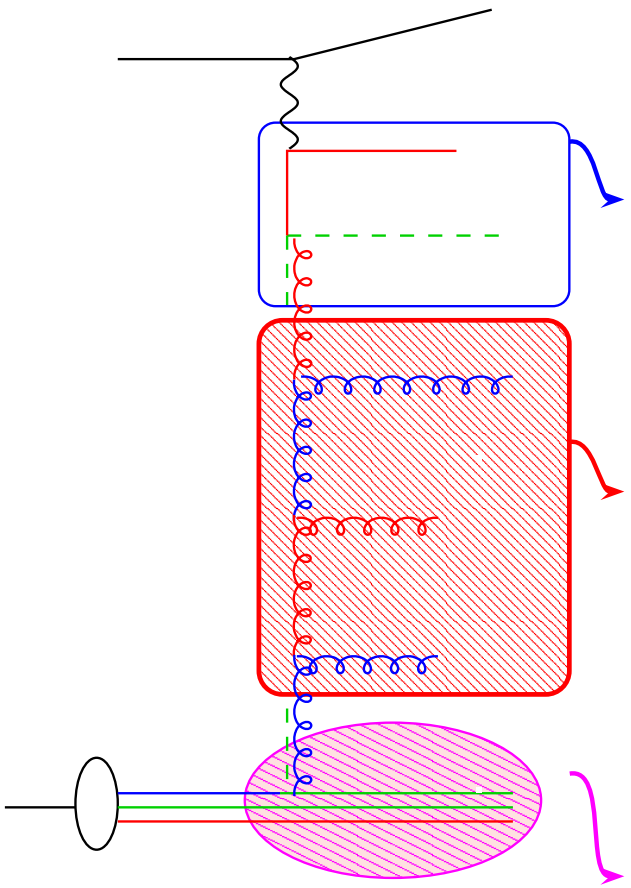
Status of CCFM - un-integrated gluon densities

H. Jung, University of Lund

DIS 2003, St. Petersburg, 2003

- Status of CCFM in 2002
- doing it better, now !
  - new fits to new data
  - non leading contributions ...
- forward jets, again...
- un-integrated gluon density of the photon
  - $b\bar{b}$ production in $\gamma\gamma$
- conclusion

Basic idea - k_t factorisation



CCFM

BGF matrix element off mass shell

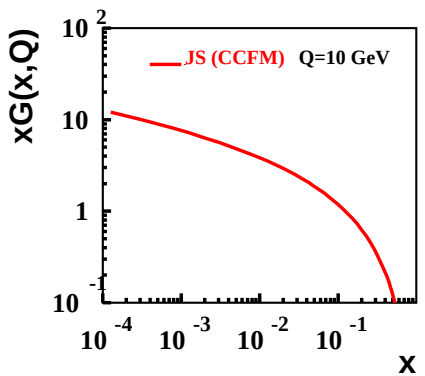
evolution of parton cascade with CCFM splitting fct.

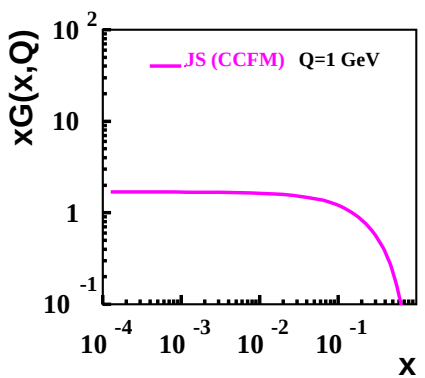
$$\tilde{P} = \bar{\alpha}_s \left(\frac{1}{1-z} + \frac{1}{z} \Delta_{ns} \right)$$

initial distribution: flat

CCFM !!!

- **angular ordering (instead of q_t ordering)**
- **Δ_{ns} (non - Sudakov)**





Structure Function $F_2(x, Q^2)$

together with G.P. Salam, EPJC 19, 351 (2001)

With $\sigma = \int dk_t^2 dx_g \mathcal{A}(x_g, k_t^2, \bar{q}) \sigma(\gamma^* g^* \to q\bar{q})$ fit $F_2(x, Q^2)$

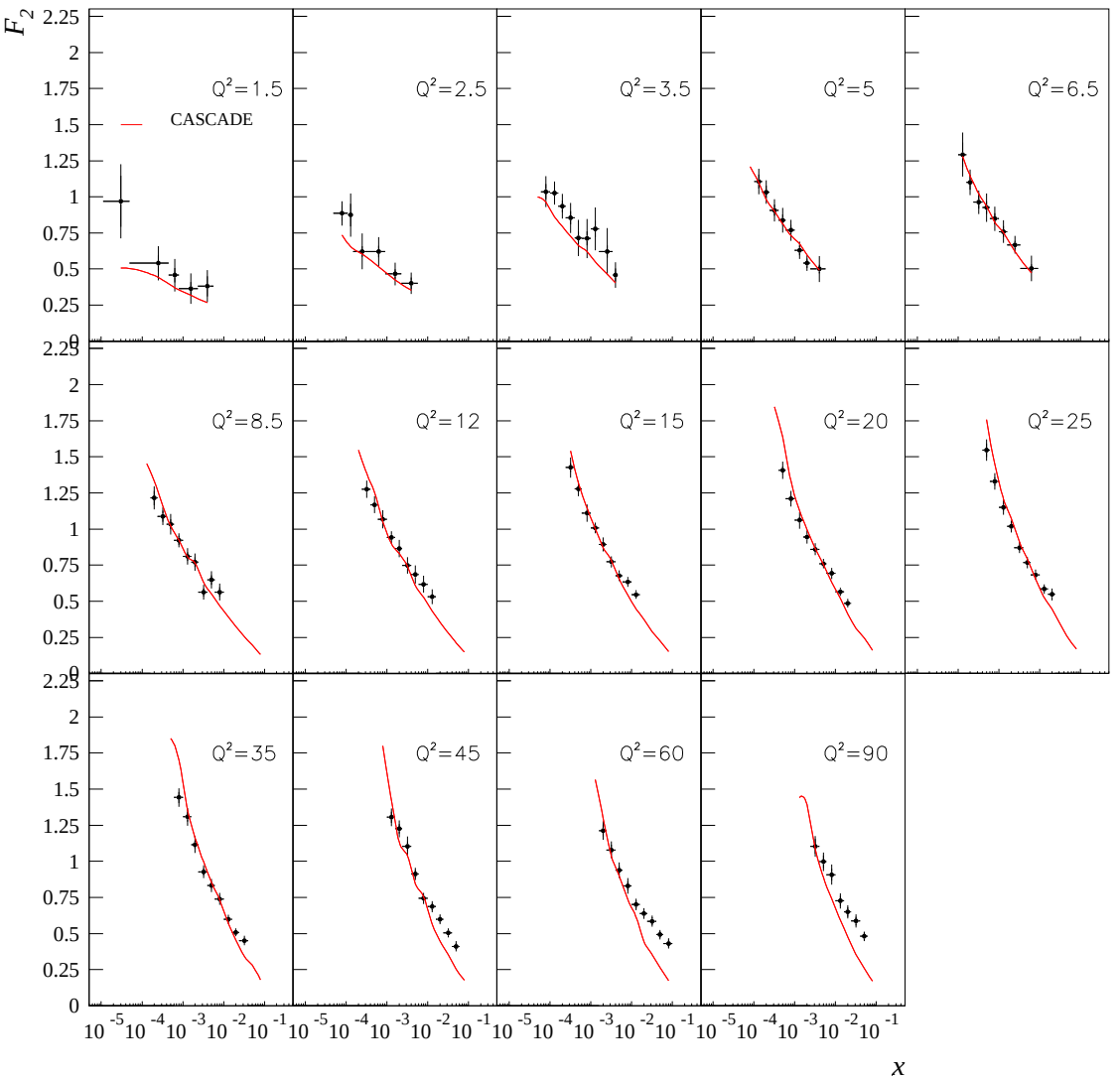
(data from H1 Coll, NPB 470 (1996) 3.)

Parameters in fit

(fitted for $Q^2 > 5$ GeV^2, $x < 10^{-2}$)

- starting scale & cut-off for resolvable branching
  $Q_0 = 1.4$ GeV
- freezing of $\alpha_s(k_t)$ for $k_t \to 0$
  treatment of soft region
  ☛ see later
- quark masses:
  $m_q = 0.250$ GeV, $m_c = 1.5$ GeV
- initial gluon $x\mathcal{A}_0(x, k_{t0}^2)$

unintegrated gluon density
$x\mathcal{A}(x, k_t^2, \bar{q})$
obtained from fit to F_2



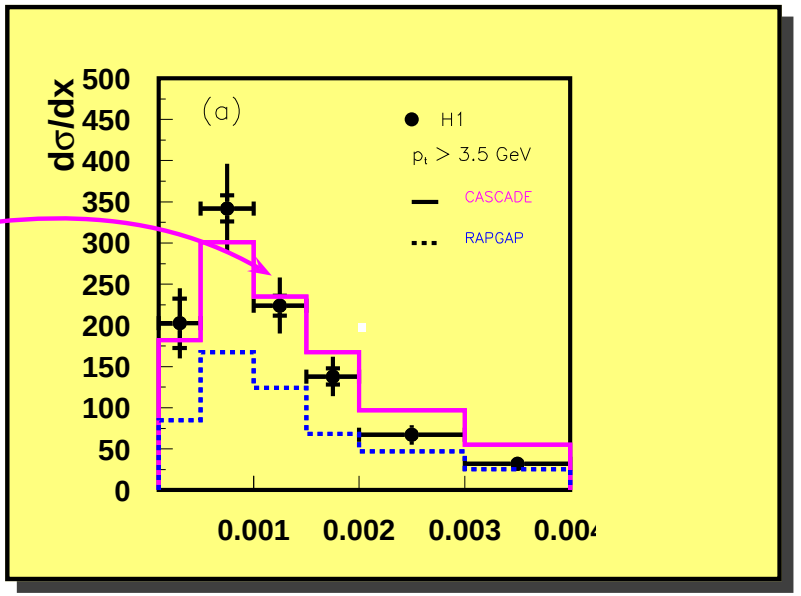
CASCADE with CCFM: the solution ...

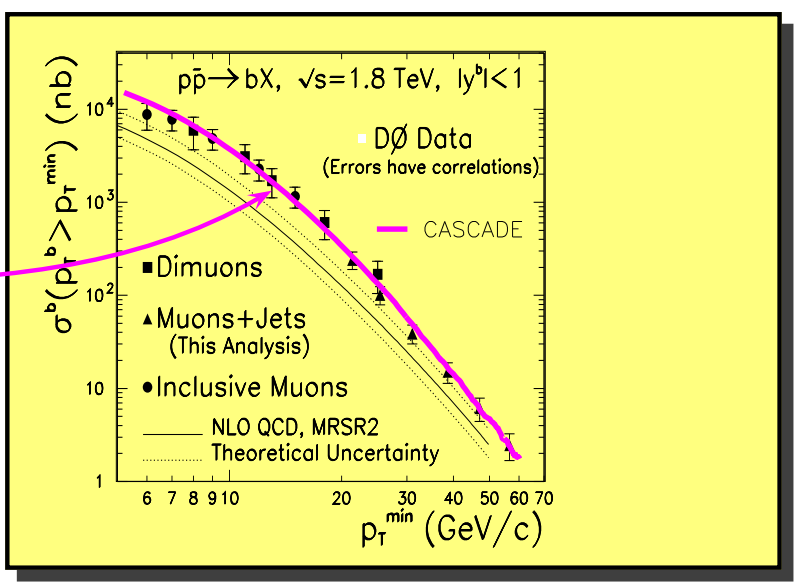
Solve CCFM equation
to fit F_2 data from HERA

- obtain CCFM un-integrated gluon
  CASCADE MC implements CCFM:
- predict fwd jet x-section at HERA ✔
- predict charm at HERA ✔
- predict bottom at HERA ✔

- test universality of un-integrated gluon density from HERA
- predict bottom at Tevatron ✔
- w/o additional free parameters

WOW !!!





What is new ?

- last year:
- non-leading contributions (non-sing. terms, scale in α_s)
- But: problems with cutoffs, stabilities, etc ....
- And problems to describe forward jet data...

- NEW
- fit to 94 and 96-97 F_2 data
- investigation of soft region in cascade, cutoffs, ...
- non-leading contributions (non-sing. terms, scale in α_s)
- un-integrated pdf in photon

- complicated machinery: MC generation of pdf used in fits
  ($50 \otimes 2 \cdot 10^6$ calculations of full evolution for pdf, $3 \cdot 10^6$ for x-section)
- only way for consistent results for hadron level calcs (never done for DGLAP !!!)
- precision level now reached for k_t - factorization

New fits of un-integrated gluon density

- use H1 F_2 data from 94 and 96-97
- fit for $x < 0.01$ $Q^2 > 3.5$ GeV^2
- fit Q_0 and normalization

Treatment of soft region

no k_t ordering ☛ diffusion into soft

- **what about α_s at small k_t ?**
- **splitting fct and non-Sudakov ?**

☛ **non - resolvable branching**

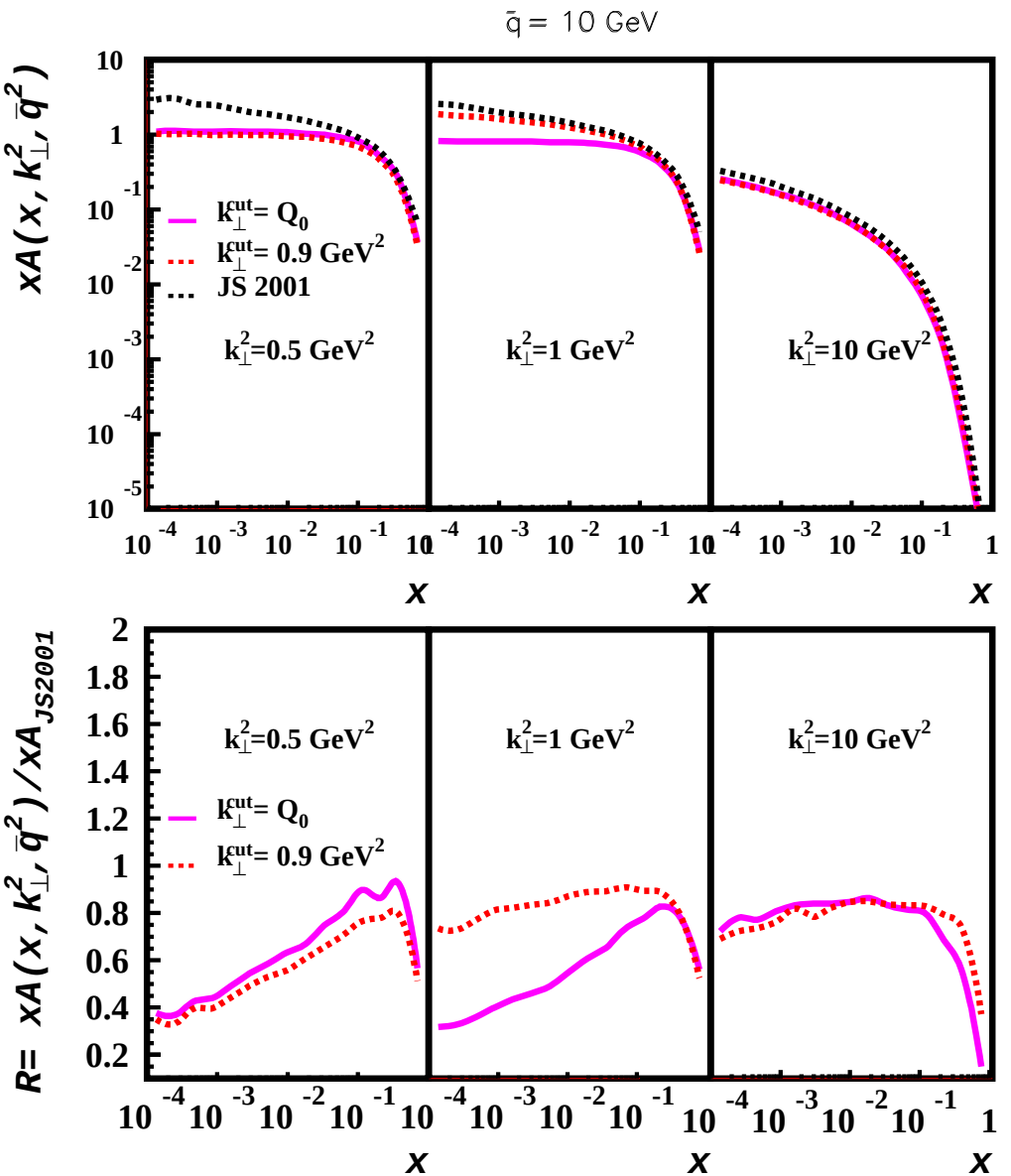
☛ **but keep full kinematics**

☛ **no x-section enhancement**

☛ **no real emission**

What is actual cut - what is soft?

- **JS2001 had soft cut $k_t > 0.25$ GeV**
- **now $k_t > Q_0$**



Improve CCFM Splitting Function: $\alpha_s(q_t)$

together with G.P. Salam

Original CCFM Splitting Fct:

$$\tilde{P} = \frac{\bar{\alpha}_s(q_t(1-z))}{1-z} + \frac{\bar{\alpha}_s(k_t)}{z}\Delta_{ns}(z,q_t,k_t)$$

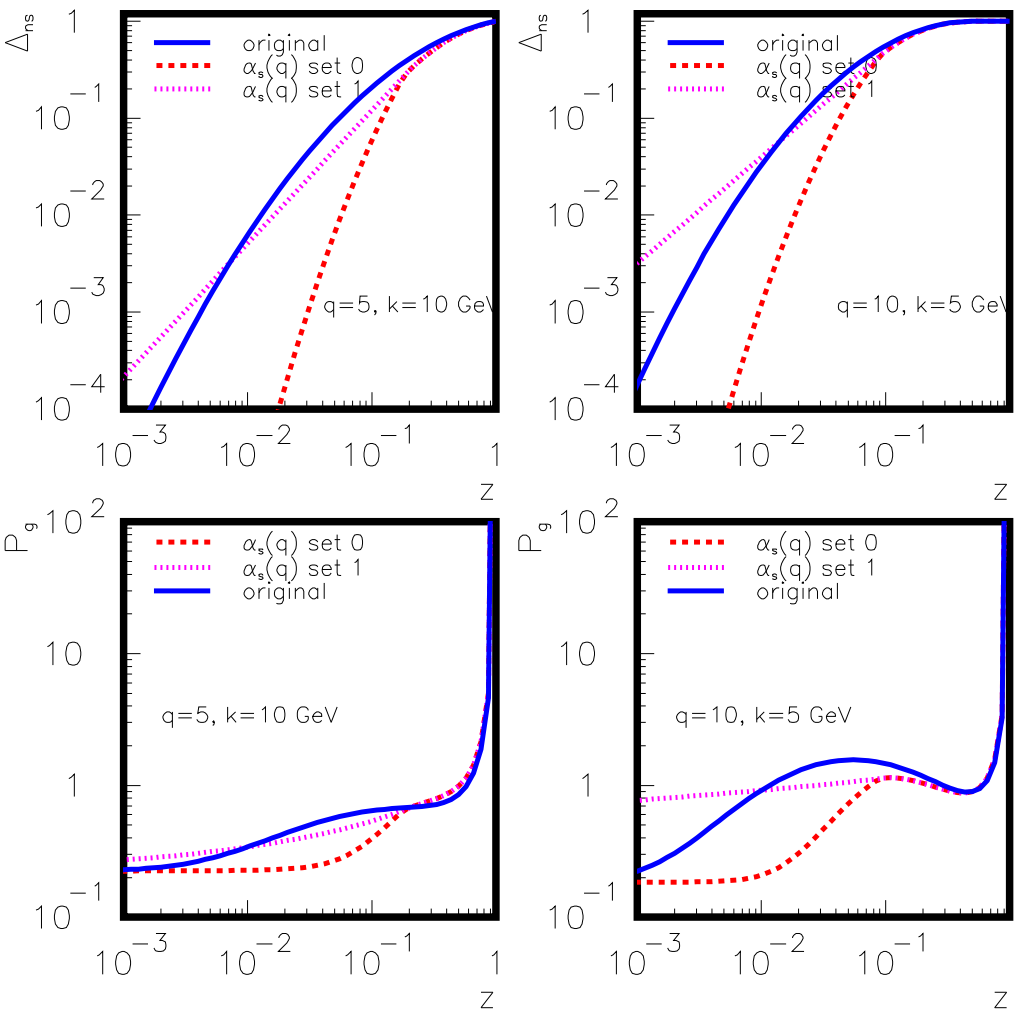
$$\log\Delta_{ns} = -\bar{\alpha}_s(k_t^2) \int_0^1 \frac{dz'}{z'} \int \frac{dq^2}{q^2}\Theta(k_t-q)\Theta(q-z'q_t)$$

Change scale from k_t to q_t in α_s:

$$\tilde{P} = \frac{\bar{\alpha}_s(q_t(1-z))}{1-z} + \frac{\bar{\alpha}_s(q_t)}{z}\Delta_{ns}(z,q_t,k_t)$$

$$\log\Delta_{ns} = -\int_0^1 \frac{dz'}{z'} \int \frac{dq^2}{q^2}\alpha_s(q)\Theta(k_t-q)\Theta(q-z'q_t)$$

$$\log\Delta_{ns} = \cdots \int_{(z'q_t)^2}^{k_t^2} \frac{dq^2}{q^2}\frac{1}{\log(q/\Lambda_{QCD})}$$



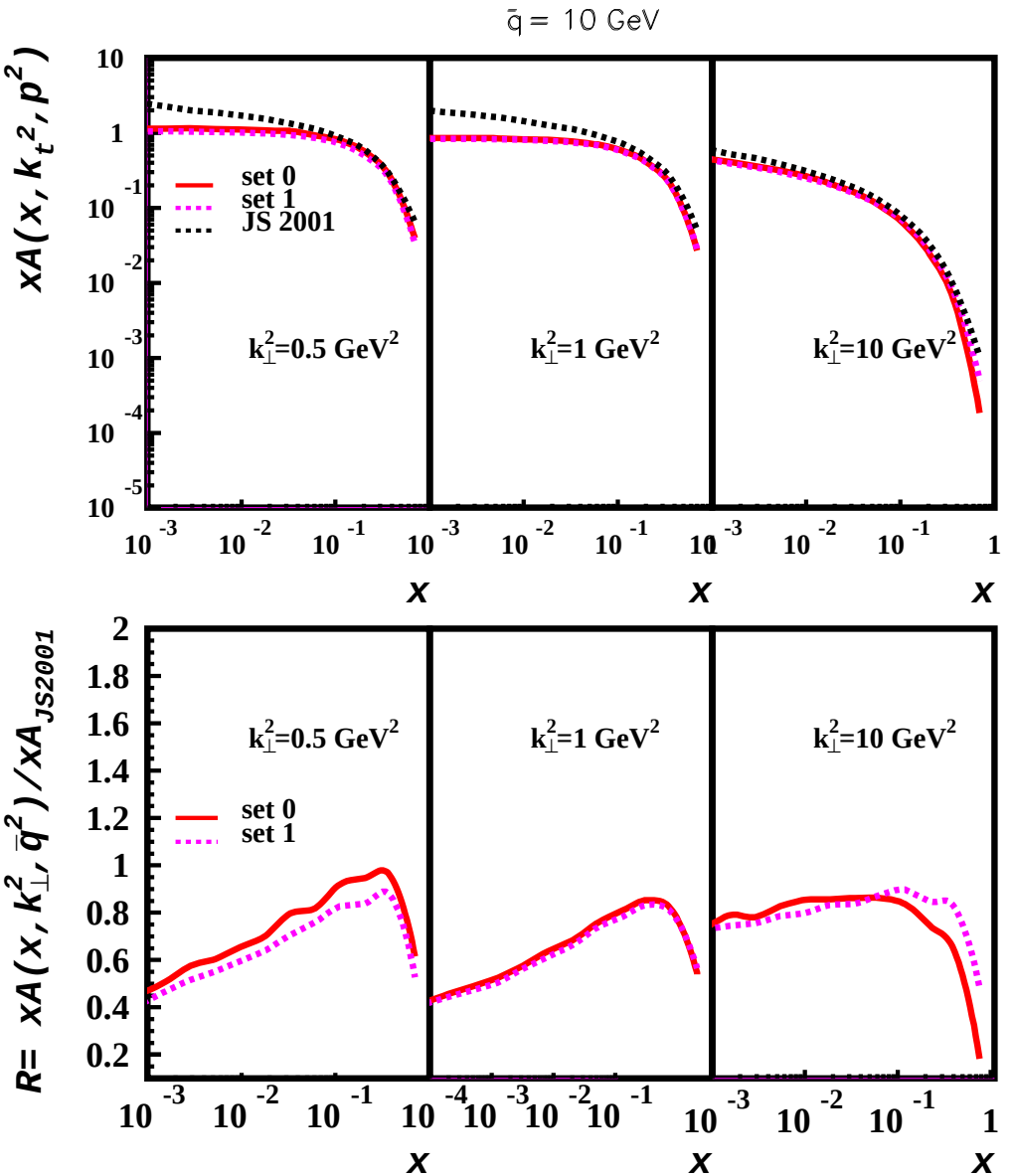
worry: lower limit $z'q_t \ll \Lambda_{QCD}$:

- **keep angular ordering (integral limits),**
  - ☛ **but fix α_s below $q^{cut} = 0.9$ (set 0)**
- **cut angular ordering (set 1)**
  - ☛ **lower limit: $\max(z'q_t, q^{cut})$**

Improve CCFM Splitting Function: $\alpha_s(q_t)$ un-integrated gluon density

- for set 0/1 fit F_2 data
  $x < 0.01$ $Q^2 > 3.5$ GeV^2
  new treatment of soft region
- set 0:(fix α_s, keep ang.ord.)
  $\chi^2/N = 1.27$ for $N = 147$
- set 1: (cut ang. ord)
  $\chi^2/N = 2.3$ for $N = 147$

  (also large fluctuations !)
- compare to old set JS2001



- **angular ordering important also in non-Sudakov**
- **χ^2 of fit prefers set 0**

CCFM including full splitting function

- **improve splitting function**

$$P_{gg} \sim \bar{\alpha}_s \left(\frac{1}{z} \Delta_{ns} + \frac{1}{1-z} \right)$$

☛ **to include non-singular terms**

$$P_{gg} \sim \bar{\alpha}_s \left(\frac{1}{z} \Delta_{ns} - 2 + z(1-z) + \frac{1}{1-z} \right)$$

- **new attempt (idea by G.P. Salam):**

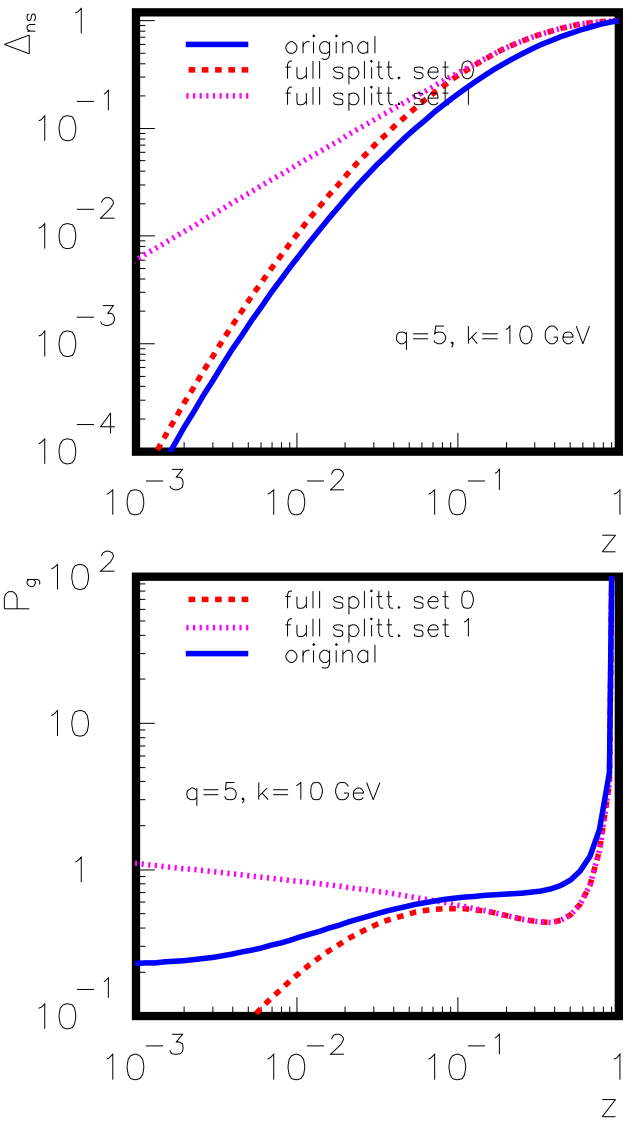
$$P = \bar{\alpha}_s \left(\frac{(1-z)}{z} + \frac{z(1-z)}{2} \right) \Delta_{ns} + \bar{\alpha}_s \left(\frac{z}{1-z} + \frac{z(1-z)}{2} \right)$$

- **need also new Sudakov:**

$$\log \Delta_s = - \int_0^1 \frac{dq'^2}{q'^2} dz' \bar{\alpha}_s \left(\frac{z'}{1-z'} + \frac{z(1-z)}{2} \right)$$

and new non-Sudakov

$$\log \Delta_{ns} = -\bar{\alpha}_s(k) \int \int dz' \frac{dq'^2}{q'^2} \left(\frac{1-z}{z'} + \frac{z(1-z)}{2} \right)$$



- **soft region in non-Sudakov ???**

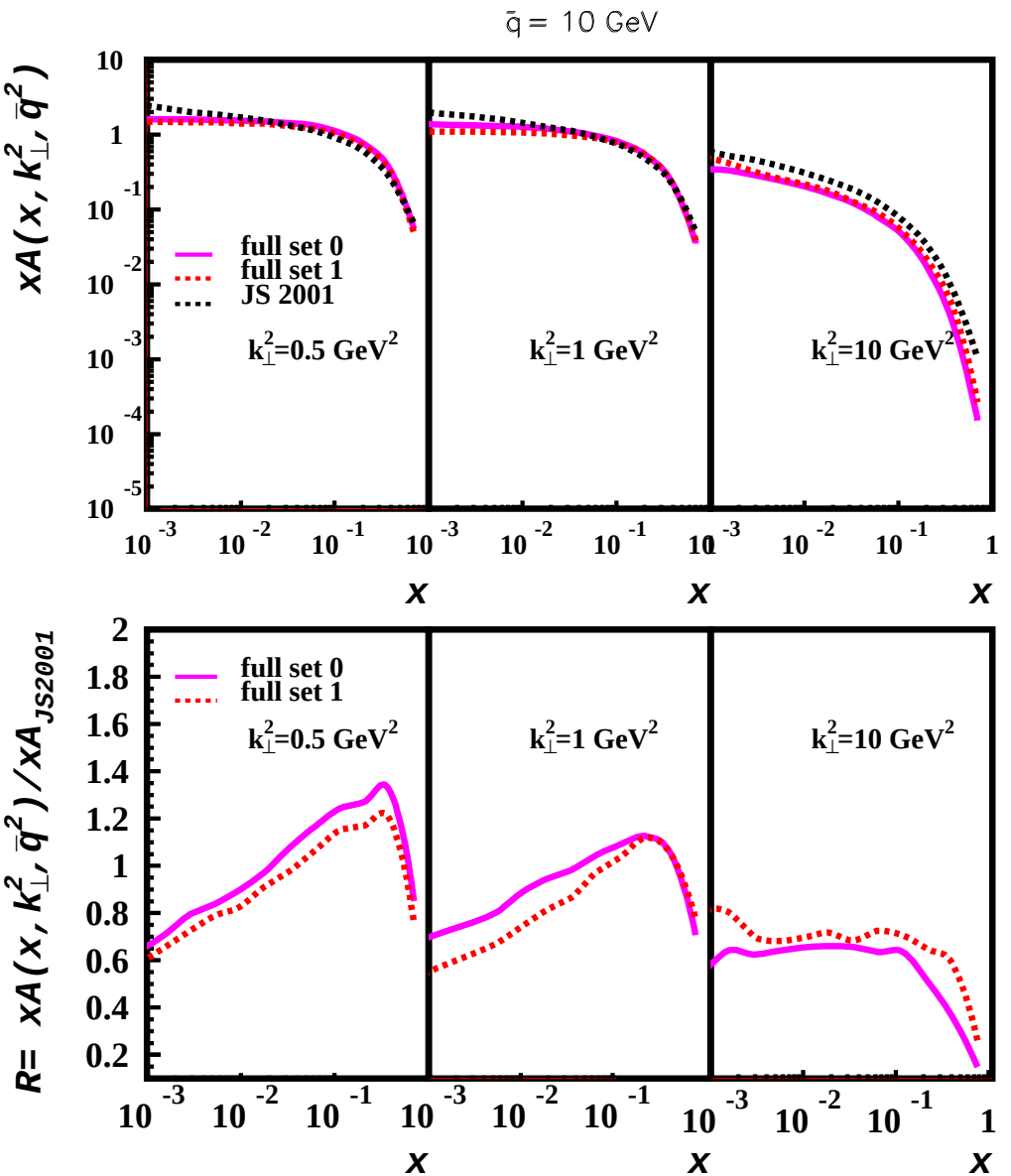
☛ **keep angular ordering: set 0**

☛ **cut angular ordering: set 1**

Improve CCFM: full splitting function

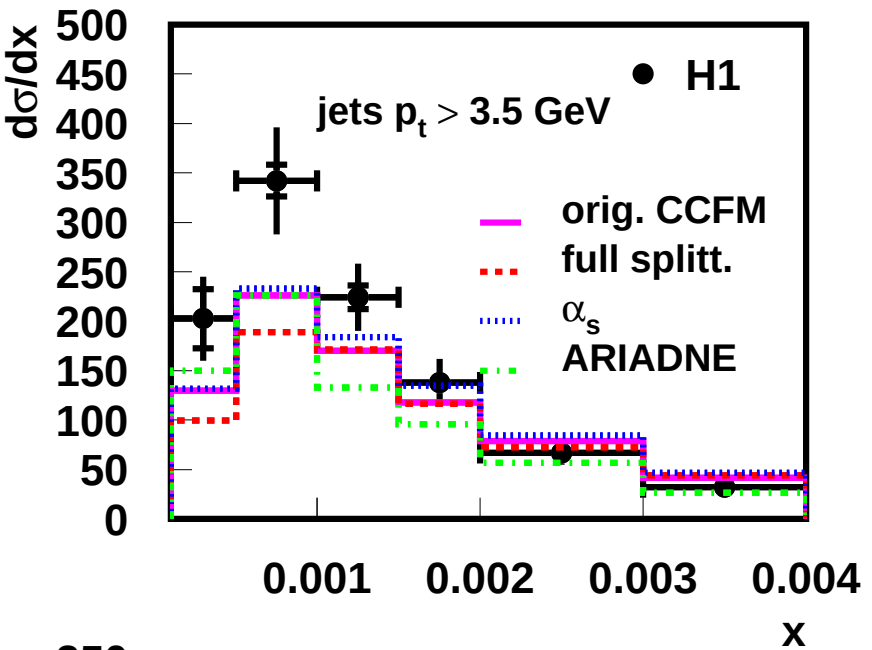
- for set 0/1 fit F_2 data
  $x < 0.01$ $Q^2 > 3.5$ GeV^2
  new treatment of soft region
- set 0:(fix α_s, keep ang.ord.)
  $\chi^2/N = 1.48$ for $N = 147$
- set 1: (cut ang. ord)
  $\chi^2/N = 1.5$ for $N = 147$
  (but also large fluctuations)
- compare to old set JS2001

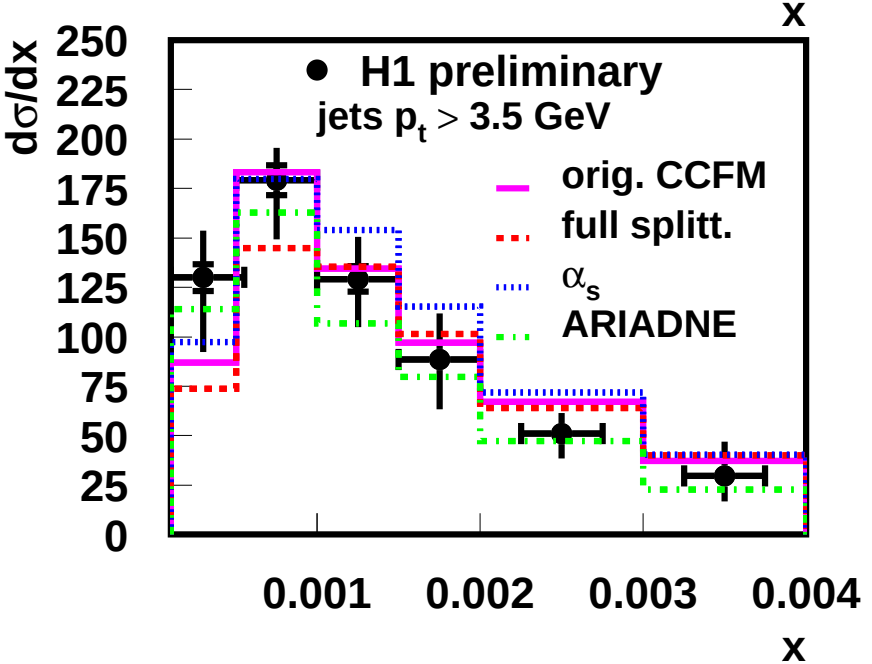
- gluon pdfs are different
- different shape in x
- effect of non-sing. terms visible
- cuts in non-Sudakov (set 0/1) ...



New pdfs and forward jets

- comparisons to data:
  - cone jet algorithm (published H1 data)
  - incl. kt algorithm (prel. H1 data)
- ☛ x-sect. are different
- ☛ old set (JS2001) overshoots data
- ☛ new fits ☛ smaller x-sect.
- ☛ agrees better with new data
- ☛ even with full splitting fct.
- similar to ARIADNE
- success!!! was it only problem with data ???

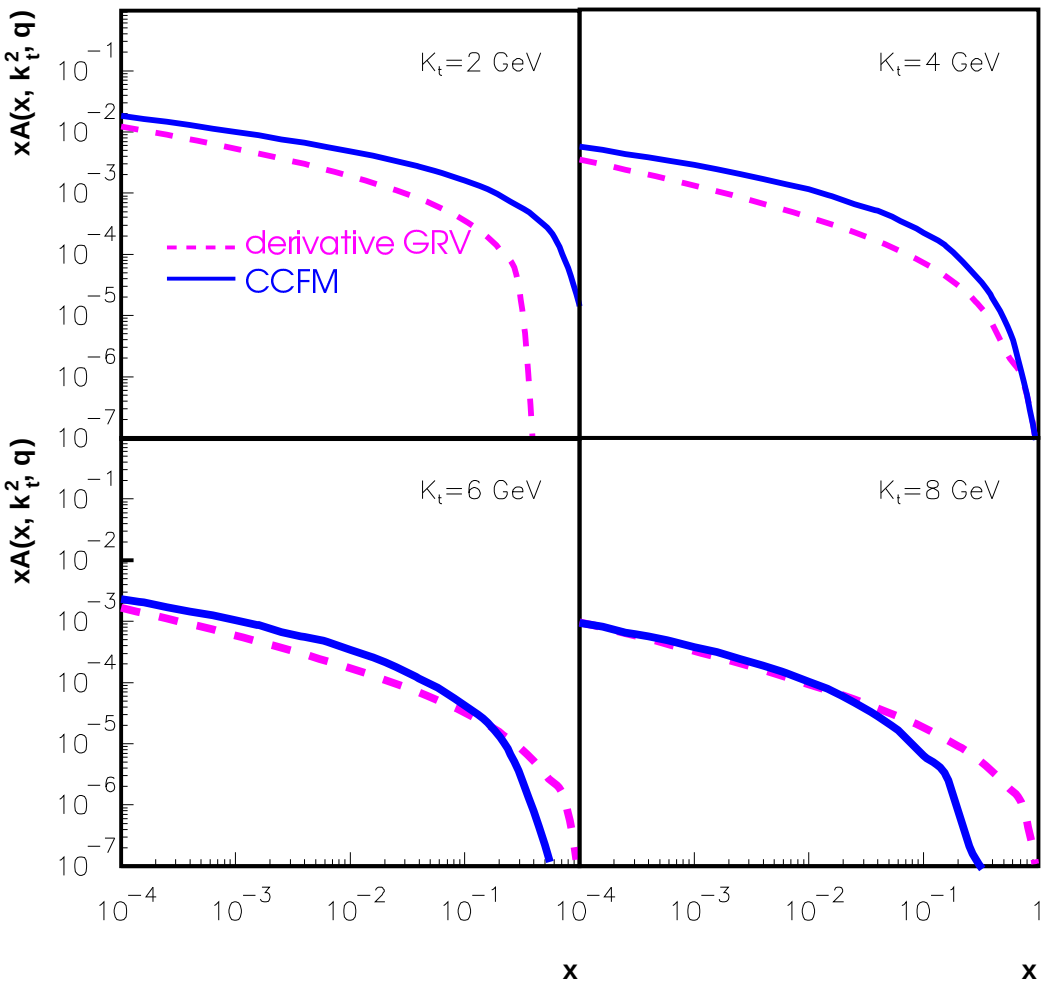




Un-integrated Gluon Density of Photon

together with M. Hansson

- test machinery with one-loop (DGLAP)
- use gluon in photon from GRV as input
  use normalization at input scale
- apply CCFM evolution (sing. terms only)
  with parameters obtained from proton ($Q_0 = 1.4$ GeV)

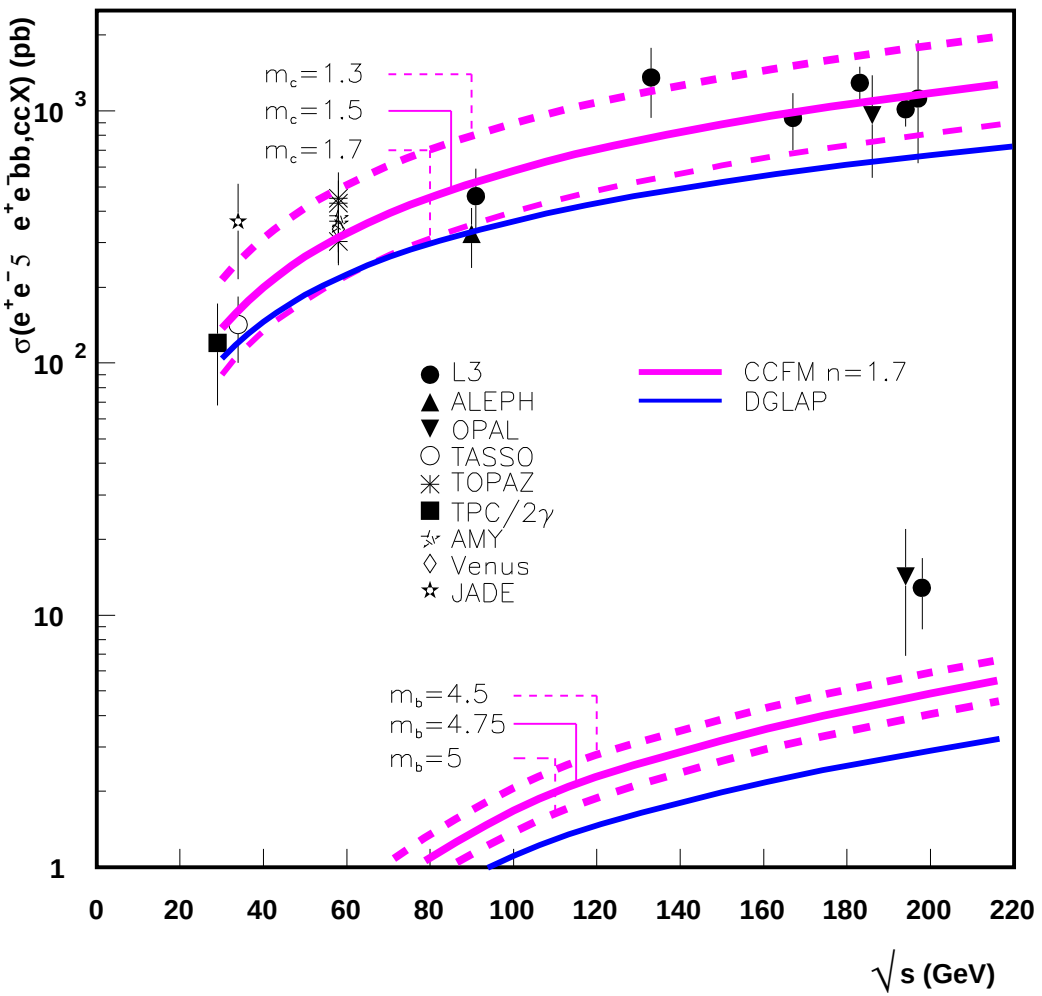


First un-integrated gluon density of real photon with full CCFM evolution

$\gamma\gamma \to b\bar{b}$

together with M. Hansson

- use matrix elements in k_t - factorization
  - $\gamma\gamma \to b\bar{b}$
  - $\gamma g \to b\bar{b}$
  - $gg \to b\bar{b}$
  - universality...



- **compare k_t -factorization & CCFM with NLO:**
- **using norm. from pdf**
  - **CCFM similar to NLO**
- **determine norm. for gluon from charm ($n = 1.7$ for res.γ)**
  - **CCFM larger than NLO**

BUT still low for $\gamma\gamma \to b\bar{b}$

What has been achieved ???

- full machinery for CCFM MC fits developed
- new CCFM un-integrated pdfs from fits to more F_2 data
- new studies of non-leading effects in CCFM:
  - ☛ new treatment of soft region
  - ☛ scale in α_s
  - ☛ full splitting function with non-leading terms
- new pdfs agree better with new, prel. forward jet data ... even including non-leading effects
- un-integrated gluon of real photon obtained better than collinear NLO for $\gamma\gamma \to b\bar{b}$ data, **BUT still ...**

Outlook

- new CCFM parameterizations available
- perform also One-Loop (DGLAP) fits
- uncertainties: changing upper scales

- CASCADE also with resolved photons for ep and ee
- other hadronic final states:
- ☞ jets
- ☞ heavy flavors

Un-integrated gluon density and CCFM evolution - entering now precision level and fine tuning !!!!