Forward Jets and Particles in ep collisions and parton dynamics

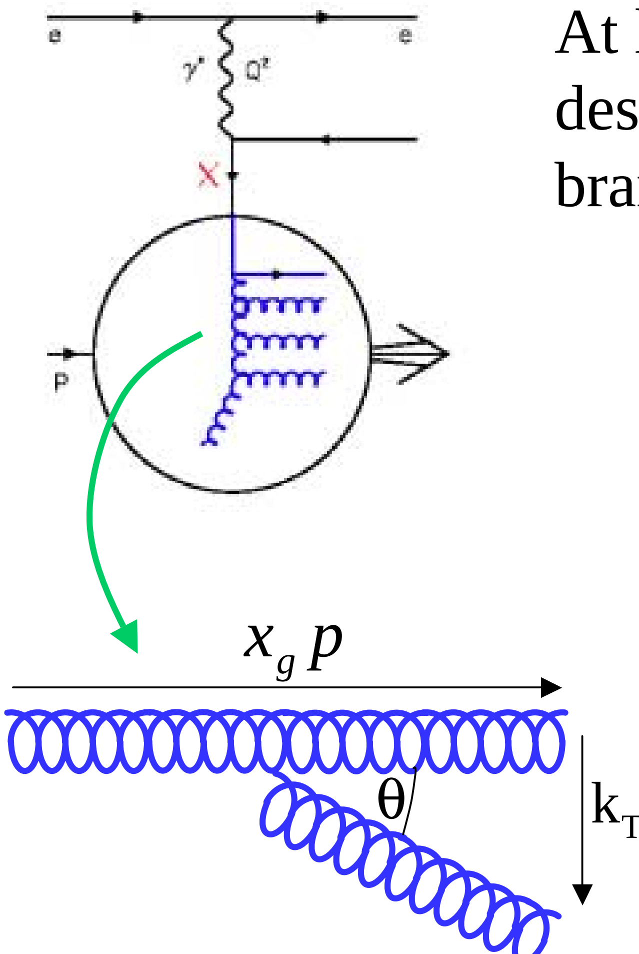
On behalf of H1 and ZEUS Collaborations

Jacek Turnau, Institute of Nuclear Physics, Cracow

ep (27.5 + 820 GeV) collisions

- Parton dynamics at high energies
- Central region
- Forward Jets
- Forward π^0
- Conclusions

QCD Evolution at low x



At low x scattered parton usually descends from long cascade of parton branchings.

$$\Delta\tau_{g1} \geq \Delta\tau_{g2} \geq \Delta\tau_{g3} \geq \ldots \Delta\tau_{gn}$$

$$\Delta\tau_g \sim \frac{1}{\Delta E} \sim \frac{2xp}{k_T^{\,2}}$$

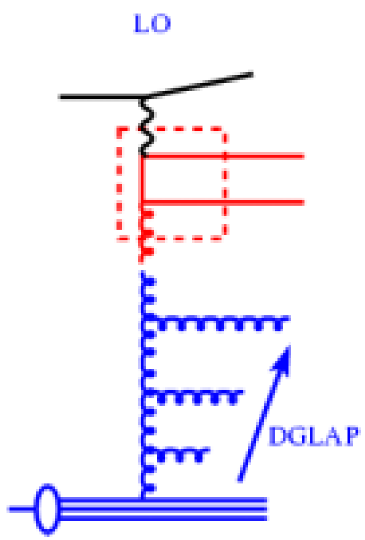
$$k_{T1} \leq k_{T2} \ldots \leq k_{Tn}$$ DGLAP

$$x_{g1} \geq x_{g2} \geq \ldots \geq x_{gn}$$ BFKL

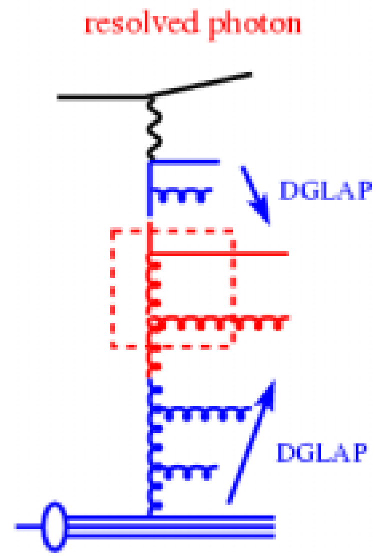
$$\theta_1 \leq \theta_2 \leq \ldots \leq \theta_n$$ CCFM

Comparison of the data to MC models with different QCD dynamics

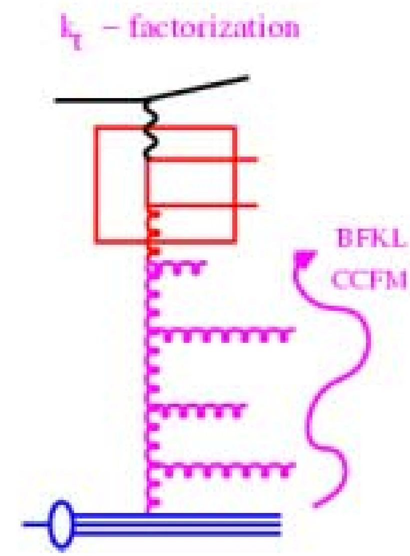
$E_T < Q$



$E_T > Q$



$E_T \approx Q$



k_t ordered initial state radiation

RAPGAP DIR

No k_t ordering in initial state radiation

Resolved photon

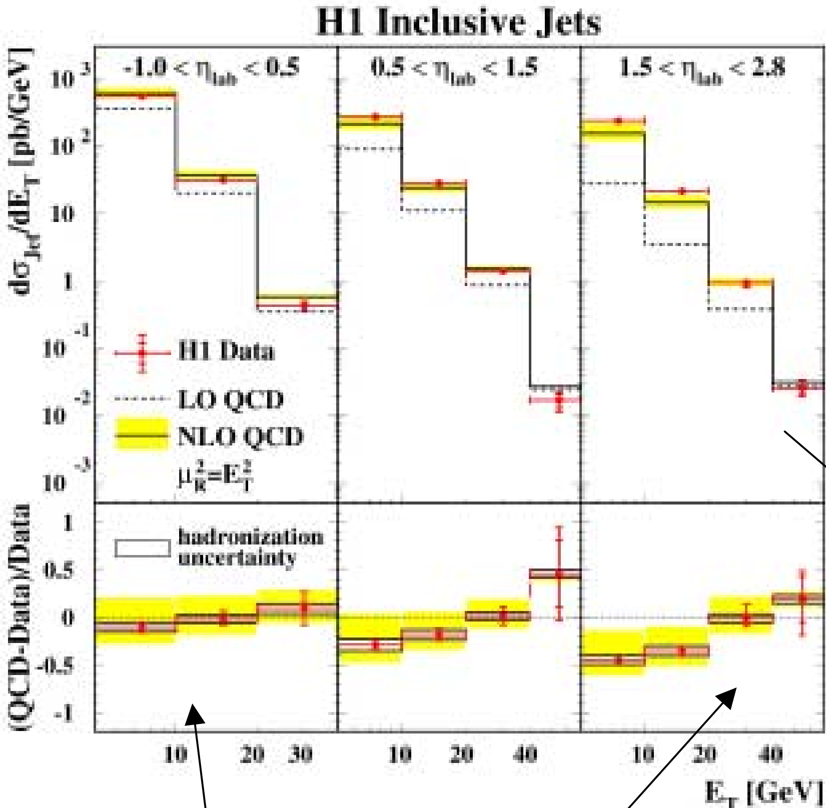
RAPGAP RES at scale $Q^2 + p_t^2$ (jets) or $Q^2 + 4p_t^2$ (π^0)

CCFM evolution equation

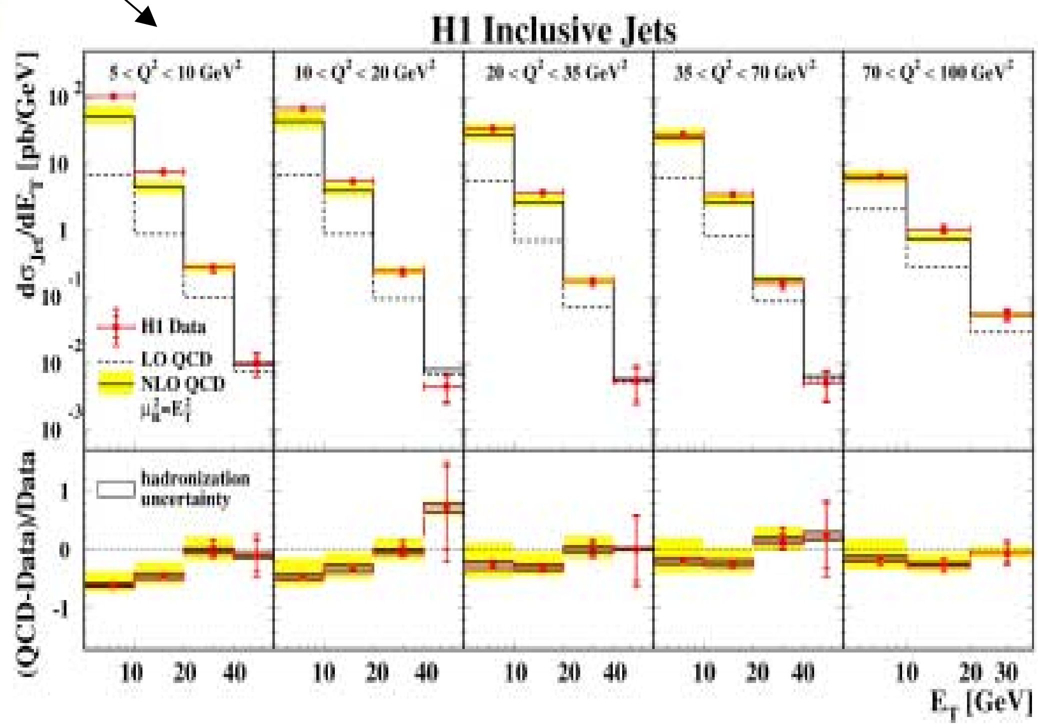
CASCADE 1.0

Inclusive Jets in DIS

$5 < Q^2 < 100$ GeV^2, $0.2 < y < 0.6$
incl. k_T algorithm in Breit frame



DGLAP description gradually deteriorates when going from backward to forward direction



Forward region:

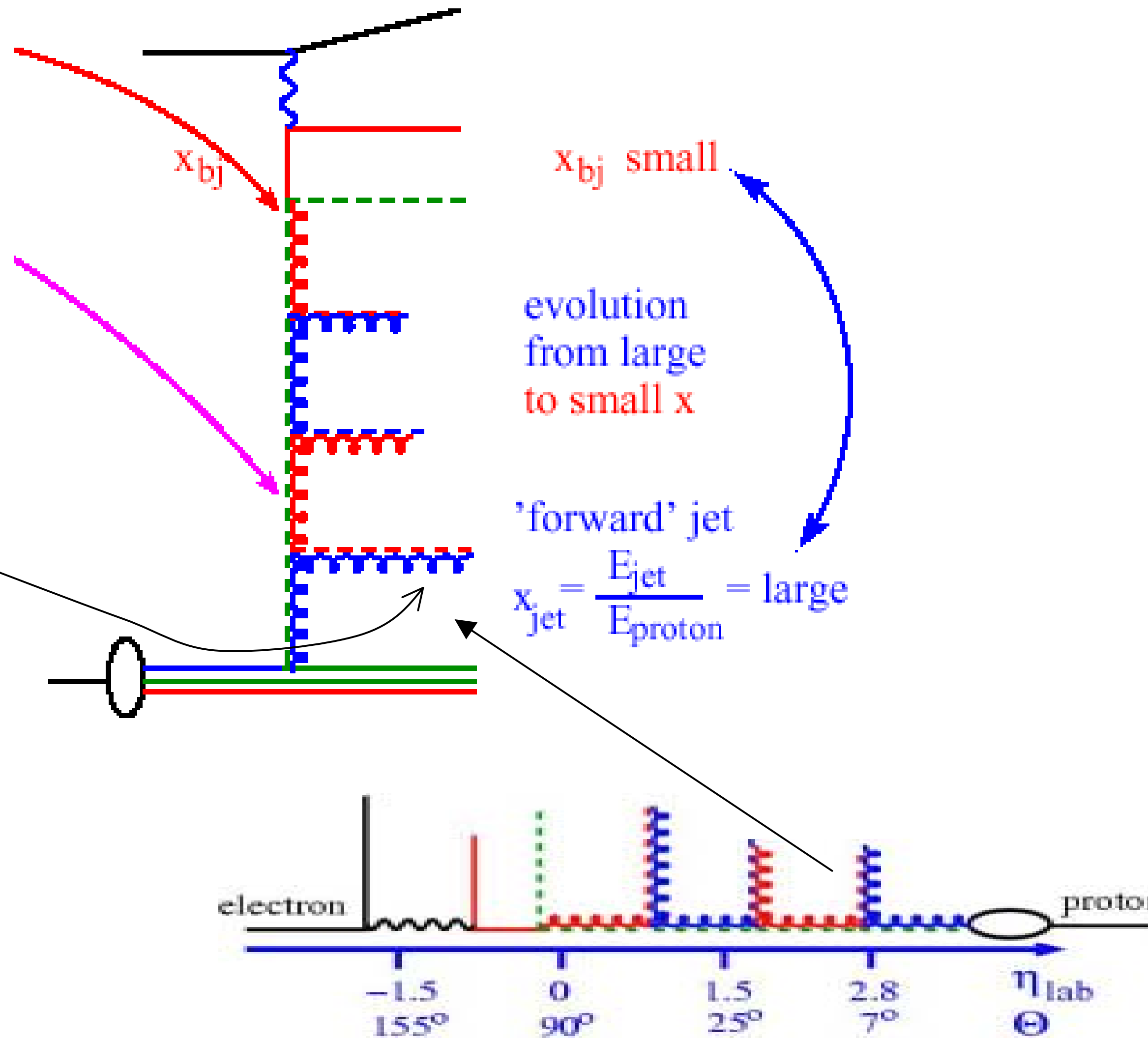
- huge NLO correction
- large deviations at small Q^2 & E_T

Moral: NNLO may be important in forward region

Forward jets : forward region under special scrutiny

Large x_{jet}/x_{bj} to enhance phase space for BFKL evolution

$E_{Tjet}{}^{2} \approx Q^{2}$
to suppress DGLAP evolution



Forward Jets

$\text{DIS}: 5 < Q^2 < 75\ \text{GeV}^2$

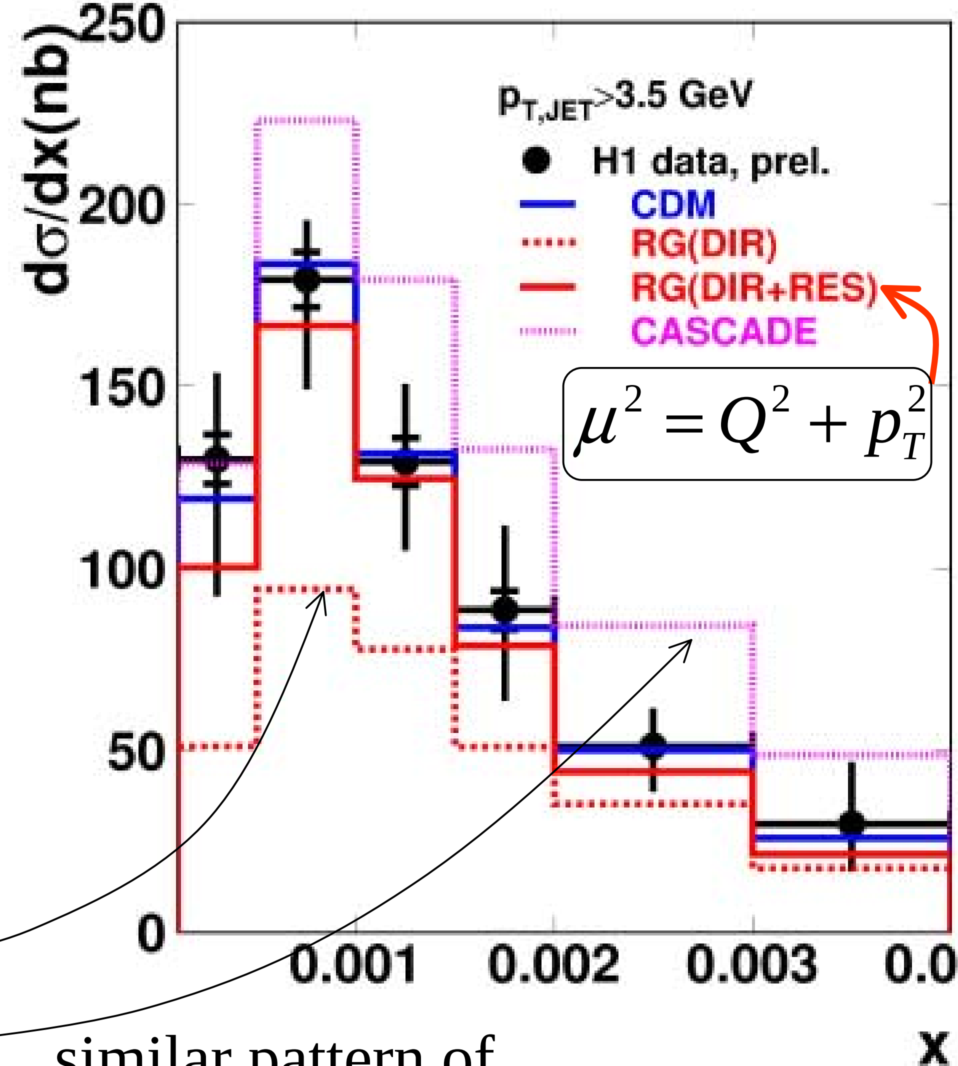
Forward jet (incl. k_t algo.)

$$7.0^\circ < \theta_{jet} < 20.0^\circ$$

$$x_{jet} > 0.035$$

$$0.5 < \frac{p_{tjet}^2}{Q^2} < 2.0$$

H1 Forward Jet Data (1997)



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

- DGLAP direct : too low
- CCFM: too high
- DGLAP (DIR+RES): OK

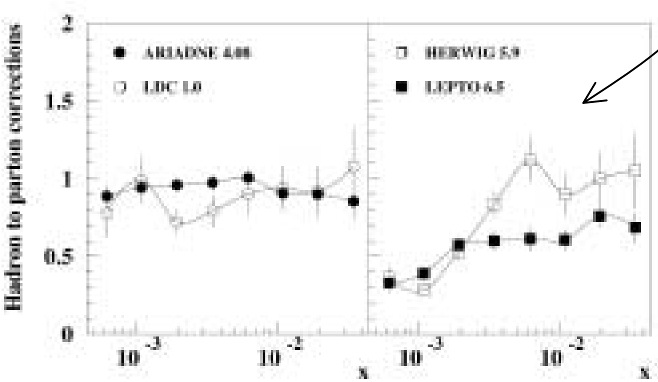
similar pattern of agreement/disageement for x_{jet}, p_{Tjet}

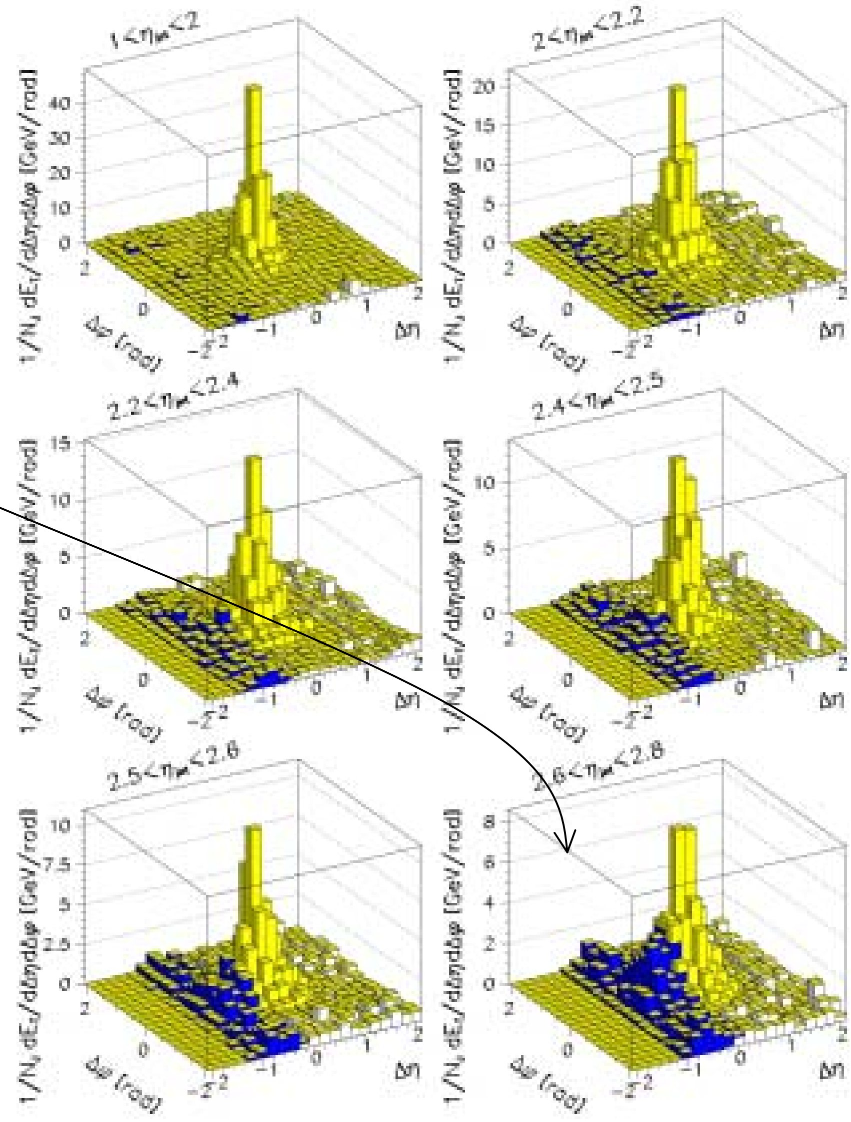
Forward jets in ZEUS detector

Forward jets are experimentally difficult:

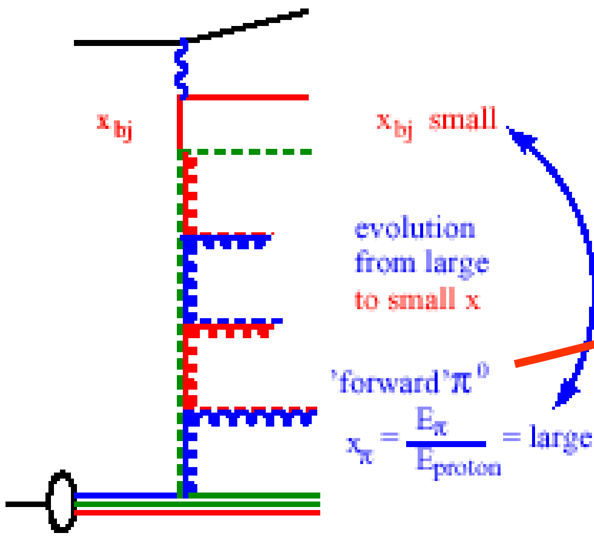
• Interference with proton remnant

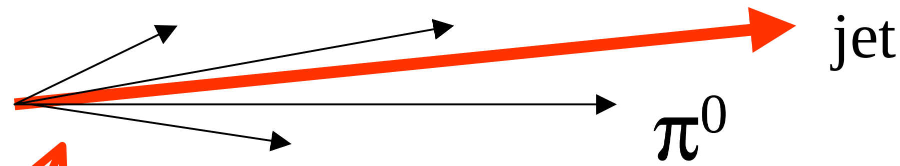
•Hadronic corrections strongly model dependent at small *x*





Forward jets ⇔ forward particles (π^0)





$$\sigma(\pi^0) = \left(\begin{array}{l}\text{fragmentation} \\ \text{by Lund} \\ \text{model or} \\ \text{convolution} \\ \text{with FF}\end{array}\right) \otimes \sigma(jet)$$

Jet measurements

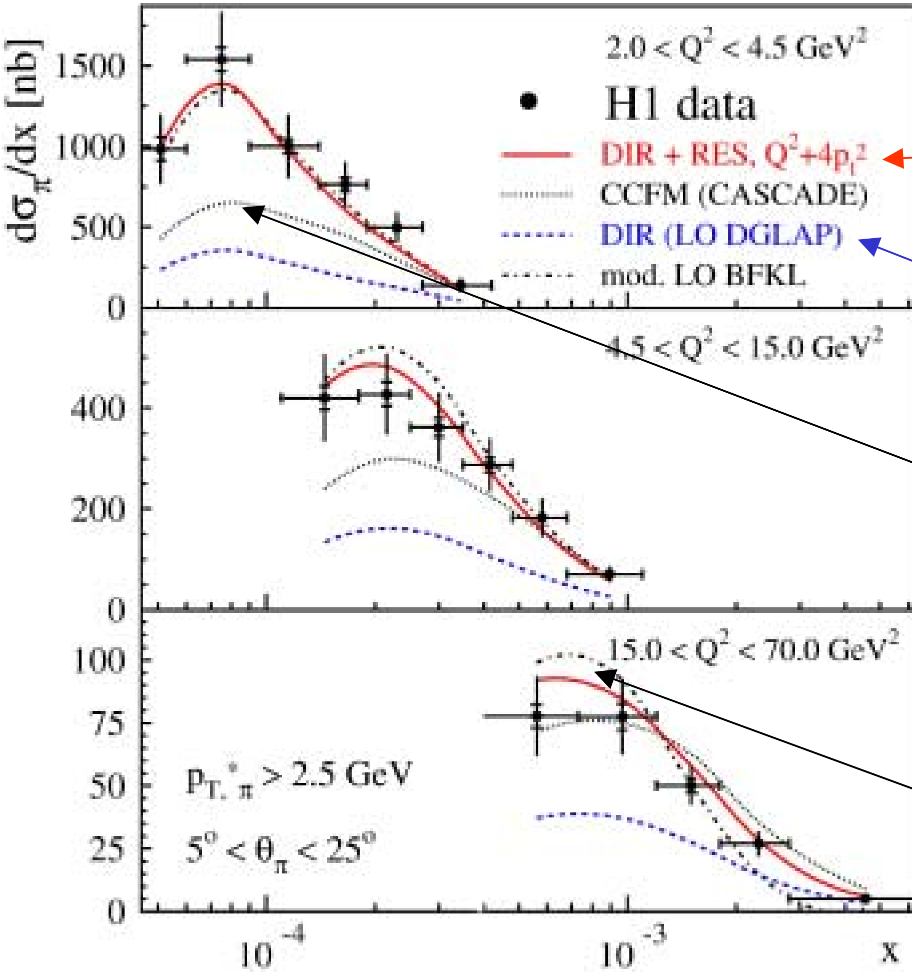
- \+ **better parton correlation**
- \+ **higher rates**
- — **ambiguities of jet** algorithms
- — **exp. difficult in very forward (*p*) region**

forward particle detection π^0

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

There is another interesting aspect of bringing particle into the game - later

Forward π^0 cross section : x dependence



Best description:

direct + resolved at scale $\mu^2 = Q^2 + 4p_T^2$

DGLAP direct: too low

CCFM too low at small x

Mod. LO BFKL tuned to H1 1997 data + recent FF describes the data

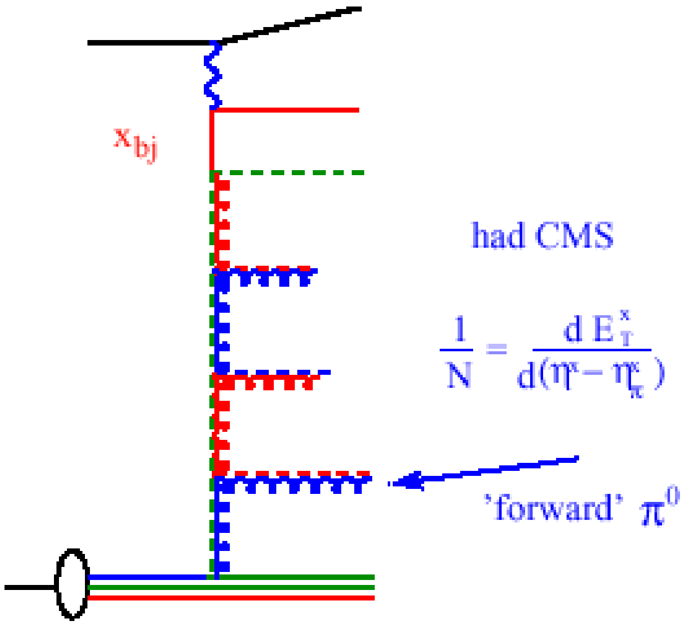
Similar pattern of agreement/disagreement for other distributions

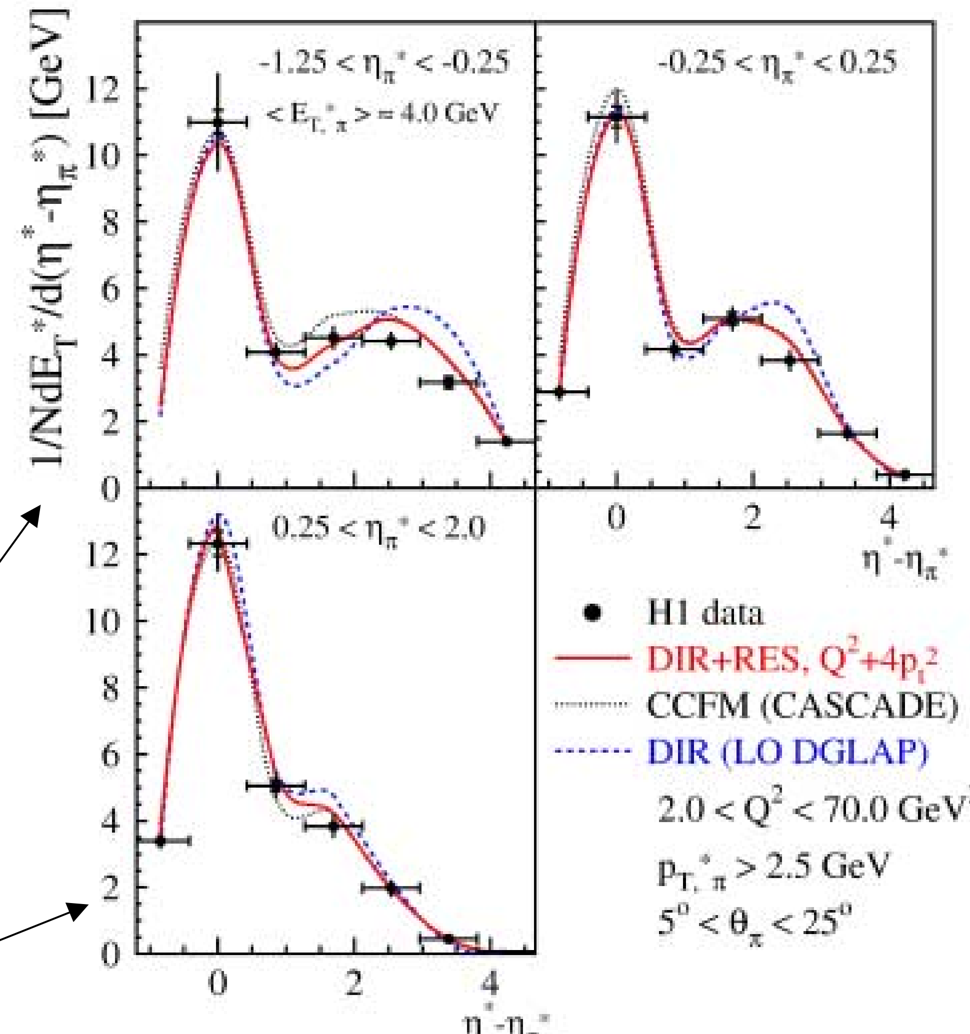
Overview of description of jet/particle x-sections

Evolution scheme	Renor. & factor.scale	Fragmentation scheme	Fragmen-tation scale	Forward jets	Forward π^0
DGLAP (dir+res) RAPGAP	$\mu^2=Q^2+p^2_t$ Up to $\mu^2=Q^2+4p^2_t$	JETSET 7.4 (Lund model)	String inv. mass	OK	OK at upper limit of renor. scale
CCFM CASCADE	$\mu^2= Q^2+4m_Q^2$	PYTHIA 6.2 (Lund model)	String inv. mass	too high	too low
Mod. LO BFKL	$\mu^2=k_{Tjet}^2$	LO KKP FF	z_pi* Q^2	OK	OK

Something wrong either in mod. LO BFKL (KMO) or CASCADE

Transverse energy flow associated with forward π^0





In hadronic CMS:

• π^0 close to proton (most forward)

•π^0 towards to photon (less forward)

SUMMARY AND CONCLUSIONS

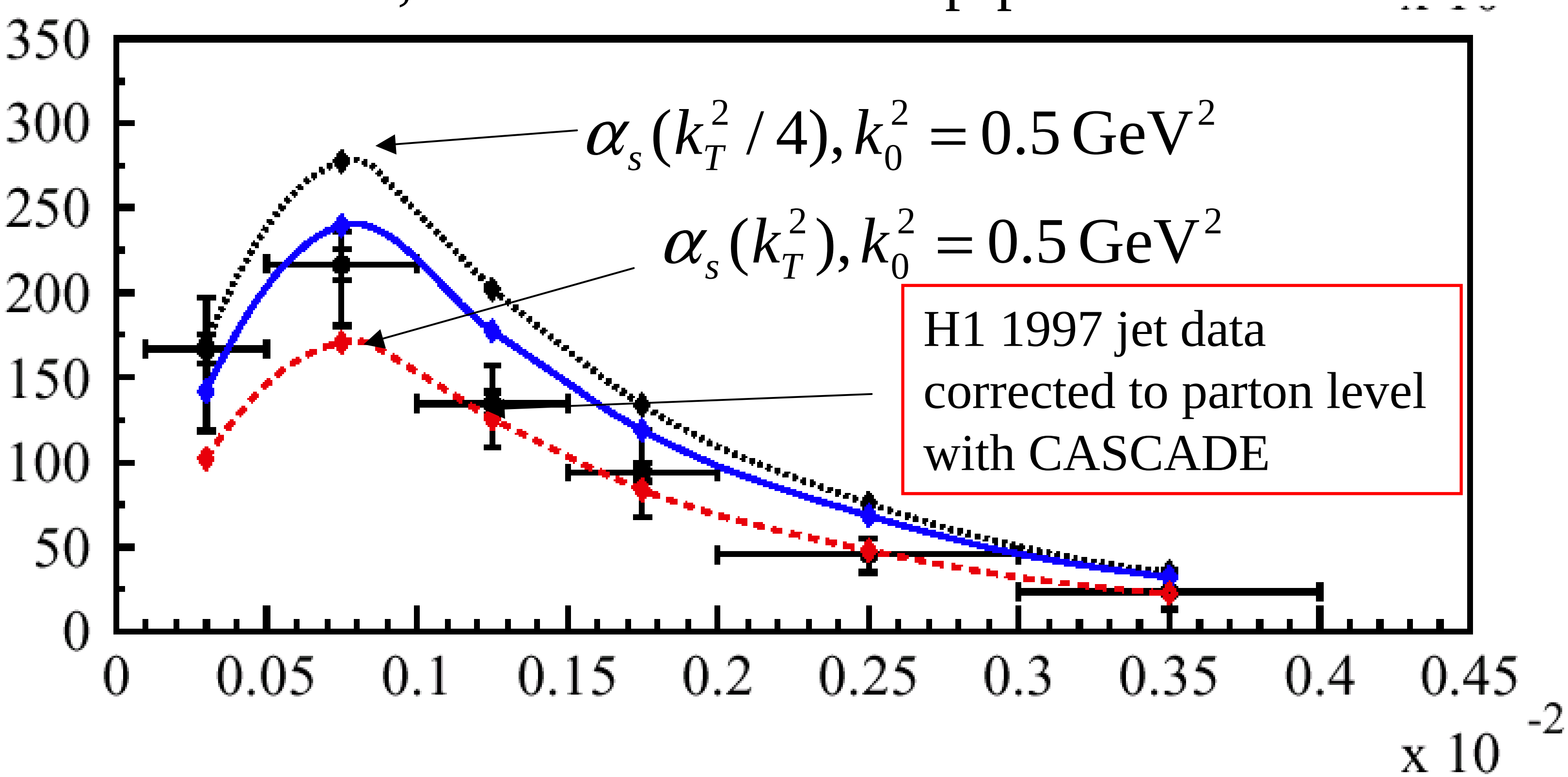
Forward jets at HERA: after ~10 years description still difficult.

- NLO DGLAP not enough to describe forward jet data
- DGLAP direct + resolved describes the fwd jet & π^0 data
- Energy flow pattern slightly favors DGLAP direct + resolved in comaprison with other schemes
- Mod. LO BFKL tuned to jet data describes π^0 data
- CCFM slightly overshoots jet data and underestimates π^0 data
- There seems to be contradiction between last two points : something must be wrong...

Forward jets and BFKL

Modified LO BFKL calculation

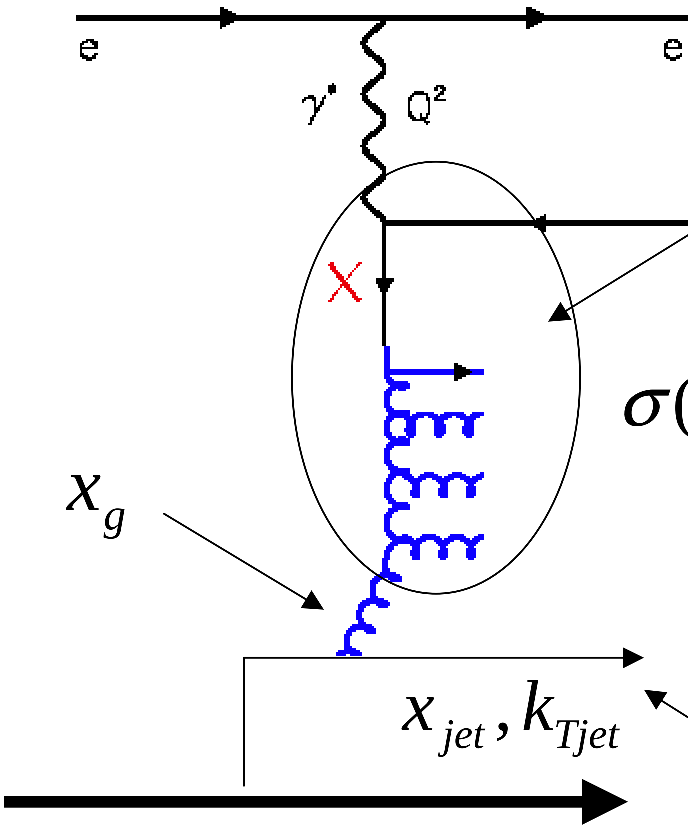
Kwiecinski, Martin Outhwaite hep-ph/9903439



Normalization very sensitive to infrared cut-off k_0 and scale for α_S

Modified LO BFKL calculation

Kwiecinski, Martin Outhwaite hep-ph/9903439

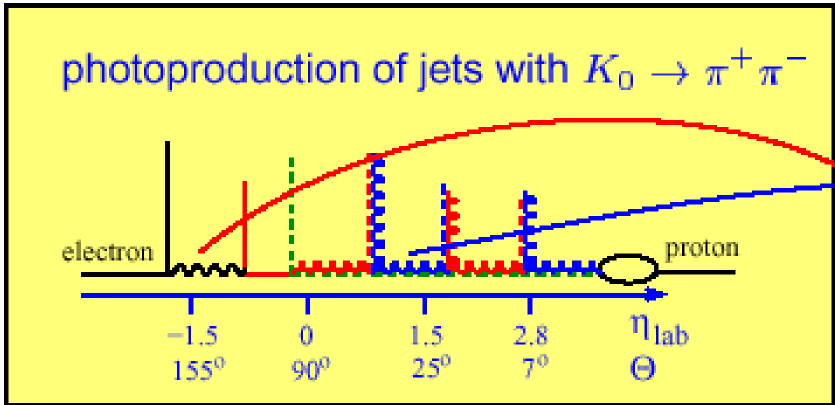


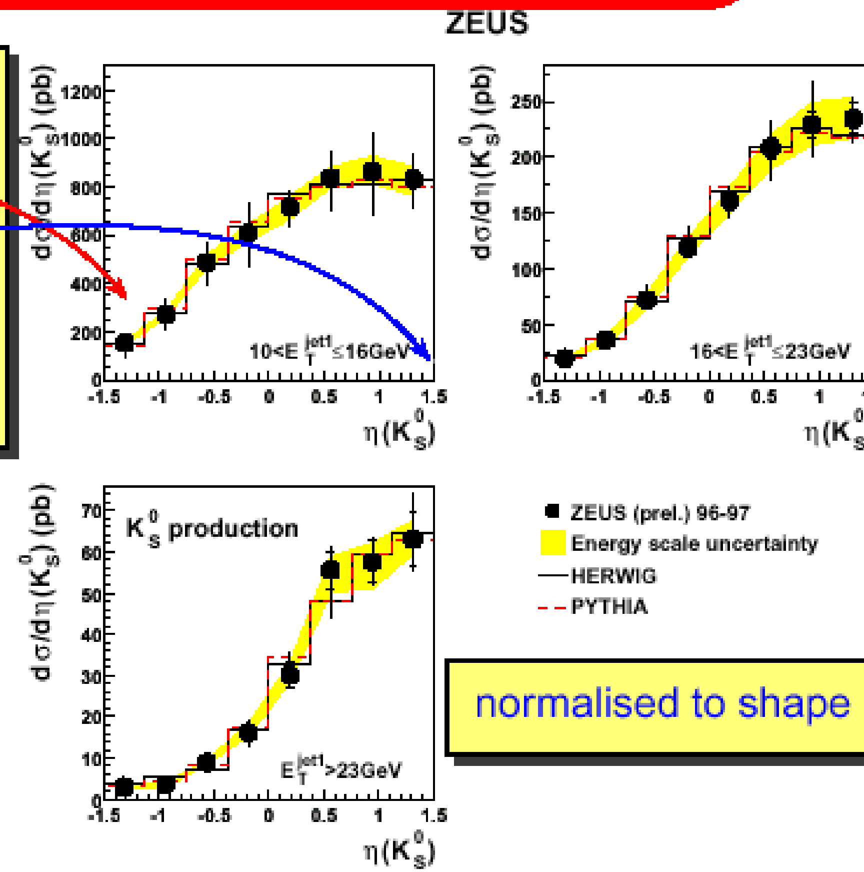
$$\Phi(x_g, Q^2)$$

$$\sigma(jet) \approx \frac{\alpha_s}{k_{jT}^4} \Phi\left(\frac{x}{x_j}, k_{jT}^2, Q^2 \right) \otimes F_2(x_j, k_{jT}^2)$$

$$\sum_a f_a(x_{jet}, k_{Tjet})$$

Particle production in central region e.g. K_s in photoproduction





large E_T central η_{lab} region
well described by:

- LO Monte Carlo PYTHIA/HERWIG
- based on DGLAP
- including fragmentation

normalised to shape

Particle Production well understood !!!

Forward Jets

	H1 cuts	ZEUS cuts
E'_{e}	> 11 GeV	> 10 GeV
y_{e}	> 0.1	> 0.1
$E_{\mathrm{T,jet}}$	$> 3.5\ (5)$ GeV	> 5 GeV
η_{jet}	$1.7 - 2.8$	< 2.6
$E_{\mathrm{T,jet}}/Q^2$	$0.5 - 2$	$0.5 - 2$
x_{jet}	> 0.035	> 0.036
$p_{\mathrm{z,jet}}^{\mathrm{Breit}}$		> 0 i.e. TF
x	$0.0001 - 0.004$	$0.00045 - 0.045$