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Experimental Approaches to low x at HERA

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main approaches to test low x QCD dynamics

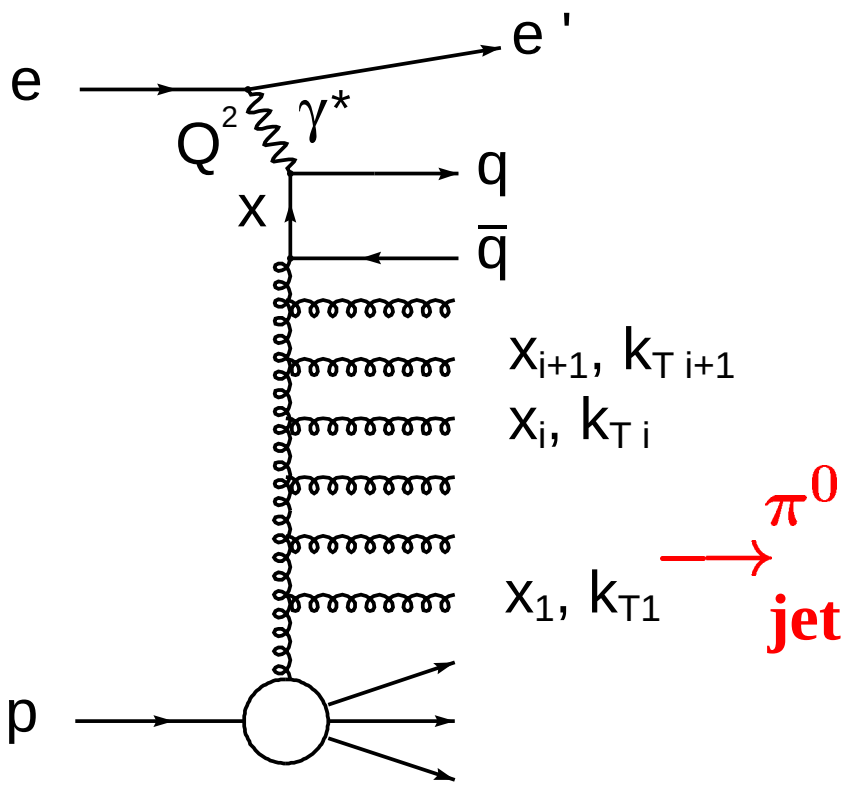
$F_2(x, Q^2)$

Heavy quark production in DIS

Forward jets/particles

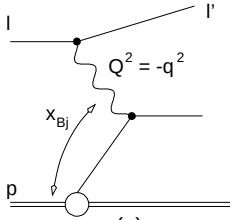
this talk :

- **Introduction**
- **forward jet production in DIS**
- **forward π^0 production in DIS**
- **Conclusion**

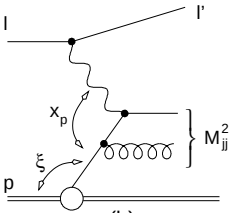


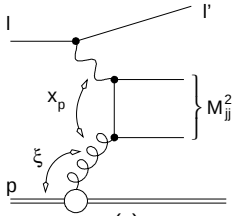
$$W^2 = Q^2(1/x - 1)$$

Forward jets in NLO QCD $O(\alpha_s^2)$



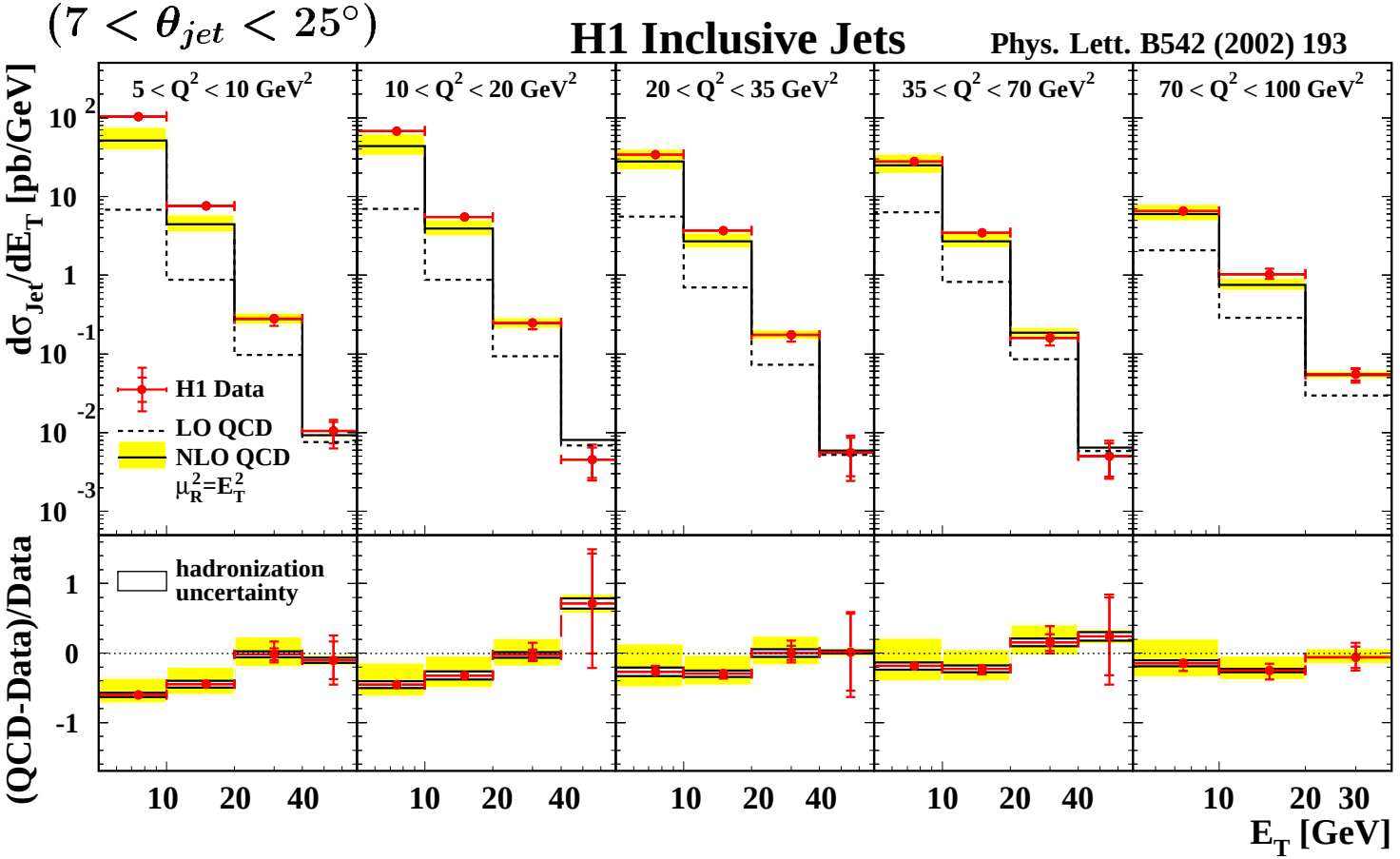
LO





$1.5 < \eta_{lab} < 2.8$

$(7 < \theta_{jet} < 25°)$

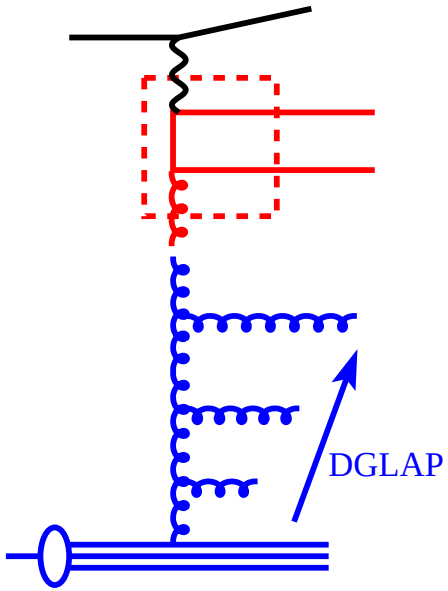


- **huge NLO corrections**
- **problems at small Q^2**

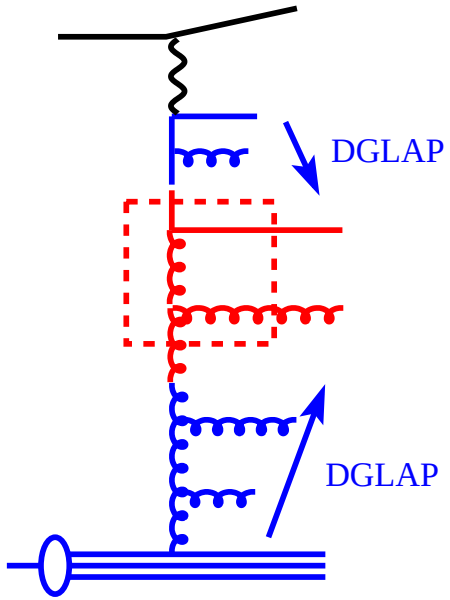
Approaches to the dynamics at small x

DGLAP **BFKL** **CCFM**

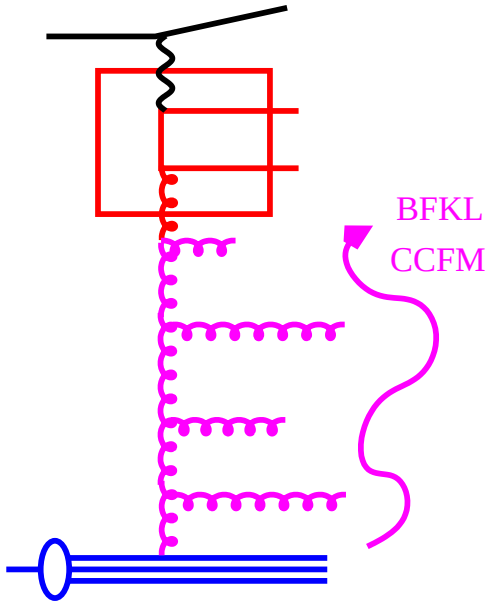
LO



resolved photon



k_t – factorization



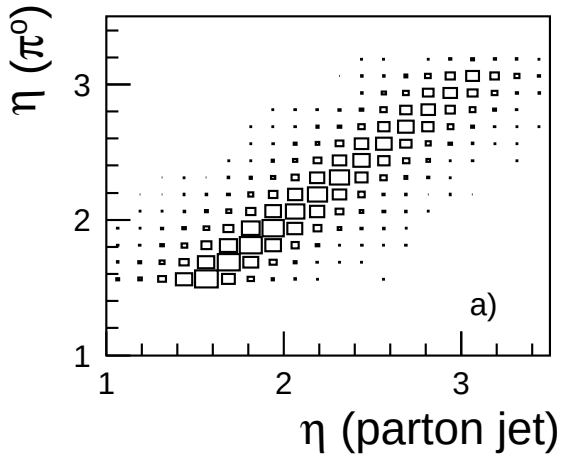
ordered in p_t **ordered in energy** **in angle**

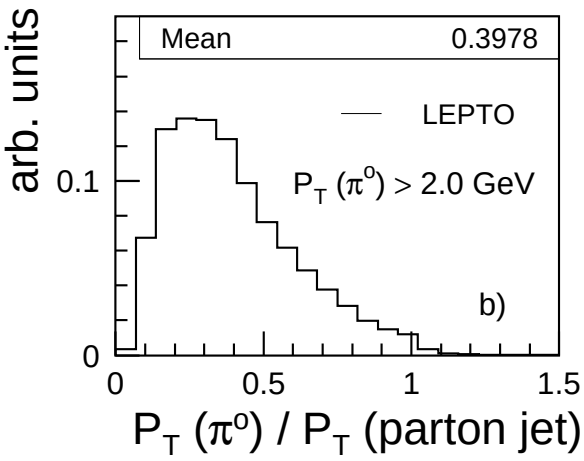
suppression of DGLAP (Q^2) evolution , but not BFKL (x) evolution, selecting jets/particles close to p direction with

small x_{bj}, $p_t^2 \approx Q^2$, **large** $x_{jet} \equiv E_{jet}/E_{proton}$ **(Mueller - Navelet jets)**

Forward jet or particle production in DIS

high p_t forward jets and forward particles are sensitive to underlying partons dynamics





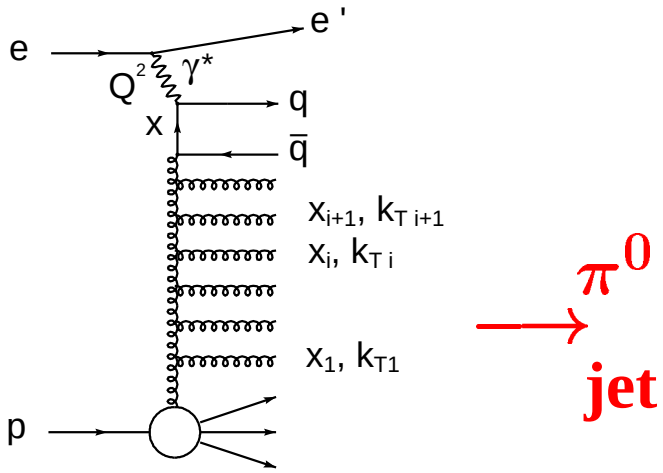
Jet measurements

- \+ **better parton correlation**
- \+ **higher rates**
- – **ambiguities of jet algoriths**
- – **exp. difficult in very forward (p) region**

forward particle detection π^0

- – **fragmetation effects more significant**
- – **smaller rate**
- \+ **identification possible in more forward region**

Selection of DIS forward jets and π^0



similar event selections for forward jets and π^0

forward jets

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

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

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

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

inclusive k_t algorithm

forward π^0 detection

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

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

$p^*_{t\pi^0} > 2.5$ GeV (hCMS)

$x_{\pi^0} = E_{\pi^0}/E_p > 0.01 \ \rightarrow \ E_{\pi^0} > 8GeV$

$\pi^0 \rightarrow 2\gamma$ reconstructed as one narrow cluster in H1 LAr calorimeter

Forward jets vs. x

CDM Colour Dipole Model in ARIADNE

(parton emissions random in transverse momentum, BFKL like?)

excellent description of data

RG RAPGAP (DIR)

(LO matrix elements with DGLAP parton showers)

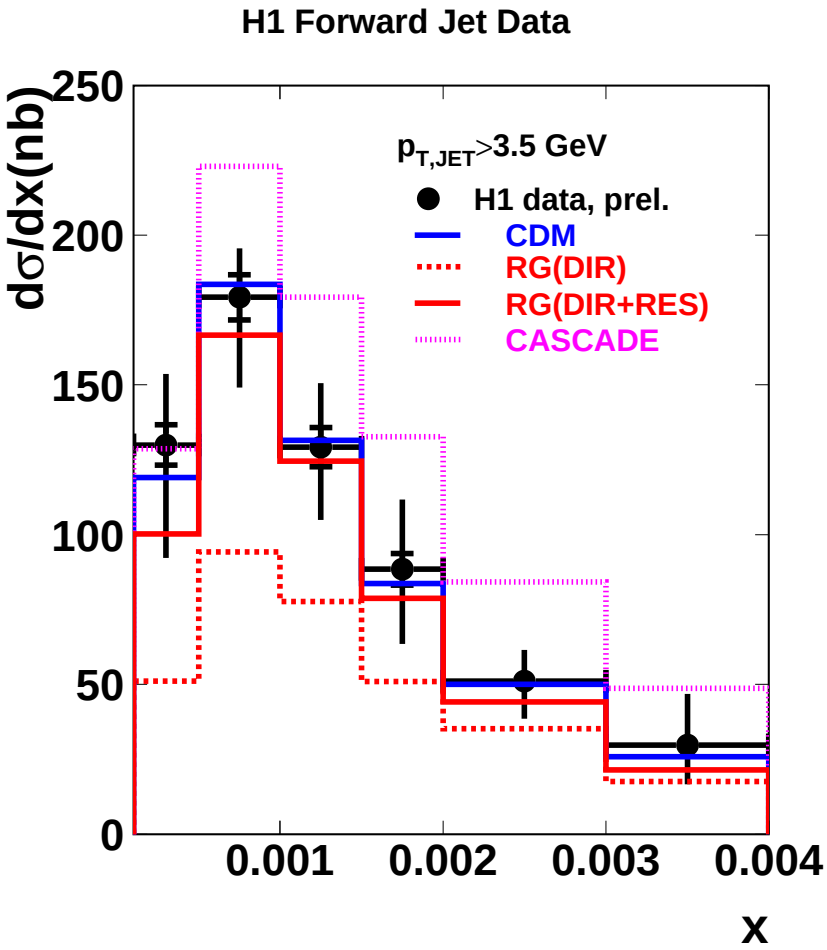
well below the data

RAPGAP (DIR + RES) **(addition of resolved γ^*)**

o.k. with inclusion of resolved γ^*

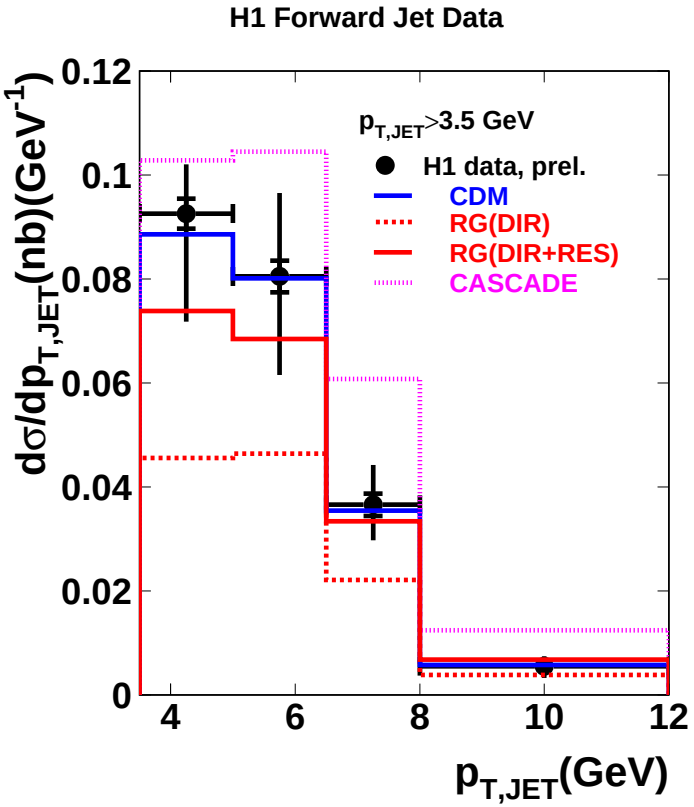
CASCADE (based on CCFM evolution equation)

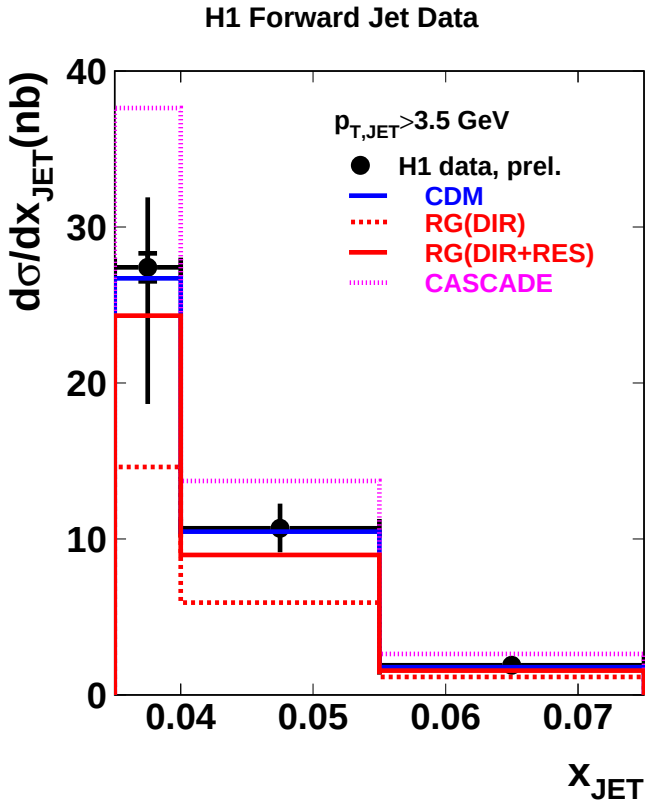
above the data



DGLAP too small, but what needed ? x ordering or resolved γ ?

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



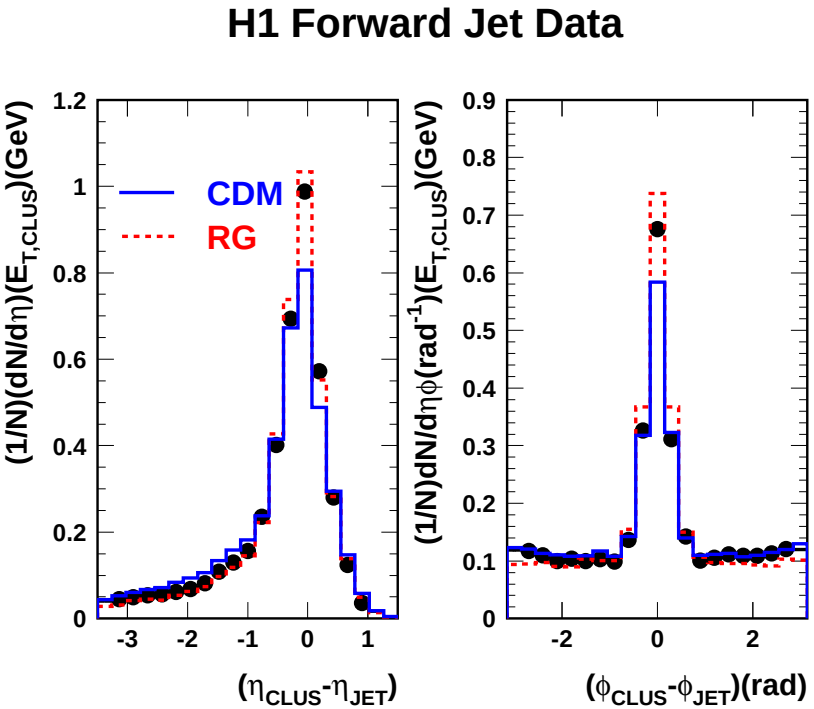


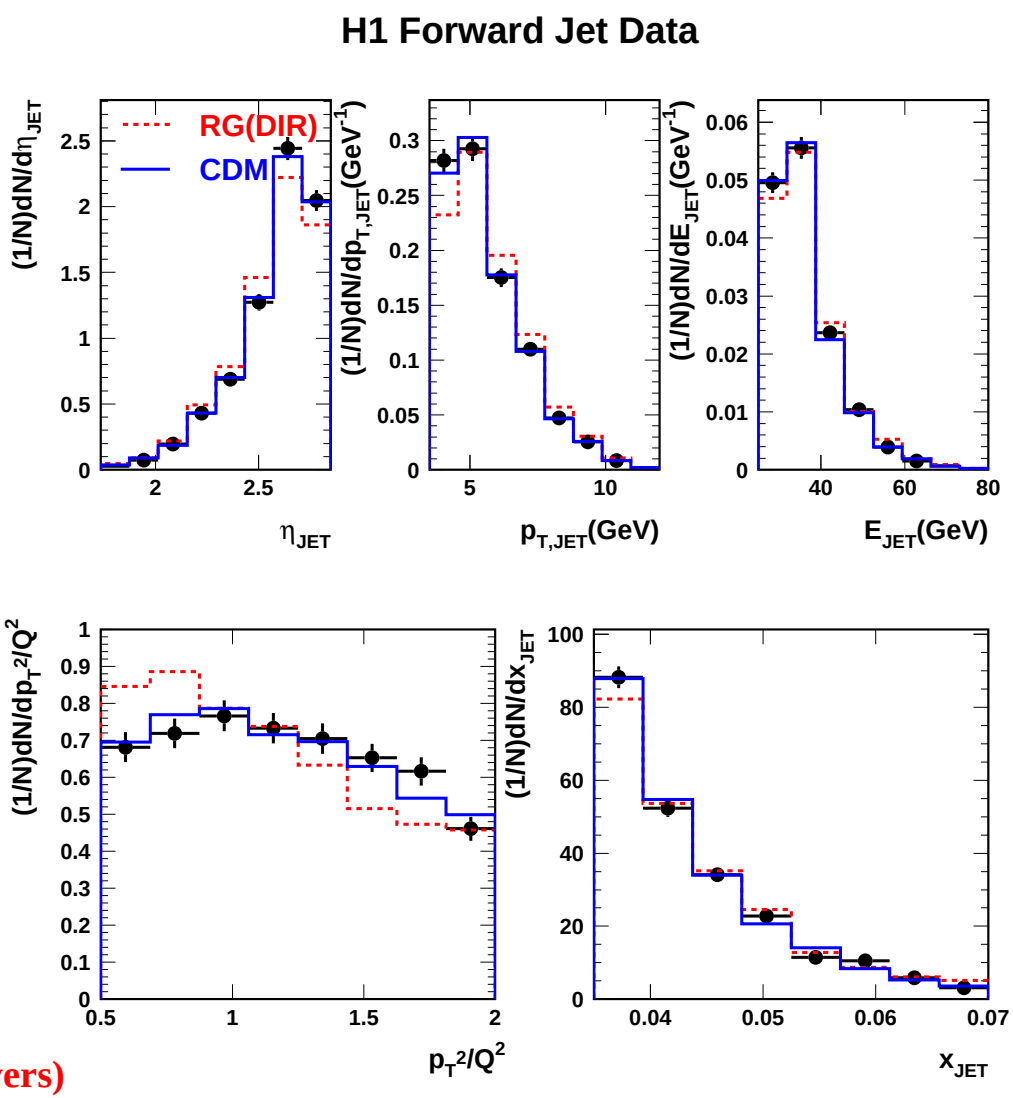
$x_{JET} = E_{JET}/E_p$

patterns of (dis)agreement same as for $d\sigma/dx$

- **CDM** **o.k.**
- **DGLAP (RG dir)** **low**
- **DGLAP + resolved γ^*** **o.k.**
- **CASCADE** **high**

normalised Jet distributions (forward jet selection)





basic distributions reasonably described

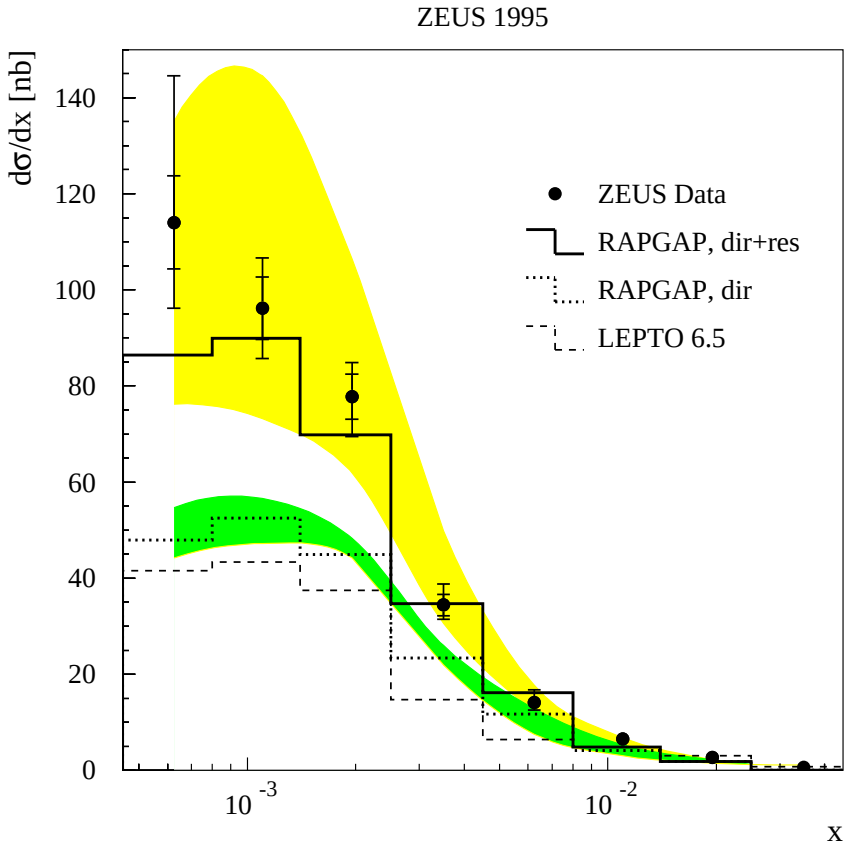
jets have more p_t^2/Q^2
than predicted in RG (LO + DGLAP parton showers)

Former HERA results in present context

forward π^0 : H1, Phys. Lett. B 462 (1999) 440 **improved by present analysis**

forward jets: H1, Nucl. Phys. B 538 (1999) 3 **improved by present analysis**

Forward jets $0.5 < E_T^2/Q^2 < 2$ **Phys. Lett. B474 (2000) 223**



- **DGLAP direct γ below the data**
- **+ resolved γ o.k.**

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

RAPGAP (DIR+RES)

(DGLAP, direct + resolved $\gamma*$)

reasonable description of data

RAPGAP (DIR)

below the data

CASCADE (CCFM)

below the data at small x, Q^2

(was high for forward jets for $x \gtrsim 0.001$ only)

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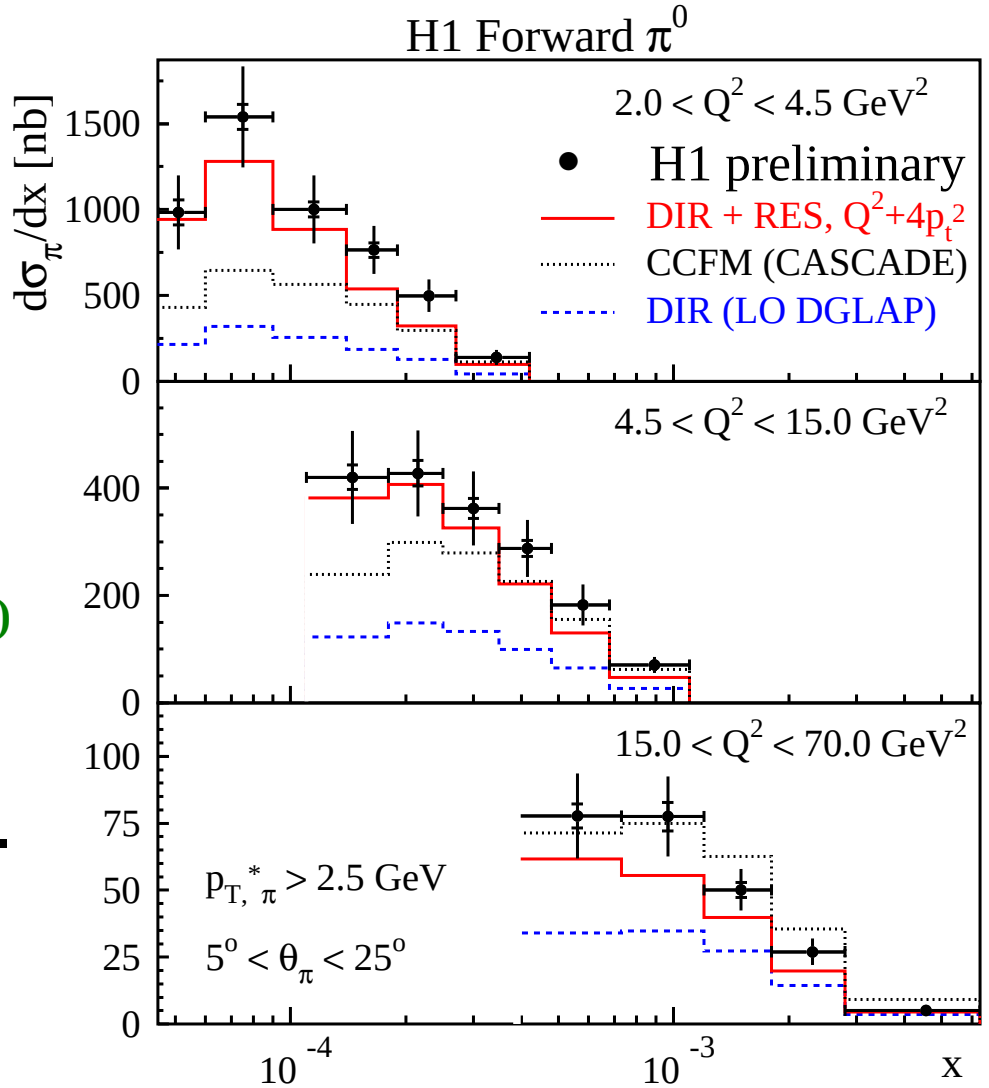
as in jets, DGLAP + direct γ interaction not sufficient



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

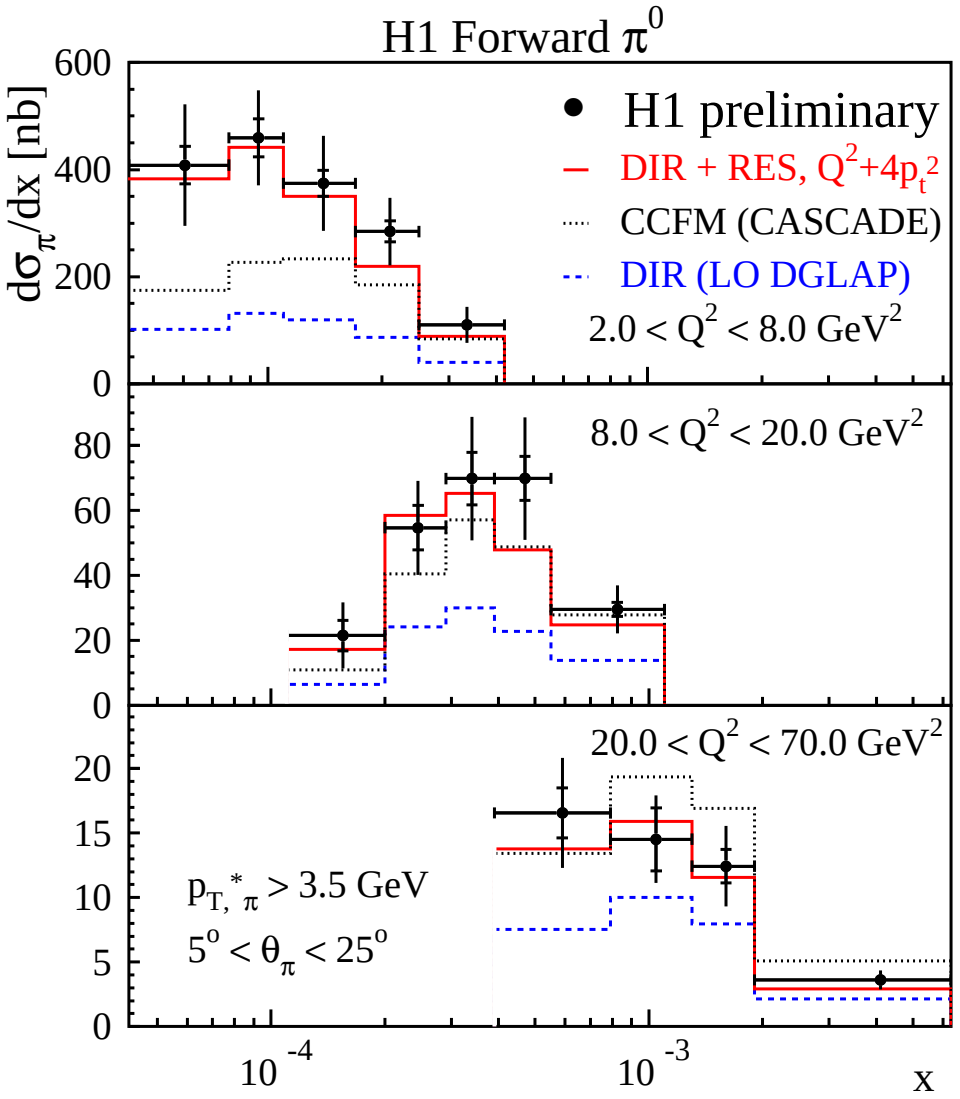
as for $p^*_{T,\pi} > 2.5$

DGLAP + direct γ interaction

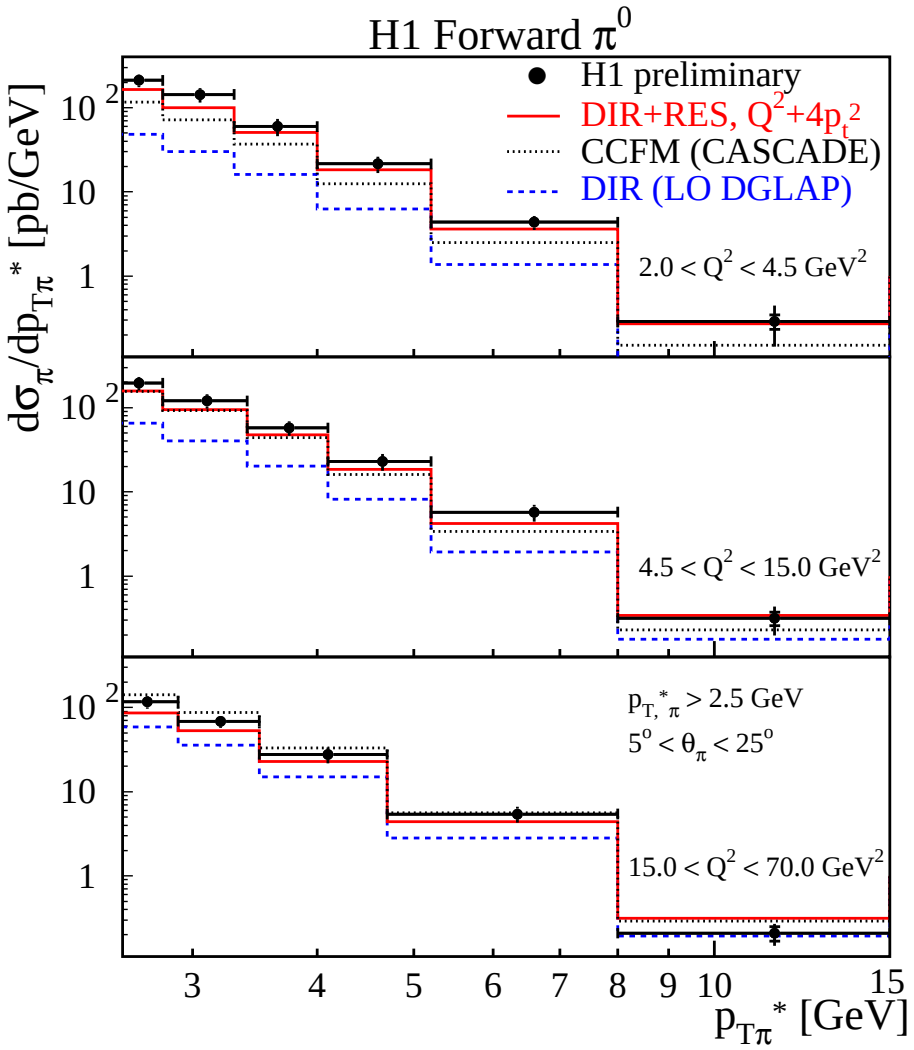
too low everywhere

+ resolved γ o.k.

CASCADE low at small x, Q^2



Comparisons of p_t dependence at different Q^2

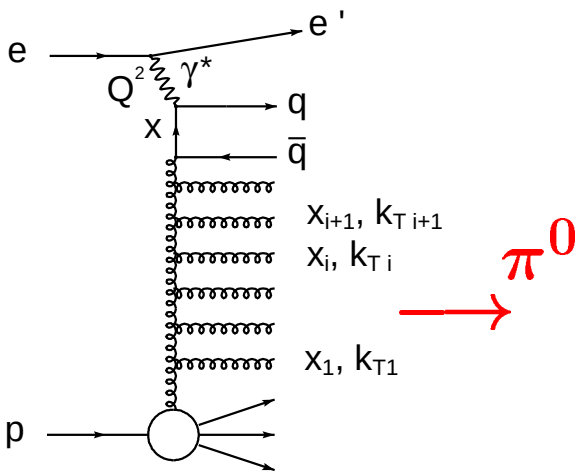


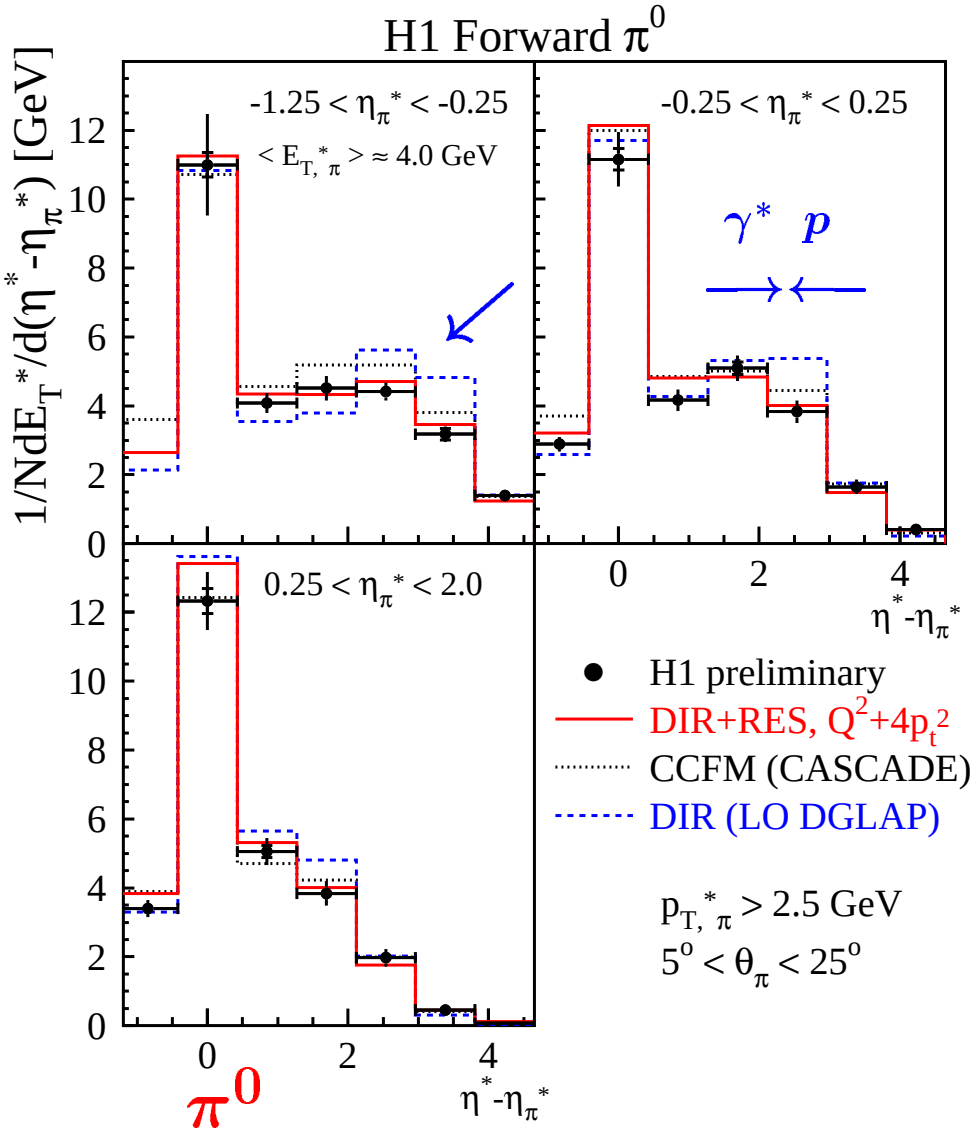
$p^*_{T\pi}$: p_t **in hadronic CMS**

p_t dependence well described everywhere by all calculations

Transverse energy flow around π^0 in 3 ranges of η^*_π

η^*_π **rapidity in had CMS**





at large $\eta^* - \eta^*_\pi$ less E_t in data
than expected in RAPGAP DIR.

Indication that in DGLAP approach
too much p_t compensation close to γ^* ?

Conclusions

- **data on forward (close to p remnant) jets and π^0 s in DIS shown**
- **NLO ($O(\alpha_s^2)$) calculations problematic in this region where phase space for DGLAP evolution small**
- **DGLAP MC models with direct γ^* interactions : too small cross sections**
- **with resolved γ^* interactions good description of of the data**
- **Coulour Dipole Model (CDM) describes the jet data very well (resembling the BFKL approach in the non ordered p_t production)**
- **CASCADE MC, based on the CCFM equation, predicts too small cross sections at $x \lesssim 0.001$.**
- **possible progress :**
  - ▽ **further experimental studies of ladder**
  - ▽ **more complete CCFM calculations**
  - ▽ **NLO ($O(\alpha_s^2)$) for presented data**
  - ▽ **NLO ($O(\alpha_s^2)$) MC with hadrons**