Sudakov resummation effects for parton distributions

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Outline

Soft gluon resummation

Extending the range of perturbative QCD

- Soft and collinear gluons generate *large logarithms* in QCD cross sections near kinematic thresholds.

$$\text{DIS} \quad \longrightarrow \alpha_s^n \log^{2n-1}(1-x)/(1-x)$$

- Soft and collinear logarithms can be computed to all orders and they *exponentiate* in moment space.
  $\sum_k \alpha_s^k \sum_p^{2k} c_{kp} L^p \to \exp\left[L g_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \ldots\right]$
- Resummation *extends the range* of perturbation theory
  $\alpha_s L^2 \ll 1 \longleftrightarrow \alpha_s \ll 1$
- Resummation reaches beyond perturbation theory
  finite order $\longrightarrow$ resummation $\longrightarrow$ power corrections

The case of Deep Inelastic Scattering

- *DIS* coefficient functions are known to *NNLL* accuracy

$$C_{\rm res}(N,Q^2) = \bar{C}_{\rm NLO}(N,Q^2) + C_\delta(Q^2)\ \exp\left[E(N,Q^2)\right] \ ,$$

$$E(N,Q^2) = \int_{Q^2/\bar{N}}^{Q^2} \frac{d\mu^2}{\mu^2} \left[\log(\bar{N}\mu^2/Q^2) A(\alpha_s(\mu^2)) + B(\alpha_s(\mu^2))\right]$$

$\longrightarrow$ A,B known to *(N)NNLO* $\longrightarrow$ *NNLL* accuracy

- The structure of *power corrections* to the DIS cross section *near threshold* begins to be understood (powers of Λ^2/W^2).

- Ansatz for *nonperturbative* factorization (Korchemsky *et al.*)
$F_2^N(Q^2) = H\left(Q^2\right)\ J_N\left(Q^2/N, \mu_F^2\right)\ q_N(\mu_F^2)\ J^{\rm NP}\left(N\Lambda^2/Q^2\right)\ .$

- Improved perturbative calculations *can be trusted* at large x.

A case for resummed PDF's

Phenomenology

- Resummation justifies including *more* data in PDF fits.
  $W^2 \sim Q^2(1-x) \longrightarrow$ close to resonance region

- Large-x quarks influence large-x gluons and smaller-x partons via *sum rules* and *evolution*.
  Q^2 evolution of partons at x_0 determined by partons at $x > x_0$.

- Light Higgs@LHC (made at small x) should not be *unique* focus: large-x is *new physics* region.

  t-channel exchange of heavy particles?
  High-E_T jets?

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A case for resummed PDF's

Theory

- The boundary between *perturbative* and *nonperturbative* must be *defined*.

  Leading Twist ↔ NLO ↔ $\overline{\mathrm{MS}}$ do not mix well!

- Resummation provides a gate to nonperturbative corrections.

  Define resummed exponent ↔ define power correction

  NOTE: consistency recently checked for F_2 (Korchemski *et al.*)

- QCD *models* for power corrections to structure functions can be *tested* (as done for event shapes).
- *Lattice* determinations of PDF's use different, precise definition of *leading twist* ... comparison?

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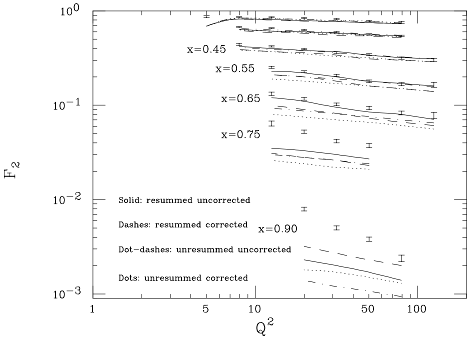
Global resummed fits?

Soft gluon resummation to *NLL* is now *standard* in all simple QCD cross sections.

- *DIS*. The best understood cross section in QCD.
  (N)NNLO, NNLL, OPE, conjectured nonperturbative factorization.
- *Drell-Yan*. Next best. NNLO, NNLL, rapidity distribution
- *Prompt photon*. Problematic phenomenology.
  NLO, NLL, joint resummation, fragmentation component? Data?
- *Jet production*. Incomplete.
  NLO, formal NLL, non-global logs! `Caesar?`

A fully consistent *global resummed fit* is not yet possible but realistically *achievable*

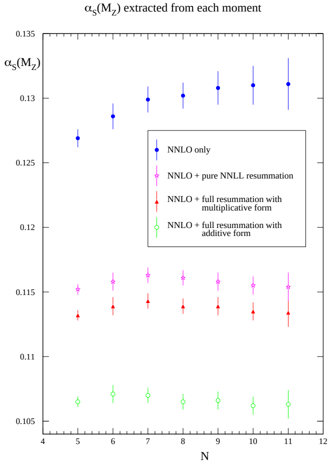
Large-x data: charged current



- NuTeV $\neq$ CCFR at large x.
- Resummations $\rightarrow$ right direction.
- CTEQ partons *contain* CCFR data.
- Some large-x data *perturbative*.

Large-x data: neutral current

Gardi, Roberts, hep-ph/0210429



- α_s depends on *moment* at NNLO.
- Resummation *fixes* N dependence.
- Resummation lowers α_s .
- Inclusion of power corrections still *ambiguous*.
- SLAC/BCDMS large-x data *can* be fitted by including soft gluon effects.

A toy large-x parton fit

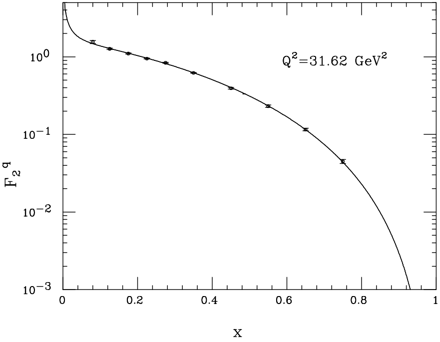
G. Corcella, LM, preliminary

We consider *NuTeV* data for charged current F_2 and F_3, and *NMC/BCDMS* data for neutral current F_2.

- Data are *parametrized* at different *fixed* values of Q^2
- *Moments* of data can be computed with reasonable uncertainties.
  NOTE: resummation takes place in *moment* space $\longrightarrow$ natural determination of PDF moments
- *Extract* moments of linear combinations of PDF's, *solve* for valence quarks with *assumptions* on gluon and sea.
- *Fit* x-space functional forms to moments.

Parametrizations of different data sets

Charged current F_2 from $NuTeV$

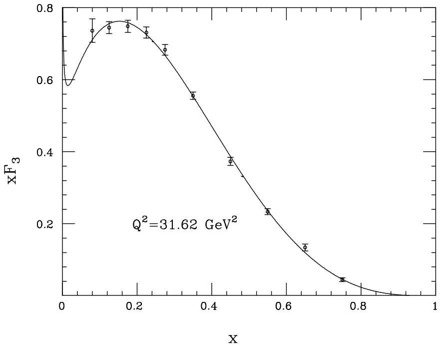


- $F_2^q = x \sum_q |V_{qq}|^2 (q + \bar{q})$
- CTEQ *gluon* subtracted point by point.
- $F_2^q(x) = ax^{-\alpha}(1-x)^{\beta}(1+bx)$
- $a = 0.170 \pm 0.014$, $\alpha = 0.611 \pm 0.025$ $\beta = 3.004 \pm 0.053$, $b = 17.2 \pm 1.37$

Parametrization of charged current F_2 from $NuTeV$ at $Q^2 = 31.62$

Parametrizations of different data sets

Charged current F_3 from NuTeV



- $F_3 = \sum_q |V_{qq}|^2 (q - \bar{q})$
- $xF_3(x) = cx^{-\rho}(1-x)^{\sigma}(1+kx)$
- $c = 0.170 \pm 0.019$, $\rho = 0.226 \pm 0.032$ $\sigma = 3.169 \pm 0.081$, $k = 25.7 \pm 2.78$

Parametrization of charged current F_3 from $NuTeV$ at $Q^2 = 31.62$

Parametrizations of different data sets

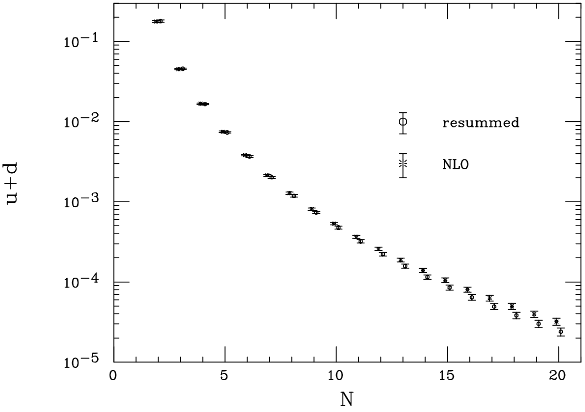
Neutral current F_2 (nonsinglet) from NMC/BCDMS

For $F_2^{(NS)}(x) \sim x(u(x) - d(x))$ we use the *Neural Network* parametrization of the *NNPDF* collaboration.

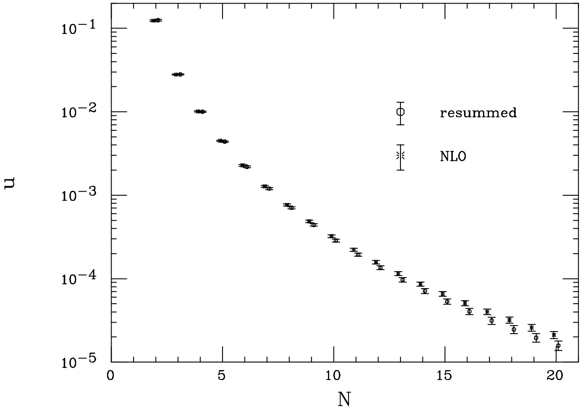
- *NN* provide *unbiased* and *faithful* parametrization of data.
- *Moments* and *errors* are computed treating NN set as *Monte Carlo* sample of probabilty distribution of F_2.
- Large N moments probe region *beyond data*: stronger *smoothing assumptions* than provided by NN *required*.

  NOTE: different smoothing assumptions *change errors* but *not* qualitative behavior.

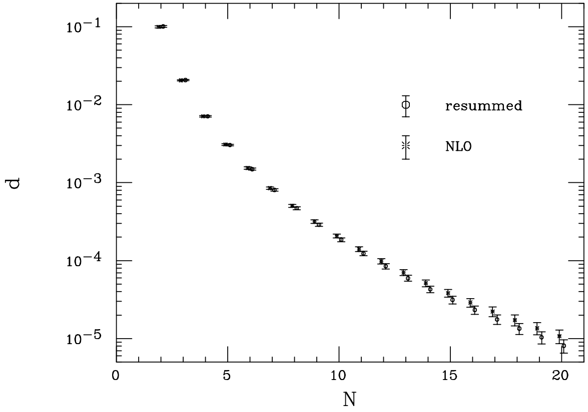
Moments of $u + d$ quark distribution



Moments of u quark distribution

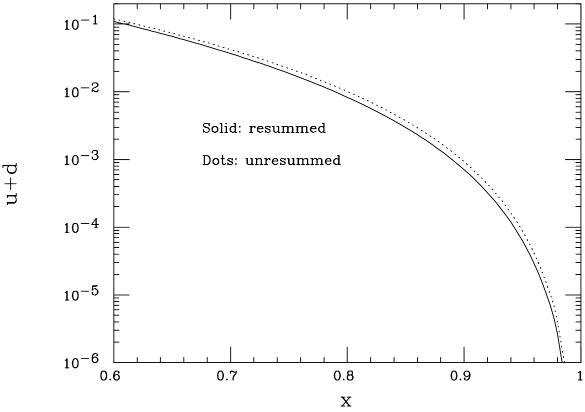


Moments of d quark distribution



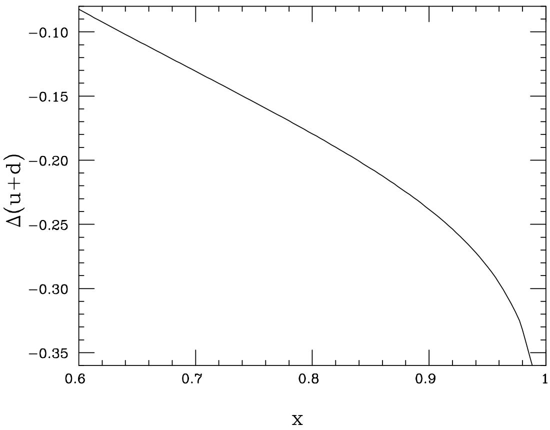
Large x $u+d$ quark distribution

preliminary



Relative variation of $u + d$ at large-x

preliminary



Perspective

- *Soft gluon resummations* have become a *standard tool* in perturbative QCD.
  - Extended *applicability* of perturbative calculations.
  - A tool to identify *power corrections*.
- *PDF fits* including resummation effects are *possible*, and would be *necessary* to achieve 1% precision.
- *More data* can be included in resummed fits.
- A *qualitative analysis* shows -10% effects on valence quarks in the range $x \sim 0.6 \to 0.7$ with a possible *enhancement* at smaller x, for $Q^2 \sim 30 \text{ GeV}^2$.
- A *quantitative analysis* would require including more *data*, and ... more *work* ...

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