

# Particle Production at HERA

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on behalf of the H1 and ZEUS collaborations

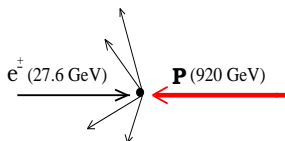
Low  $x$  workshop, Santiago de Compostela, Spain  
07 June 2011



# Outline

- Kinematics at HERA
- Charged particle production
- Strange particle production
- Summary

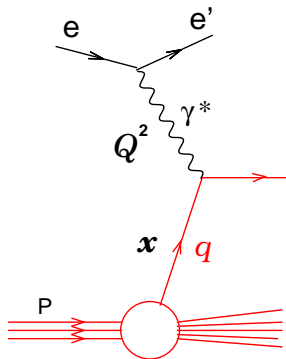
## HERA kinematics



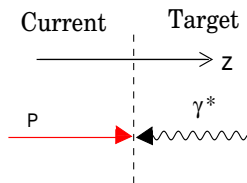
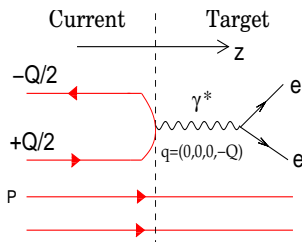
- Photon virtuality:  

$$Q^2 \equiv -q^2 = -(p_e - p_{e'})^2$$
- Momentum fraction of the struck parton of the proton:

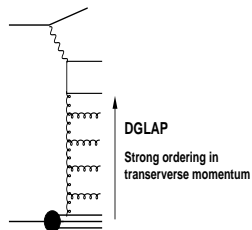
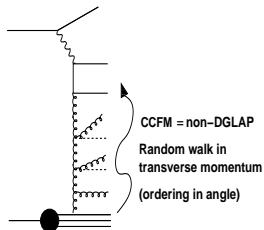
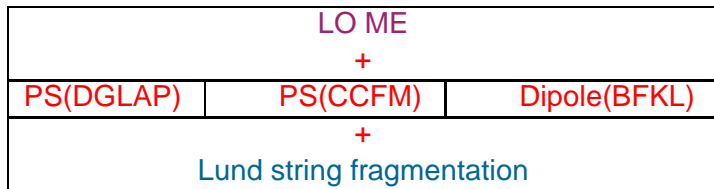
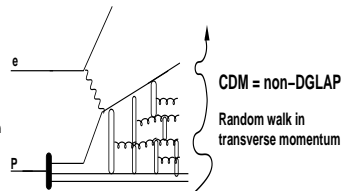
$$x_{bj} = x \equiv \frac{Q^2}{2(p \cdot q)}$$



## Reference frames

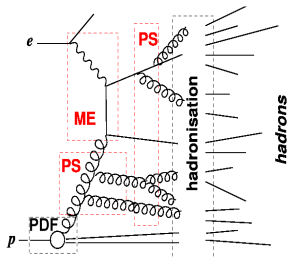
Hadronic centre-of-mass system (HCM):Breit frame (BF):

- The division into current and target hemisphere is frame dependent
- Similarity expected between  $e^+e^-$  and  $ep$  in current regions in leading order

Models for  $ep$  scatteringRAPGAP  
DGLAPCASCADE  
CCFMDJANGO  
CDM (Colour Dipole Model)

Fragmentation parameters tuned to  $e^+e^-$  data (ALEPH tune)

## Charged particle spectra



## Charged particle momentum spectra

### Motivation:

- Low- $x$  dynamic is challenging
- Semi-inclusive measurements  $ep \rightarrow e' hX$  can potentially discriminate between DGLAP and beyond-DGLAP

### H1 preliminary results:

- $5 < Q^2 < 100 \text{ GeV}^2, 10^{-4} < x < 10^{-2}$
- Measurements are performed in HCM system ( $p_T^*, \eta^*$ )

### Observable:

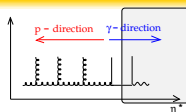
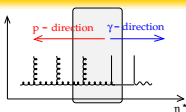
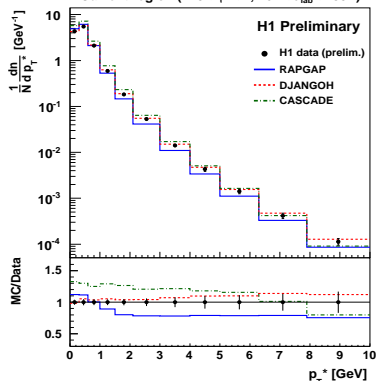
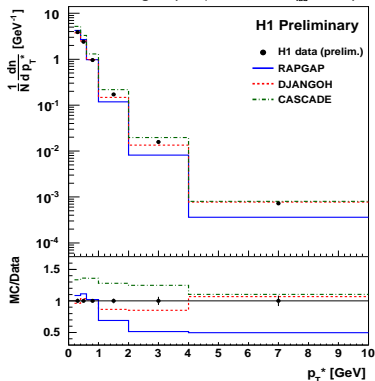
Event normalised charged particle distribution:  $\frac{1}{N_{event}} \frac{dn}{dp_T^*}$

### Low $p_T$ region:

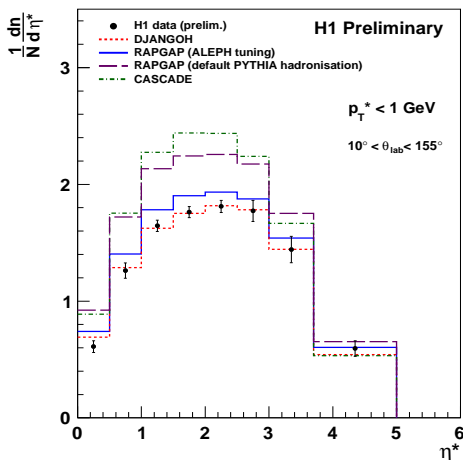
hadronisation is expected to play a role. Small sensitivity to different parton dynamic models.

### Hadrons at large $p_T$ :

disfavoured by the strong  $p_T$  ordering  $\rightarrow$  difference between different parton dynamics

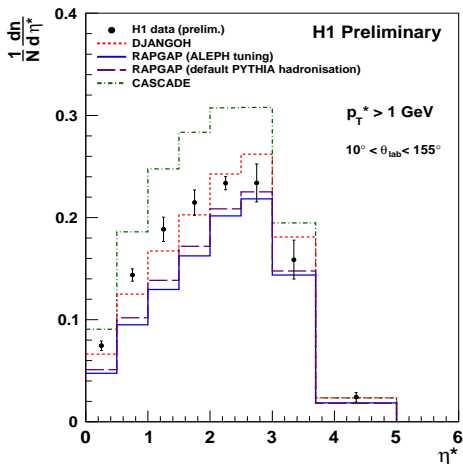
$p_T^*$  distributionCentral region ( $0 < \eta^* < 1.5$ ,  $10^\circ < \theta_{\text{lab}} < 155^\circ$ )Current region ( $1.5 < \eta^* < 4$ ,  $16^\circ < \theta_{\text{lab}} < 155^\circ$ )

- DJANGO(CDM) describes the data for whole  $p_T^*$  spectra
- RAPGAP(DGLAP) is below the data for  $p_T^* > 1$  GeV (especially in the proton direction)
- In contrast, CASCADE(CCFM) is systematically above the data (except high  $p_T^*$ )

$\eta^*$  distributionCharged particles with  $p_T^* < 1$  GeV:

Strong sensitivity to hadronisation parameters.

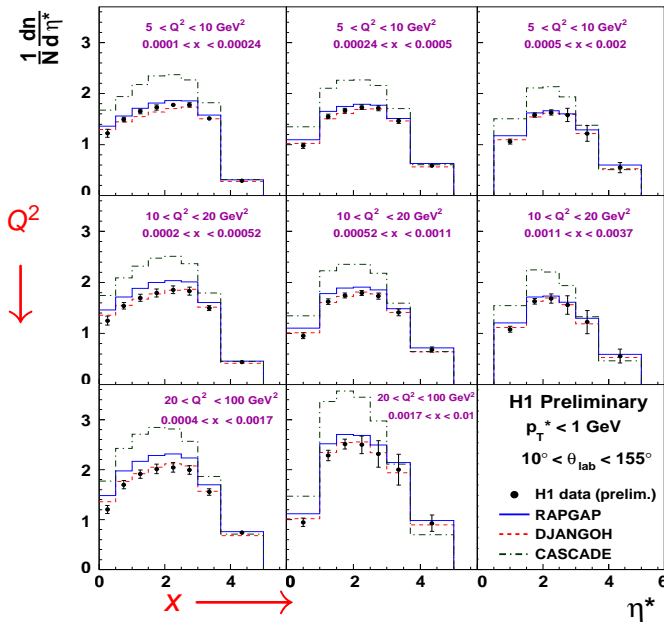
Little sensitivity to different parton dynamics.

Charged particles with  $p_T^* > 1$  GeV:

Strong sensitivity to different parton dynamics.

Little sensitivity to hadronisation parameters.



$\eta^*$  distribution in bins of  $(x, Q^2)$  for  $p_T^* < 1$  GeV

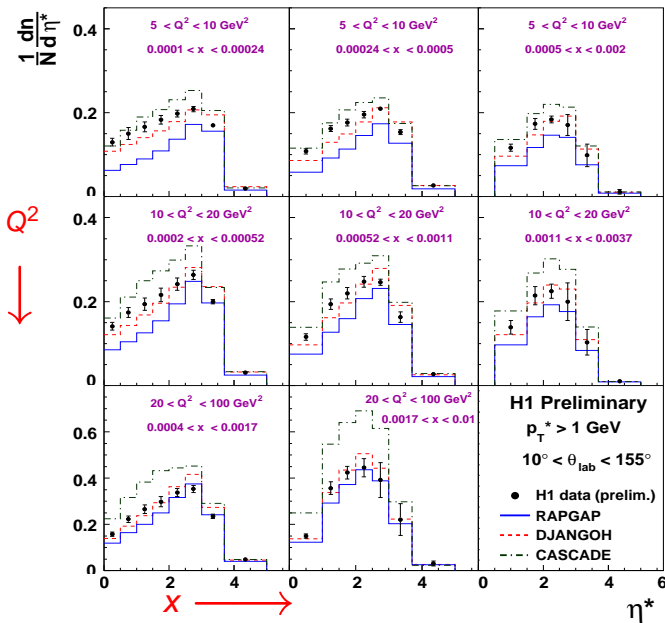
DJANGO(CDM)

provides reasonable

description of the data for  
all  $(x, Q^2)$ -bins.

RAPGAP(DGLAP) is

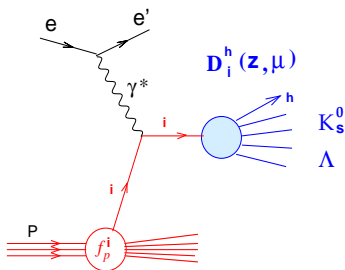
slightly above the data for  
lowest  $x$

$\eta^*$  distribution in bins of  $(x, Q^2)$  for  $p_T^* > 1$  GeV

RAPGAP(DGLAP) is below the data for almost all  $(x, Q^2)$ -bins. The difference is more pronounced in proton direction ( $\eta^* < 2$ )

## Fragmentation function

### Fragmentation function (FF) for $K_S^0$ and $\Lambda$



#### Motivation:

- Scaling violations in fragmentation functions
- Test NLO QCD calculations and universality of factorization theorem

#### ZEUS preliminary results:

- $10 < Q^2 < 40000 \text{ GeV}^2$ ,  $0.001 < x < 0.75$
- Measurements are performed in current region of Breit frame (similarity with  $e^+e^-$ )

$$\frac{d\sigma}{dx_p} = f(x, Q^2) \otimes \hat{\sigma}(Q^2) \otimes D(z, Q^2)$$

Scale dependence of FF is governed by an evolution equation

#### Observables:

$$x_p = \frac{|\vec{p}_h|}{p_{h,max}} = \frac{2p_h}{Q} \text{ (Breit frame); } h = K_S^0 \text{ and } \Lambda$$

Event normalised scaled momentum distribution:  $\frac{1}{N_{event}} \frac{dn}{dx_p}$

## NLO QCD calculations

### Comparison of $K_S^0$ and $\Lambda$ production with NLO QCD calculations + FF

$$\frac{d\sigma}{dx_p} = f(x, Q^2) \otimes \hat{\sigma}(Q^2) \otimes D(z, Q^2)$$

$\hat{\sigma}(Q^2)$  - hard-scattering process calculated with NLO matrix element

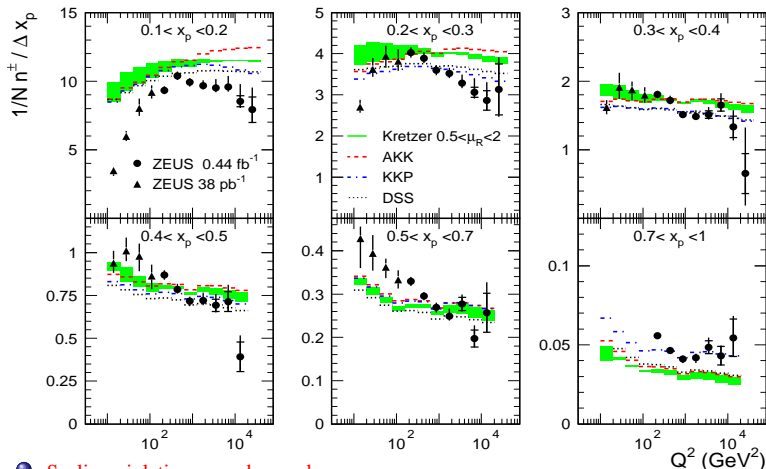
Two different approaches are compared with the data:

- AKK05+CYCLOPS (for  $K_S^0$  and  $\Lambda$ )
  - S. Albino, B.A. Kniehl, G. Kramer, Nucl. Phys. B 725 (2005) 181  
S. Albino, B.A. Kniehl, G. Kramer, Nucl. Phys. B 734 (2006) 50
  - FFs were obtained from fits to  $e^+e^-$  data
  - Hadrons mass effect are included
- DSS (for  $K_S^0$ )
  - D. de Florian, R. Sassot, M. Stratmann, Phys. Rev. D75 (2007) 114010
  - FFs were obtained from fits to  $lp$  and  $pp$  data
  - Hadrons mass effect are not included

## Scaled momentum distributions for charged particles

ZEUS: JHEP06(2010)009

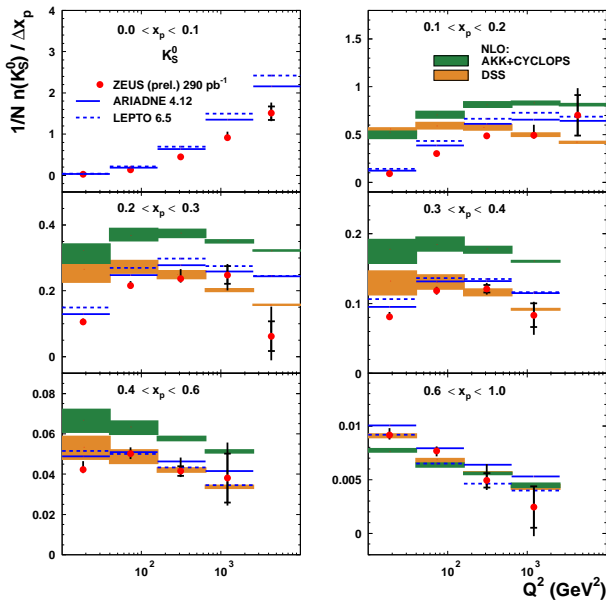
## ZEUS



- Scaling violations are observed
- NLO QCD calculations describe the data only in certain region of the phase space

Scaled momentum distributions:  $K_S^0$ 

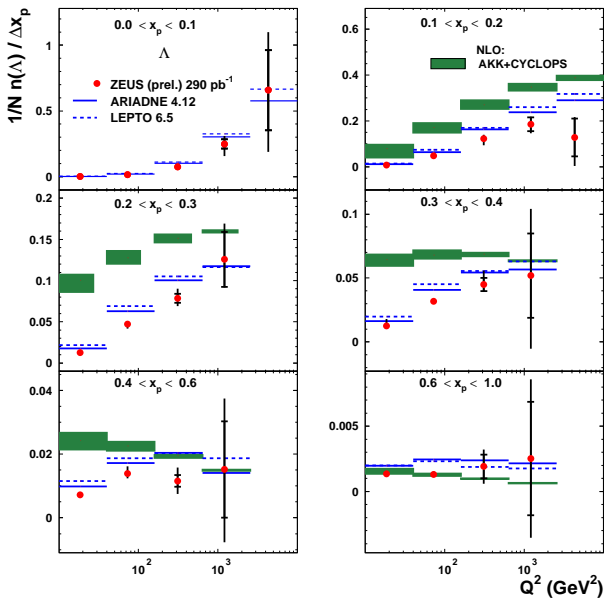
## ZEUS



- Scaling violations are observed
- ARIADNE(CDM) and LEPTO(DGLAP) describe the data in full phase space
- QCD NLO predictions describe the data only in certain regions of the phase space

Scaled momentum distributions:  $\Lambda$ 

## ZEUS



- Scaling violations are observed
- ARIADNE(CDM) and LEPTO(DGLAP) describe the data in most parts of phase space
- QCD NLO predictions do not describe the data

## Summary

### ● Charged particle production

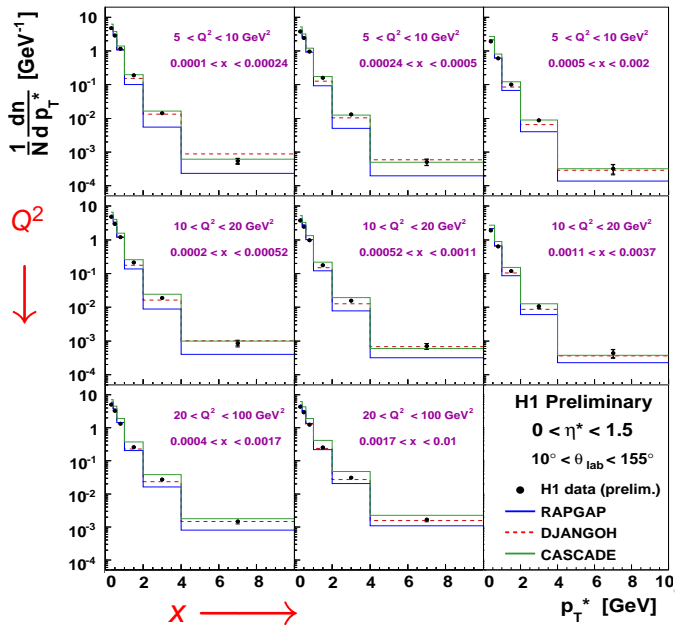
- Low  $p_T^*$  region ( $p_T^* < 1$  GeV):
  - Sensitivity to the fragmentation parameters
  - Both DGLAP and CDM provide reasonable description of the data for both  $p_T^*$  and  $\eta^*$  distributions
- Hard  $p_T^*$  region ( $p_T^* > 1$  GeV):
  - Sensitivity to the different parton dynamic models
  - CDM is better than DGLAP in describing both,  $p_T^*$  and  $\eta^*$  measured spectra, especially at low  $x$

### ● Strange particle production

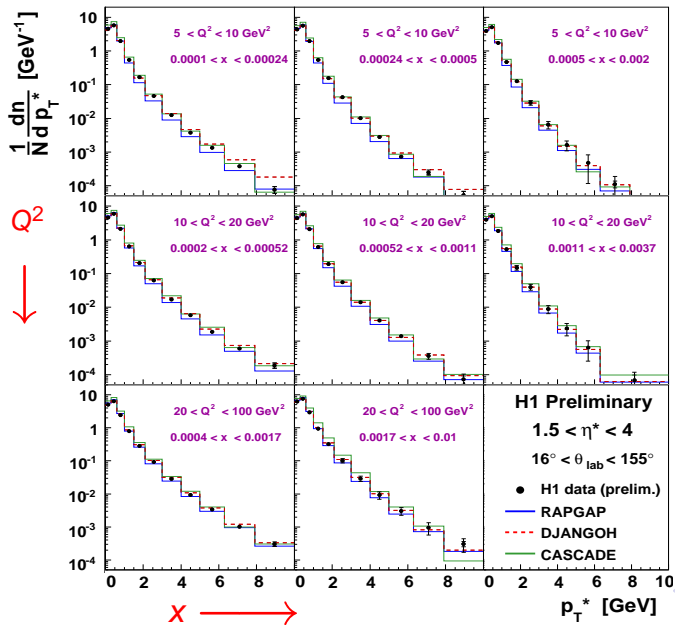
- Scaled momentum distributions ( $K_S^0, \Lambda$ ) show the scaling violation
- Both DGLAP and CDM describe the data in all phase space
- NLO QCD calculations describe the data only in certain region of the phase space



# Back up slides

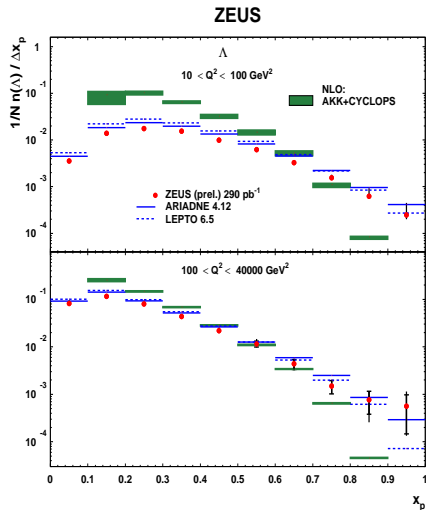
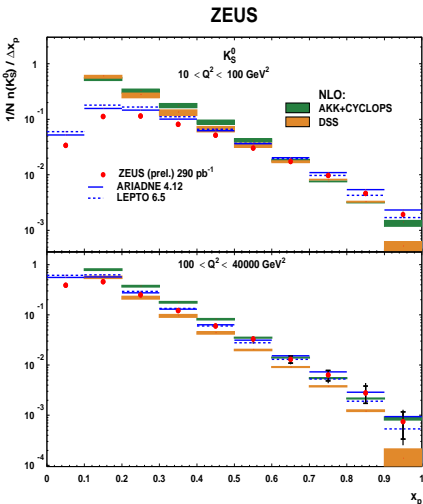
$p_T^*$  distribution in bins of  $(x, Q^2)$ ; central region

RAPGAP(DGLAP) is substantially below the data at lowest  $x$  and  $Q^2$  region at large  $p_T^*$

$p_T^*$  distribution in bins of  $(x, Q^2)$ ; current region region

RAPGAP(DGLAP)  
 provides better  
 description of the data  
 compared to the forward  
 region

# Scaled momentum distributions in low and high $Q^2$ as function of $x_p$



- MCs describe the data in all phase space.
- Description of NLO QCD calculations (AKK+CYCLOPS, DSS) become better at high  $Q^2$  and high  $x_p$