Particle Production at HERA

Anastasia Grebenyuk

on behalf of the H1 and ZEUS collaborations

Low x workshop, Santiago de Compostela, Spain
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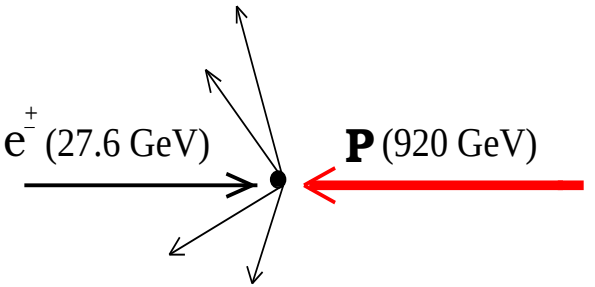
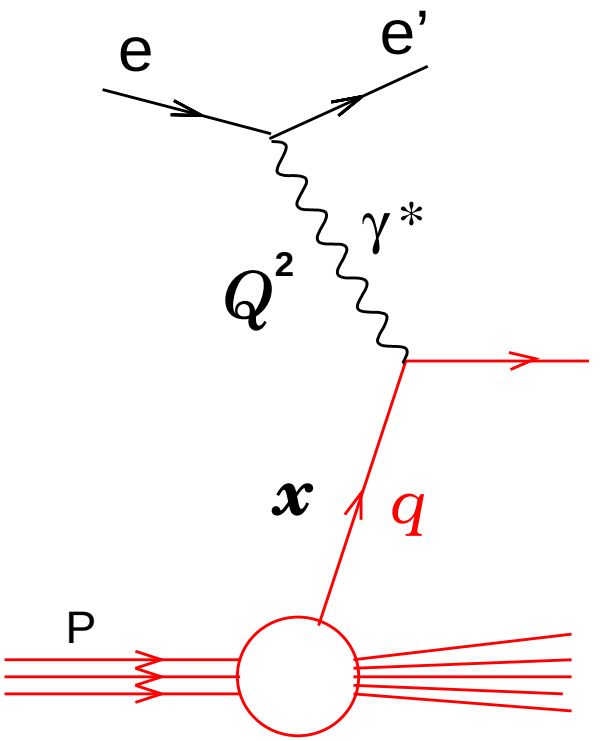
Outline

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

HERA kinematics

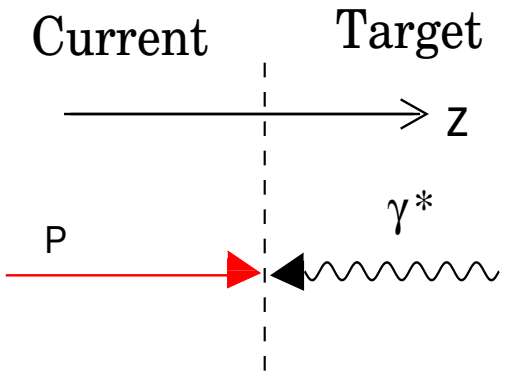




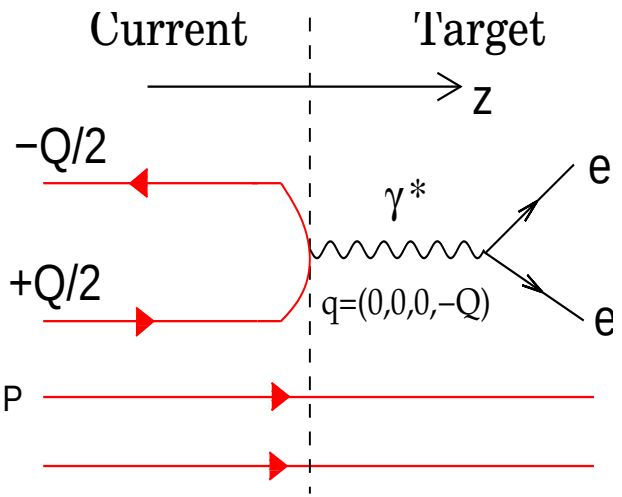
- Photon virtuality:
  $Q^2 \equiv -q^2 = -(p_e - p'_e)^2$
- Momentum fraction of the struck parton of the proton:
  $x_{bj} = x \equiv \frac{Q^2}{2(p,q)}$

Reference frames

Hadronic centre-of-mass system (HCM):



Breit frame (BF):



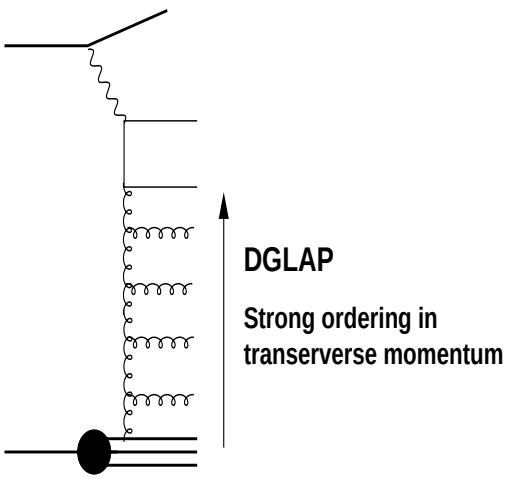
- The division into current and target hemisphere is frame dependent
- Similarity expected between e^+e^- and ep in current regions in leading order

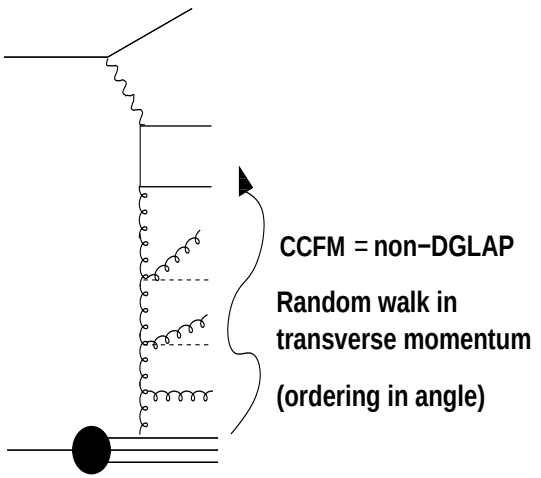
Models for *ep* scattering

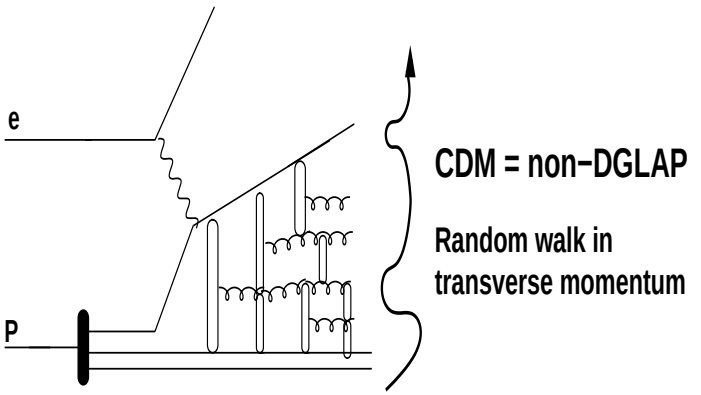
RAPGAP
DGLAP

CASCADE
CCFM

DJANGOH
CDM (Colour Dipole Model)



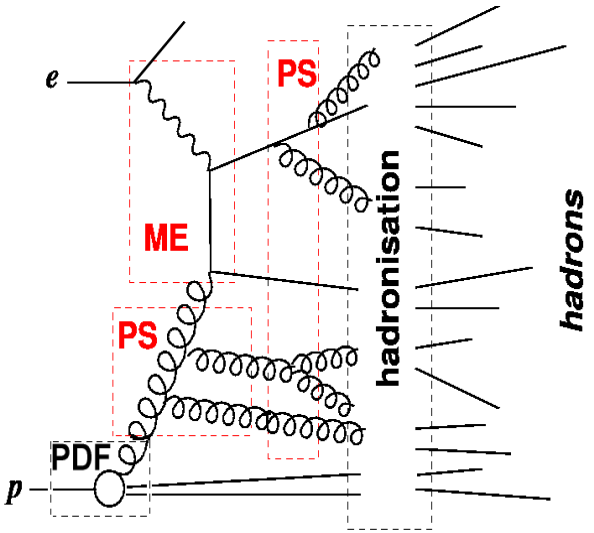




LO ME +
PS(DGLAP) | PS(CCFM) | Dipole(BFKL)
+ Lund string fragmentation

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

Charged particle spectra



H1 preliminary results:

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

Observable:

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

Charged particle momentum spectra

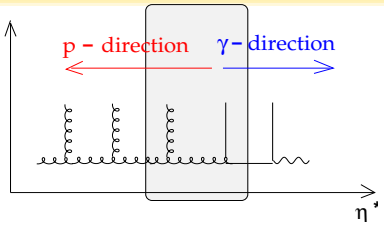
Motivation:

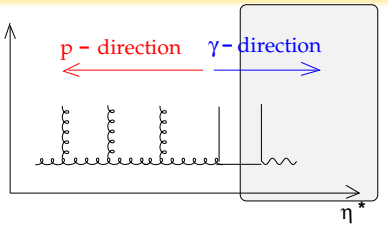
- Low-x dynamic is challenging
- Semi-inclusive measurements $ep \to e'hX$ can potentially discriminate between DGLAP and beyond-DGLAP

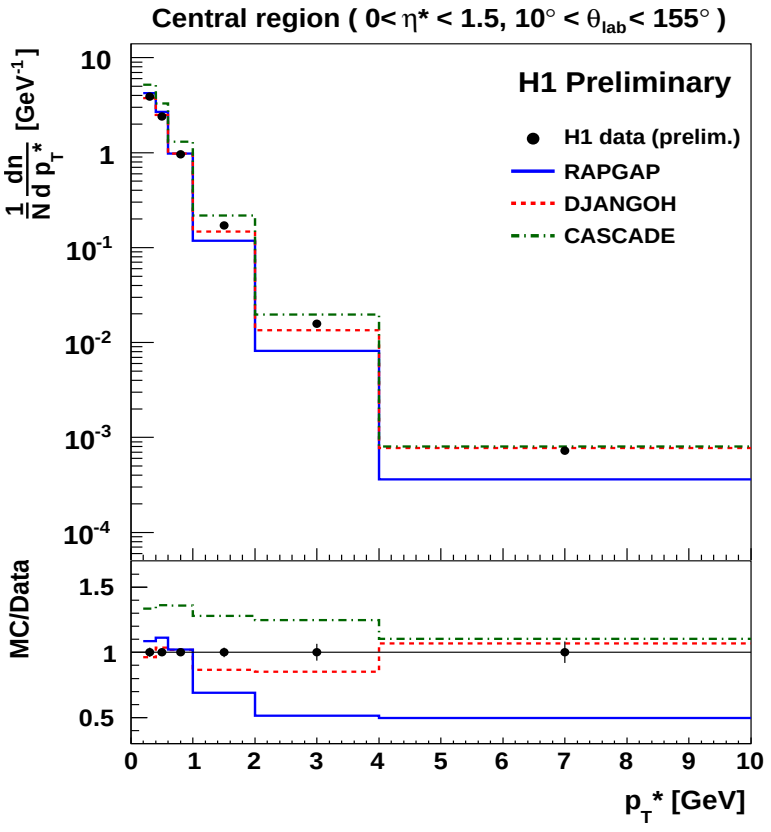
Low p_T region:
hadronisation is expected to play a role.
Small sensitivity to different parton dynamic models.

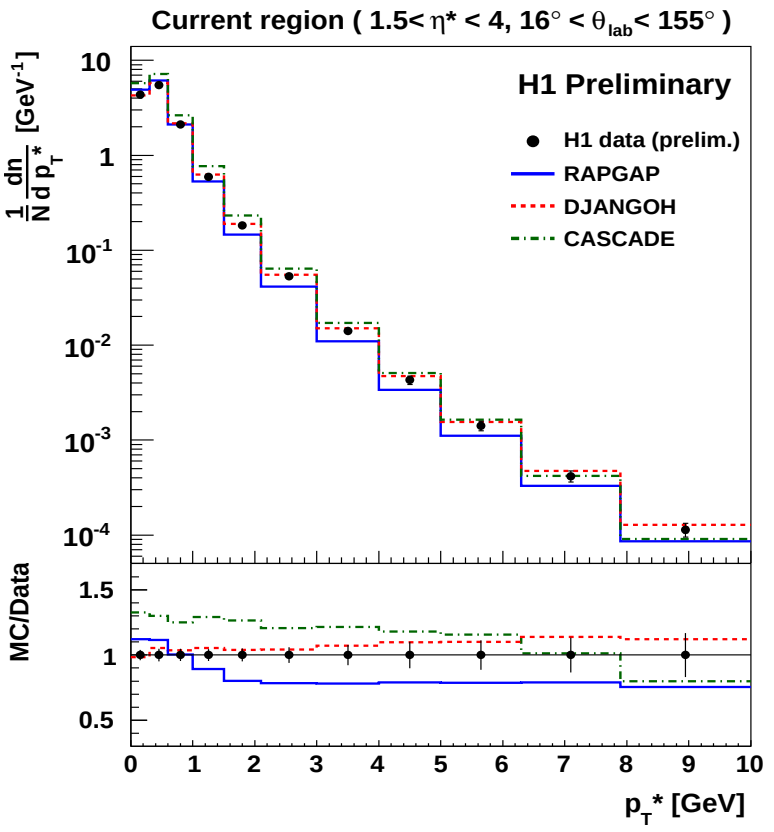
Hadrons at large p_T:
disfavoured by the strong p_T ordering $\to$ difference between different parton dynamics

p_T^* distribution





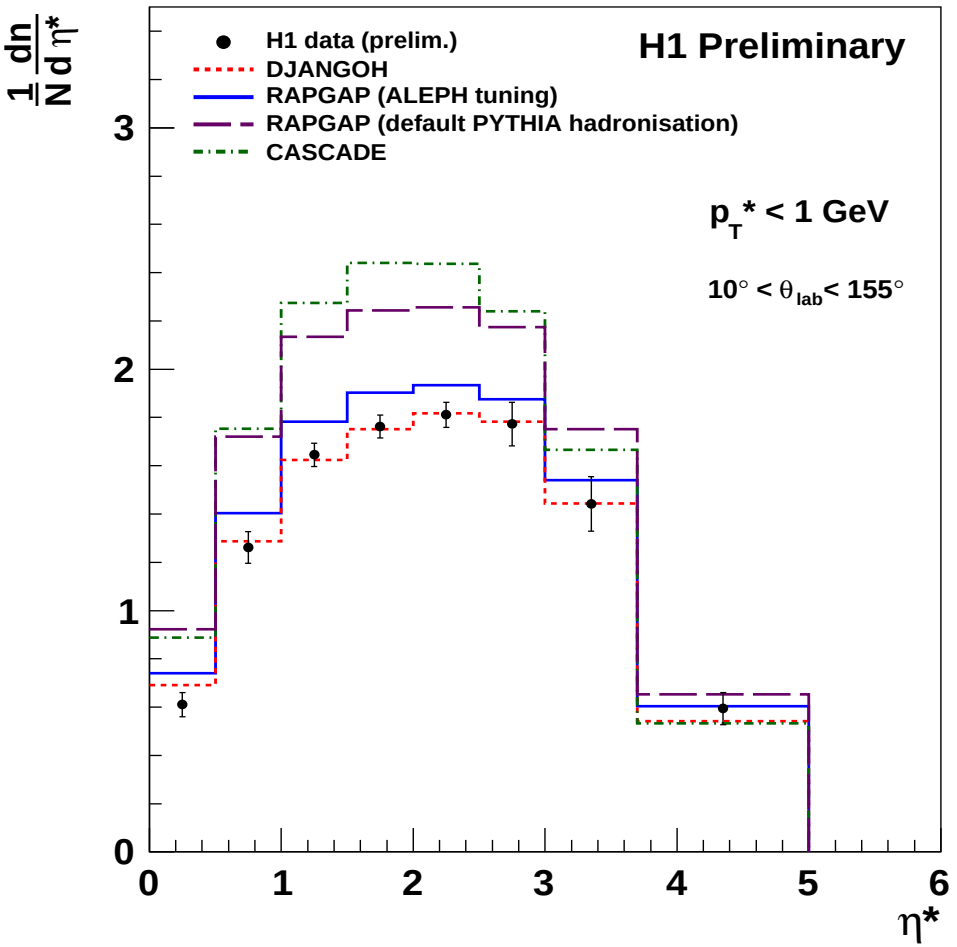




- DJANGOH(CDM) describes the data for whole p_T^* spectra
- RAPGAP(DGLAP) is below the data for $p_T^* > 1$ GeV (especially in the proton direction)
- In contrast, CASCADE(CCFM) is systematically above the data (except high p_T^*)

η^* distribution

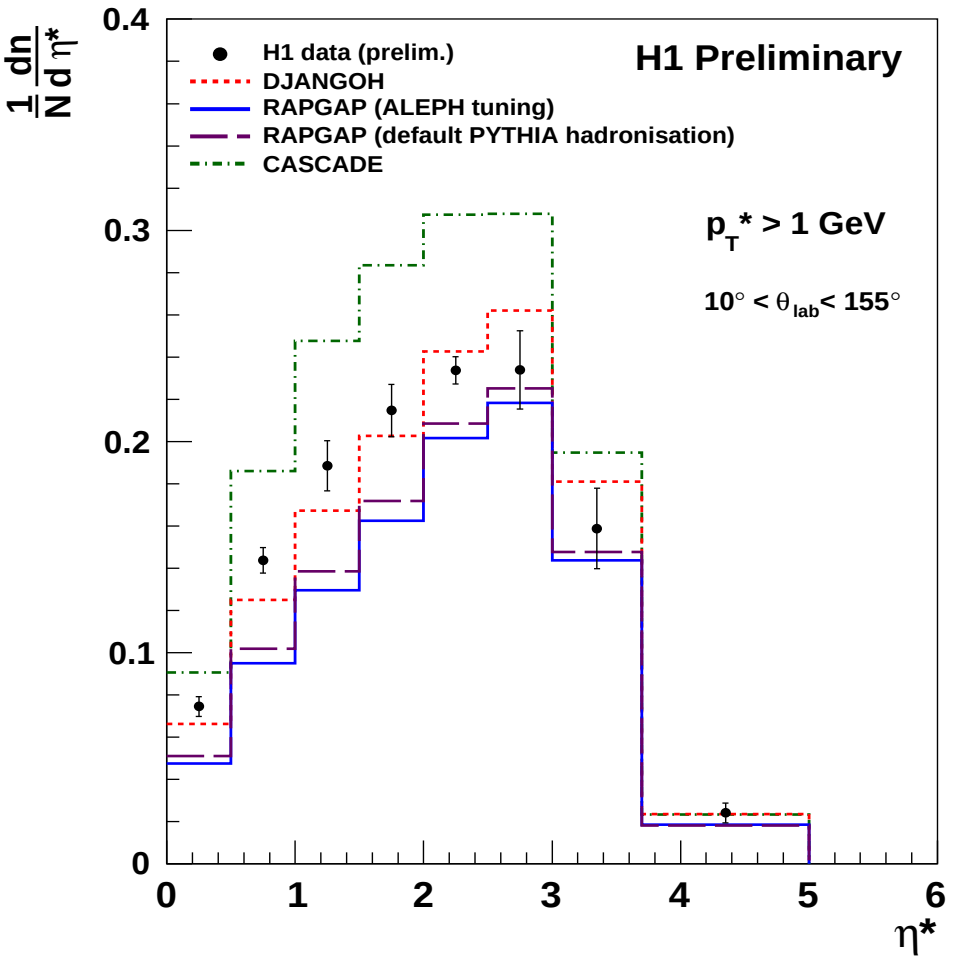
Charged particles with $p_T^* < 1$ GeV:



Strong sensitivity to hadronisation parameters.

Little sensitivity to different parton dynamics.

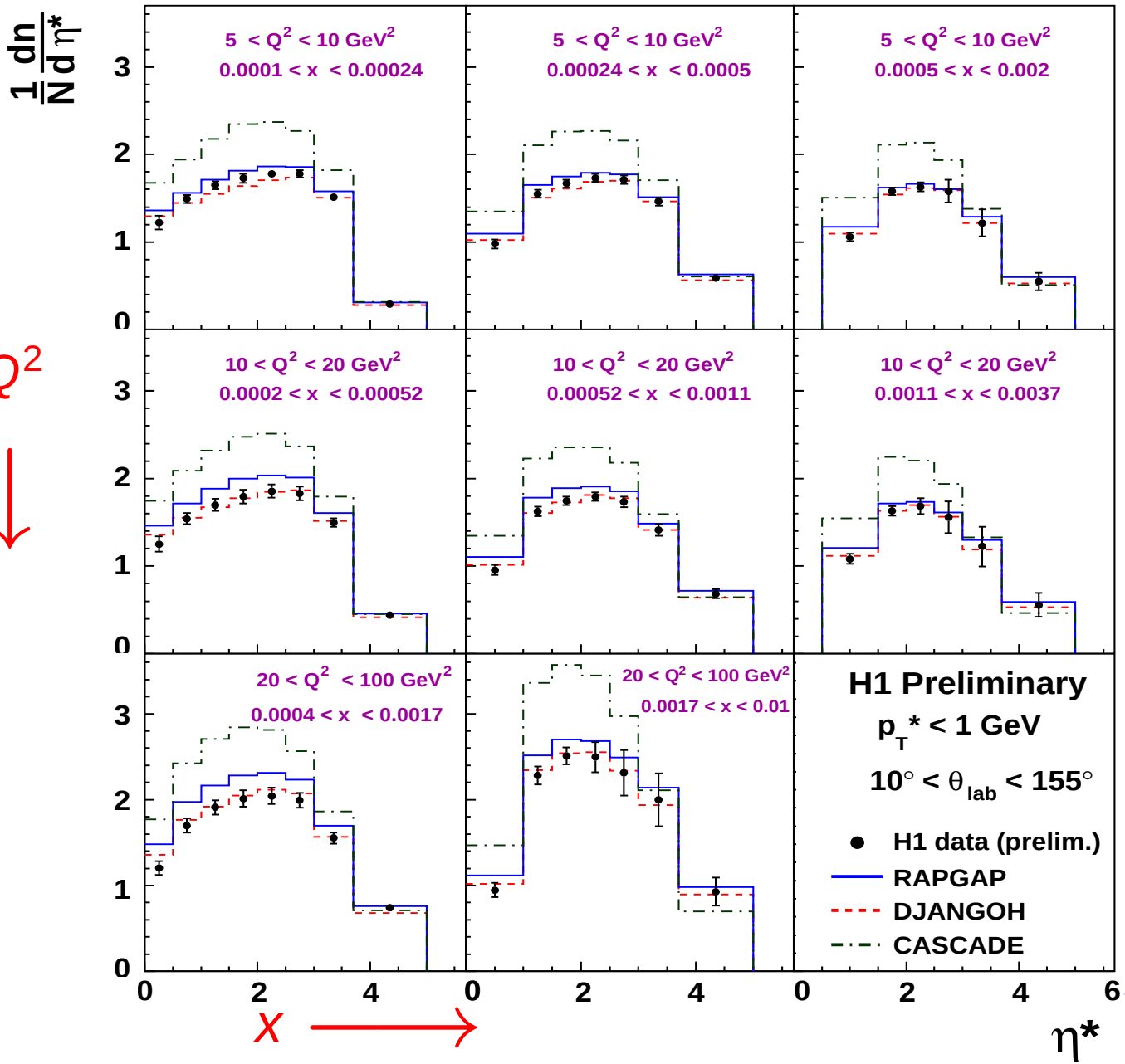
Charged particles with $p_T^* > 1$ GeV:



Strong sensitivity to different parton dynamics.

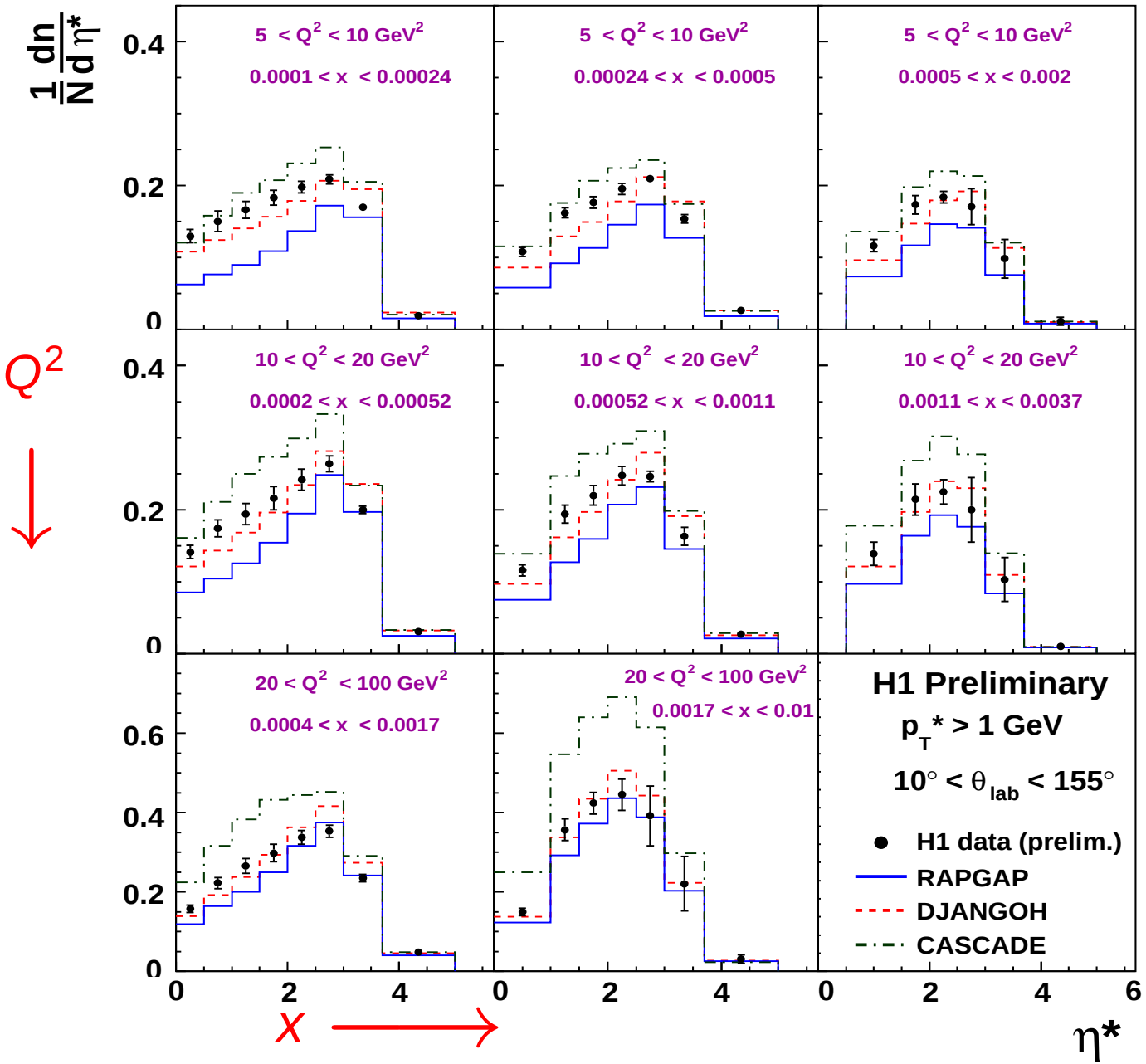
Little sensitivity to hadronisation parameters.

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



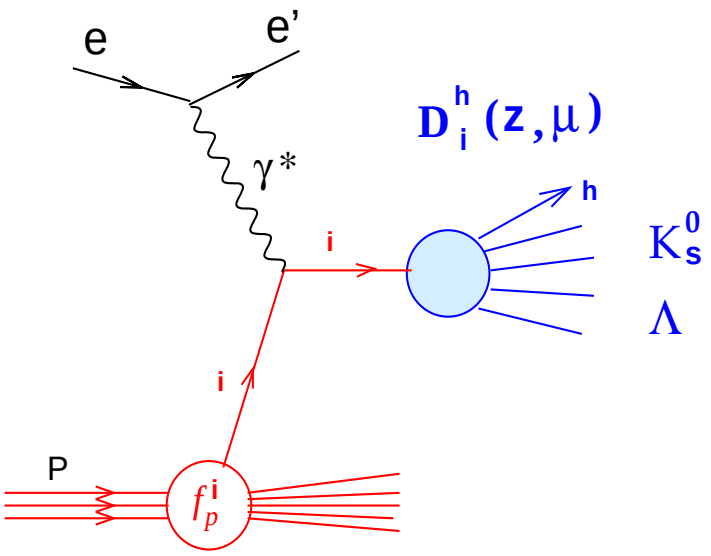
DJANGOH(CDM) provides reasonable description of the data for all (x, Q^2)-bins. RAPGAP(DGLAP) is slightly above the data for lowest x

η^* 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



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

Scale dependence of FF is government by an evolution equation

Fragmentation function (FF) for K_s^0 and Λ

Motivation:

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

ZEUS preliminary results:

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

Observables:

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

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

NLO QCD calculations

Comparison of K_s^0 and Λ production with NLO QCD calculations + FF

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

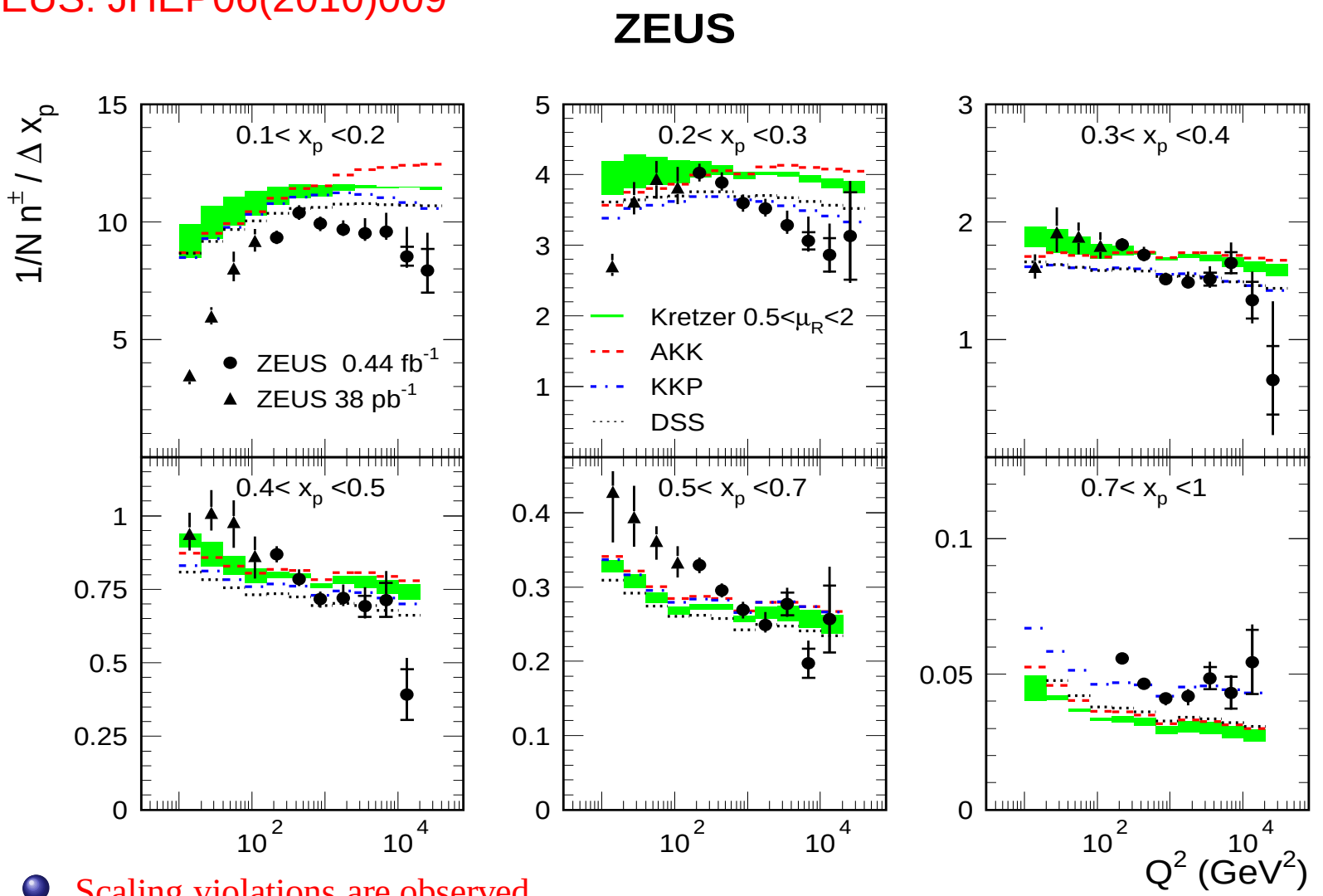
$\hat{\sigma}(Q^2)$ - hard-scattering process calculated with NLO matrix element

Two different approaches are compared with the data:

- AKK05+CYCLOPS (for K_s^0 and Λ)
  - 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

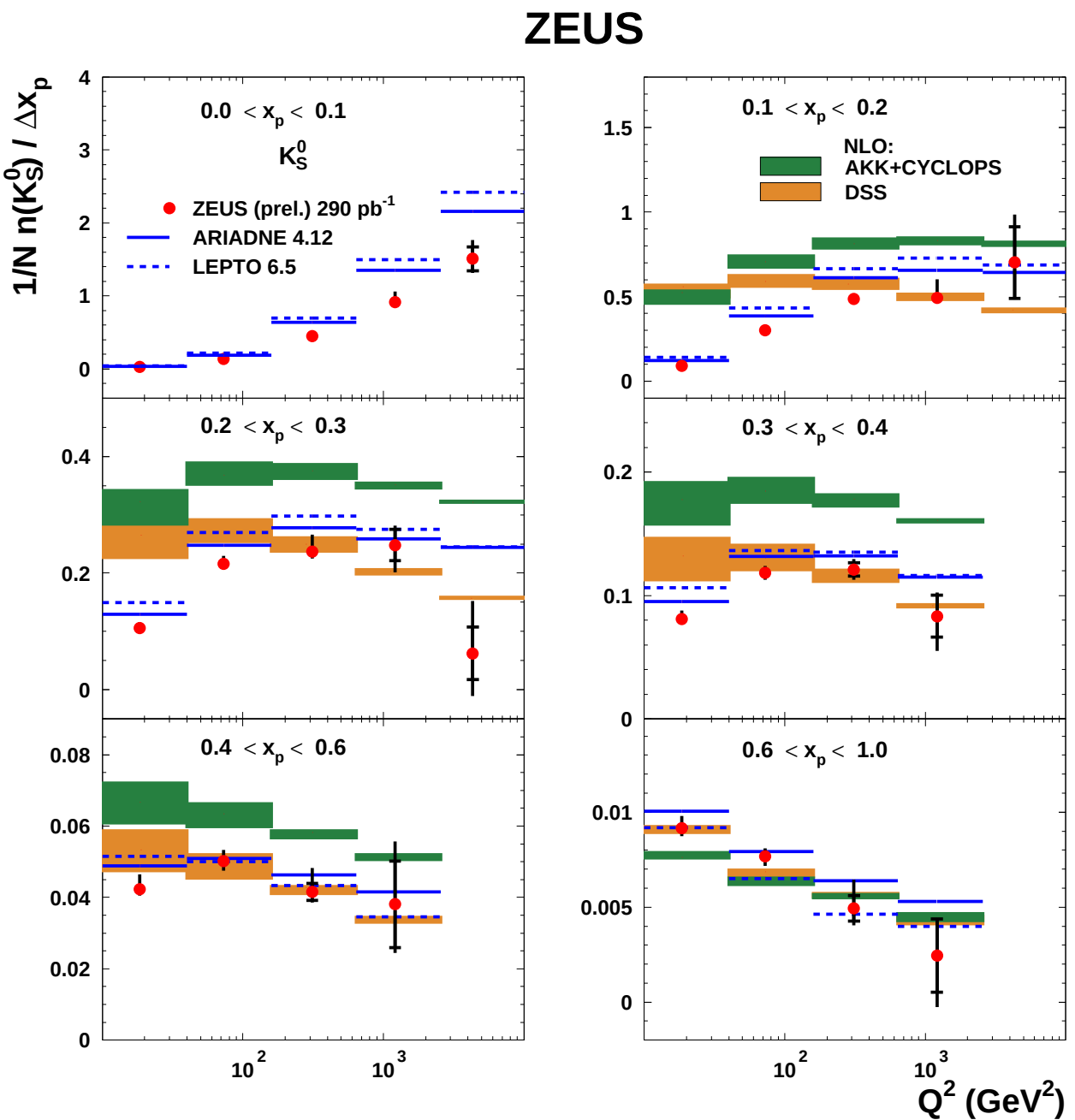
Scaled momentum distributions for charged particles

ZEUS: JHEP06(2010)009



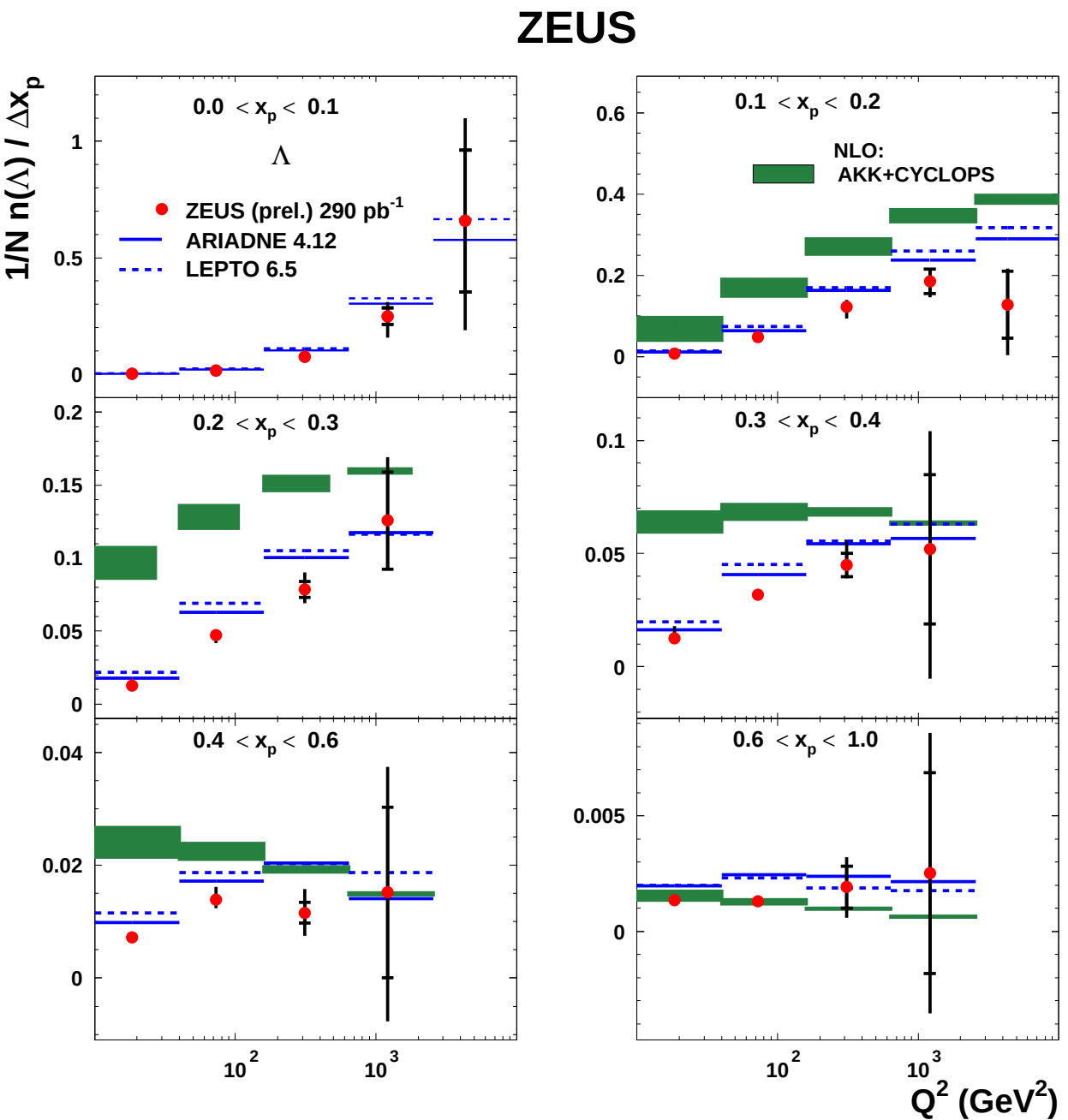
- Scaling violations are observed
- NLO QCD calculations describe the data only in certain region of the phase space

Scaled momentum distributions: K^0_S



- 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: Λ



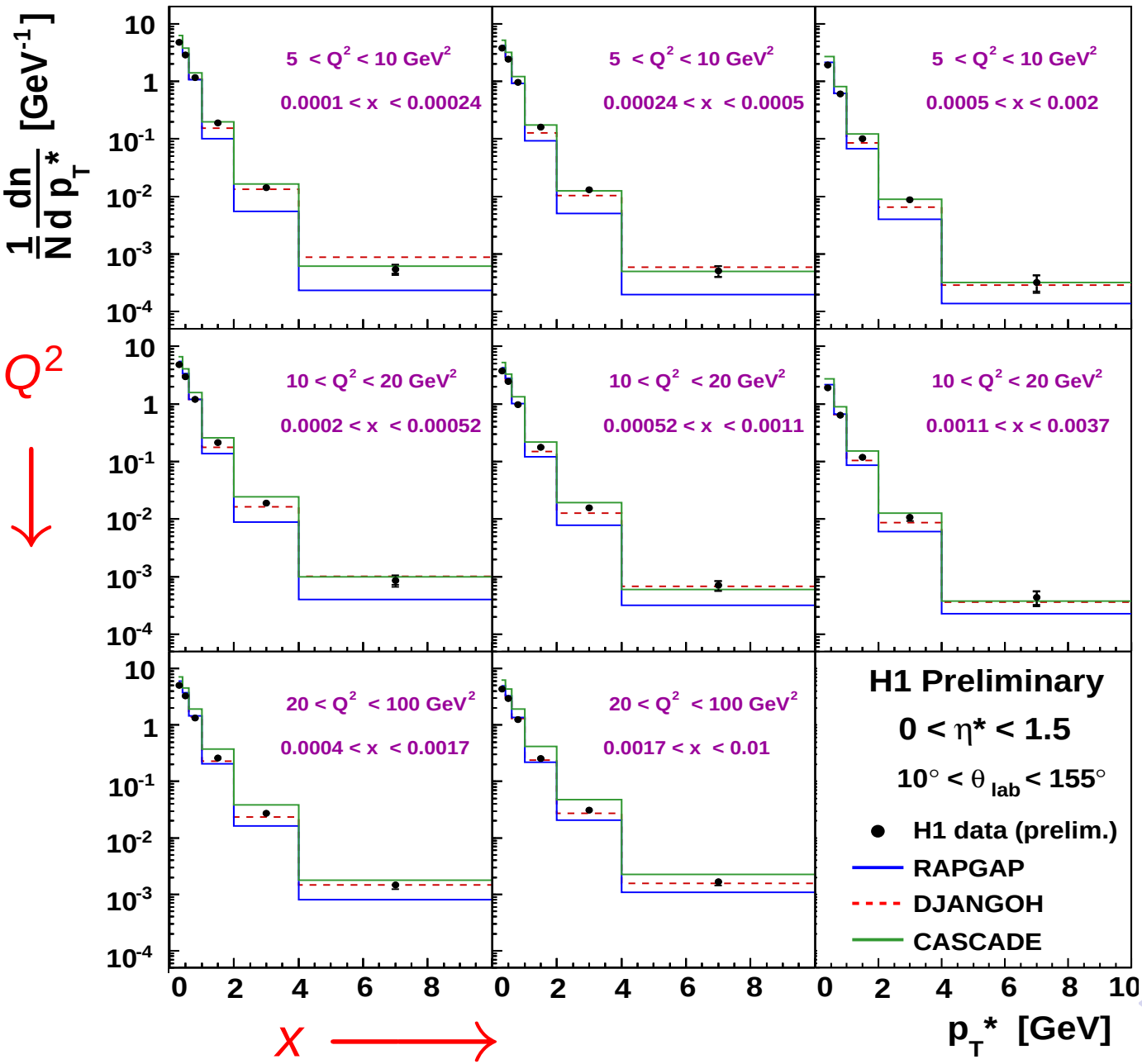
- Scaling violations are observed
- ARIADNE(CDM) and LEPTO(DGLAP) describe the data in most parts of phase space
- QCD NLO predictions do not describe the data

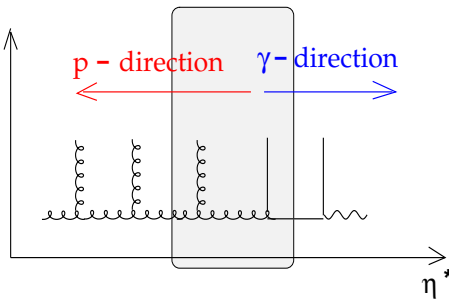
Summary

- 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 η^* 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 η^* measured spectra, especially at low x
- Strange particle production
  - Scaled momentum distributions (K_s^0,Λ) 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

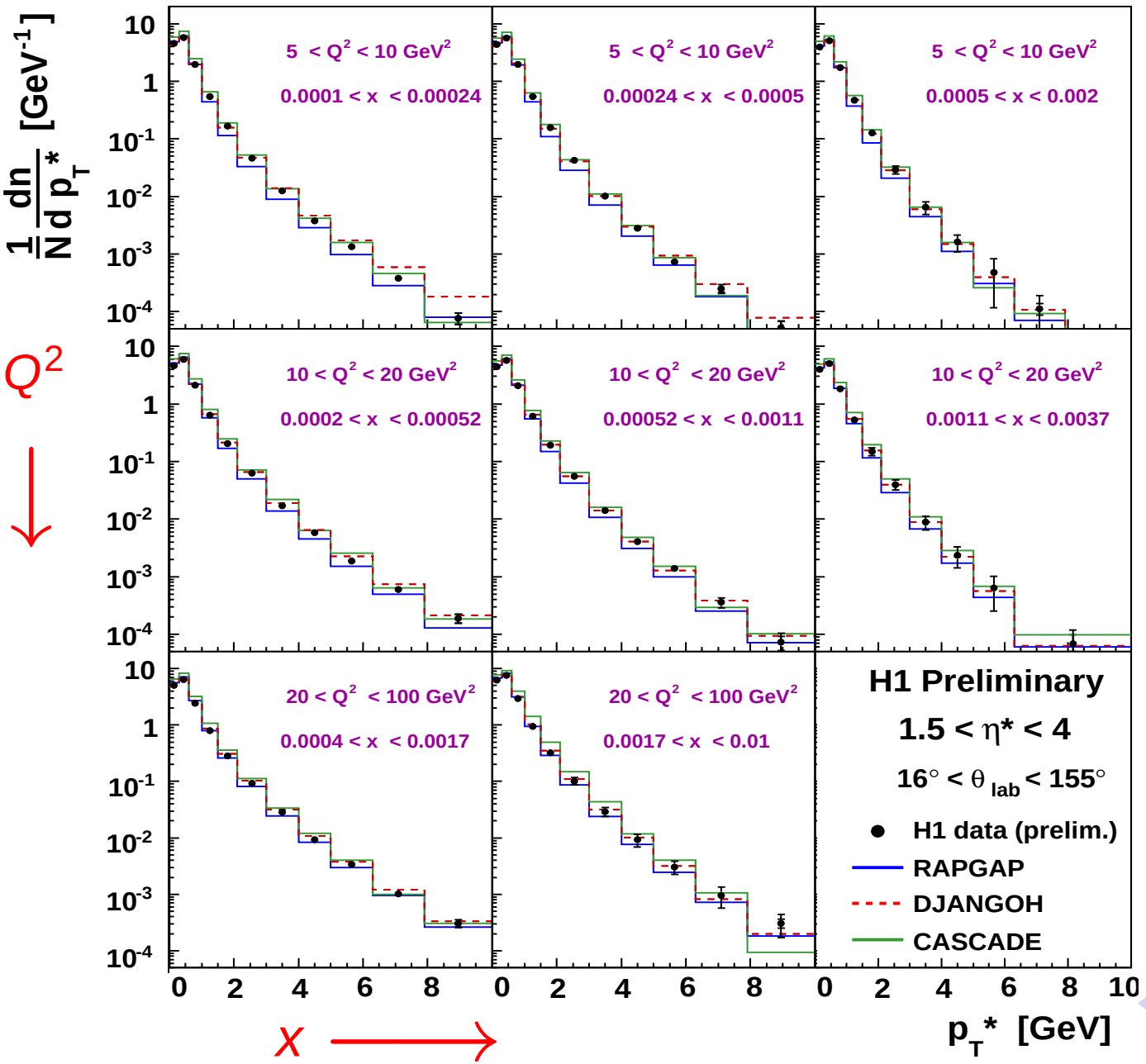
p_T^* distribution in bins of (x, Q^2); central region

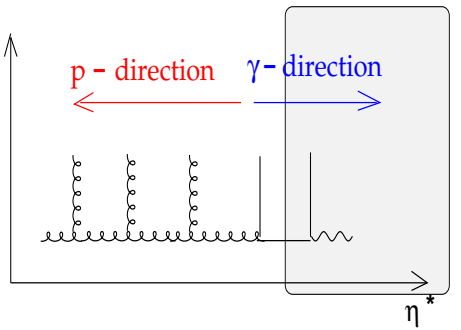




RAPGAP(DGLAP) is substantially below the data at lowest x and Q^2 region at large p_T^*

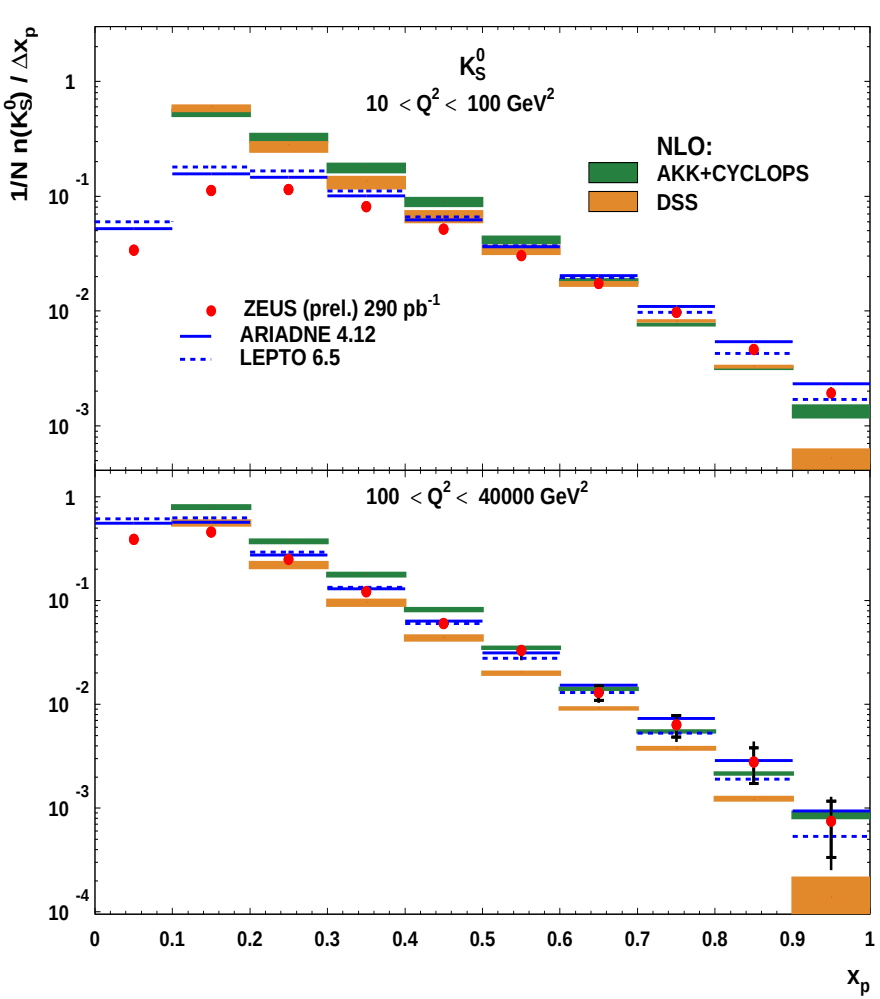
p_T^* distribution in bins of (x, Q^2); current region region

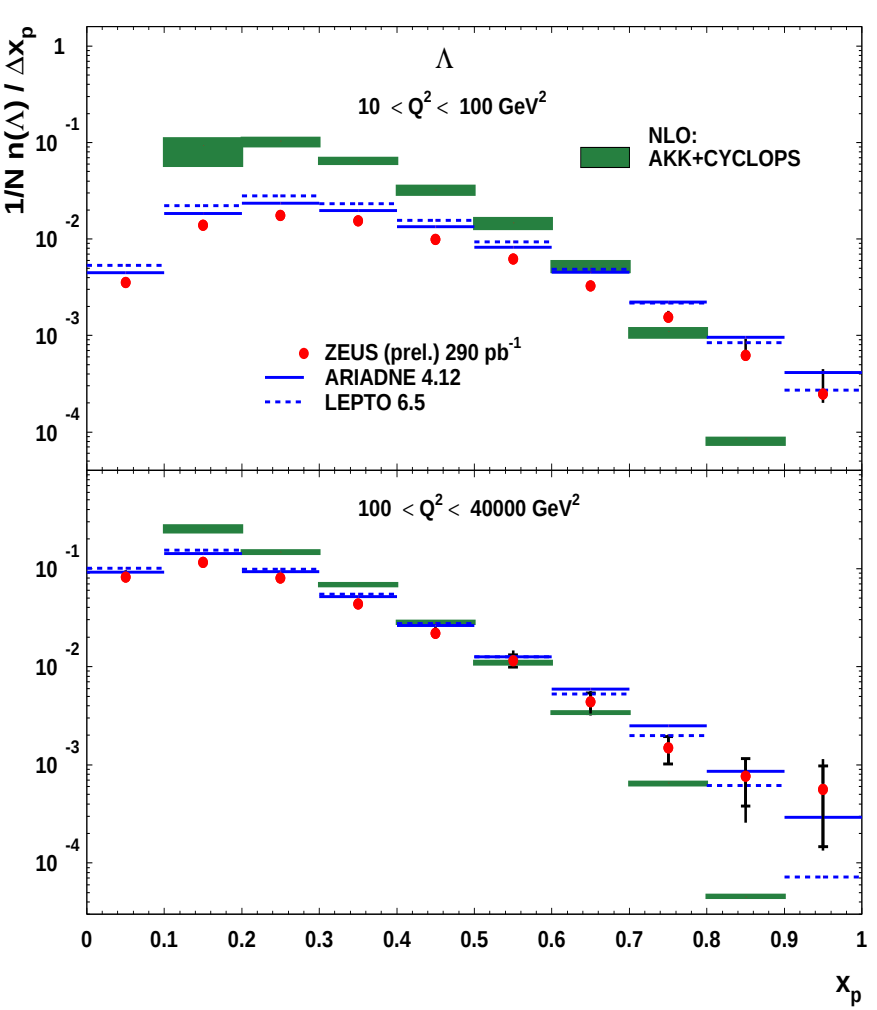




RAPGAP(DGLAP) provides better description of the data compared to the forward region

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