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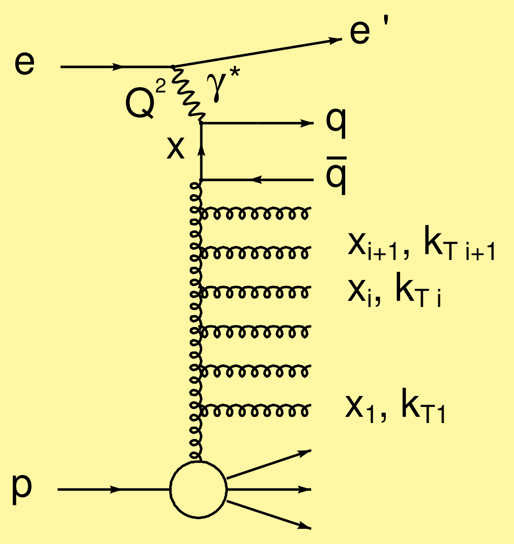
Forward jet and pion production in deep-inelastic scattering at H1

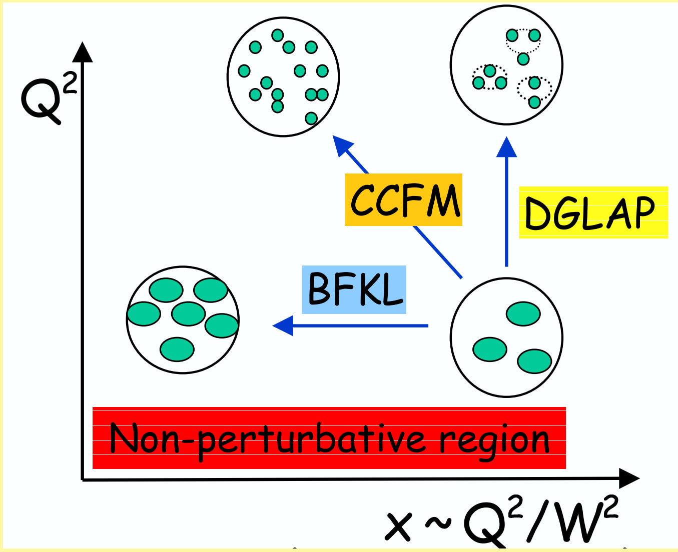
DIS 2003 St.Petersburg, April 2003

- **QCD dynamics at low x**
- **Forward jets**
- **Forward π^0**
- **Comparison to MC models with different QCD dynamics**
- **Comparison to analytical BFKL calculations**
- **Summary**

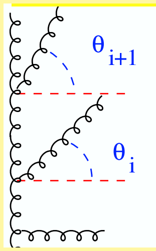
QCD dynamics at low x

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



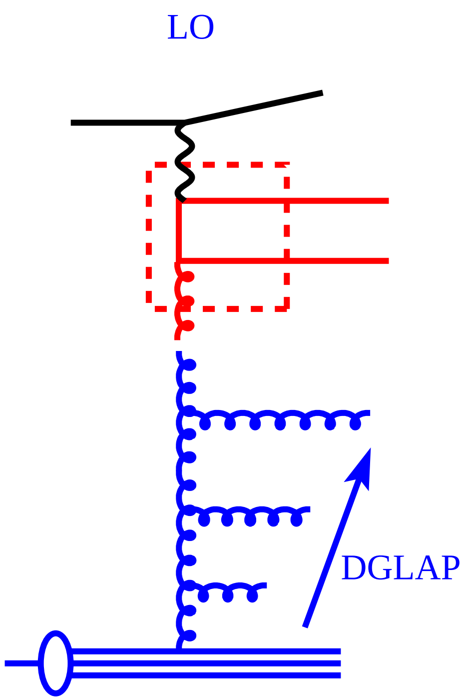


- **DGLAP** : strong ordering of parton k_T
- **CCFM** : angular ordering of parton emissions
- **BFKL** : strong ordering in x_i/no k_T ordering



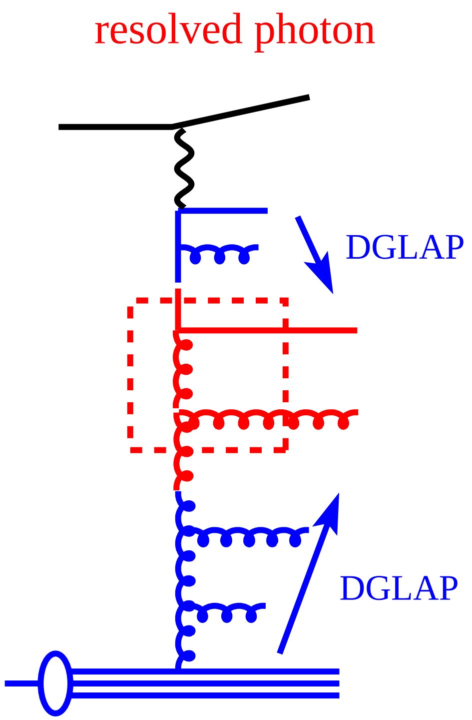
Monte Carlo models with different QCD dynamics

RAPGAP DIR



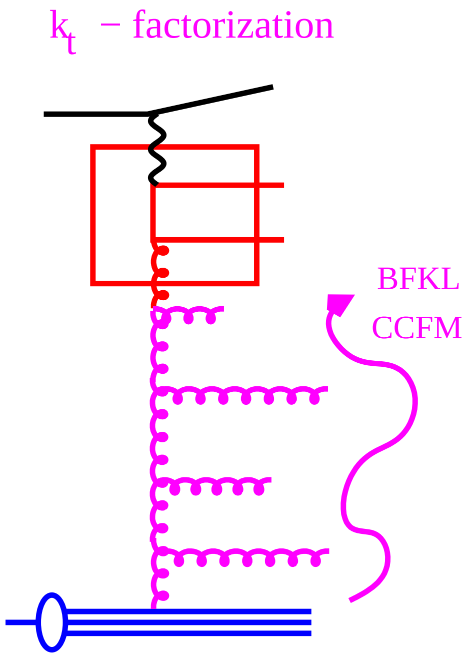
single ladder
ordered in k_T
$\rightarrow$
$\rightarrow$

RAPGAP RES



2 ladders
each ordered in k_T
scale $Q^2 + p_T^2$ for jets
scale $Q^2 + 4p_T^2$ for π^0

CASCADE



CCFM evolution
DGLAP/BFKL

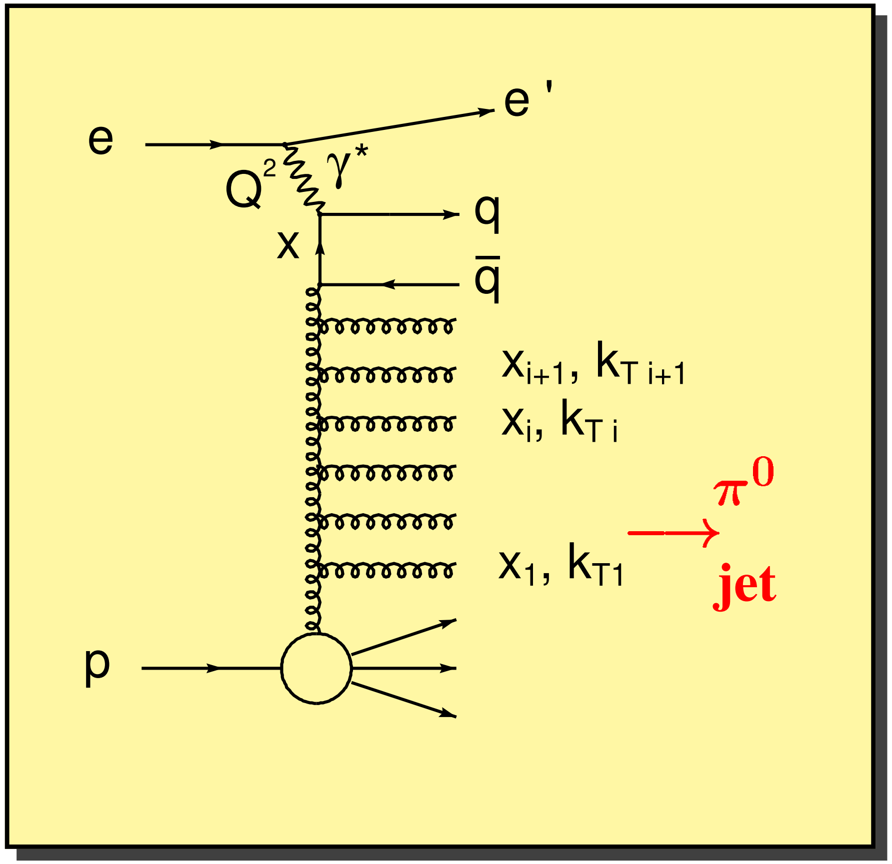
Comparison to theoretical predictions

- ARIADNE :
  - ✓ perturbative QCD radiation is modelled with radiative colour dipoles according to the Colour Dipol Model (CDM)
  - ✓ Monte Carlo program without k_t ordering
- Modified LO BFKL calculation (Kwiecinski, Martin, Outhwaite hep-ph/9903439)
  - ✓ gluon emissions limited by "consitency constraint"
  - ✓ major part of the non-leading contributions to the BFKL equation included
  - ✓ normalization very sensitive to infrared cut-off and scale of α_S

$$\sigma(\pi^0) = \sigma(jet) \times (\text{ convolution with FF })$$

- this π^0 analysis:
  - ✓ fragmentation functions of Kniehl,Kramer and Pőtter (2000)
  - ✓ Mod. LO BFKL calculations tuned to H1 1997 forward jet data

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

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

enhance BFKL evolution in x

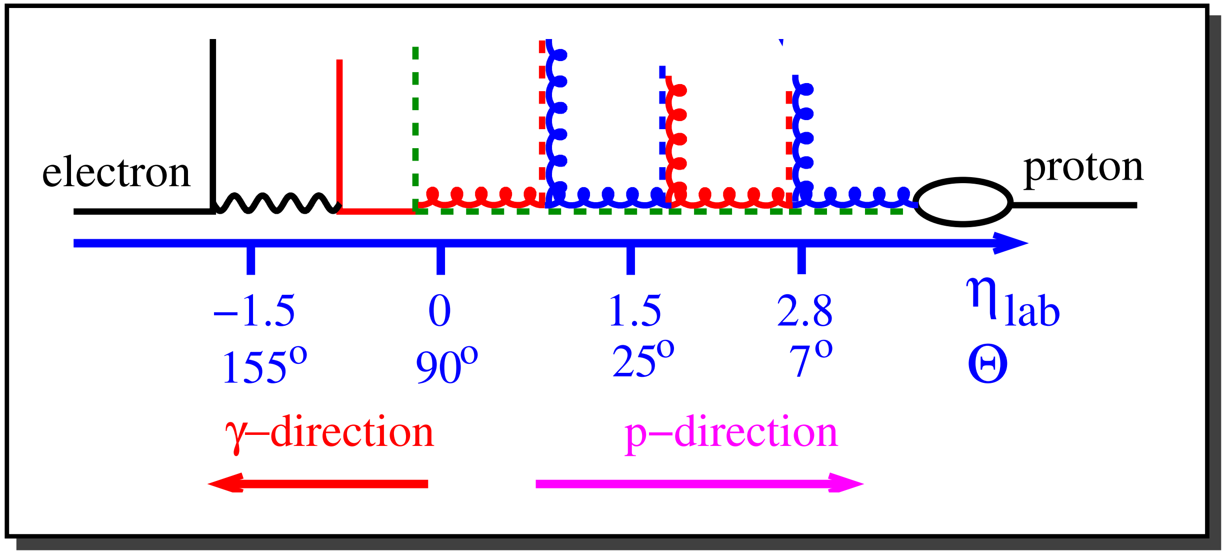
$$x_{jet/\pi^0} = E_{jet/\pi^0}/E_p >> x_B$$

high k_T and high energy forward particle production in DIS:

✓ complementary/refined version of the forward jet mesurement

✓ forward jet identified by its energetic fragmentation product

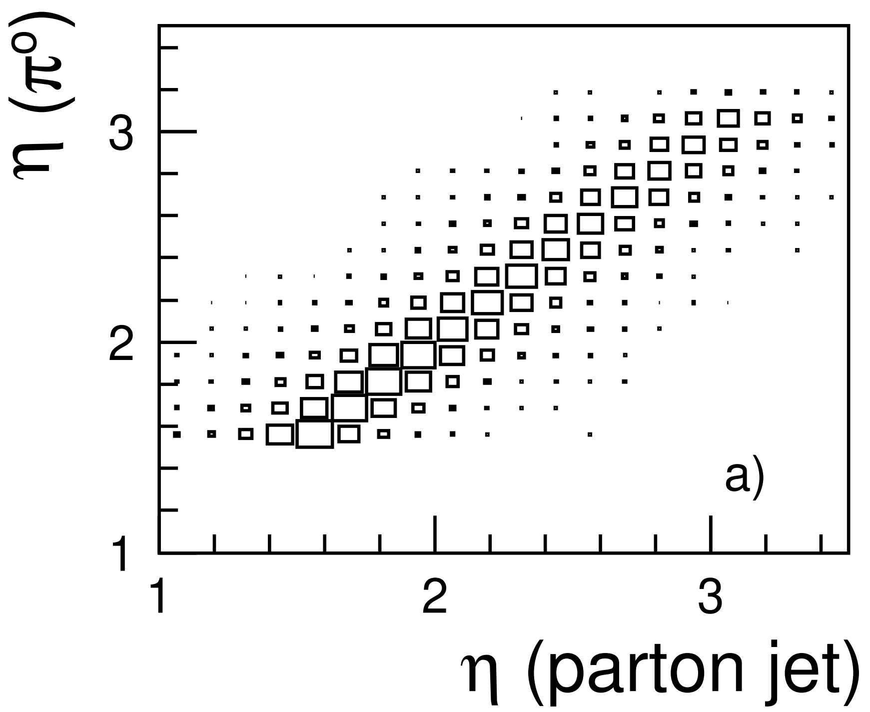
Forward jet and particle production in DIS

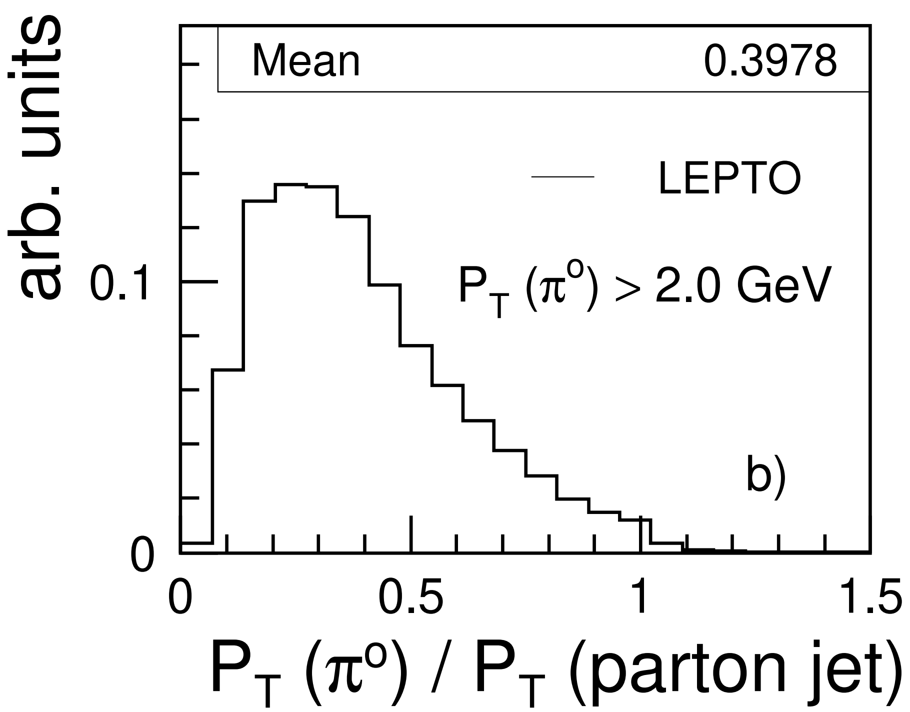


	forward jet mesurements
+	better parton correlation
+	higher rates
−	ambiguities of jet algorithm
−	exp. difficult in very forward (p) region

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

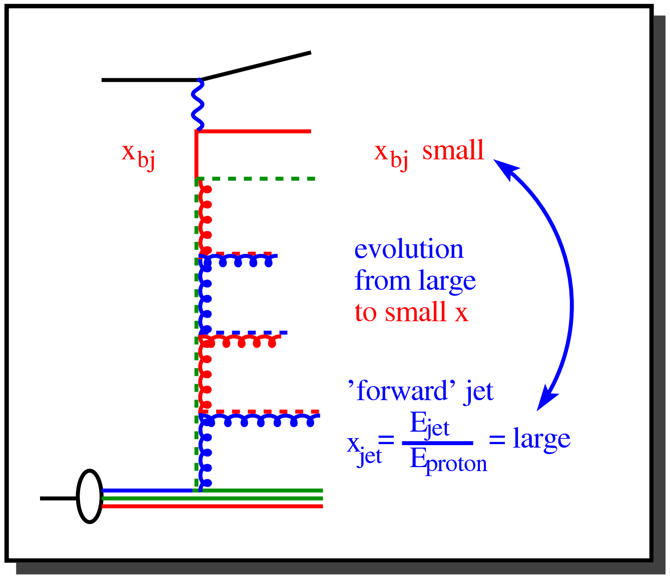
Correlation forward particle - parton





high transverse momentum forward jet/particle sensitive to underlying parton dynamics

Selection of DIS forward jets and π^0



$$e + P \rightarrow e + jet/\pi^0 + X$$

similar event selection for forward jets and π^0

DIS kinematics from the scattered electron

forward jets : data 97 $\alpha \approx 13.72\ \mathrm{pb}^{-1}$

forward π^0 : data 96/97 $\alpha \approx 21.21\mathrm{pb}^{-1}$

forward jets

$5 < Q^2 < 75$ **GeV^2**

$0.1 < y < 0.7$

$7 < \theta_{jet} < 20^\circ$

$p_{t\ jet} > 3.5(5.0)$ **GeV (LAB)**

$x_{jet} = E_{jet}/E_p > 0.035$

$0.5 < p^2_{t\ jet}/Q^2 < 2$

inclusive k_t algorithm

Breit frame

forward π^0 detection

$2 < Q^2 < 70$ **GeV^2**

$0.1 < y < 0.6$

$5 < \theta_{\pi^0} < 25^\circ$

$p_{\pi^0} > 2.5(3.5)$ **GeV (hCMS)**

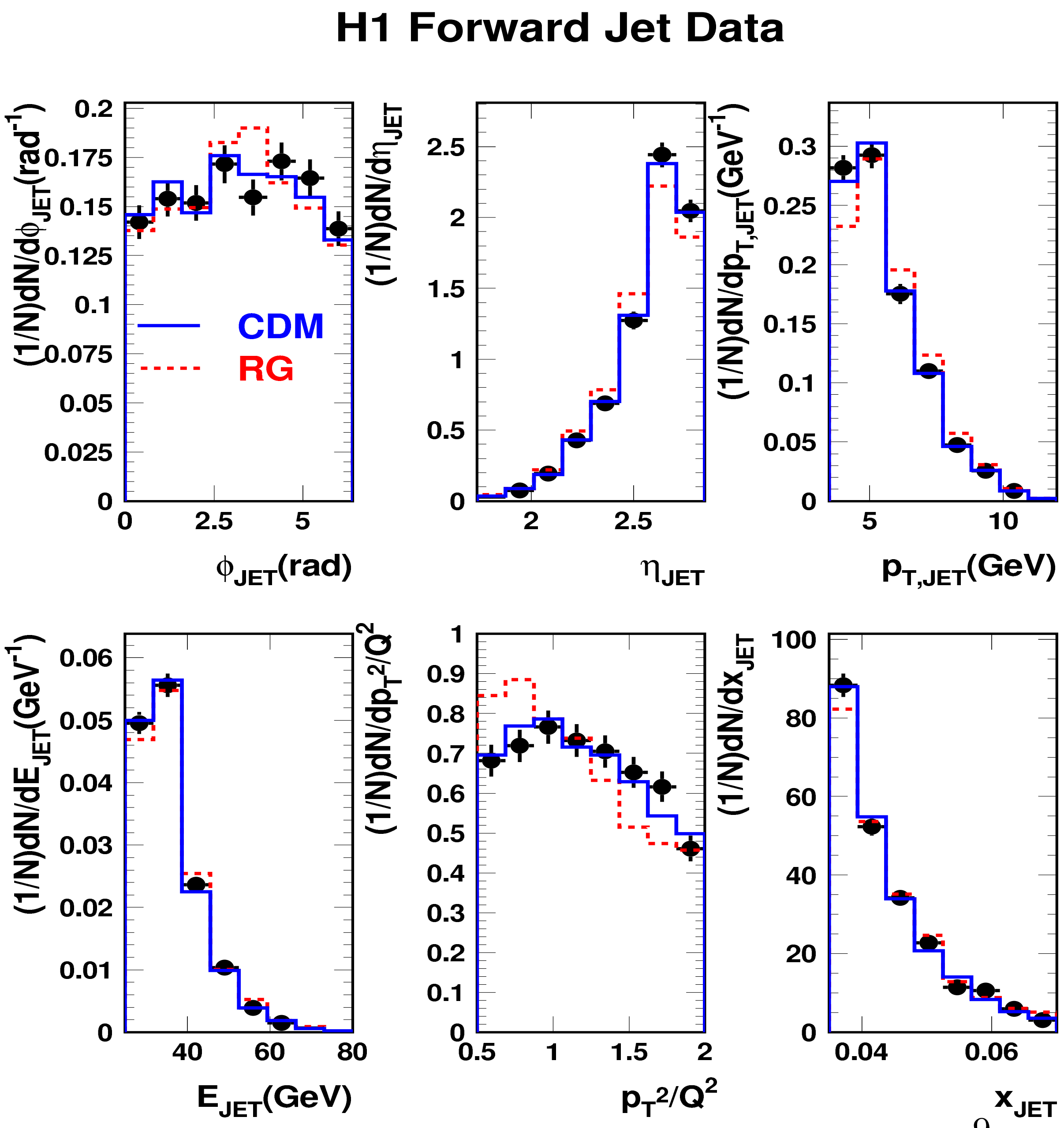
$x_{\pi^0} = E_{\pi^0}/E_p > 0.01$

$\rightarrow E_{\pi^0} > 8.2GeV$

$\pi^0 \rightarrow 2\gamma$ **reconstructed**

as one em cluster in H1 calo

Forward jet selection

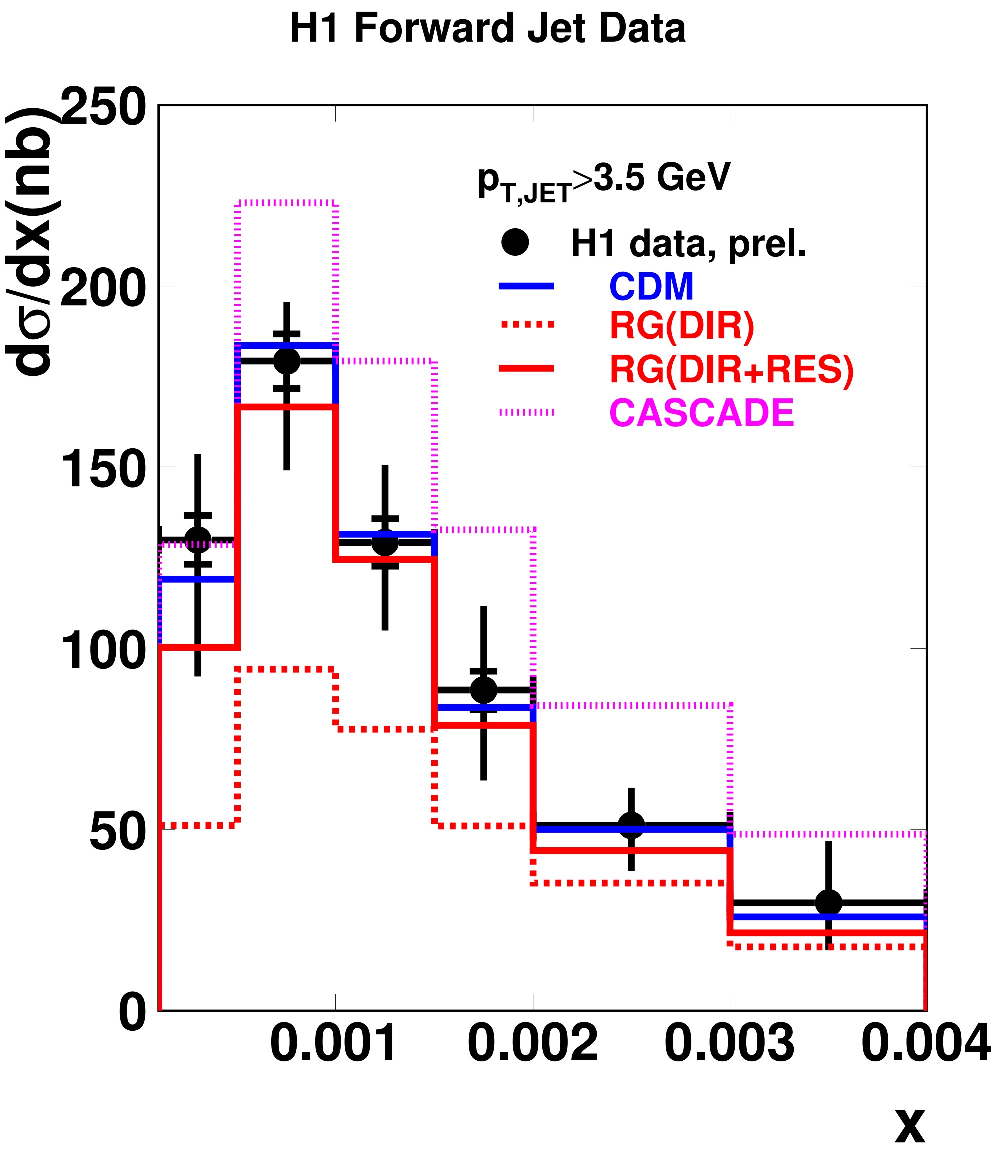


basic distributions reasonably described

jets have more p_T^2/Q^2 than predicted in RAPGAP DIR

ure 3: *Distribution of basic jet variables after the forward jet selection. The solid (dashed)*

Forward jet cross section - x dependence



DGLAP : well below data

resolved photon component ➤ improvement of the description

$\mu^2 = Q^2 + P_T^2$

Color Dipole Model (CDM) :

good description of the data

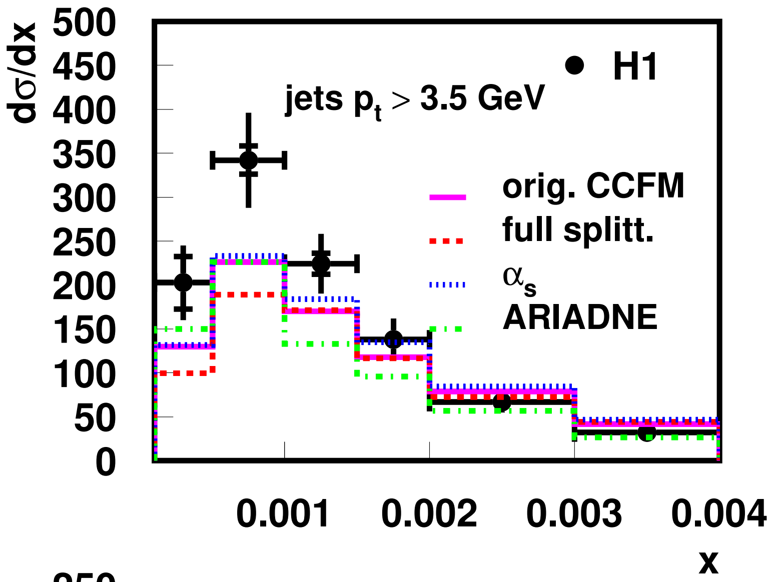
CCFM :

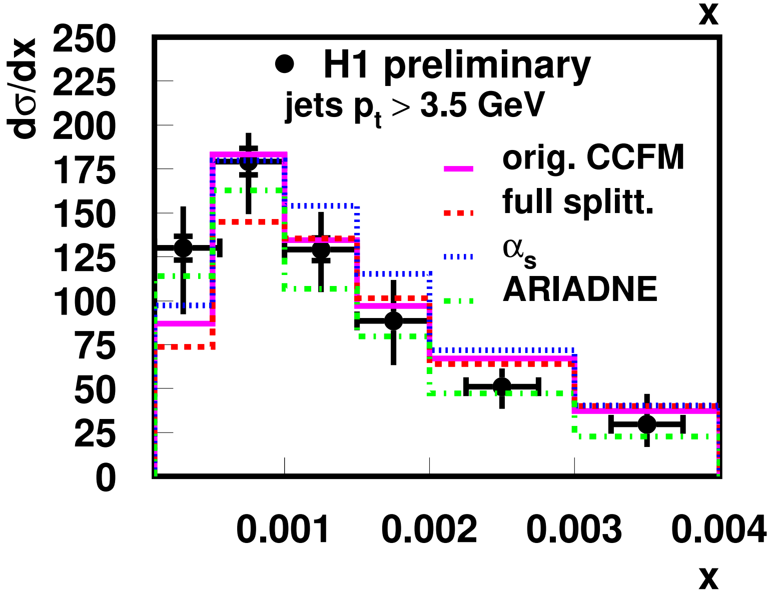
above the data

proper treatment of next-to-leading-log effects in CASCADE may help (talk of Hannes Jung)

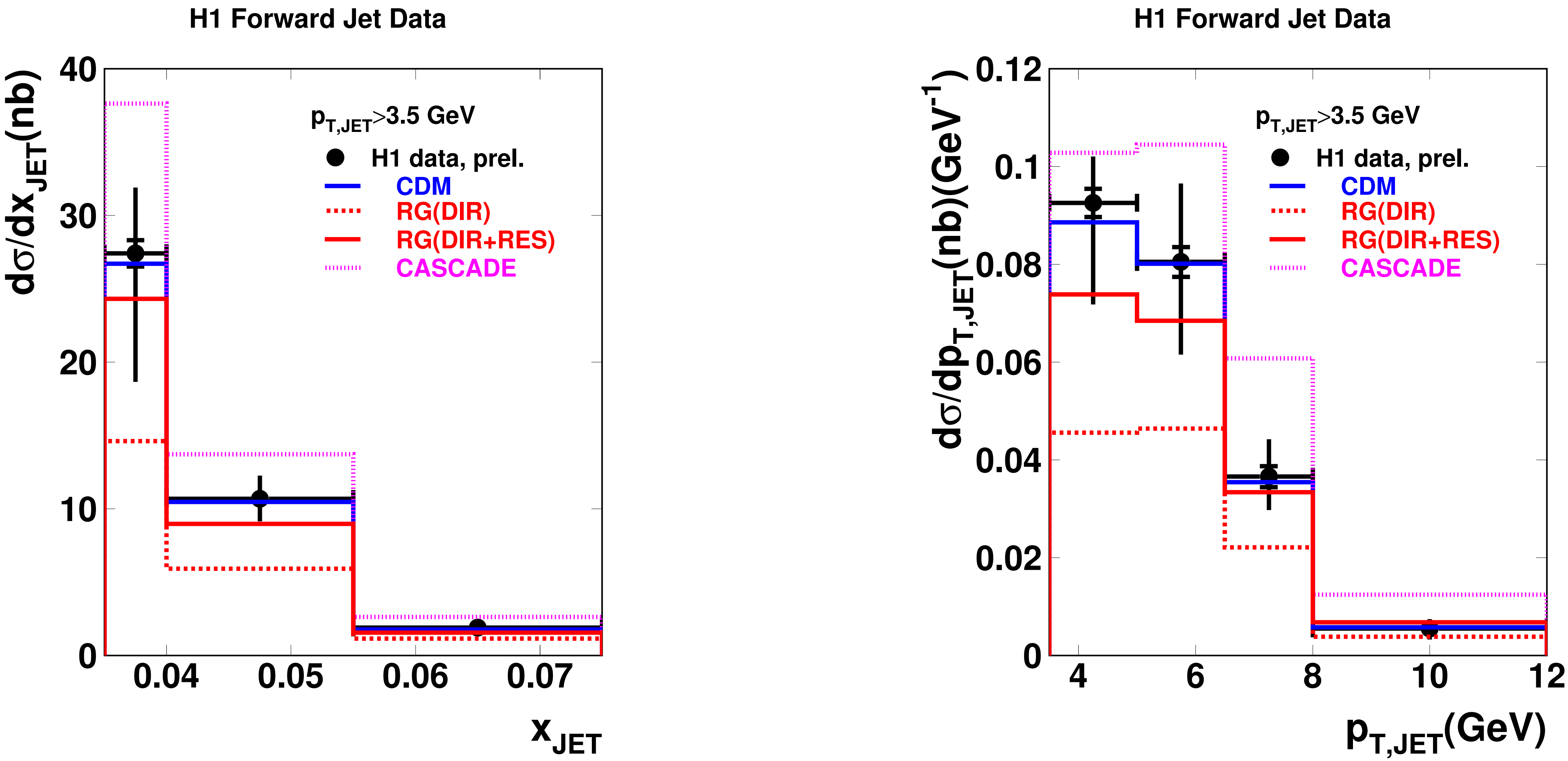
New pdfs and forward jets

- too small for old H1 data with cone jet algo
- ok for prel data with incl. kt jet algo
- similar to ARIADNE !!!!
- new soft treatment visible
- small differences between diff. pdfs
- even full splitting function agrees reasonably



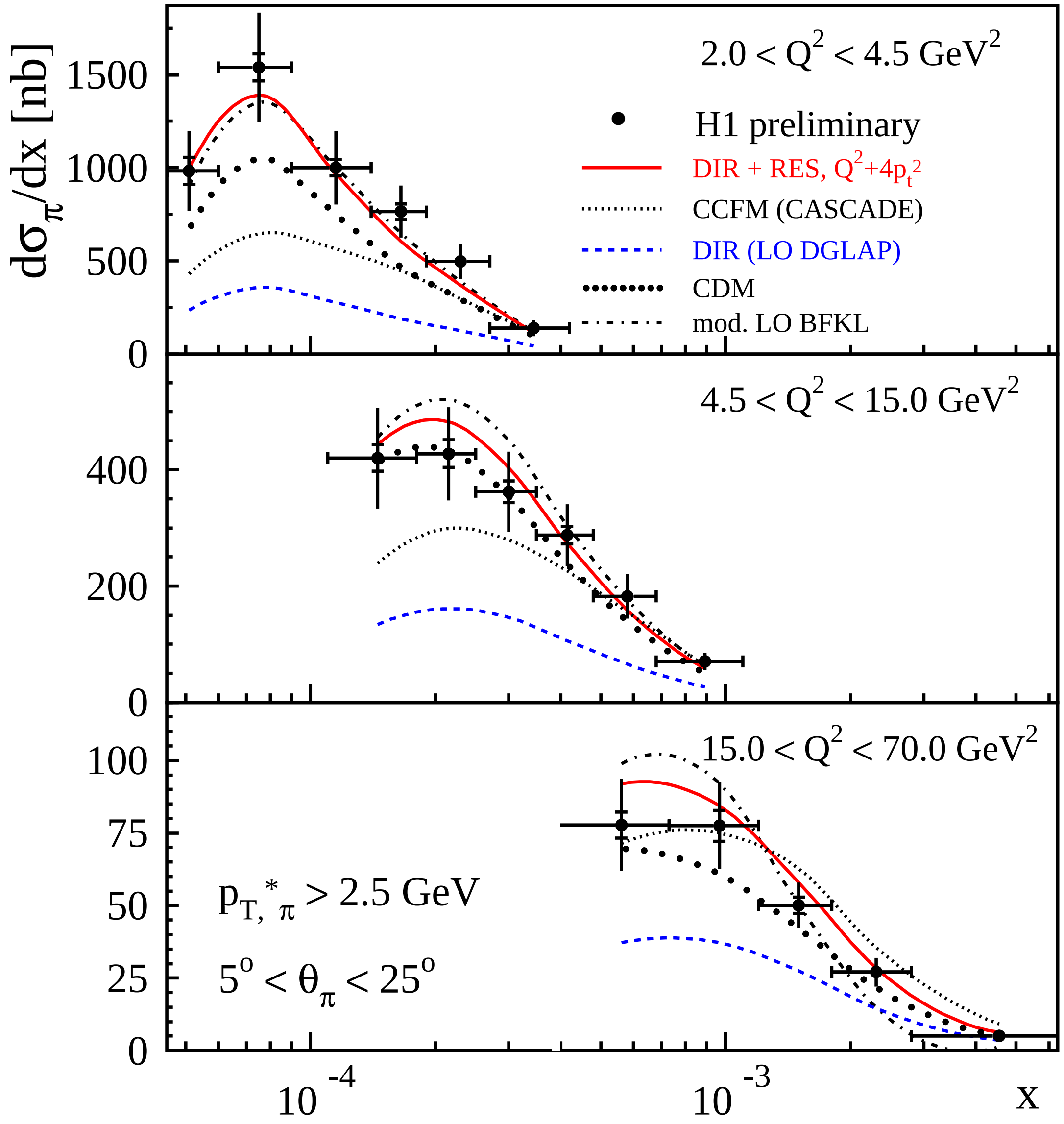


forward jets $d\sigma/dp_t$ and $d\sigma/dx_{jet}$



similar pattern of agreement/disagreement as for $d\sigma/dx$

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



DGLAP : too small

resolved photon component improves the description

$\mu^2 = Q^2 + 4p_T^2$

CDM:

reasonable description

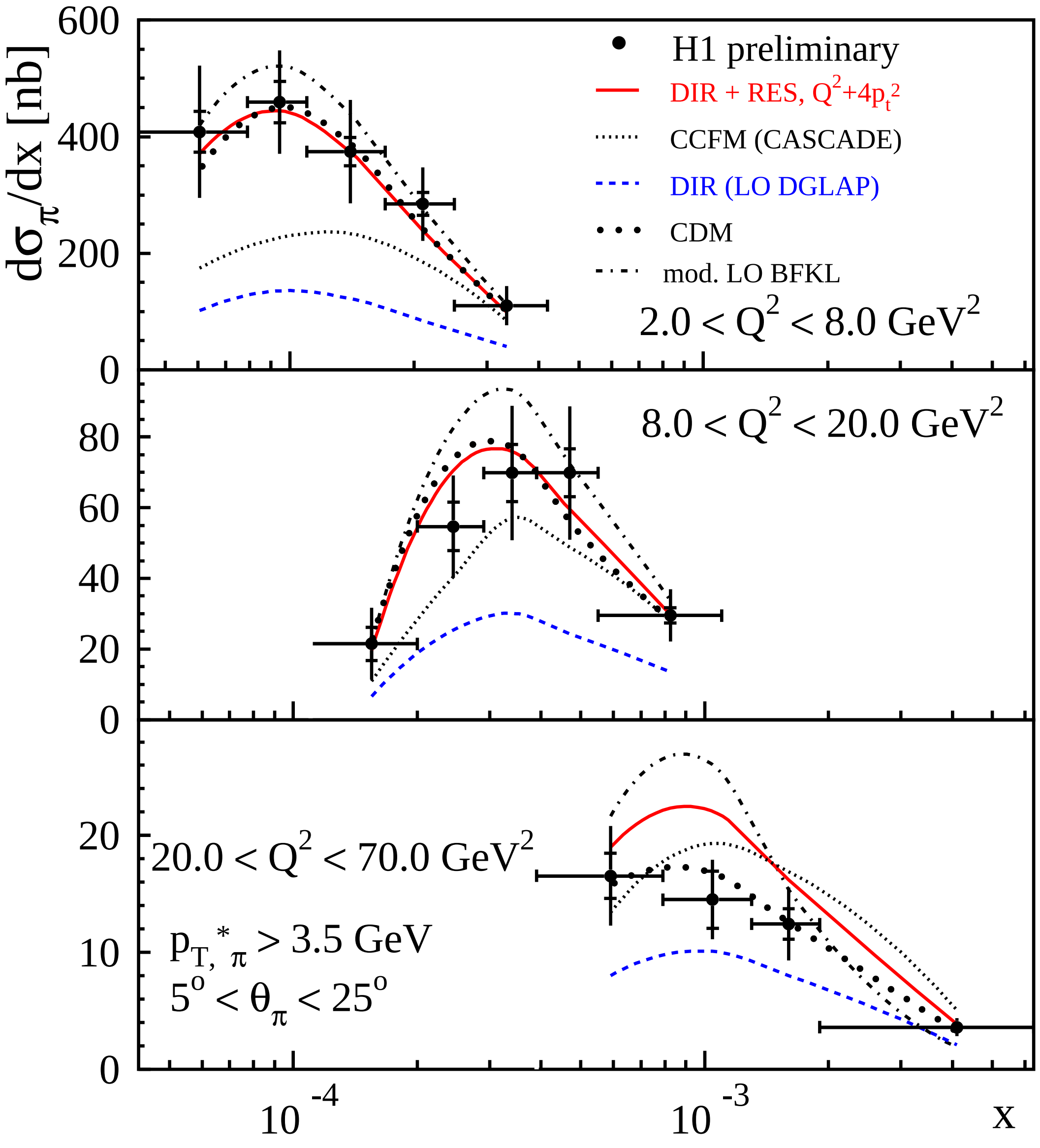
CASCADE:

too small at low x and Q^2 in the region not covered by forward jets

mod. LO BFKL

resonable description

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



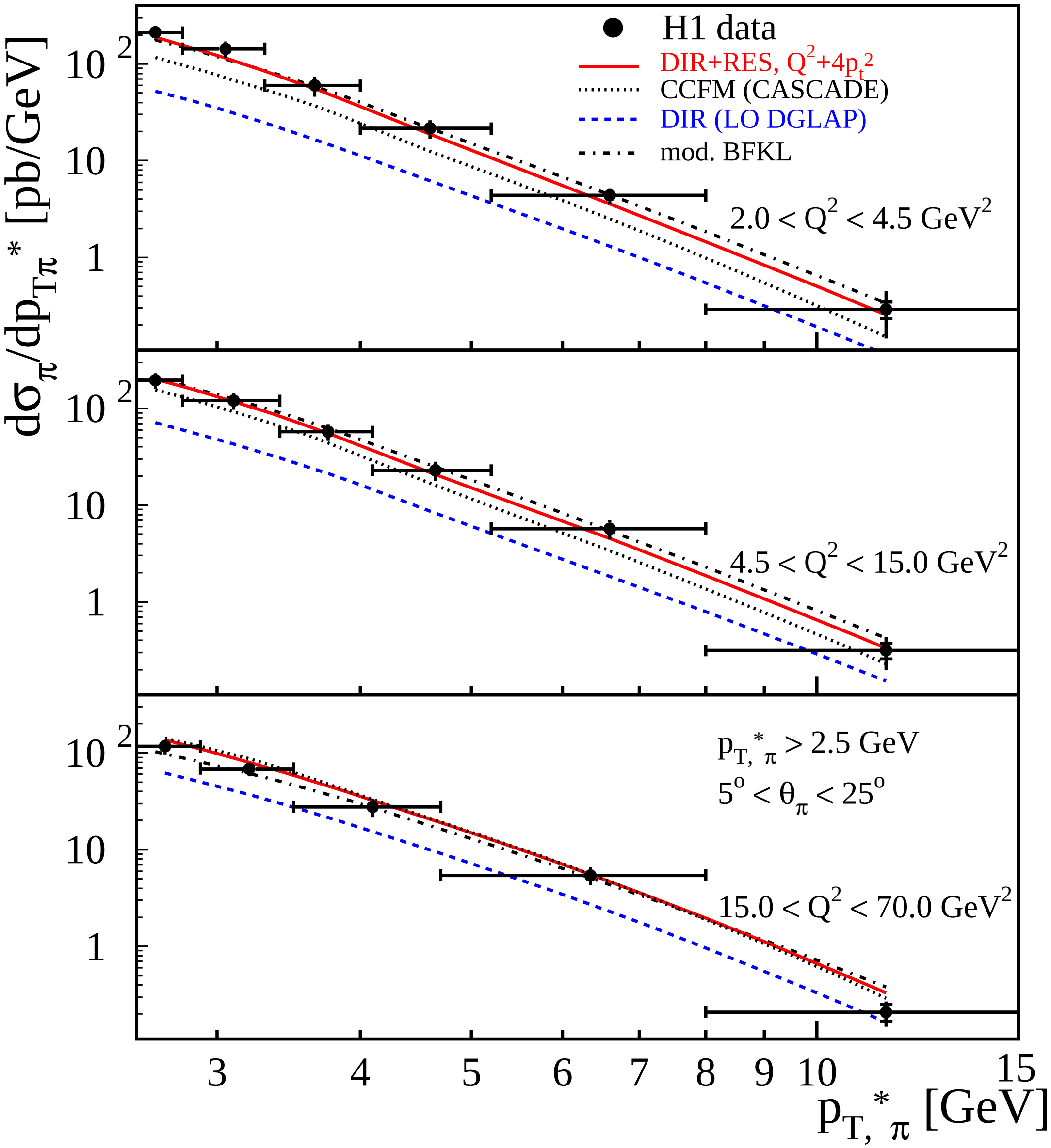
DGLAP too low
resolved photon component improves the description
$\mu^2 = Q^2 + 4p_T^2$

the best description of the data by CDM

CASCADE:
too small at lower x and Q^2,
inclusion of quarks
in the evolution will help ???

mod. LO BFKL
too high at higher Q^2

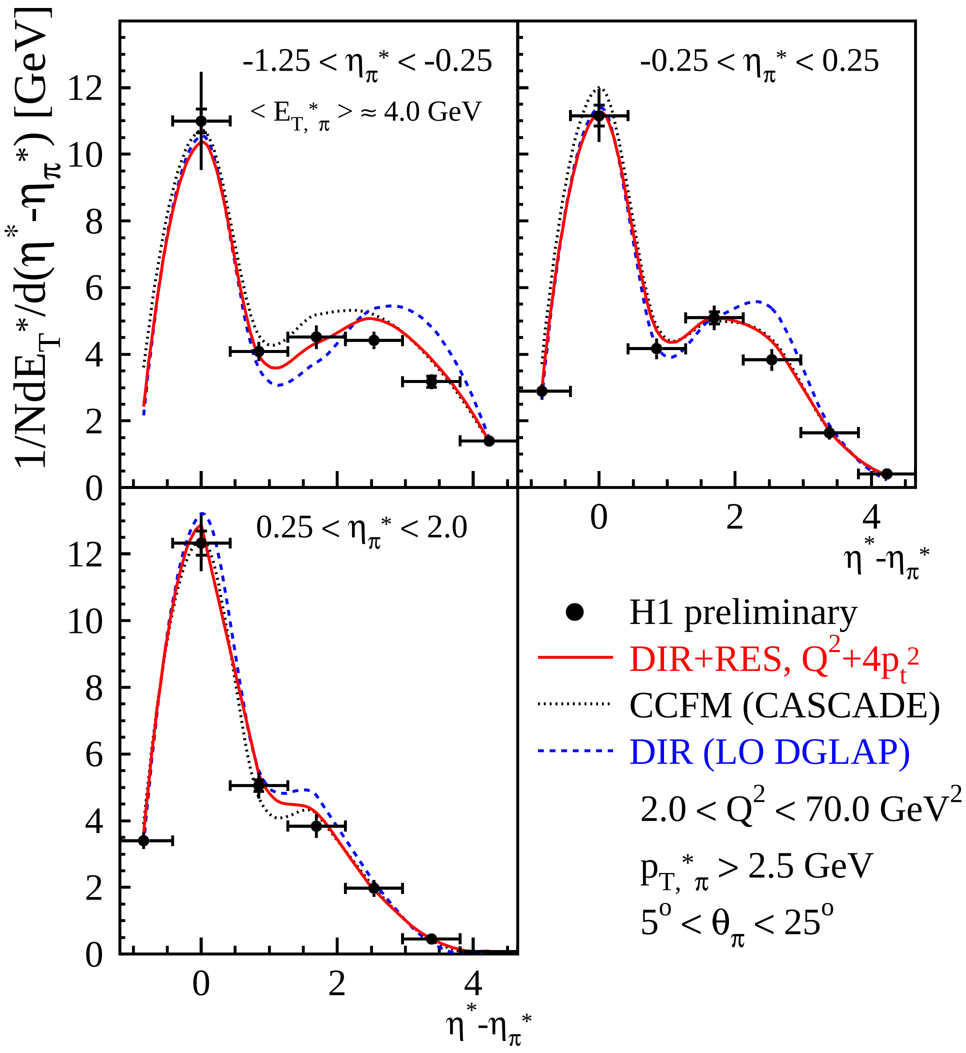
Forward π^0 : $d\sigma/p_T$ in different Q^2 regions



The same relation between the data and MC models observed in the whole range of p_T^*

Transverse energy flow associated with forward π^0

$\boldsymbol{\pi^0}$ close to proton $\searrow$ $\qquad \gamma^*$ p $\longrightarrow \longleftarrow$



hadronic CMS

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

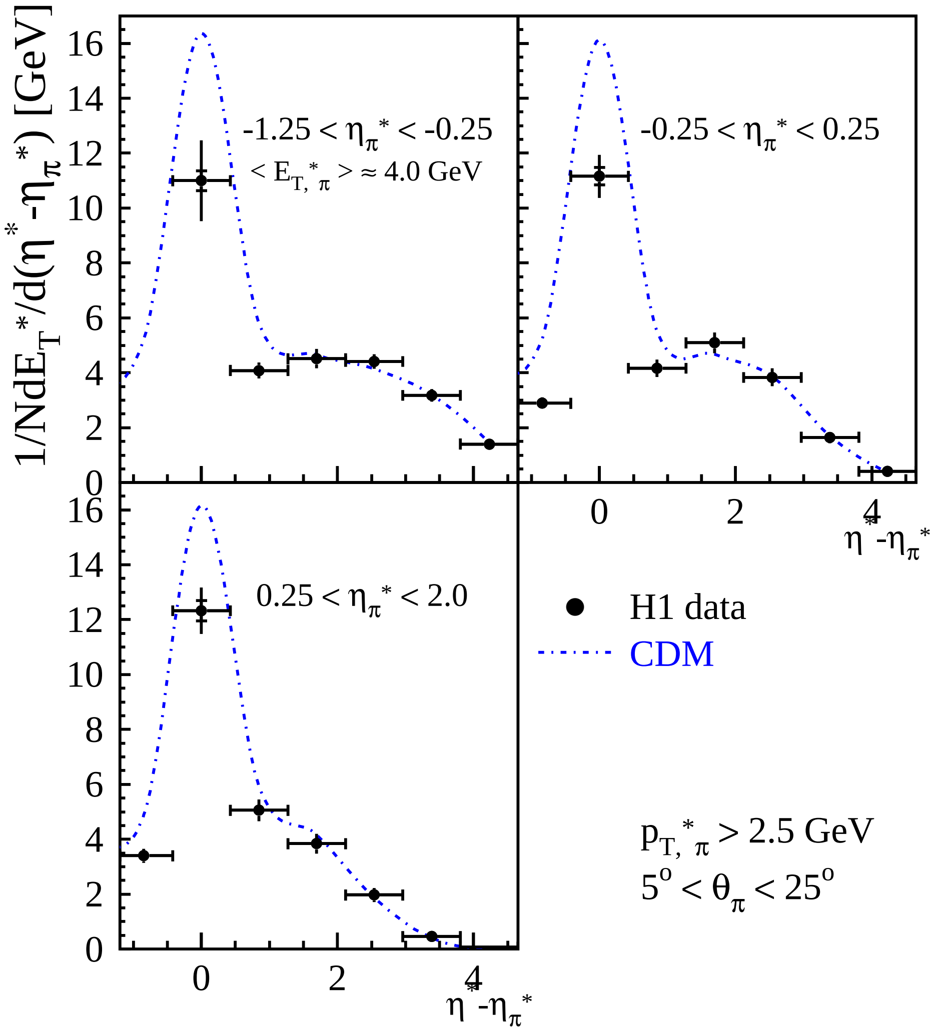
Transverse energy flow as a function of the difference in pseudorapidity $\Delta\eta^* = \eta^* - \eta^*_\pi$ from the forward π^0

contribution from E_T of π^0 included

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

Transverse energy flow associated with forward π^0

$\boldsymbol{\pi^0}$ close to proton ↘ $\qquad\qquad$ γ^* p $\longrightarrow \; \longleftarrow$



hadronic CMS

$$\frac{\mathbf{1}}{\boldsymbol{N}}\, \boldsymbol{dE_T^*/d(\eta^* - \eta_\pi^*)}$$

CDM :

too hard transverse momentum spectrum of the forward $\boldsymbol{\pi^0}$
$\longrightarrow$ too much $\boldsymbol{E_T}$ in the vicinity of $\boldsymbol{\pi^0}$

Summary and conclusions

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

Conclusions from forward jet/π^0 studies :

- standard DGLAP model fails to describe cross sections
- inclusion of resolved photon component results in considerable improvement of the forward jet and π^0 data description however with different choice of renormalisation and factorisation scale
- CDM gives reasonable description of cross sections but too much transverse energy in the vicinity of the π^0
- CASCADE (CCFM) below the data at lower $\boldsymbol{x}$
- mod. LO BFKL tuned to jet data describes $\boldsymbol{\pi^0}$ data