The CASCADE MC

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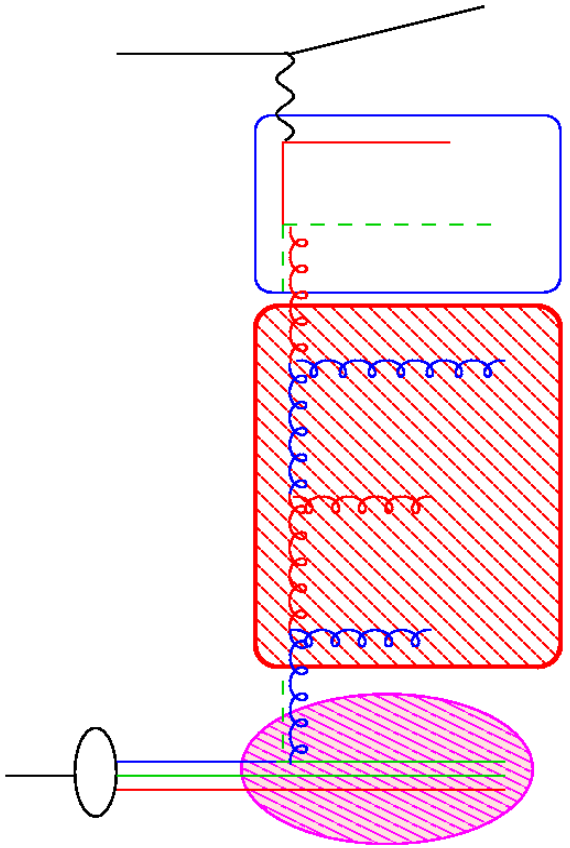
- CASCADE
  - Basic idea
  - Status
  - Further plans

CASCADE – C$_{atani}$C$_{iafaloni}$F$_{iorani}$M$_{archesini}$ evolution

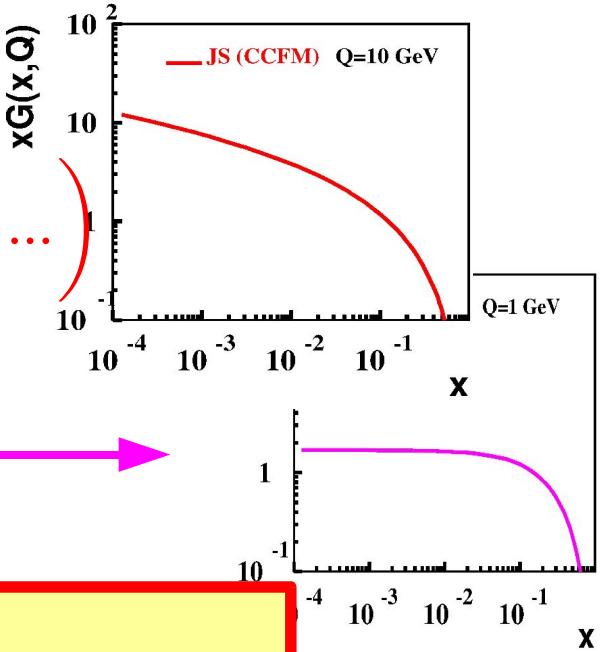


BGF matrix element off shell

CCFM (all loops)
- angular ordering
- non – Sudakov Δ_{ns}

evolution of parton cascade:

$$\tilde{P} = \bar{\alpha}_s \left(\frac{1}{1-z} + \frac{1}{z}\Delta_{ns} + ... \right)$$



initial distribution ~ flat

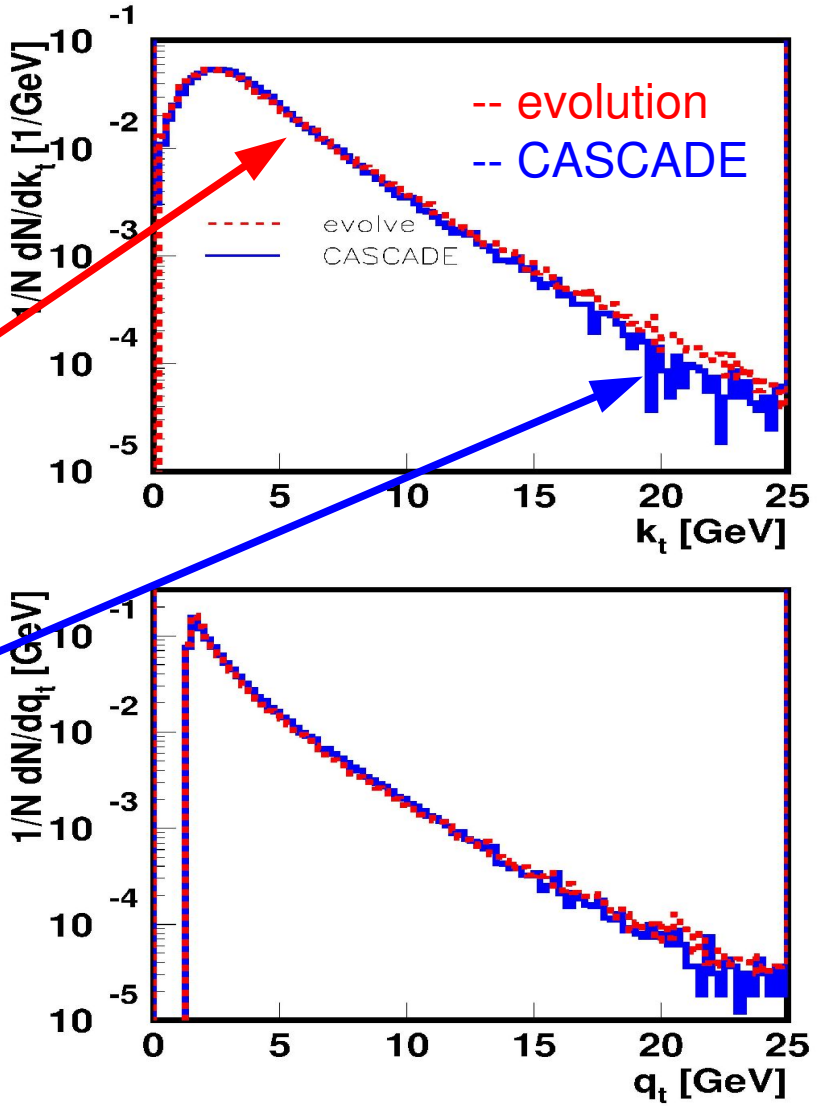
$$\sigma(ep \to e' q\bar{q}) = \int \frac{dy}{y} d^2Q \frac{dx_g}{x_g} \int d^2k_t \hat{\sigma}(\hat{s}, k_t, Q) x_g \mathcal{A}(x_g, k_t, \bar{q})$$

$$\int d^2k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) \simeq x_g G(x_g, Q^2)$$

CASCADE MC generator

- DGLAP or CCFM
- ➔ only inclusive predictions
- ➔ no information on emitted partons
- CCFM treats explicitly
  partons emitted during cascade
  color coherence
  energy momentum conservation

- best to implement in MC generator
- ➔ compare evolution and parton shower
- need unintegrated parton densities



CACADE MC event generator II

- Processes included (gluon induced)

$$\gamma g^* \to q\bar{q},\ \gamma^* g^* \to Q\bar{Q},\ \gamma g^* \to J/\psi g$$

$$g^* g^* \to q\bar{q},\ g^* g^* \to Q\bar{Q},\ g^* g^* \to h$$

- initial state parton shower, backward evolution, according to CCFM
- final state PS
- p-remnant treatment
- Hadronization

➔ full PYTHIA final state PS & remnant treatment included

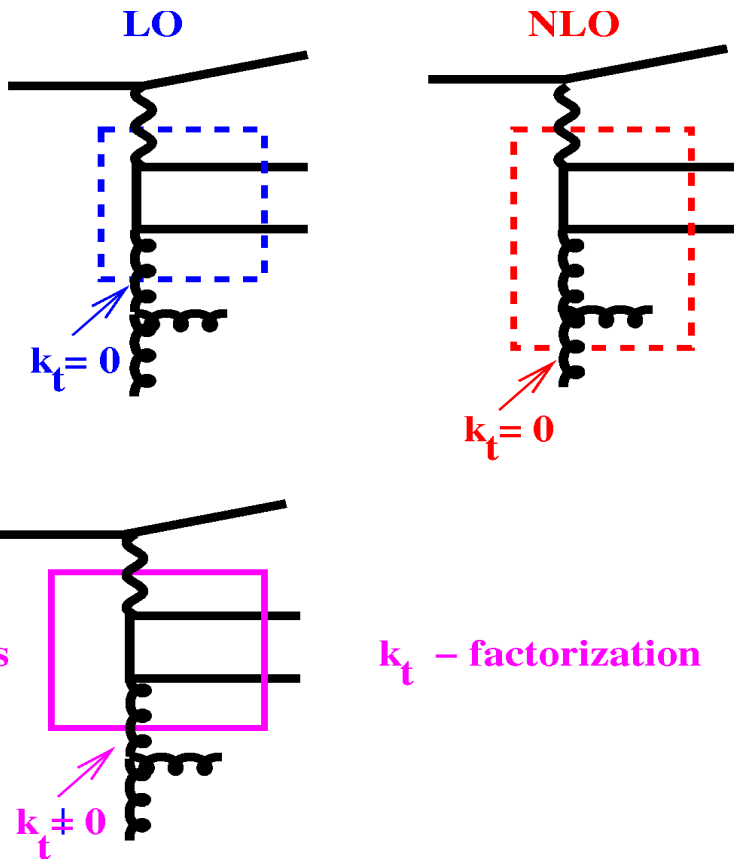
➔ applicable for $t\bar{t}$ -production

NEW:
using LHA interface to PYTHIA/HERWIG
for
- final state PS
- p-remnant
- hadronization

CASCADE for ep and pp

CASCADE and coll. NLO calcs

- fit of uPDF to inclusive structure functions /x-sections used to determine normalization
  - ➔ includes "all-orders" !!!!
- off-shell matrix element simulates part of real NLO corrections
  - ➔ study of scale dependence
  - ➔ compare to coll. NLO calculations
  - ➔ check with benchmark x-sections



uPDFs are THE important incredient for CASCADE ...

Evolution of uPDFs and x-section

- only gluons densities are considered **here !!!**
- evolve with **CCFM** using
  - ✗ full gluon splitting function and $\alpha_s(M_Z) = 0.118$
  - ✗ starting scale for evolution $Q_0 = 1.2\ \mathrm{GeV}$

see also: A. Cholewa in HQ session
M. Hansson in Jets session

Fitting **uPDFs**:

- using **FitPDF** (E. Perez [Saclay])
  - ➔ applicable also for collinear **DGLAP** evolution
  - ➔ allowing different treatment of correlated systematic uncertainties
- **uPDF** is a convolution of starting distribution $\mathcal{A}_0(x_0)$ with perturbative evolution:

$$x\mathcal{A}(x, k_\perp, \bar{q}) = \int dx_0 \mathcal{A}_0(x_0) \cdot \frac{x}{x_0} \tilde{\mathcal{A}}\left(\frac{x}{x_0}, k_\perp, \bar{q}\right)$$

- Calculate x-section for x,Q^2 for inclusive quantities
  - Optionally use full event simulation including parton showering and hadronization of CASCADE MC generator for final state predictions
  - optimize parameters in starting distribution $\mathcal{A}_0(x_0)$ with χ^2
- **General procedure, applicable also for DGLAP fits**

Fit to F_2 data

- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ uncor}} \right)$$
- fit parameters of starting distribution
  $$xg(x,\mu_0^2) = Nx^{-B_g} \cdot (1-x)^4$$
- using F_2 data H1

  (H1 Eur. Phys. J. C21 (2001) 33-61, DESY 00-181)

  $$x < 0.05 \;\; Q^2 > 5 \text{ GeV}^2$$
- parameters: $\mu_r^2 = p_t^2 + m_{q,Q}^2$

  $$m_q = 250 \text{ MeV}, m_c = 1.5 \text{ GeV}$$
- Fit (only stat+uncorr):

  $$\frac{\chi^2}{\text{ndf}} = \frac{111.8}{61} = 1.83$$

  $$B_g = 0.018 \pm 0.003$$

  ➔ similar to DGLAP fits (~1.5)

see also: A. Cholewa in HQ session
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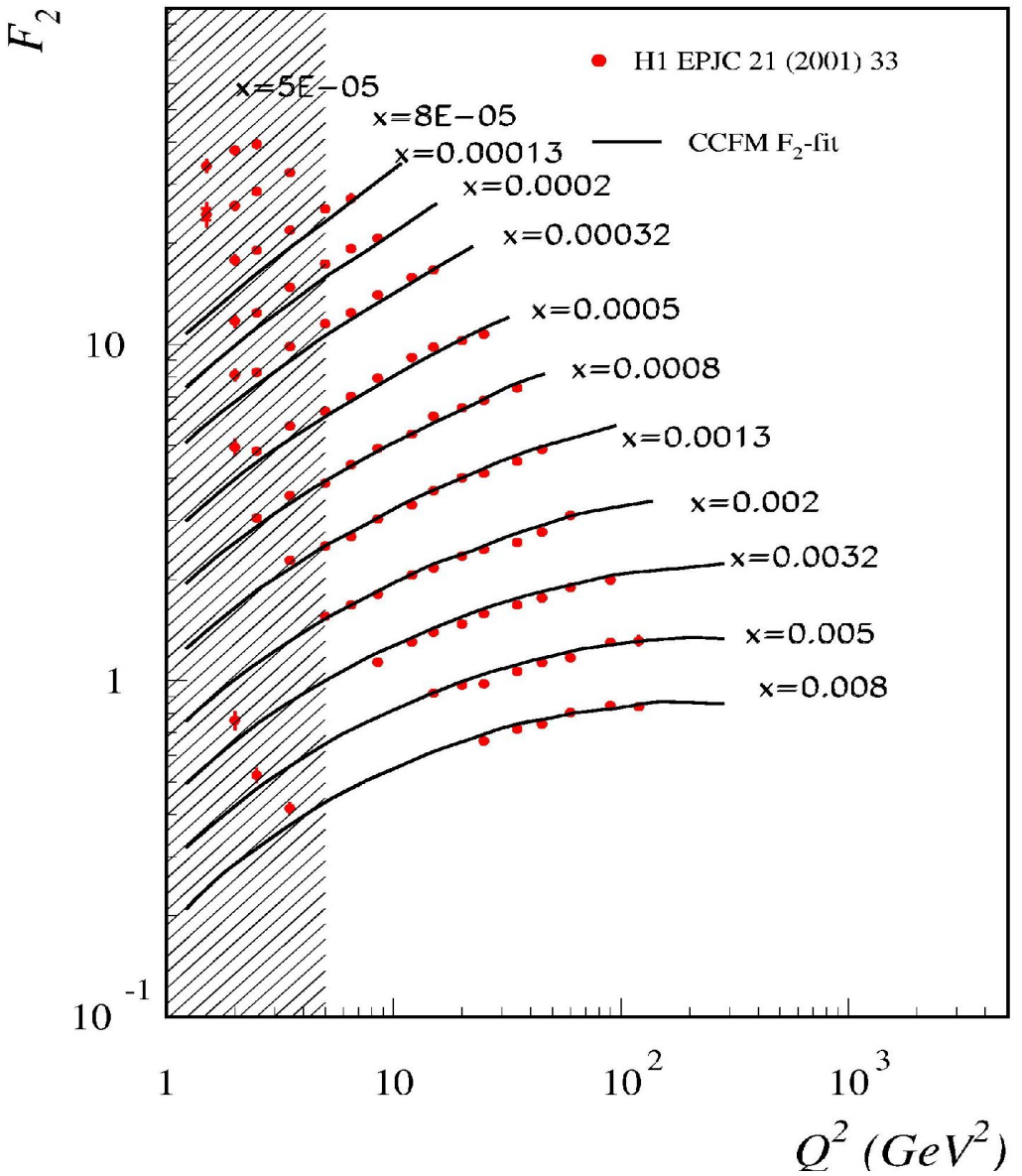


Fit to F_2^c data

- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ syst}} \right)$$
- fit parameters of starting distribution

$$xg(x,\mu_0^2) = Nx^{-B_g} \cdot (1-x)^4$$

- using F_2^c data H1

(H1 PLB528 (2002) 199, EPJC 40 (2005) 349 ,EPJC45 (2006) 23)

$$Q^2 > 1\ \mathrm{GeV}^2$$

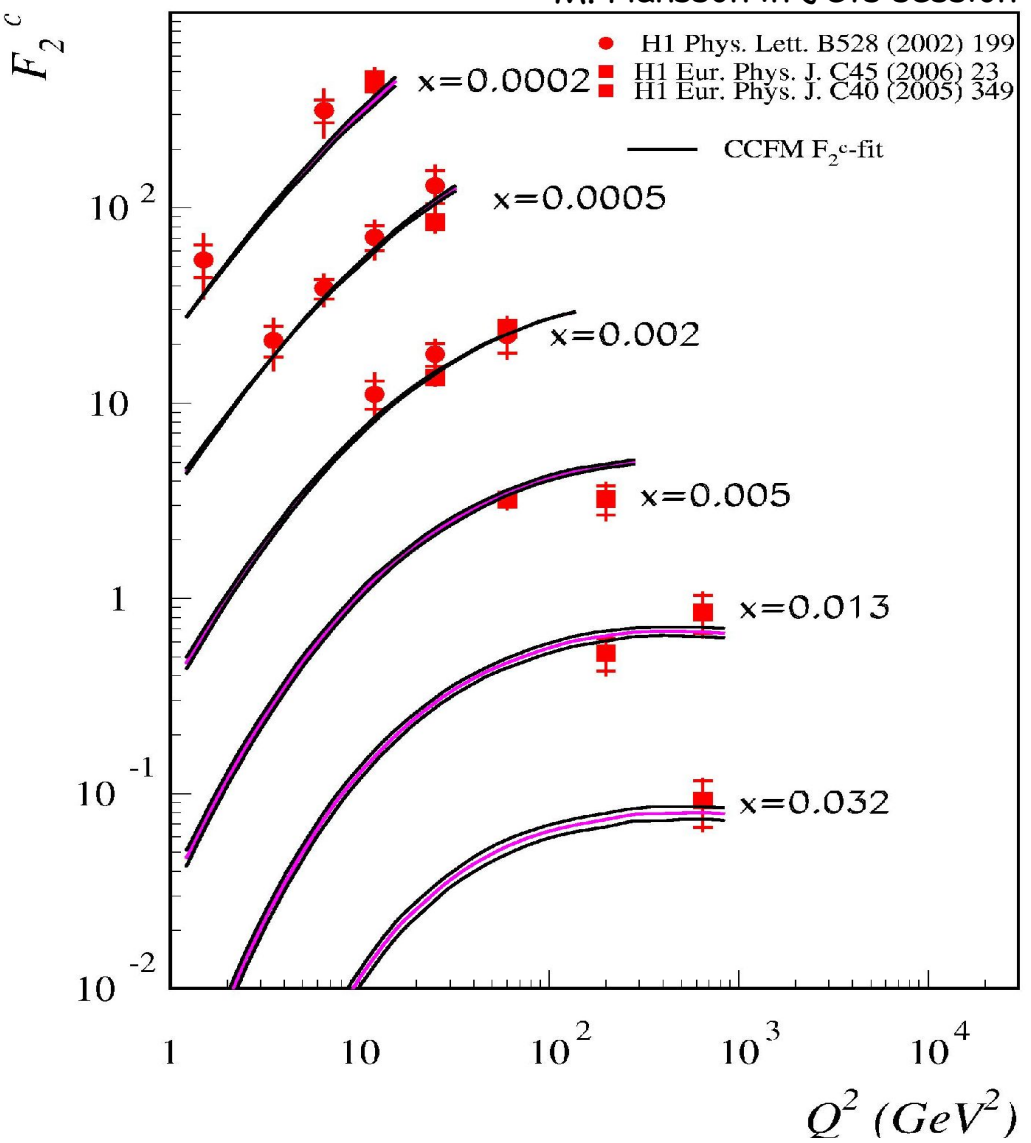
- fit result: $\frac{\chi^2}{\mathrm{ndf}} = \frac{18.8}{20} = 0.94$

with $B_g = 0.286 \pm 0.002$

➔ higher than for F_2 !?!?!?!

➔ significant change of uPDF

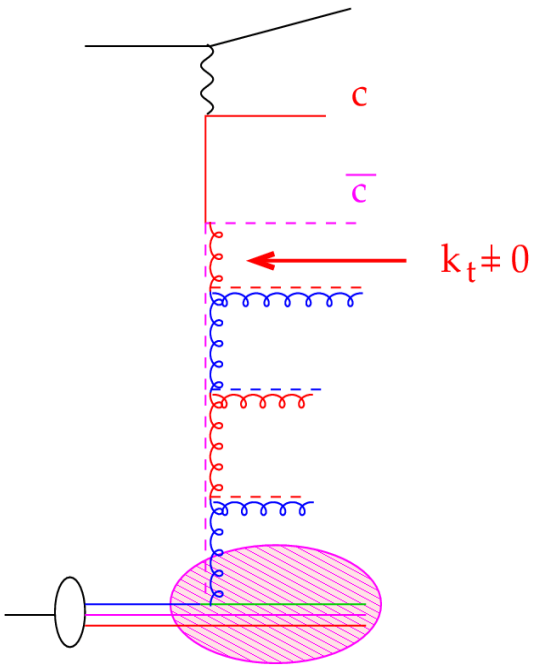
see also: A. Cholewa in HQ session
M. Hansson in Jets session

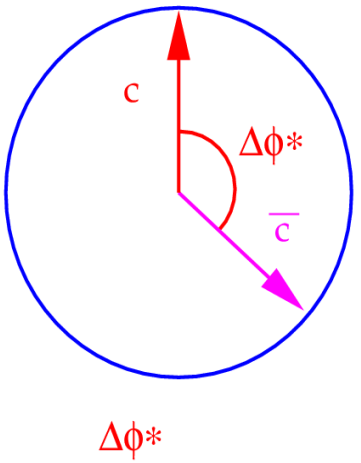


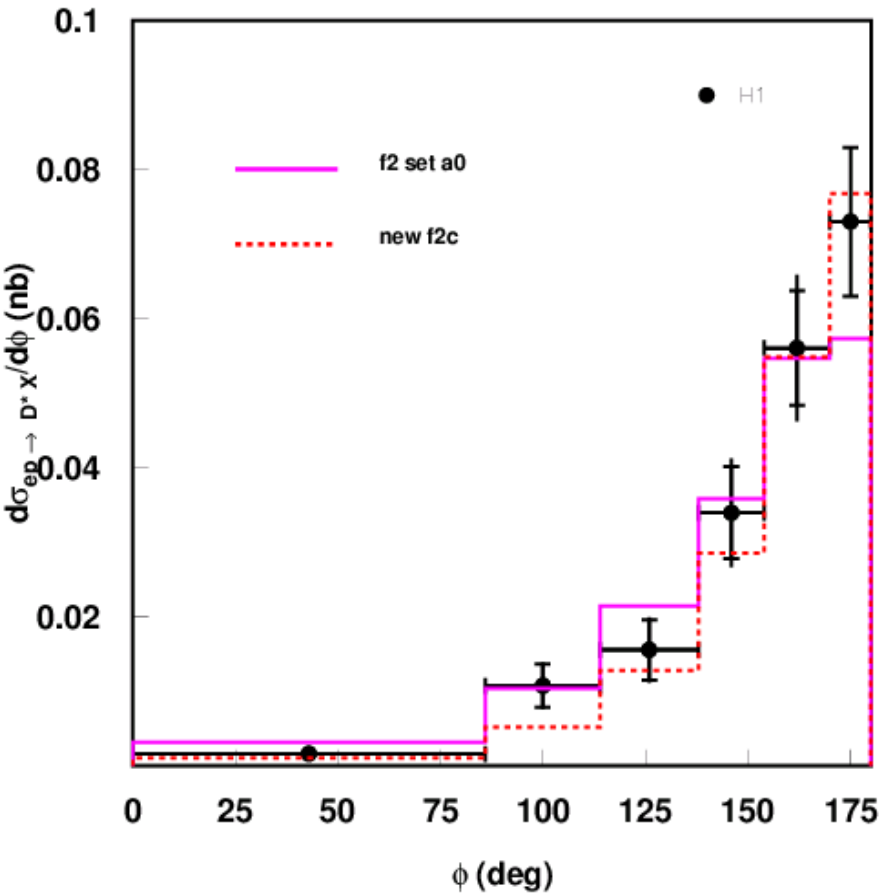
Application to D* + jets

- Photoproduction at HERA:

$\gamma p \to c\bar{c}X \to D^* + jet + X$



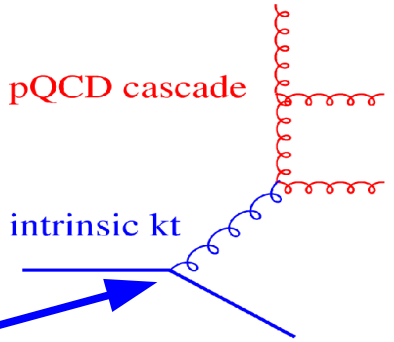


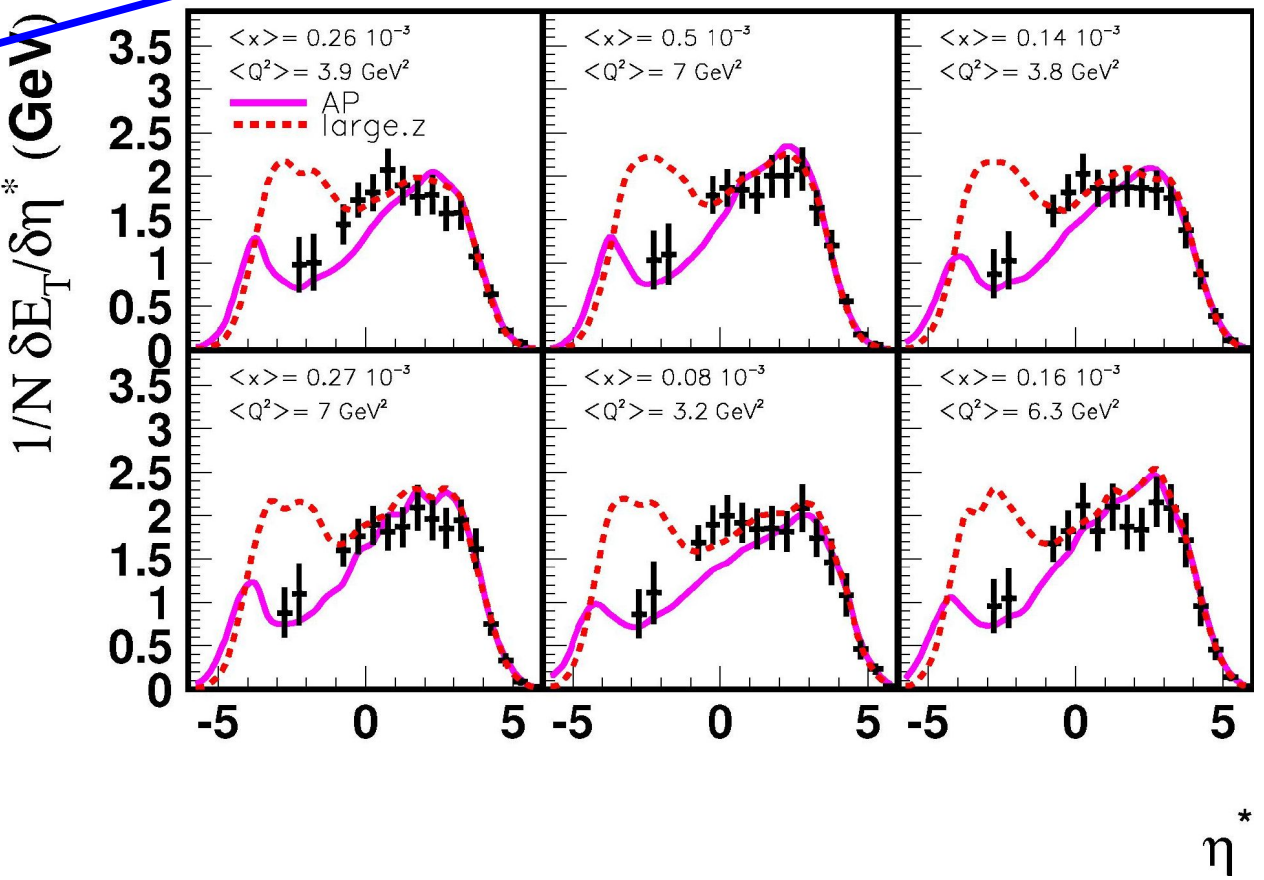


- uPDF obtained from same evolution as used in CASCADE simulation
- consistent treatment ... no matching problem as in collinear case !!!

New p – remnant treatment

- for easy interfacing with LHA: keep color flow from CASCADE, but include explicitly $q \to g + q'$ vertex as very first splitting
- ➔ transverse momentum of 1st gluon fully compensated by q'
- ➔ need to define energy sharing: energy flow in forward/ backward region depends on the details …





Other features of CASCADE

- various sets of uPDFs included (but only CCFM/KMR with parton shower):
  - CCFM
  - KMR
  - KMS
  - saturation model
  - derivative of integrated gluon
  - etc ...
  - Remember: consistent treatment only with uPDF
    - KMR prescription: one additional radiation ... useful for determination of hadronization corrections for NLO calcs
- Features of CCFM uPDFs: variation of renormalization scale
  - using uPDFs accordingly determined

  ➔ smaller uncertainty from theory
- new fits, respecting all kinematics even for inclusive x-sections

Future of CASCADE

- Extension of CASCADE towards a multipurpose event generator applying kt-factorization
- Inclusion of new processes ... matrix element calculations needed ...
- Extension of "CASCADE" collaboration:
  M. Deak, K. Kutak,
  J. Bartels, S. Baranov,
  A. Kotikov, A. Lipatov, N. Zotov

- Inclusion of new processes ...
  - $pp \to b\bar{b} + X$
  - $pp \to J/\psi + X$
  - $pp \to W^{\pm} + X$
  - $pp \to W^{\pm} + jets + X$
  - $pp \to Z^0 + X$
  - $pp \to Z^0 + jets + X$
  - $pp \to l^+ + l^- + X$ (Drell Yan)
  - $pp \to \gamma + jets + X$ (prompt photon)
  - $pp \to \gamma + \gamma + X$
  - $pp \to H^0 + X$
  - $pp \to H^0 + jets + X$

Future of CASCADE II

- Need to calculate the following off-shell MEs
  - $gg \to gg$ and $gg \to q\bar{q}$ (heavy quark and jet production) heay quarks are ready..Catani,Ciafaloni,Hautmann
  - $gg \to J/\psi g$ ready Baranov, Lipatov, Zotov
  - $gg \to Q\bar{q}W^{\pm}$, with Q being a heavy or light quark
  - $gg \to Q\bar{Q}Z_0$, with Q being a heavy or light quark work in progress (S. Baranov, M. Deak, A. Lipatov, N. Zotov)
  - $gq \to \gamma q$, $q\bar{q} \to \gamma g$, $gg \to q\bar{q}\gamma$ (prompt photon process)
  - $gg \to \gamma + \gamma$
  - $gg \to H$ ready Hautmann
  - $gg \to H + q\bar{q}$
  - new particles: SUSY particles and gravitons KK gravitons ready Lipatov,Zotov

Further Plans

- Multiple Interactions in k_t factorization
  - ➔ connect MI with saturation and diffraction (!!!!)
  - ➔ including hard diffraction (????)
- Inclusion of quarks in evolution (????)
  - ➔ gluon in proton or coming from quark ? issue on intrinsic k_t
  - ➔ is it Gaussian or $1/k^2$

Hm... has been said already a year ago !!!

Conclusions

- CASCADE 2.0 release within next weeks (March 2007)
  - available from CEDAR/HEPFORGE
  - regular updates including new processes foreseen
- Use CASCADE for pp

  ➔ can be used like PYTHIA in experiment environment
    - output format PYTHIA like...
- Plan to develop CASCADE into a multi-purpose event generator applying k_t factorization and uPDFs

CASCADE is THE k_t-factorized event generator !!!