LUND UNIVERSITY

The CCFM MC's

- Collinear vs. $k_\perp$ factorization
- The CCFM Generators
- Good News
- The Future

Krakow, 2001.06.30

Hannes Jung
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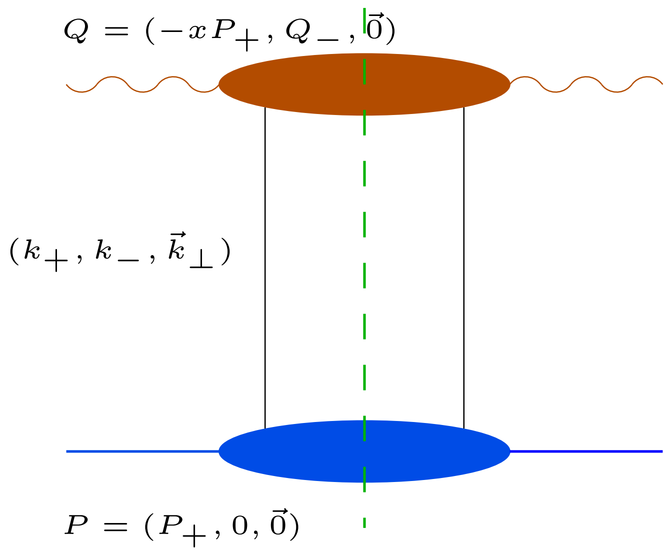
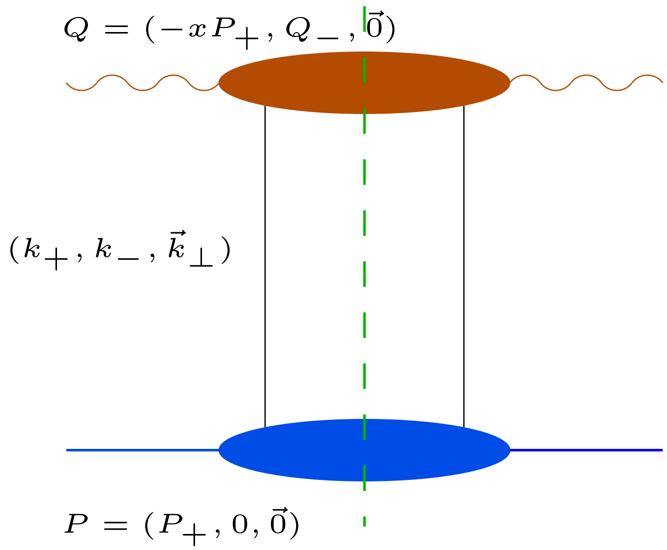
Collinear vs. $k_\perp$-factorization



Assuming $k_\perp \to 0$ and $k_- \to 0$ we can factorize any observable into process-dependent hard matrix elements and process-independent parton densities $f(x, Q^2)$.

$f(x, Q^2)$ obey DGLAP evolution equations and NLO expansion is well defined.

Works well for most inclusive observables, but there is a problem for several non-inclusive ones, where the ordering approximation is too severe.



Relaxing the constraint on $k_\perp$, but keeping $k_- \to 0$, it is still possible to factorize into process-independent *unintegrated* parton densities $g(x, k_\perp^2)$ and process-dependent off-shell matrix elements.

$g(x, k_\perp^2)$ obey BFKL evolution. But NLO corrections are HUGE.

Introducing angular ordering the parton densities obey CCFM evolution, introducing an additional parameter $g(x, k_\perp^2, \Xi)$ corresponding to a maximum angle defined by the hard matrix element.

BFKL is the right model for small-x evolution, but only in the land of Asymptotia: Assumes infinite energy, fixed α_s etc. But HERA is in Germany.

The huge NLO corrections may be an artifact of non-conservation of energy in the splittings. Introducing the kinematical constraint (a.k.a. Consistency Constraint) reduces the NLO corrections somewhat.

If we implement leading order BFKL/CCFM evolution in Event Generators we get exact energy momentum conservation - the NLO corrections could be much smaller if we're lucky...

There are now three different event generator implementations.

CCFM Evolution

$$
\begin{aligned}
g(x, k_\perp^2, \bar{q}) &= g_0(x, k_\perp^2, \bar{q}) \\
&+ \int dz \frac{dq^2}{q^2} d\phi \Delta_s(\bar{q}, zq) \tilde{P}_g(z, q, k_\perp^2) g(\frac{x}{z}, k_\perp'^2, q) \Theta(\bar{q} - zq)
\end{aligned}
$$

with $q = \frac{q_\perp}{1-z}$ (angular ordering $\Leftrightarrow z_{i-1}q_{i-1} < q_i$) and

$$
\tilde{P}_g(z, q, k_\perp^2) = \frac{\alpha_{\mathrm{s}}(q_\perp^2)}{1-z} + \frac{\alpha_{\mathrm{s}}(k_\perp^2)}{z} \Delta_{ns}(z, q^2, k_\perp^2)
$$

$$
\log \Delta_{ns}(z, q^2, k_\perp^2) = -\alpha_{\mathrm{s}}(k_\perp^2) \int_0^1 \frac{dz'}{z'} \int \frac{dq'^2}{q'^2} \Theta(k_\perp - q') \Theta(q' - z'q)
$$

Note that $k'_\perp$ depends on q, z, $k_\perp$ and ϕ.

Smooth transition to DGLAP in the relevant limit.

Smallx

Originally by Marchesini and Webber, updated, improved and maintained by Hannes Jung

Implements forward CCFM evolution of gluons from non-perturbative input $g_0(x, k_{\perp 0}^2) = N(1-x)^4 e^{-k_{\perp 0}^2/k_0^2}$.

Produces both final-state hadrons (although no final-state shower) and F_2. $g(x, k_{\perp 0}^2)$ must be tuned to fit F_2

CASCADE

By Hannes Jung and Gavin Salam

Implements backward CCFM evolution using evolved unintegrated gluon densities $g(x, k_{\perp}^2, \bar{q})$ extracted from a SMALLX fit.

Final state hadrons only (again without final-state showers).

LDCMC

Uses the Linked Dipole Chain model which is a reformulation of CCFM, making it forward-backward symmetric and canceling the non-Sudakov form factor Δ_{ns}

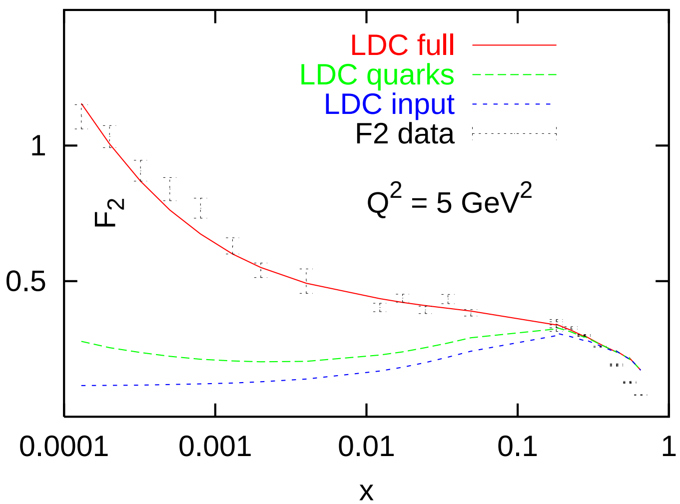
LDCMC includes final-state cascade and hadronization.

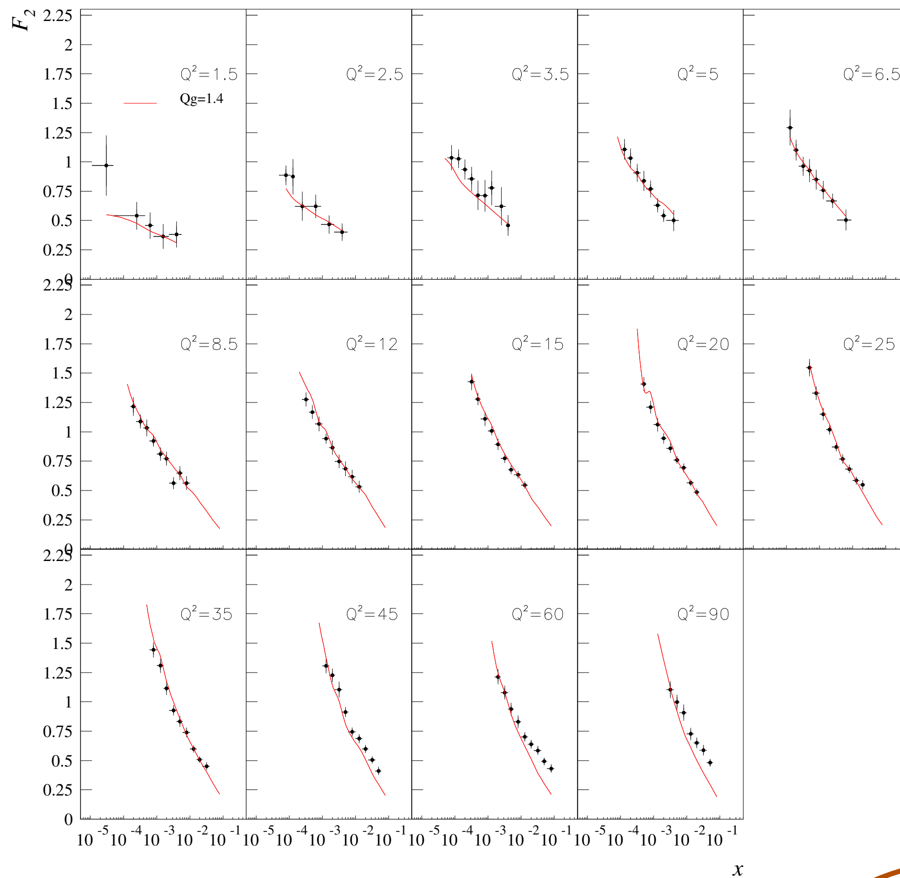
Optionally uses full splitting functions and quark ladders.

Input distributions are fitted to reproduce F_2, but unintegrated parton densities are not extracted.

Good News

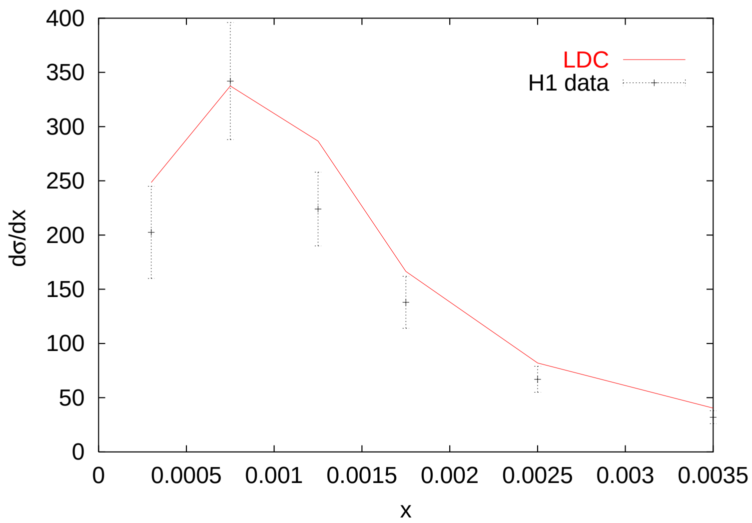
All three reproduce F_2 at HERA:

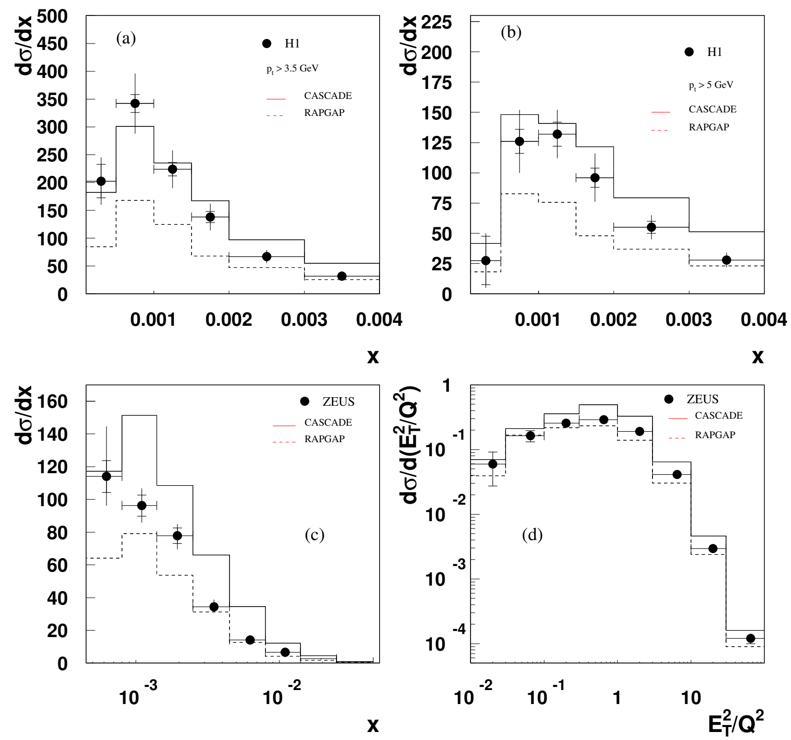




More Good News

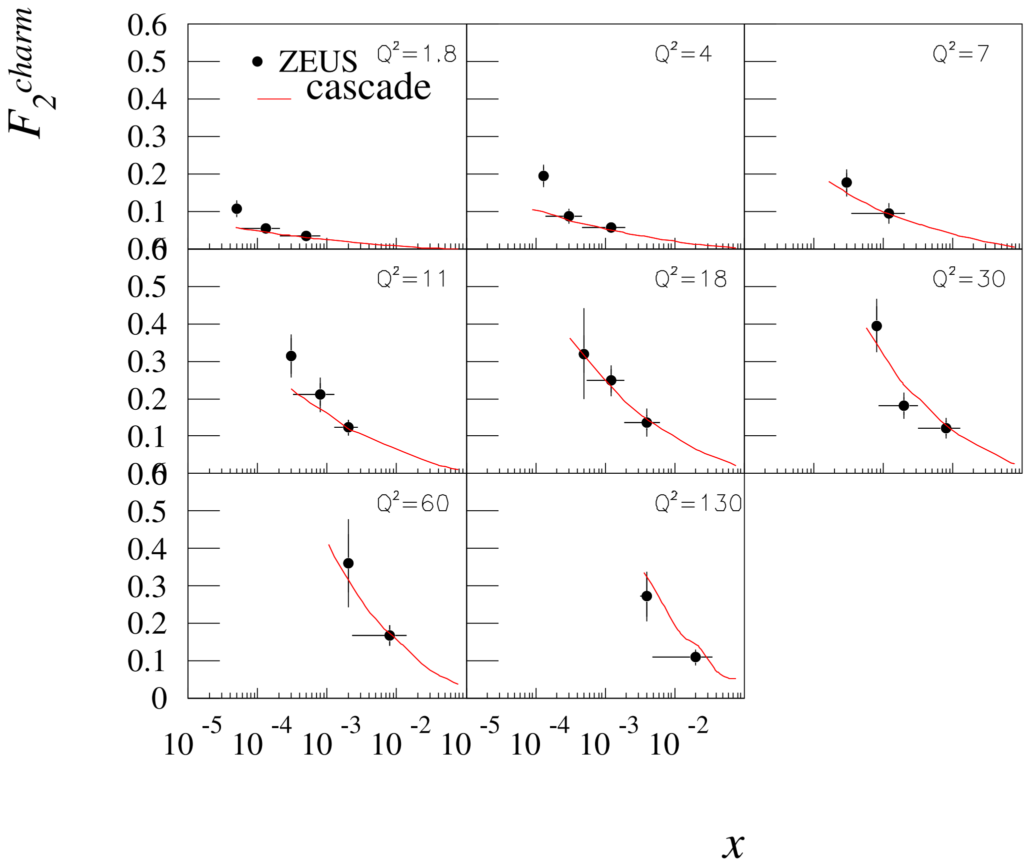
All three generators give consistent results for forward jets.





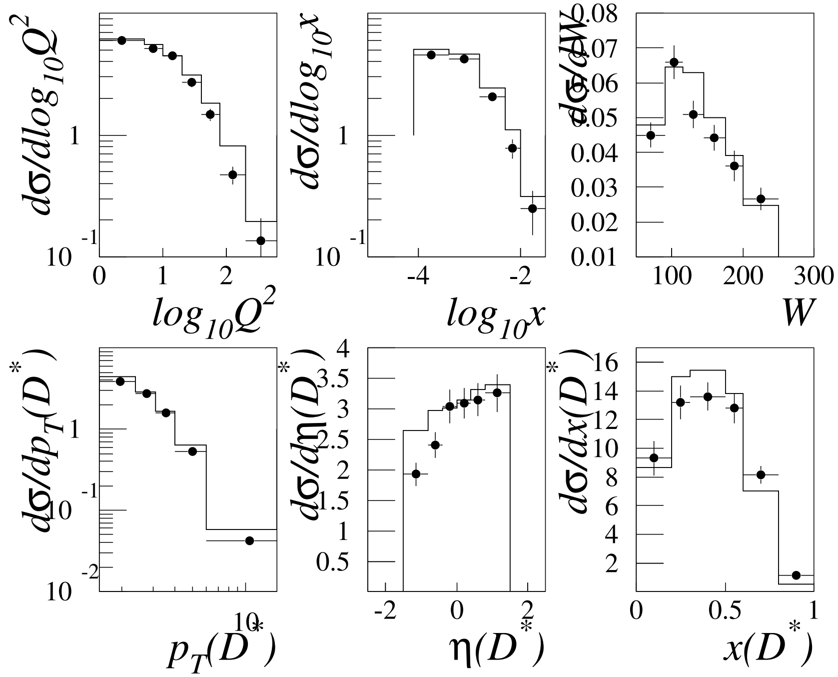
Armed with the unintegrated gluon densities from SMALLX we can use other off-shell matrix elements and have some fun.

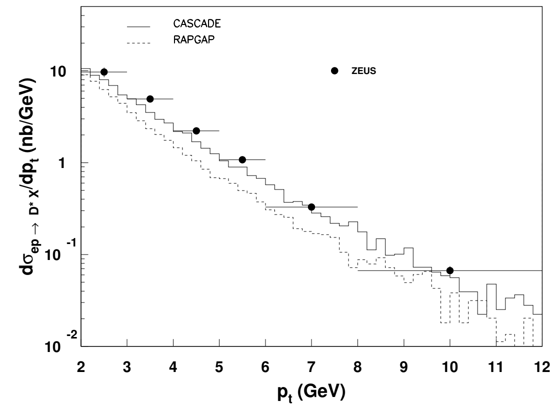
Good News

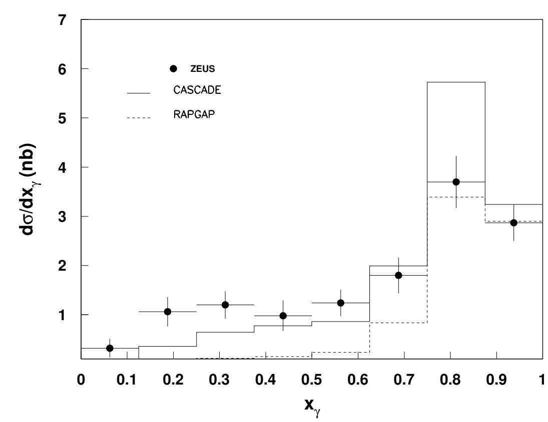

F_2^{charm}
ZEUS
cascade
Q²=1.8
Q²=4
Q²=7
Q²=11
Q²=18
Q²=30
Q²=60
Q²=130
0.6
0.5
0.4
0.3
0.2
0.1
0
10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻²
x

Good News

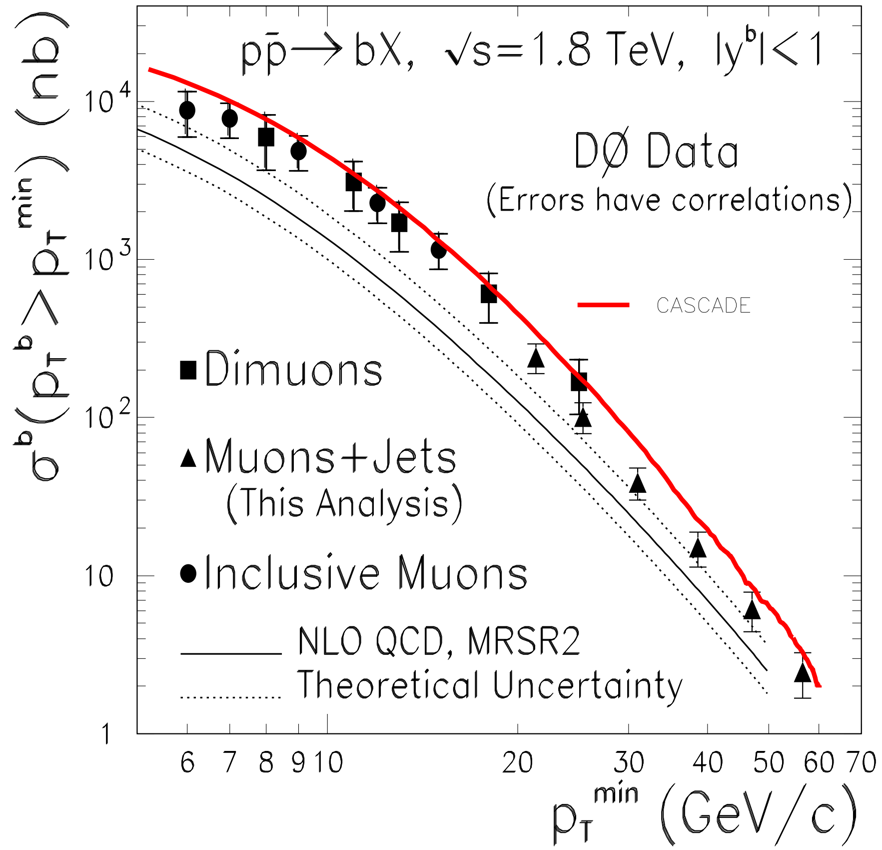
D* in DIS and photoproduction (ZEUS)







GOOD NEWS!



$p\bar{p} \rightarrow bX$, $\sqrt{s}=1.8$ TeV, $|y^b|<1$
DØ Data
(Errors have correlations)
CASCADE
Dimuons
Muons+Jets
(This Analysis)
Inclusive Muons
NLO QCD, MRSR2
Theoretical Uncertainty
$\sigma^b(p_T^b > p_T^{min})$ (nb)
p_T^{min} (GeV/c)

Bad News

Bad News

All results were obtained using only the singular terms in the gluon splitting function $P(z) = \frac{1}{z} + \frac{1}{1-z} + z(1-z) - 2$. Should be alright as long as x is small and all splittings z are small or close to 1.

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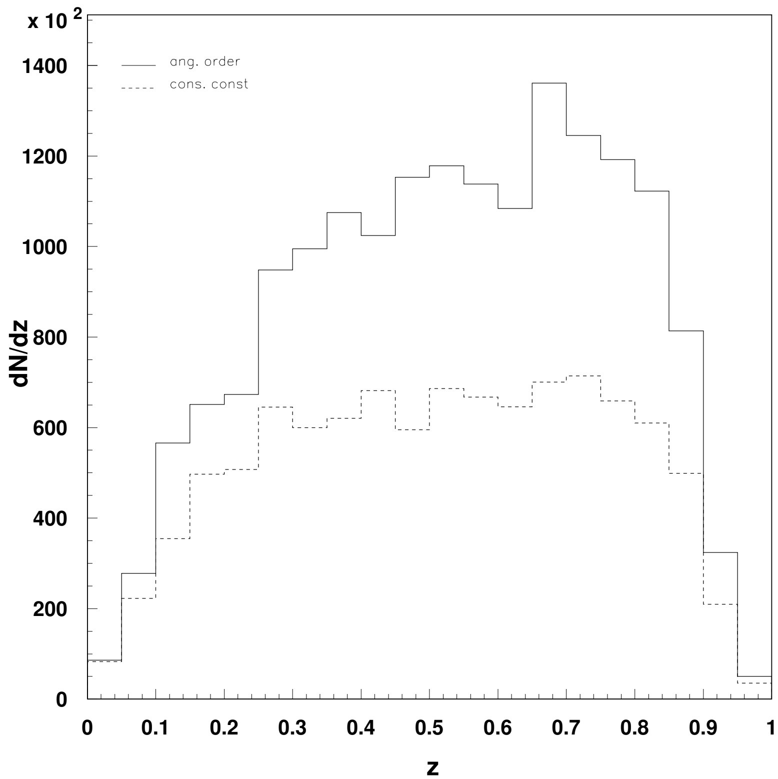
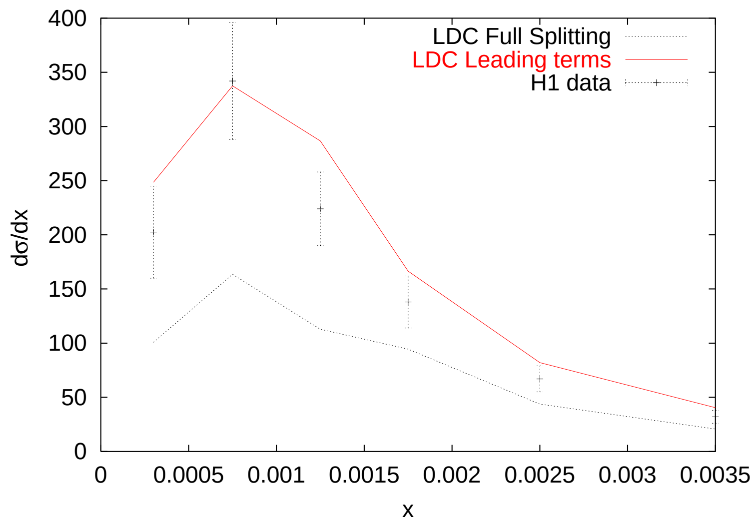
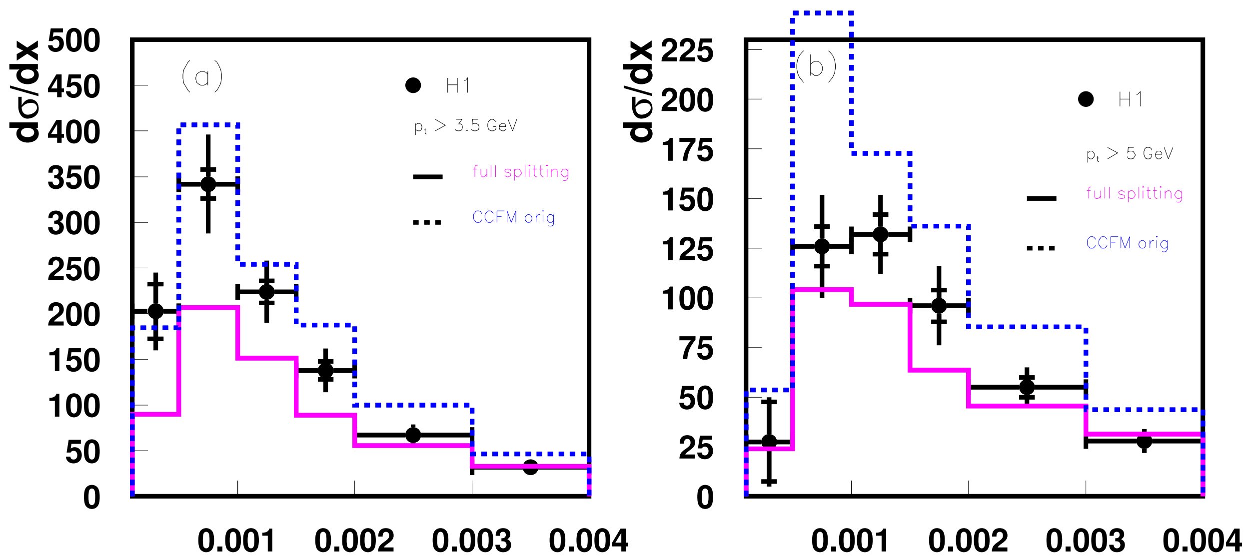
But this is not the case



If we include the non-singular terms, F_2 can still be fitted, but forward jets are suppressed:





Conclusions

- $k_\perp$-factorization is maturing.
- There are three independent implementations of CCFM evolution in event generators
- With unintegrated gluon densities and off-shell matrix elements we can reproduce a wide range of experimental data. In particular some data which cannot be described by DGLAP evolution.
- But some results are very sensitive to the treatment of non-leading terms.
- Very promising, but much more work is needed.

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  Time to get organized...

In March we had an informal workshop in Lund on small-x evolution, which resulted in a new collaboration. An attempt to start a coherent effort to systematically study small-x phenomena and theory.

- Phenomenological and theoretical study of non-leading corrections to BFKL/CCFM/LDC.
- Compile unintegrated parton distributions and off-shell matrix elements. (cf. CTEQ and MRS)

Start small: A web page and a mailing list.

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