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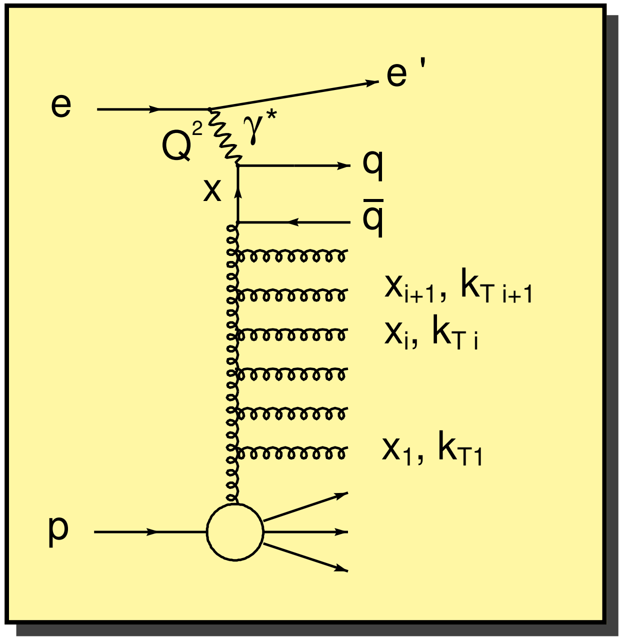
Forward π° production in deep-inelastic scattering at H1

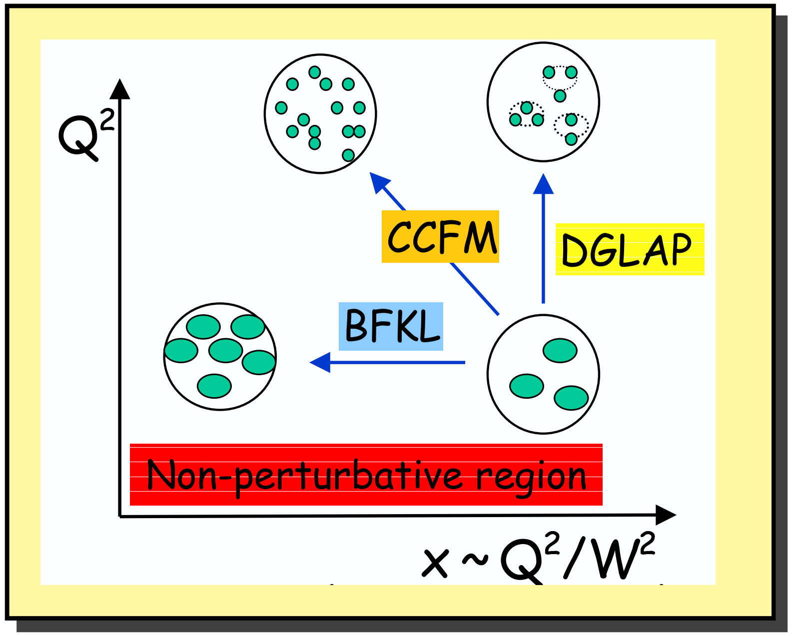
DIS 2004, Štrbské Pleso, April 2004

- **QCD dynamics at low x**
- **Monte Carlo models with different QCD dynamics**
- **Analytical BFKL calculations and NLO predictions**
- **Forward π° measurements**
- **Summary**

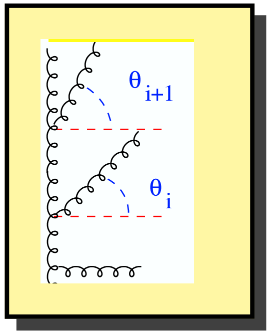
QCD dynamics at low x

In DIS at low x the quark struck by the virtual photon originates from a QCD cascade initiated by parton from the proton.



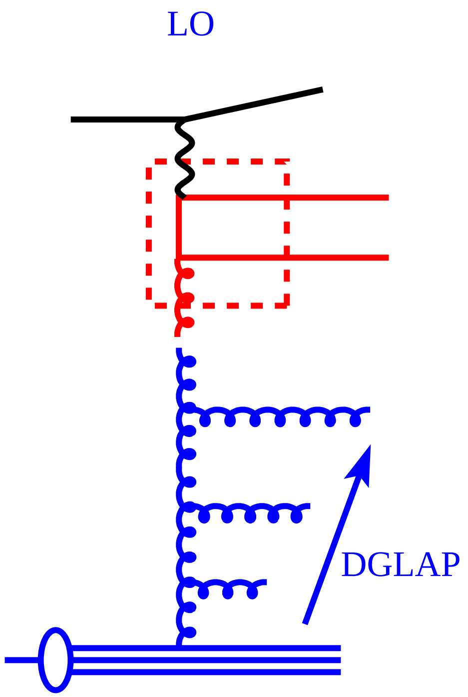


- ➤ DGLAP : strong ordering of parton k_T
- ➤ CCFM : angular ordering of parton emissions
- ➤ BFKL : strong ordering in x_i/no k_T ordering



Monte Carlo models with different QCD dynamics

RAPGAP DIR



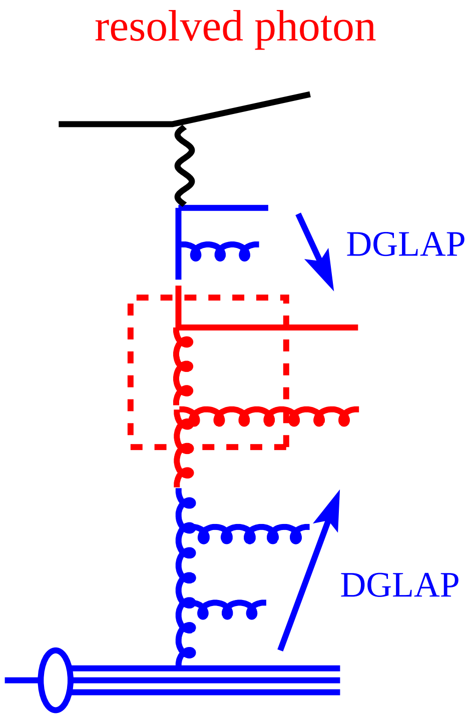
single k_T-ordered
DGLAP ladder

→

→

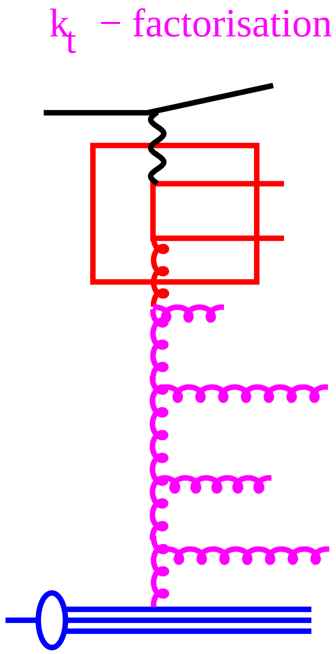
→

RAPGAP RES



2 k_T-ordered
DGLAP cascades
initiated from the proton
and the photon

CASCADE



CCFM evolution
colour coherence effects :
gluon ladder ordered in angle
BFKL @ small x
DGLAP @ large x

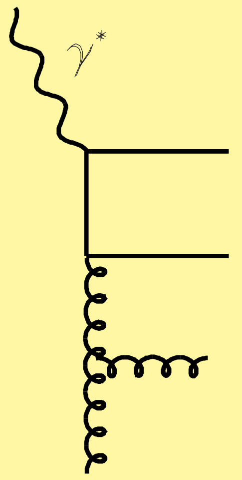
Comparison to theoretical predictions

- ARIADNE - an implementation of the Colour Dipole Model (CDM)
  - ✓ QCD radiation from the dipole formed by the struck quark and the proton remnant → chain of independently radiated dipoles spanned between emitted partons
  - ✓ "BFKL"-like Monte Carlo program without k_T ordering
- Modified LO BFKL calculation (Kwieciński, Martin, Outhwaite hep-ph/9903439)
  - ✓ gluon emissions limited by "consistency constraint"
  - ✓ major part of the non-leading contributions to the BFKL equation included
  - ✓ normalisation very sensitive to infrared cut-off and scale of α_S
- π° analysis:

$$\sigma(\pi^\circ) = \sigma(\text{parton jet}) \otimes (\ \pi^\circ \text{ fragmentation function }\ )$$

  - ✓ fragmentation functions of Kniehl,Kramer and Pőtter (2000)

NLO calculation of high p_T hadron production



BFKL Born term

Aurenche, Basu, Fontannaz, Godbole
hep-ph/0312359

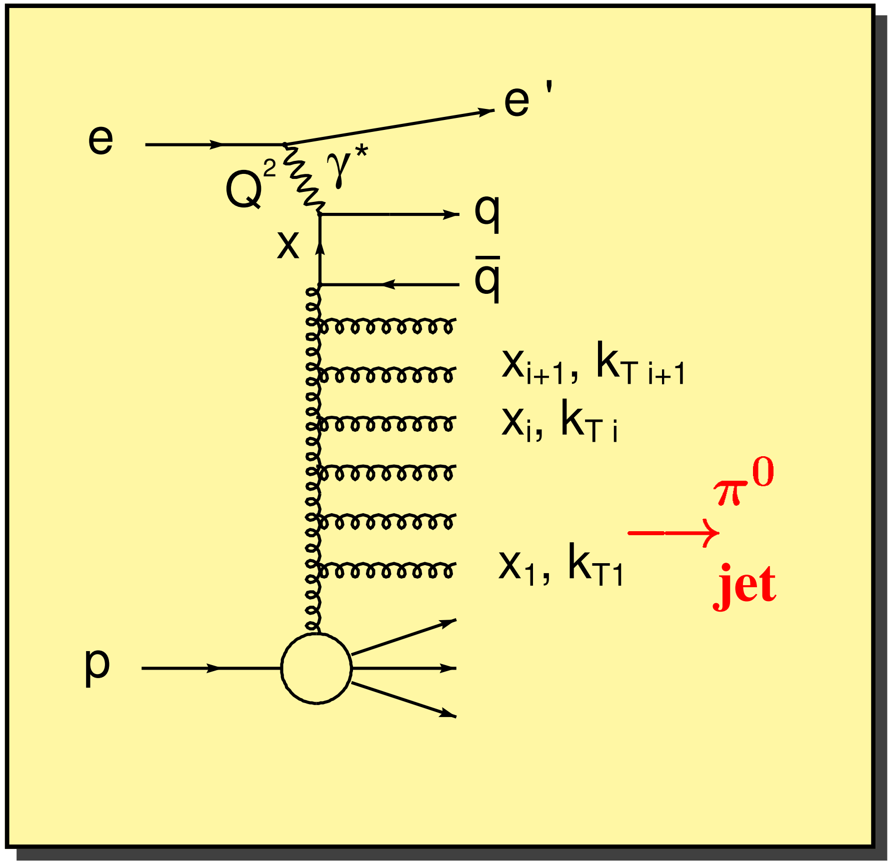
HO corrections of order $\mathcal{O}(\alpha\alpha_s^2)$ to QCD Compton and boson gluon processes

convolution with NLO parton distributions and fragmentation functions

sensivity to the renormalisation and factorisation scales

forward π° production in DIS - dominant HO contributions corresponding to the lowest order BFKL processes !

Parton dynamics at low x



Mueller - Navelet jets in DIS :
high transverse momentum and high energy jets/π^0 in p -remnant direction (forward region in LAB)

suppress DGLAP evolution in Q^2

$$\boldsymbol{k^2_{T,jet/\pi^0} \approx Q^2}$$

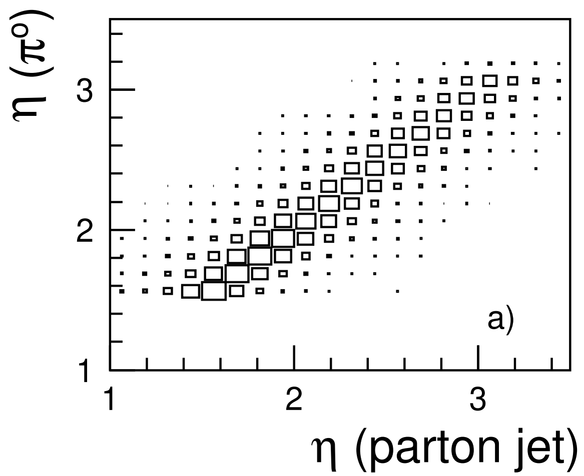
enhance BFKL evolution in $\boldsymbol{x}$

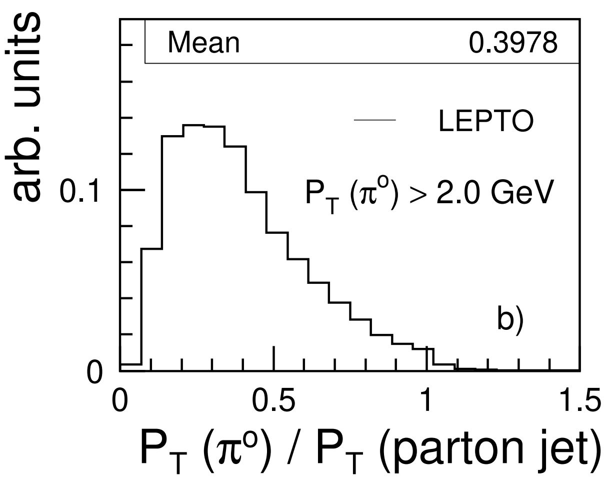
$$\boldsymbol{x_{jet/\pi^0} = E_{jet/\pi^0}/E_p >> x_B}$$

high k_T and high energy forward particle production in DIS:
✓ complementary/refined version of the forward jet measurement
✓ forward jet identified by its energetic fragmentation product

Forward jet/particle production in DIS

high p_T forward jet/particle sensitive to underlying parton dynamics





forward particle measurements

- − fragmentation effects more significant
- − smaller rate
- + identification possible in more forward region

forward jet measurements

- + better parton correlation
- + higher rates
- − ambiguities of jet algorithm
- − exp. difficult in very forward (p) region

Selection of forward π° in DIS

$$e + P \rightarrow e + \pi^\circ + X$$

data 1996-97, $E_p = 820$ GeV, $E_e = 27.6$ GeV, $\mathcal{L} \approx 21.2$ pb^{-1}
DIS kinematics from the scattered electron

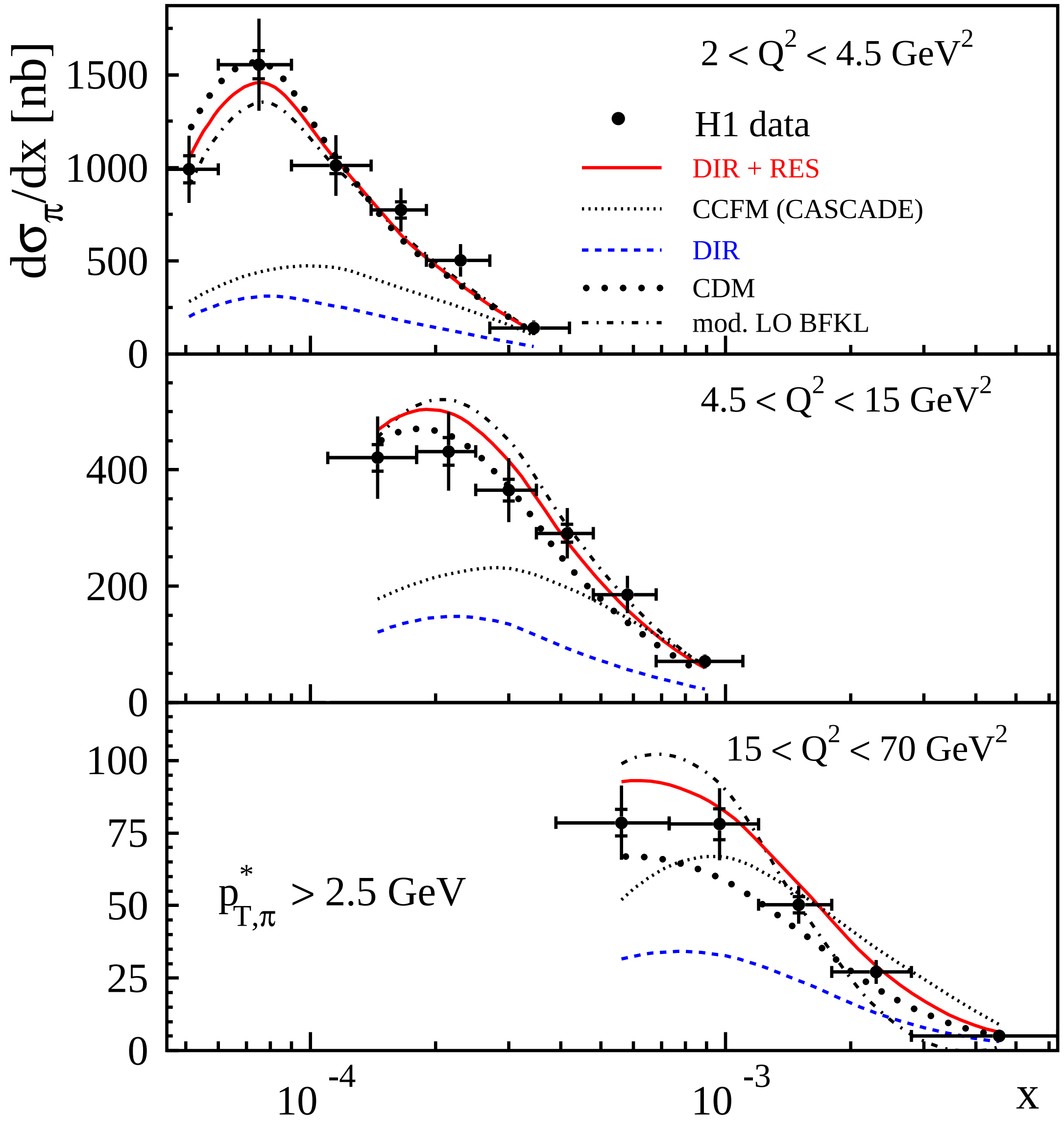
DIS sample
$2 < Q^2 < 70$ GeV^2
$0.1 < y < 0.6$
x down to 10^{-5}

forward π° detection

$5 < \theta_{\pi^\circ} < 25^\circ$	forward region
$p_{T,\pi^\circ} > 2.5(3.5)$ GeV	high p_T (hCMS)
$x_{\pi^\circ} = E_{\pi^\circ}/E_p > 0.01$	high energy

$E_{\pi^\circ} > 8.2$ GeV, high energy $\pi^\circ \rightarrow 2\gamma$ reconstructed as one electromagnetic cluster in the finely segmented H1 liquid argon calorimeter
π° selection based on the analysis of the shower shape of the energy deposition

Forward π^0 : $d\sigma/dx$, $p^*_{T,\pi} > 2.5\ GeV$



DGLAP (DIR) : below the data

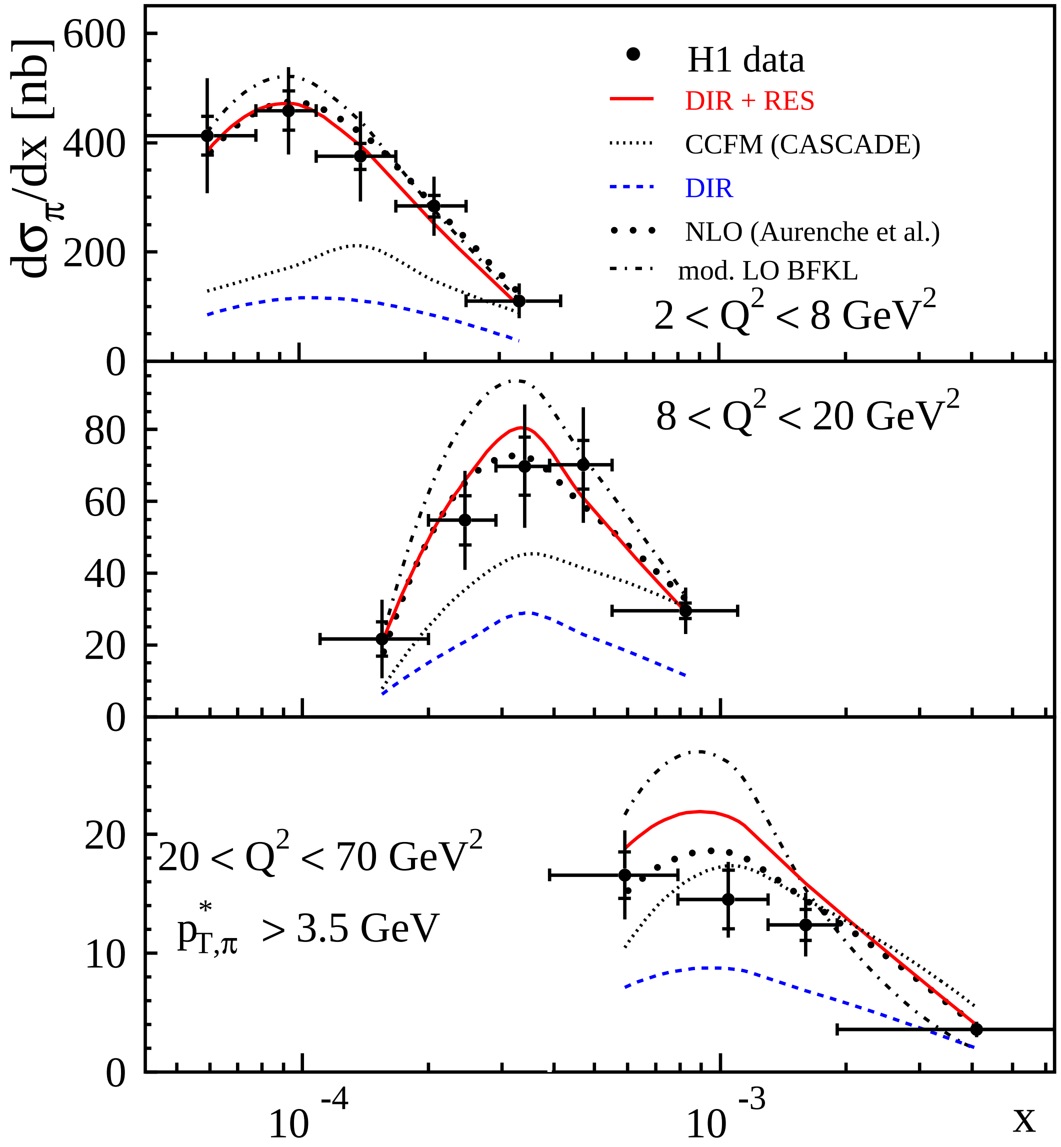
DGLAP (DIR + RES) :
resolved photon component improves the description
$\mu^2 = Q^2 + 4p_T^2$

CCFM (CASCADE) :
below the data
at low x and Q^2

CDM : reasonable description of the data

mod. LO BFKL : reasonable description of the data

Forward π^0 : $d\sigma/dx$, $p^*_{T,\pi} > \mathbf{3.5}\ GeV$



DGLAP (DIR) below the data

DGLAP (DIR + RES γ^*) ok.

NLO calculations :

describe the data well !!

$\mu^2 = (Q^2 + p^{*2}_{T,parton})/2$

BFKL-like diagrams important

CCFM (CASCADE) :

low at small x and Q^2

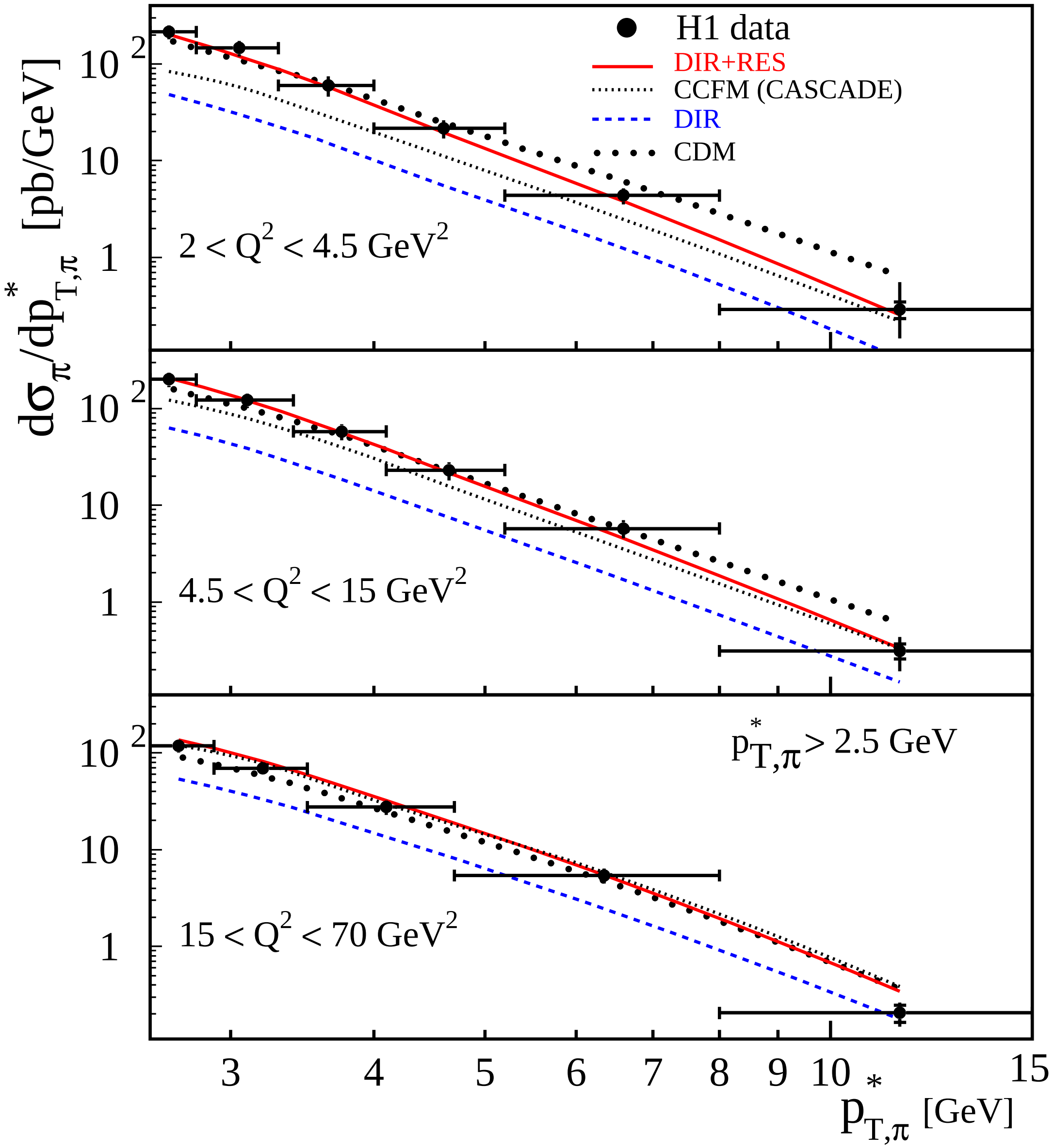
(inclusion of quarks

in the evolution will help ??)

mod. LO BFKL :

too high at higher Q^2

Forward π^0 : $d\sigma/p^*_{T,\pi}$ in 3 regions of Q^2



$p^*_{T,\pi}$ in hadronic CMS

the data fall steeply with increasing $p^*_{T,\pi}$

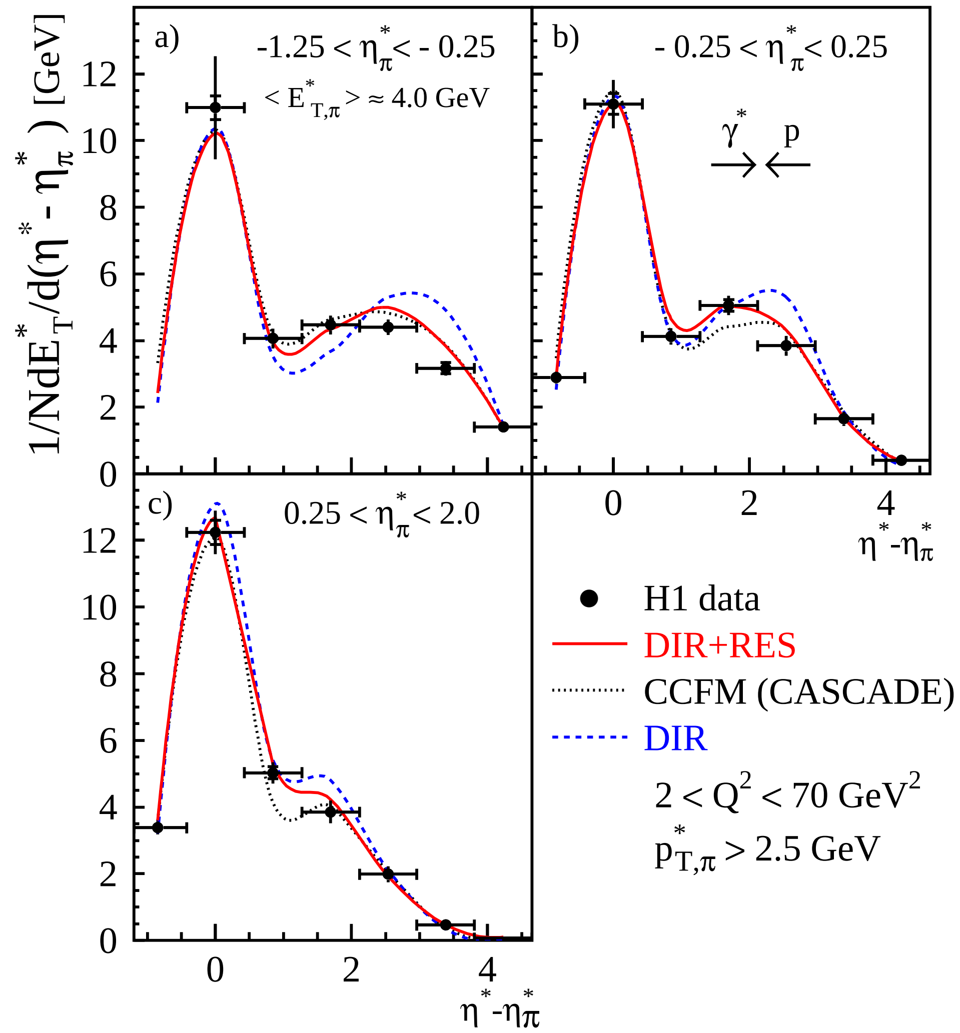
$p^*_{T,\pi}$ dependence
well described by MC models
only
CDM predicts harder spectra

E_T flow around forward π° in 3 ranges of η^*_π

hadronic CMS

γ^* p

$\longrightarrow \; \longleftarrow$



$\frac{1}{N}\, dE^*_T/d(\eta^* - \eta^*_\pi)$

Transverse energy flow as a function of the difference in pseudorapidity $\eta^* - \eta^*_\pi$ from the forward π°

contribution from E^*_T of π° included

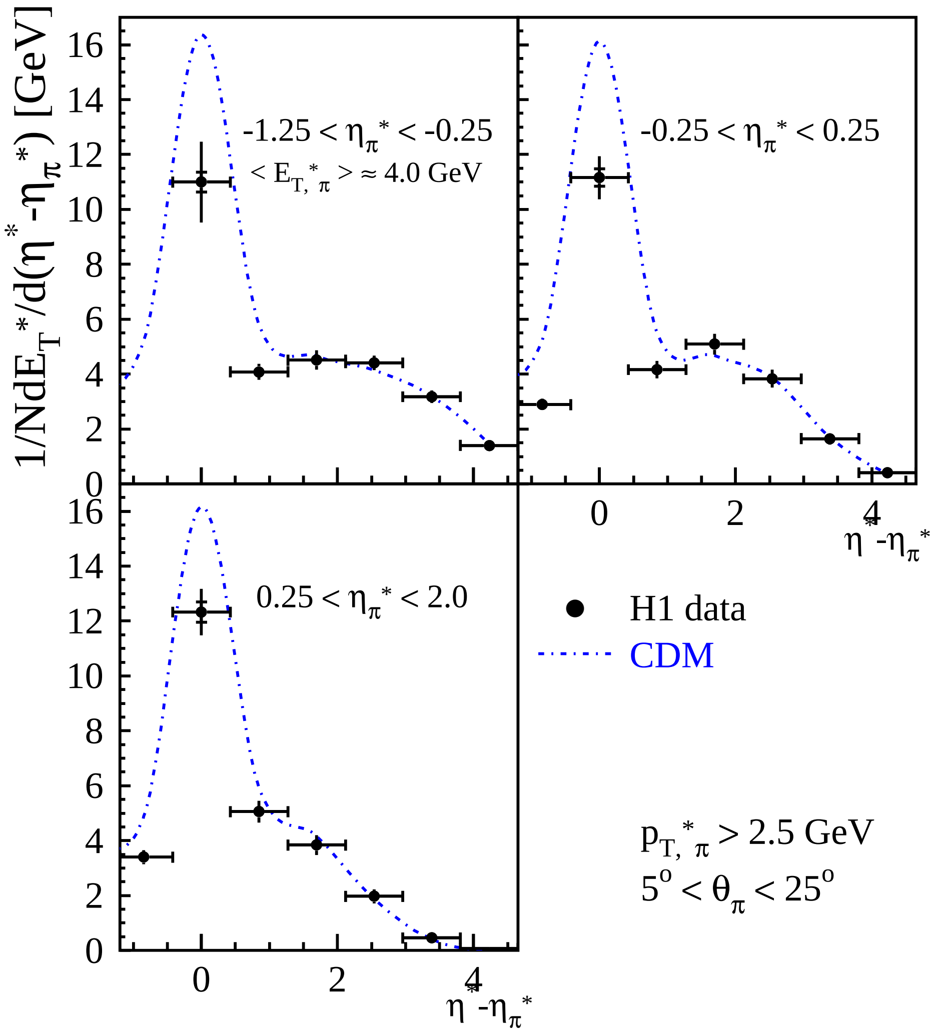
E_T flow around $\pi \longrightarrow$ transverse momentum compensation along the ladder

Transverse energy flow associated with forward π^0

hadronic CMS

γ^* p

$\longrightarrow \longleftarrow$



hadronic CMS

$\frac{1}{N}\, dE^*_T/d(\eta^* - \eta^*_\pi)$

CDM :

too hard transverse momentum spectrum of the forward π^0
$\longrightarrow$ too much E_T in the vicinity of π^0

Summary

Consistent picture in the interpretation of small-x data still missing

- standard DGLAP model fails to describe cross sections
- inclusion of resolved photon component results in considerable improvement of the π° data description however with rather large renormalisation and factorisation scale
- CDM gives reasonable description of cross sections but too much transverse energy in the vicinity of the π°
- CASCADE (CCFM) is below the data at lowest values of $\boldsymbol{x}$
- NLO calculations describe well the $\boldsymbol{x}$ dependence of forward $\boldsymbol{\pi^\circ}$ cross section
- mod. LO BFKL describes the $\boldsymbol{\pi^\circ}$ data at lower $\boldsymbol{Q^2}$ but exceeds them at higher $\boldsymbol{Q^2}$