Parton dynamics
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Hadronisation
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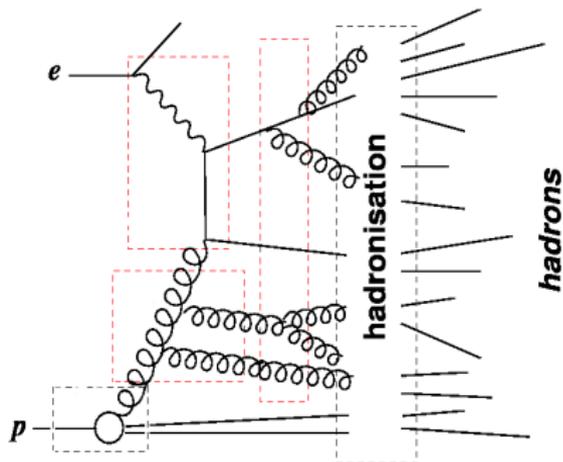
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Particle Production at HERA

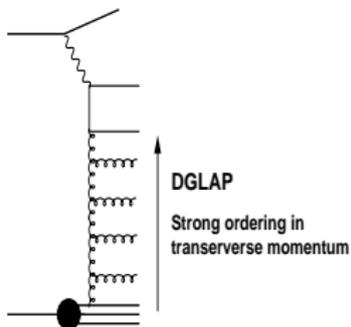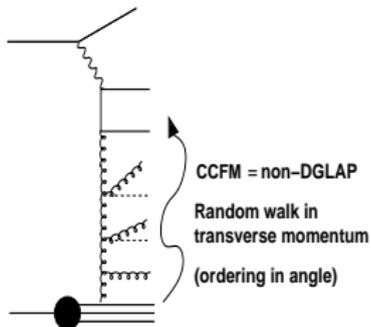### Anastasia Grebenyuk
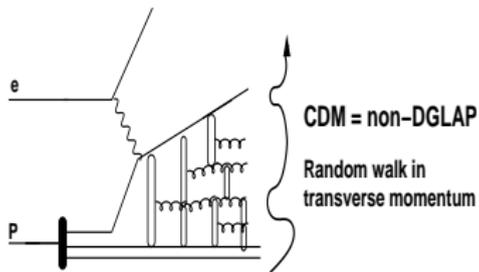
on behalf of the H1 and ZEUS collaborations

ICHEP 2012, Melbourne
5 July 2012

Outline

Models for *ep* scattering

RAPGAP
DGLAP

CASCADE
CCFM

DJANGOH
CDM (Colour Dipole Model)

LO ME		
+		
PS(DGLAP)	PS(CCFM)	Dipole(BFKL-like)
+		
String fragmentation		

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

Parton dynamics
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Transverse momentum spectra of charged particles
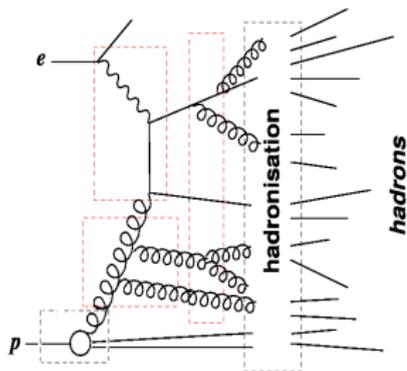
Low p_T region:
hadronisation is expected to play a role.
Small sensitivity to different parton dynamic models.

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

Observable:

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

Motivation:

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

H1 preliminary results (H1prelim-11-035):

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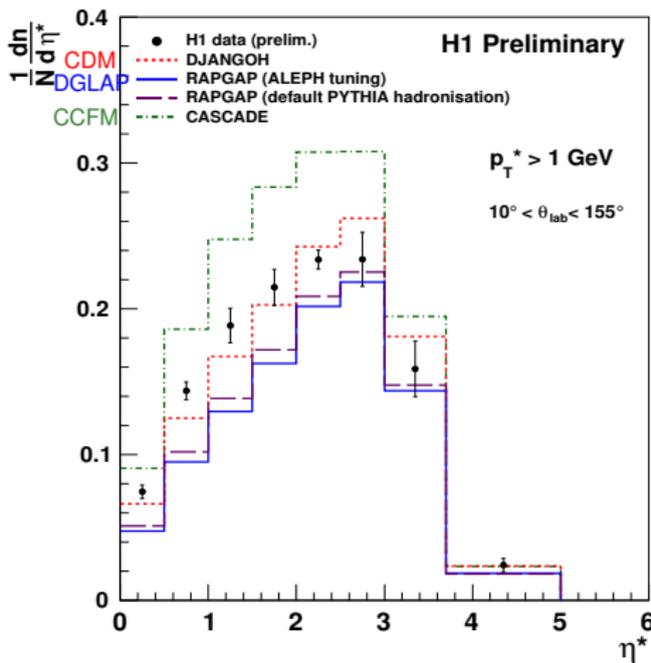- Measurements are performed in hadronic
  centre-of-mass system (p_T^*, η^*)

p_T^* distribution

Target   Current
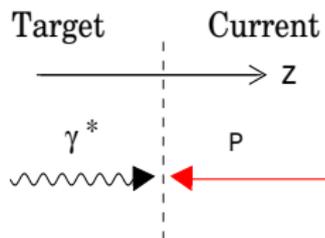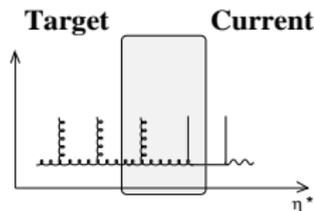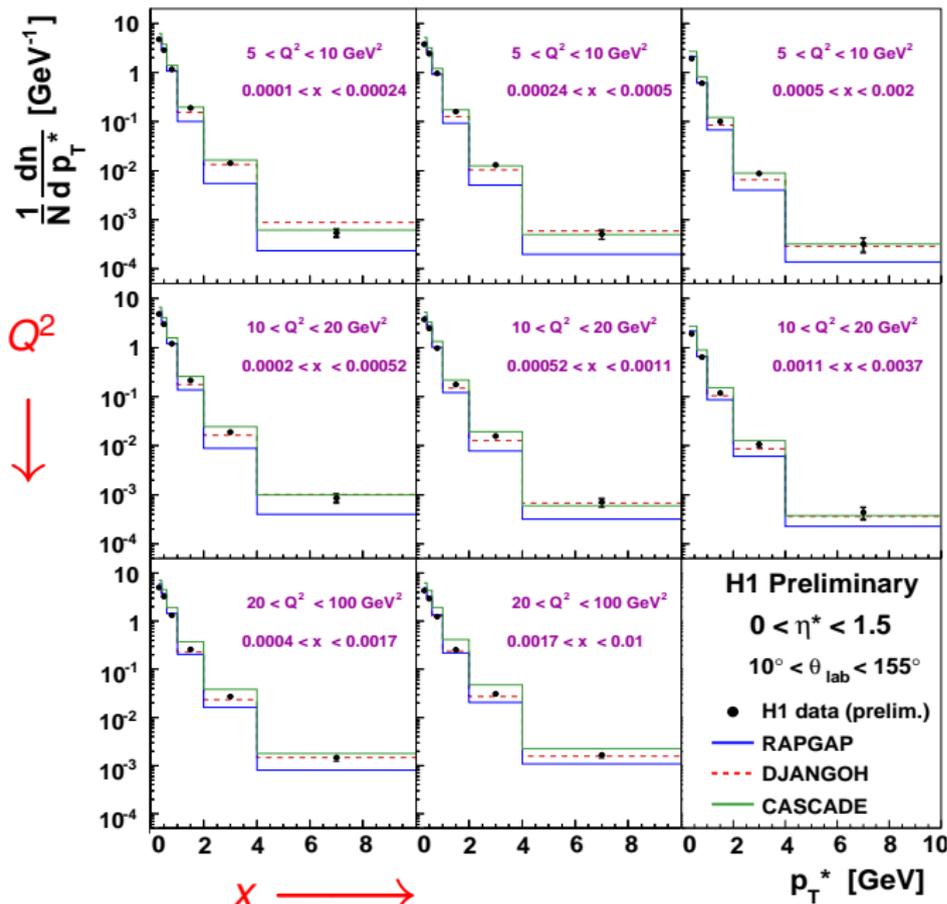
DJANGOH(CDM) describes the data for whole p_T^* spectra

strong deviation from RAPGAP(DGLAP) at low x and Q^2

CASCADE(CCFM) describes the data at high p_T^*

Figure labels:

$\frac{1}{N}\frac{dn}{dp_T^*}$ [GeV^{-1}]

$5 < Q^2 < 10$ GeV^2 $0.0001 < x < 0.00024$

$5 < Q^2 < 10$ GeV^2 $0.00024 < x < 0.0005$

$5 < Q^2 < 10$ GeV^2 $0.0005 < x < 0.002$

$10 < Q^2 < 20$ GeV^2 $0.0002 < x < 0.00052$

$10 < Q^2 < 20$ GeV^2 $0.00052 < x < 0.0011$

$10 < Q^2 < 20$ GeV^2 $0.0011 < x < 0.0037$

$20 < Q^2 < 100$ GeV^2 $0.0004 < x < 0.0017$

$20 < Q^2 < 100$ GeV^2 $0.0017 < x < 0.01$

H1 Preliminary

$0 < \eta^* < 1.5$

$10° < \theta_{lab} < 155°$

- ● H1 data (prelim.)
- — RAPGAP
- --- DJANGOH
- — CASCADE

Q^2 ↓

x ⟶

p_T^* [GeV]

Parton dynamics
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η^* - distributions

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

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

CDM
DGLAP
CCFM

Strong sensitivity to parton dynamics
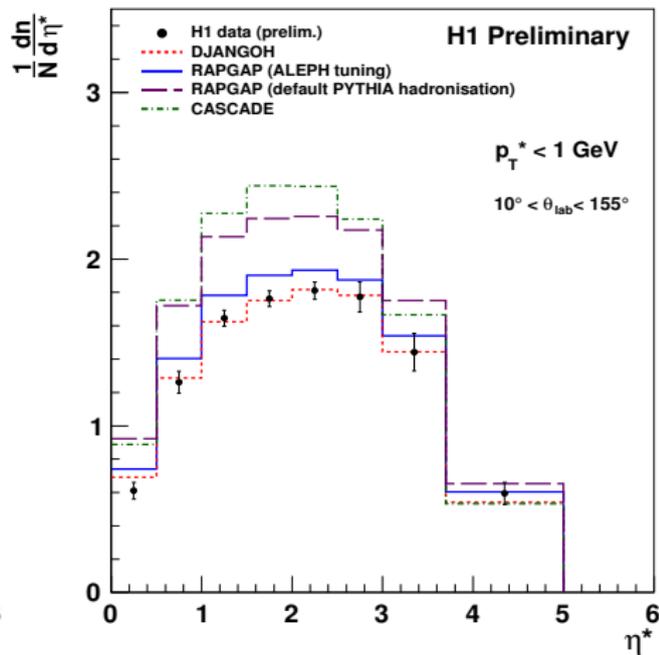
Strong sensitivity to hadronisation

Hadron production

Parton dynamics
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Hadronisation
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Fragmentation function (FF) for K_s^0 and Λ
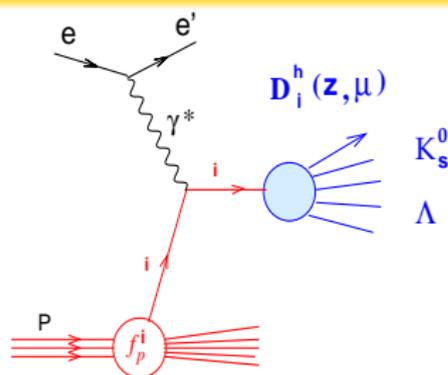
$$\frac{d\sigma}{dx_p} = f(x, Q^2) \otimes \widehat{\sigma}(Q^2) \otimes D(z, Q^2)$$

Observable:

$x_p \equiv \frac{|\vec{p}_h|}{p_{max}} = \frac{p_h}{\frac{Q}{2}}$ (Breit frame)

$\frac{1}{N_{event}} \frac{dn}{dx_p}$

NLO QCD calculations $\otimes$ FF:

AKK+CYCLOPS: FFs from fits to e^+e^- data

DSS: FFs from fits to e^+e^-, ep and pp data

Motivation:

- Scaling violations in fragmentation functions

- Universality of fragmentation function

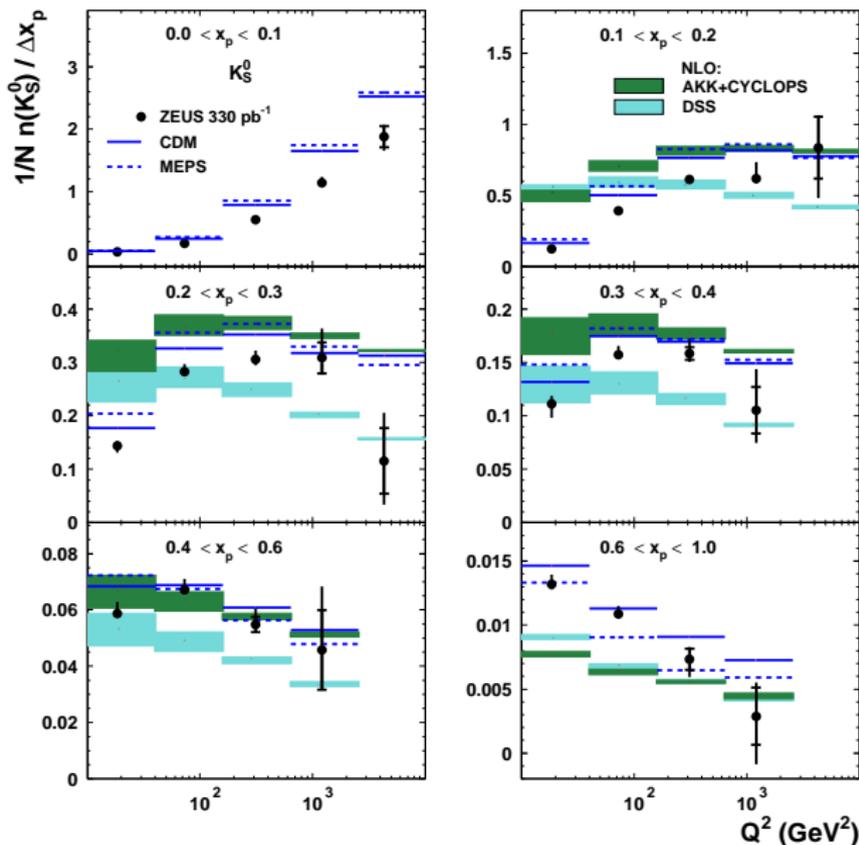- Test NLO QCD calculations and universality of factorisation theorem

  ZEUS   JHEP 03 (2012) 020

- $10 < Q^2 < 40000$ GeV^2, $0.001 < x < 0.75$

- Measurements are performed in current region of Breit frame (similarity with e^+e^-)
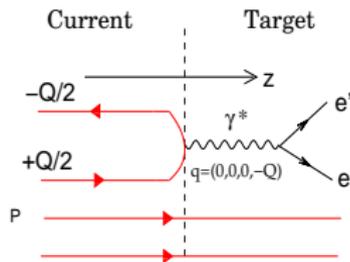
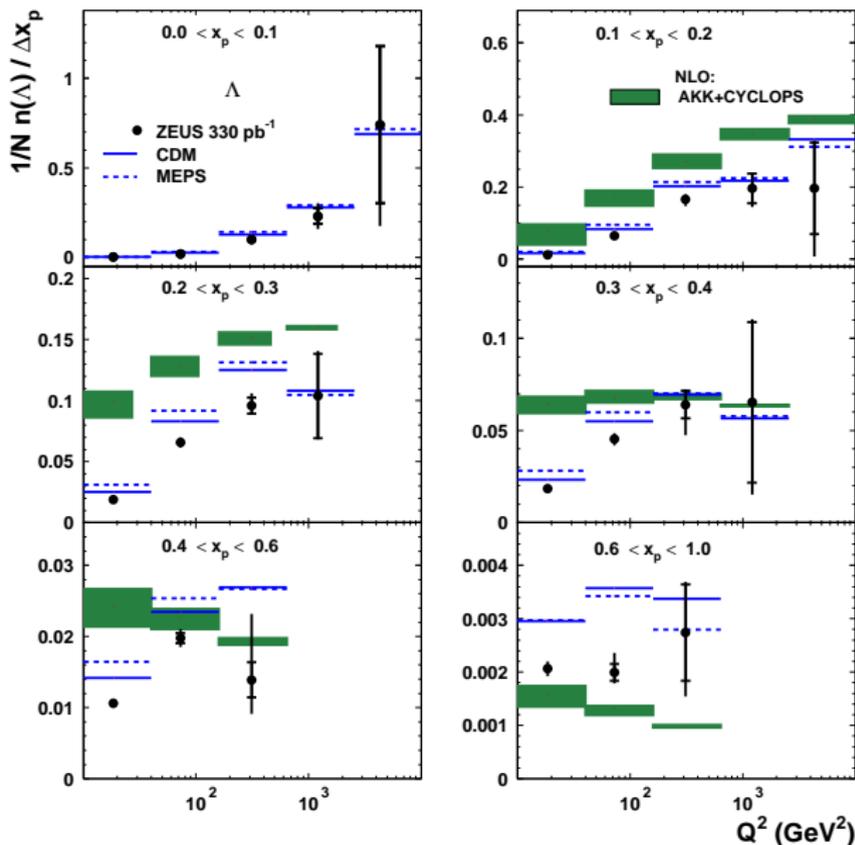**Scaled momentum distributions: K_s^0**

ZEUS

- Scaling violations: Q increases $\rightarrow$ more soft gluon radiation $\rightarrow$ more particles with low x_p
- ARIADNE (CDM) and LEPTO (MEPS) describe the data in most parts of phase space
- QCD NLO predictions fail to describe the data
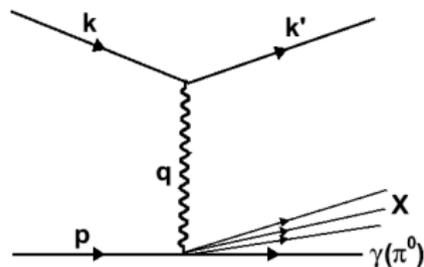- Data can be used for further FF fit

Scaled momentum distributions: Λ

ZEUS

- Scaling violations are observed
- ARIADNE (CDM) and LEPTO (MEPS) describe the data in most parts of phase space.
- QCD NLO predictions does not describe the data
- Data can be used for further FF fit

Production of very forward photon in DIS

Main source: $\pi^0 \to \gamma\gamma$

Observable:

Normalised differential cross sections for leading forward photon :
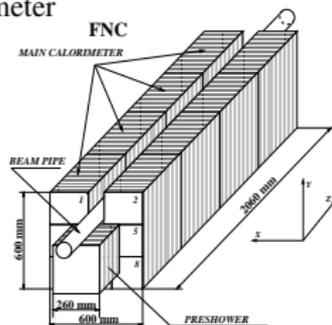
$$\frac{1}{\sigma_{\text{DIS}}} \frac{d\sigma}{dx_{\text{L}}^{\text{lead}}}$$

Motivation:

- Understanding the proton fragmentation
- Testing the hypothesis of limiting fragmentation
- Models tuning, in particular for hadron interaction Cosmic Ray models

H1   Eur. Phys. J.C71 (2011) 1771

- $6 < Q^2 < 100$ GeV^2, $0.05 < y < 0.6$
- $\eta_\gamma > 7.9$, $x_{\text{L}} = E_\gamma / E_{\text{p}} > 0.1$
- γ is detected in e/m part of Forward Neutron Calorimeter
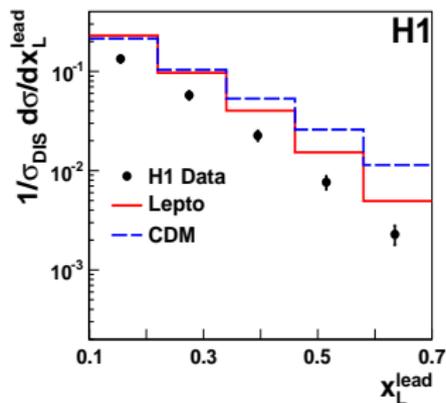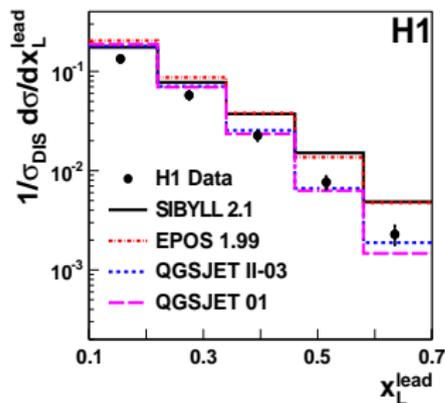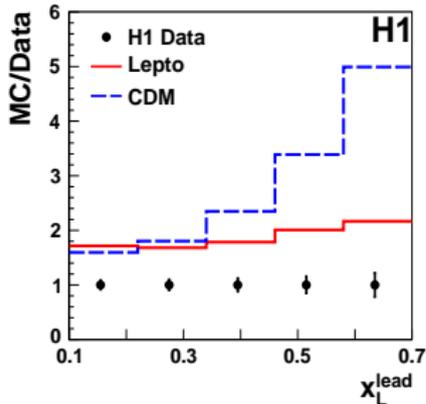
## Production of very forward photon in DIS
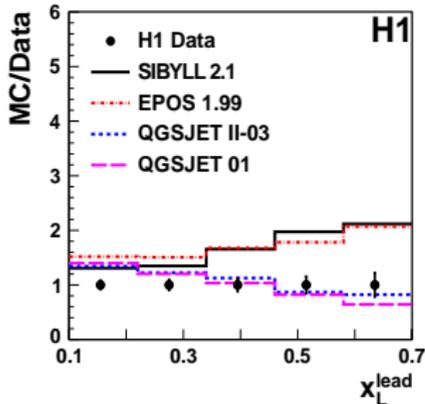
- Both CDM and LEPTO models are significantly higher than data

- QGSJET models have steeper behavior than the data, close to data in absolute values except at low x_L

- Similar behavior observed for p_T^{lead}

Fraction of DIS events with forward photons

Test of limiting fragmentation hypothesis (forward particle production insensitive to Q^2, x_{bj} and W)

H1prelim-12-111
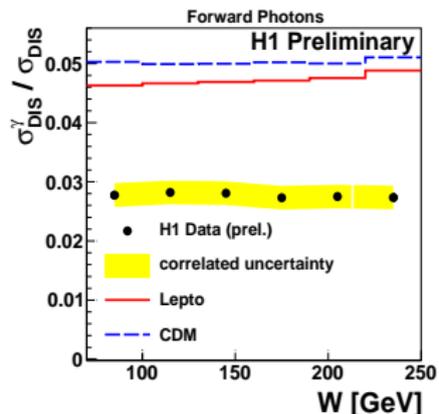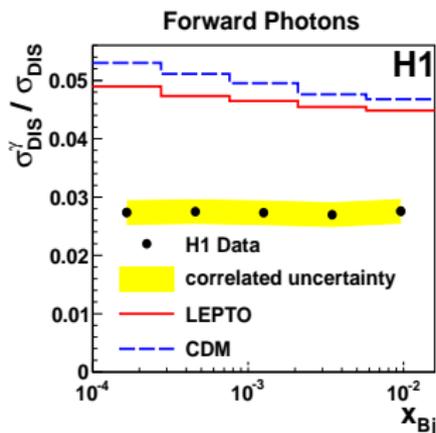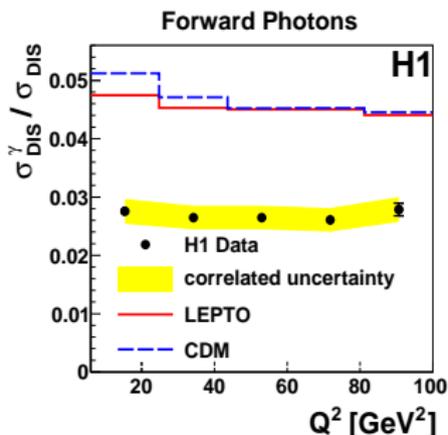


$\rightarrow$ proton remnant does not "feel" the hard interaction

Data support the hypothesis of limiting fragmentation.

Summary

- Parton dynamic
  - CDM is the best in description of charged particle spectra
  - DGLAP is below the data for low x and large p_T of charged particles
- Hadronisation
  - Fragmentation function for K_s^0 and Λ:
    - Scaled momentum distributions show the scaling violation
    - NLO QCD calculations fail to describe the data
    - Measurements can be used for further FF fit
  - Forward photon:
    - Models predict higher yield of photons than data
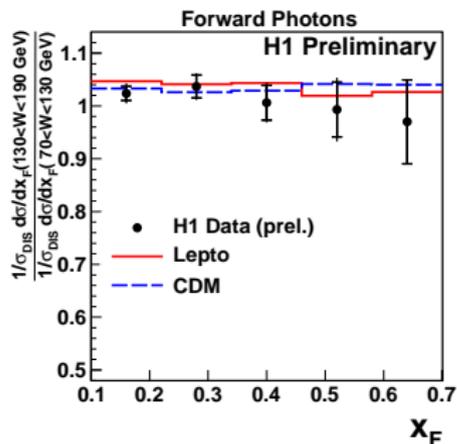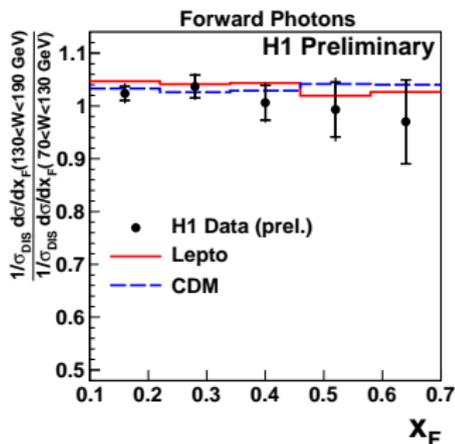   - Data support the hypothesis of limiting fragmentation

Parton dynamics
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Hadronisation
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Back up slides

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Hadronisation
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Forward photons production in DIS (H1prelim-12-111)
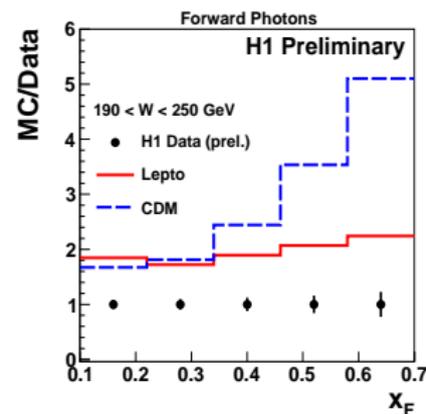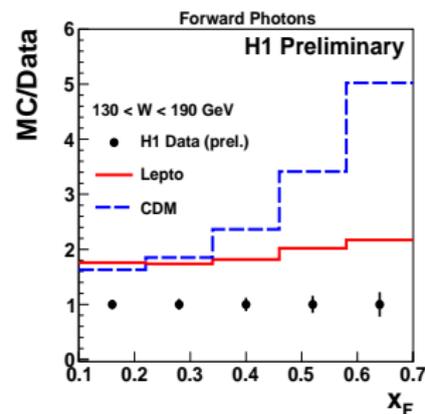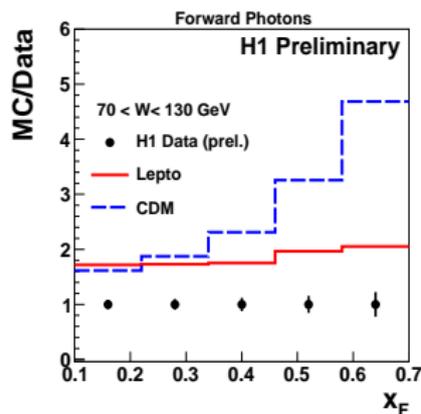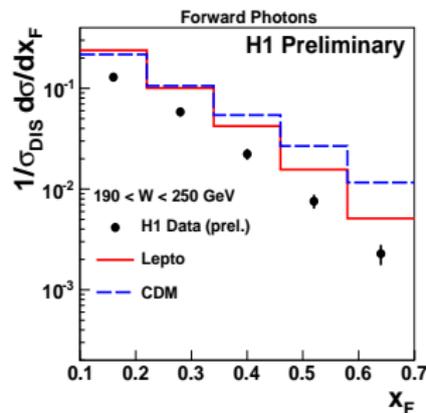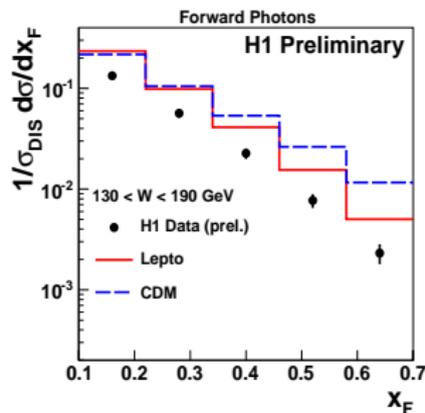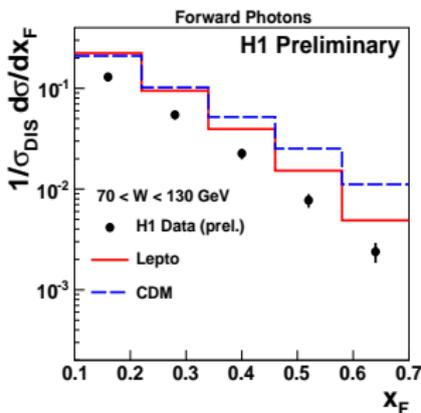
Forward photons production in DIS (H1prelim-12-111)

Ratios of normalised cross sections of forward photons production in DIS corresponding to two different W intervals:

→ Data support Feynman scaling