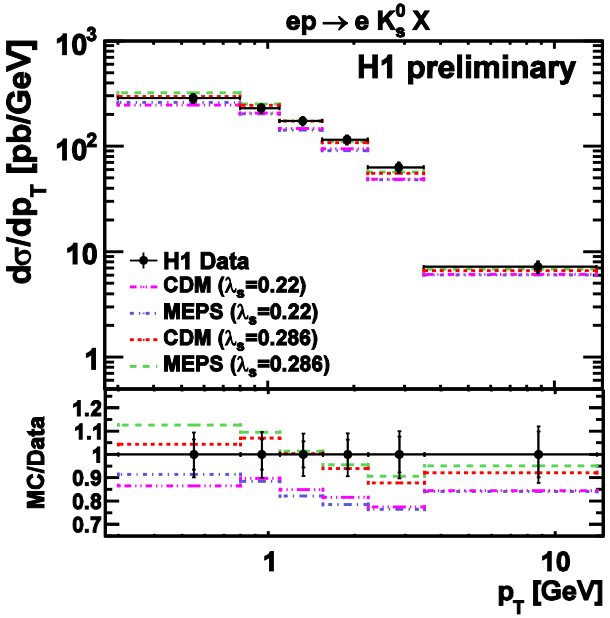
LAB: Differential cross sections - $\eta$ and $p_T$ distributions

CDM and MEPS predictions with:

$\lambda_S = 0.22$ used in low $Q^2$ measurements and

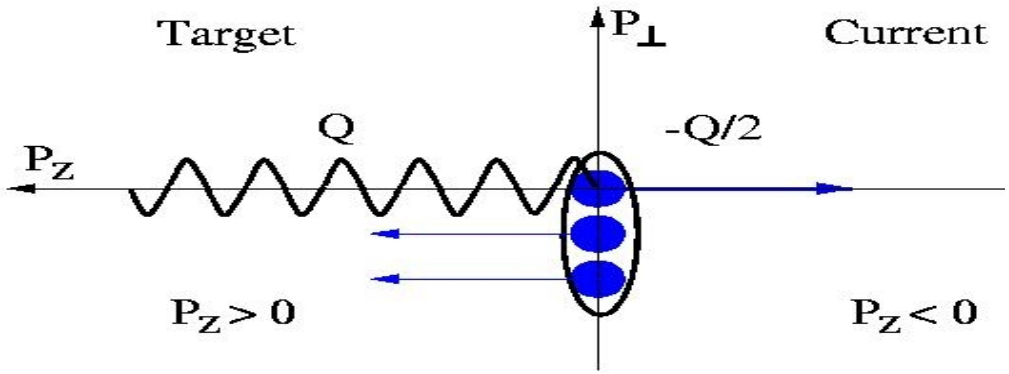
$\lambda_S = 0.286$ - used by ALEPH for $e^+e^-$ LEP data



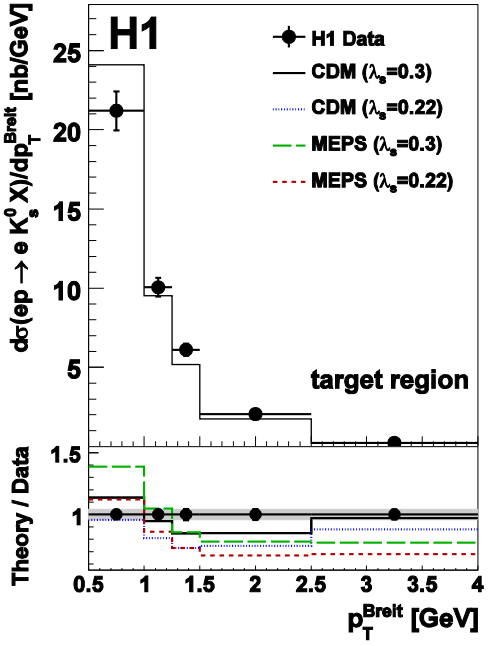




Agreement between data and Monte Carlo ( MEPS and CDM ) predictions for $\lambda_S = 0.286$

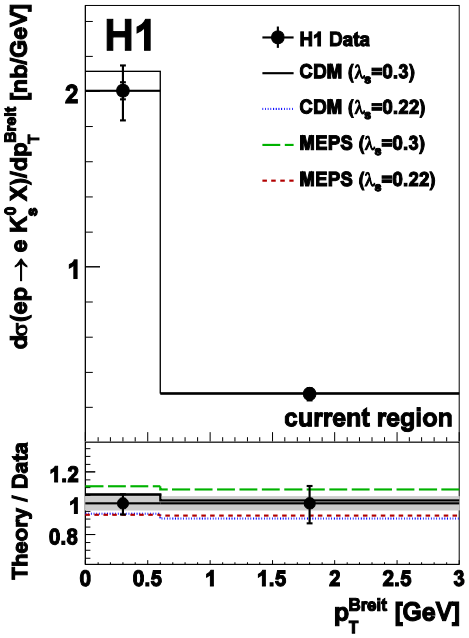
# Low $Q^2$: $K^0_s$ in the Breit frame



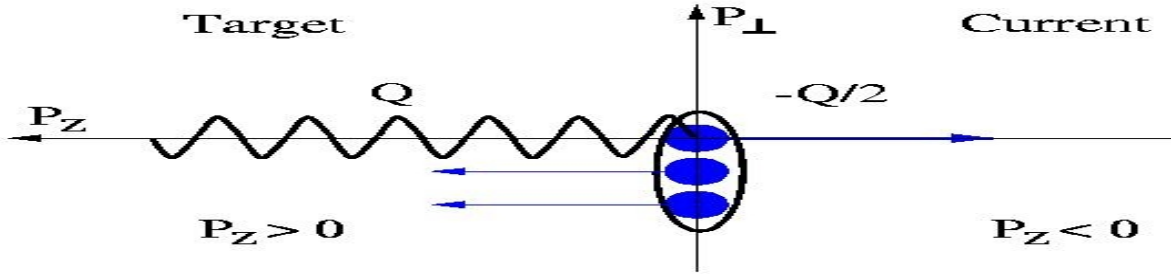

- Separates struck quark (current hemisphere) and proton remnant (target hemisphere)
- Fragmentation studies based on scaled momentum distribution $x_p = 2\, p^{Breit} / Q$
- Current region is analogous to single hemisphere of $e^+e^-$ annihilation

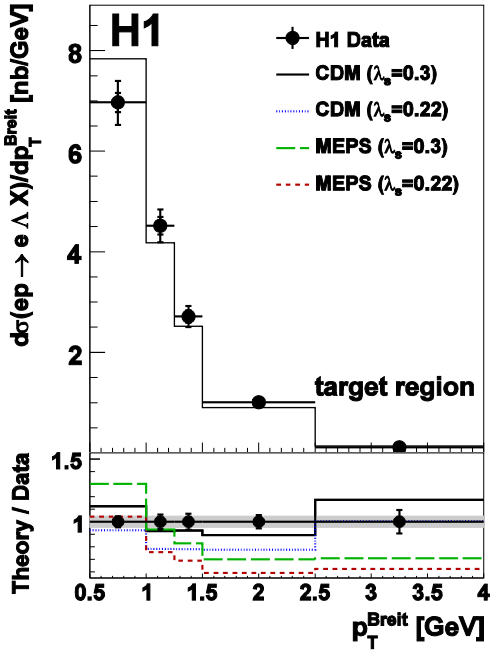



- The measured x- section in target region is ~ one order of magnitude larger than in the current region.
- The $p_T$ distributions are not described by MEPS or CDM
- The current region is less sensitive to $\lambda_s$ than target region
  → small statistics available – large errors
  → a fraction of strangeness production in perturbative processes achieve ~ 50 % in comparison to ~25 % for target region



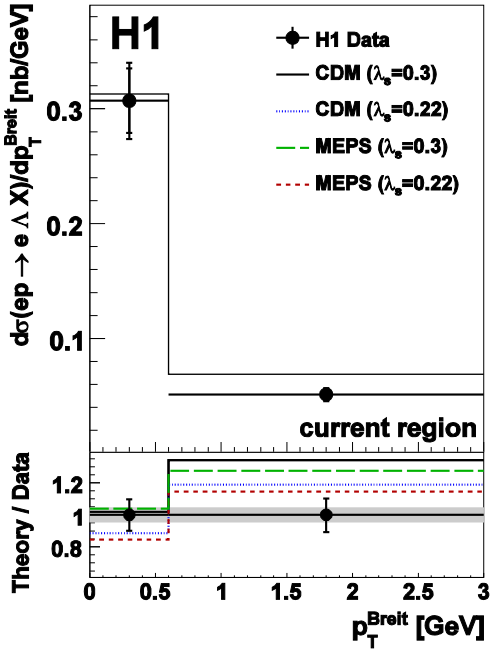
# Low $Q^2$: $\Lambda$ in the Breit frame




The similar behavior as for $K^0_s$ is observed:

- Cross section in target region is significantly larger than in current region.
- The $p_T$ distributions are not described by MC. They tend to be softer than in data.
- The ~50 % contribution to strangeness production in the current region comes from perturbative processes



# Scaled momentum distribution for $K^0_S$ and $\Lambda$ in DIS

## Motivation:

Comparison of $K^0_S$ and $\Lambda$ production in the current fragmentation region of DIS with NL0 QCD calculations plus fragmentation functions ( FF).
FF: fits to ll, lp and pp data; scaling violations in $Q^2$ are expected.

**NLO QCD:**

$$d\sigma/dx_p = f(x,Q^2) \otimes \sigma(Q^2) \otimes D(z,Q^2)$$ - universality of factorization theorem

$f(x,Q^2)$ – parton density in proton
$\sigma(Q^2)$ – hard-scattering process – NLO (full matrix elements)
$D(z,Q^2)$ – fragmentation function: probablity for a parton to fragment into a hadron carrying fraction of its momentum

Two different predictions were compared to the data:

**AKK + CYCLOPS** (**S. Albino, B. A.Kniehl, G. Kramer)** -

→ FFs were obtained from fits to $e^+e^-$ data,
→ hadrons mass effect was included

**DSS (D. de Florian, R. Sassot, M. Stratmann**)

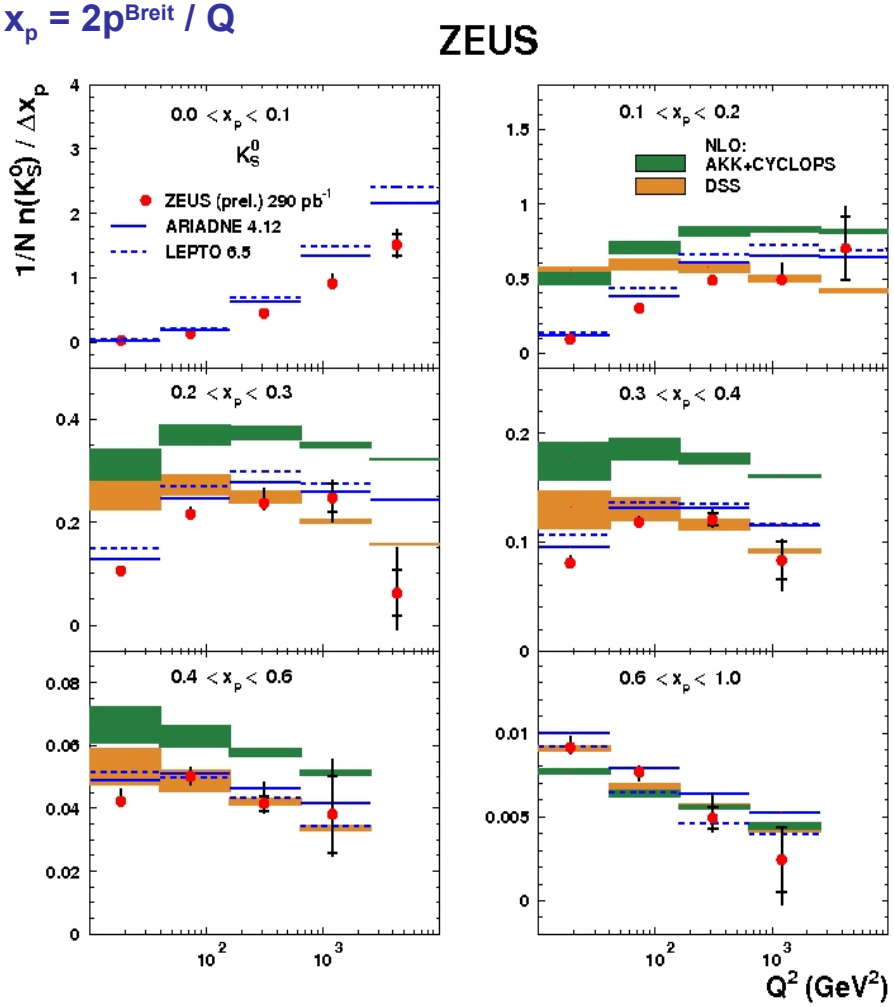
→ FFs were obtained from fits to lp and pp data,
→ hadron mass effect was not included

# $K^0_S$: scaled momentum distributions $x_p$ and QCD predictions

ZEUS : Preliminary results

Current hemisphere of the Breit frame (CBF)

$x_p = 2p^{Breit} / Q$

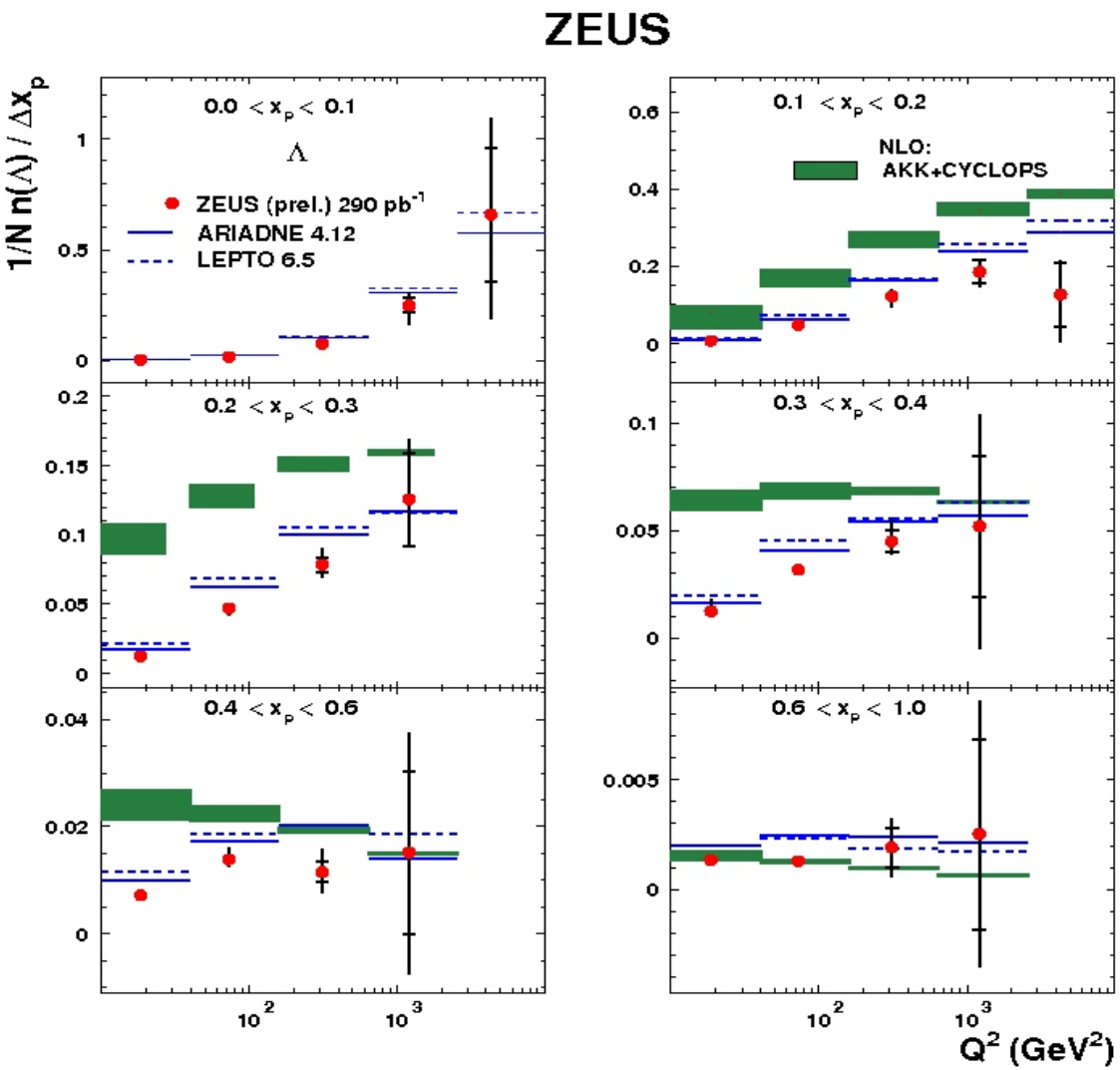



- Scaling violations are observed
- QCD NLO predictions describe the data only in certain regions of the phase space
- LO predictions :
  ARIADNE (CDM) and LEPTO (MEPS)
  describe the data in full phase space
- Hadron mass effect included in AKK+CYCLOP prediction improve agreement with the data for small $x_p$ and Q

# $\Lambda$ measurement and QCD predictions

CBF:

ZEUS : Preliminary results

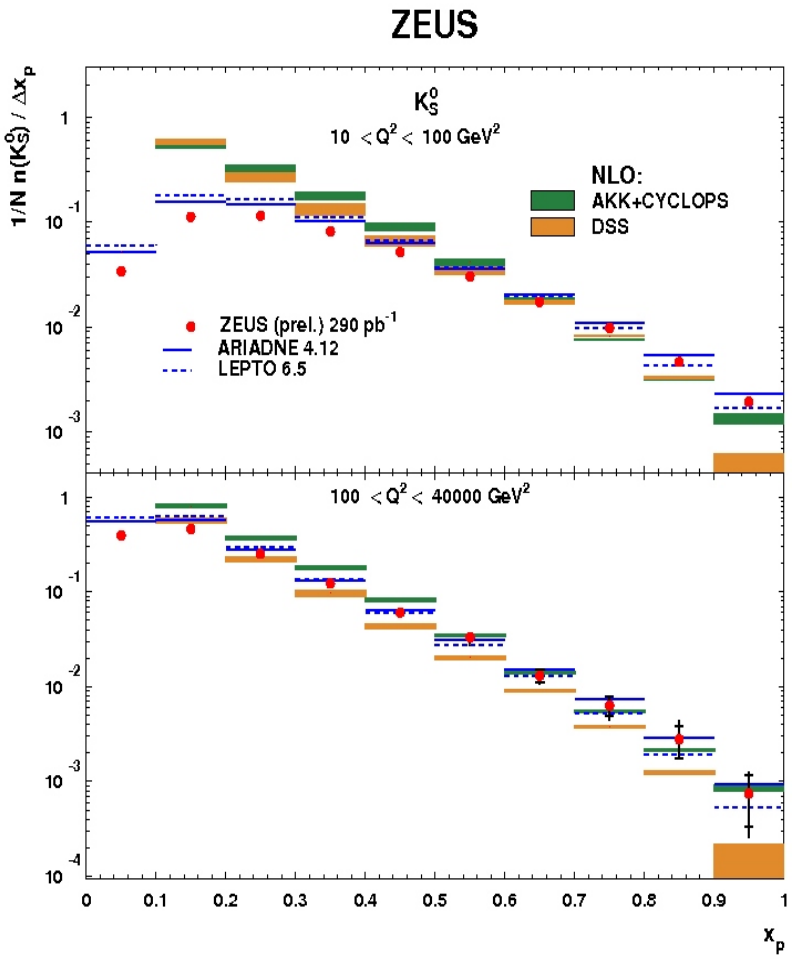


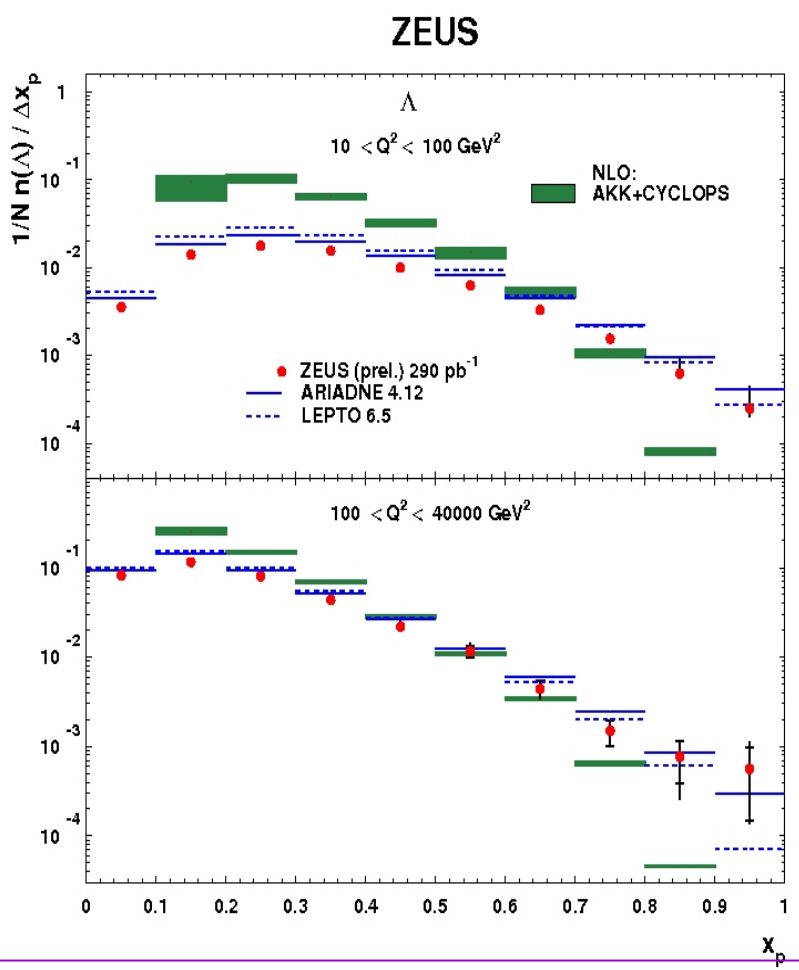

- Scaling violations are observed
- NLO QCD prediction does not descibe the data
- LO predictions : ARIADNE and LEPTO supply much better description of the data in most parts of phase space

# Scaled momentum distribution for $K^0_S$ and $\Lambda$ at low and high $Q^2$

CBF:

ZEUS : Preliminary results




- NLO QCD predictions describe the data in the high $Q^2$ region and high $x_p$
- LO MC (ARIADNE, LEPTO) gives a reasonable description of the data in full phase space

# Summary

Inclusive, light mesons and strange particles production give good tests of the hadronisation models:

- A power law distribution describes the differential cross sections for production light mesons as function of transverse momentum.
- The mesons are produced with similar value of the average transverse kinetic energy → this supports a thermodynamic picture of hadronic interactions

- $K^0_S$ and $\Lambda$ cross sections, as measured in LAB and the Breit frame, cannot be descibed at low $Q^2$ by CDM or MEPS MC using a single value of strangeness suppression factor $\lambda_s$.
  For high $Q^2$, MC with $\lambda_s = 0.286$, gives good description of the data

- Scaled momentum distributions show scaling violations
- NLO QCD predictions for different fragmentation functions, describe the data only in certain regions of the phase space.
- LO Monte Carlo (ARIADNE, LEPTO) predictions supply better agreement with data in full phase space
- We hope that the results will be useful to constrain the theoretical uncertainties in a description of the $\Lambda$ hadrons .