Summary of Working Group I

Parton Density Functions

Convenors

M. Dittmar (CMS) S. Forte (Milan) A. Glazov (H1) S. Moch (DESY)

– Workshop HERA and the LHC, CERN, Geneva, Oct 13, 2004 –

Plan

- Reference LHC processes
    - progress on experimental and theoretical accuracy for benchmark processes
- Structure functions
    - PDF error analysis, fit stability and theory improvements
    - F_2 data averaging and PDFs from HERA only
- Resummation
    - small x
    - large x

Plan

- Reference LHC processes
  - progress on experimental and theoretical accuracy for benchmark processes
- Structure functions
  - PDF error analysis, fit stability and theory improvements
  - F_2 data averaging and PDFs from HERA only
- Resummation
  - small x
  - large x
- More on LHC reference processes, final states and experimental and theoretical accuracy **M. Dittmar**

Plan

- Reference LHC processes
  - progress on experimental and theoretical accuracy for benchmark processes
- Structure functions
  - PDF error analysis, fit stability and theory improvements
  - F_2 data averaging and PDFs from HERA only
- Resummation
  - small x
  - large x
- More on LHC reference processes, final states and experimental and theoretical accuracy **M. Dittmar**

My comments in red boxes

Technical challenges

Anastasiou

- Total cross-sections: Integrations over the phase-space are very similar to loop integrations

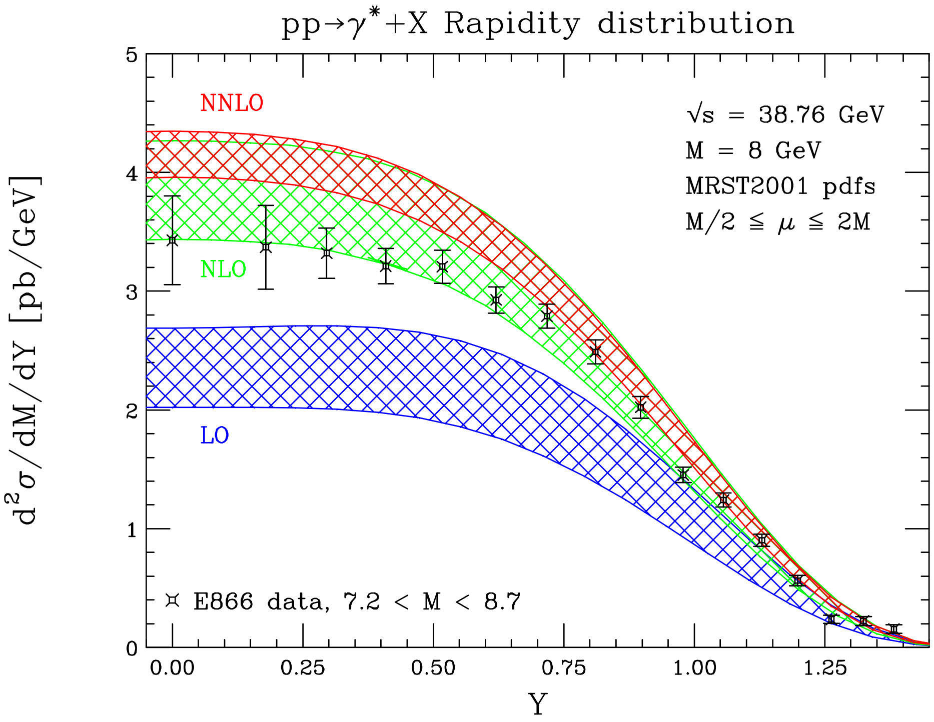
$$\delta(p^2-m^2) \to \frac{1}{p^2-m^2+i0} - \frac{1}{p^2-m^2-i0}$$

  - Use loop-methods *(very well developed in the last few years)*
  - Infrared singularities pop easily out by doing “loop-integrations”.
- Phase-space integrals for differential distributions require a very different treatment
  - Infrared singularities must be extracted before the integrations
  - Evaluate the finite integrals numerically in order to permit the computation of many different observables

New methods:
analytical: optical theorem turns phase space into loop integrals
numerical: iterated sector decomposition

Low energy DY production (E866)

Anastasiou



- NNLO distribution sharper in central rapidity regions.
- Data lower than NNLO $\longrightarrow$ smaller $\bar{q}$ densities

Fixed order partonic Monte-Carlos

Anastasiou

with Kirill Melnikov and Frank Petriello

- A cross-section is:

$$\sigma = \sum_n \int d\left(\text{Phase-Space}_n\right)\left(\text{Matrix-Elements}\right)_n \times Observable\left(\text{PhaseSpace vars}\right)$$

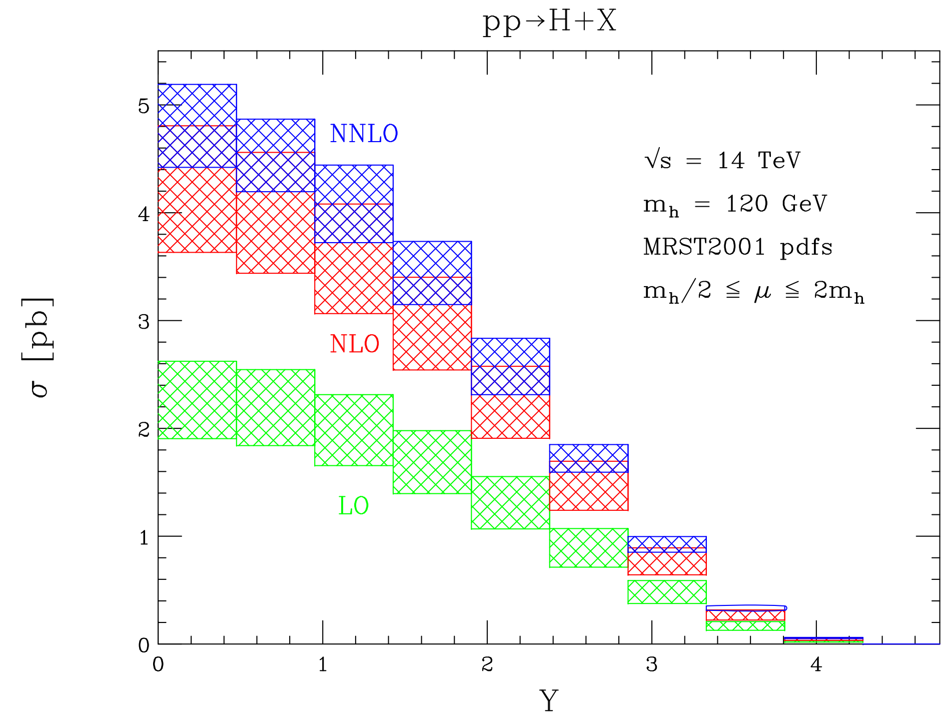
  - Obs, an arbitrarily complicated function to describe the experimentally measured configurations of the phase-space $\longrightarrow$ NUMERICAL INTEGRATION
  - Divergent Matrix-Elements $\longrightarrow D = 4 - 2\epsilon$

- TASK: Expose $1/\epsilon$ poles of individual terms; cancel them against each other; calculate the finite remainder numerically (Monte-Carlo integration).

Important application:
Higgs production via gluon-gluon fusion

Higgs rapidity distribution

Anastasiou



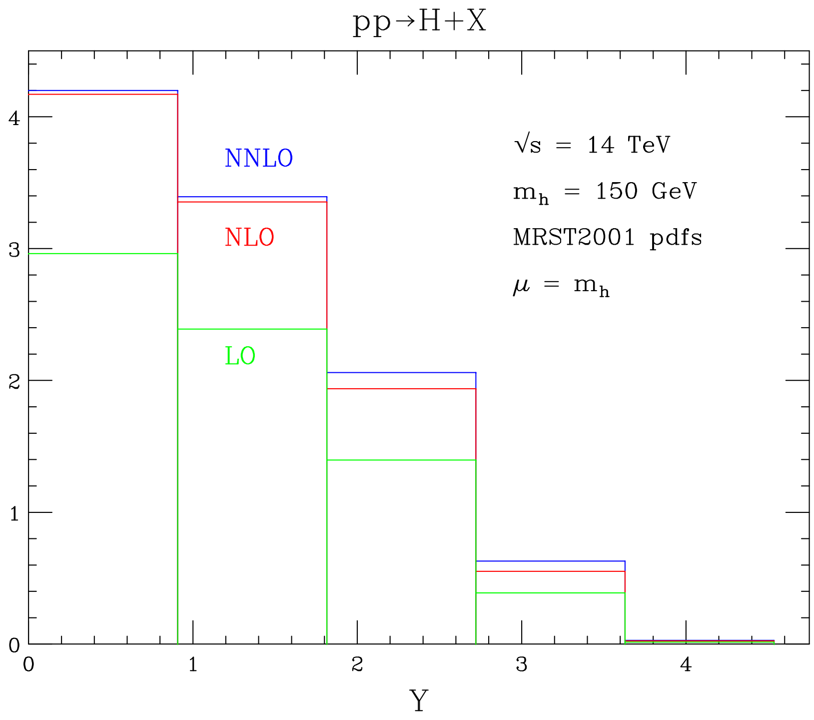
- bin-integrated rapidity distribution (MC statistical error 1%)
- Similar scale variations to the total cross-section; large K-factors.
- Small rapidity dependence of the K-factors

Rapidity distribution with a jet-vet

Anastasiou

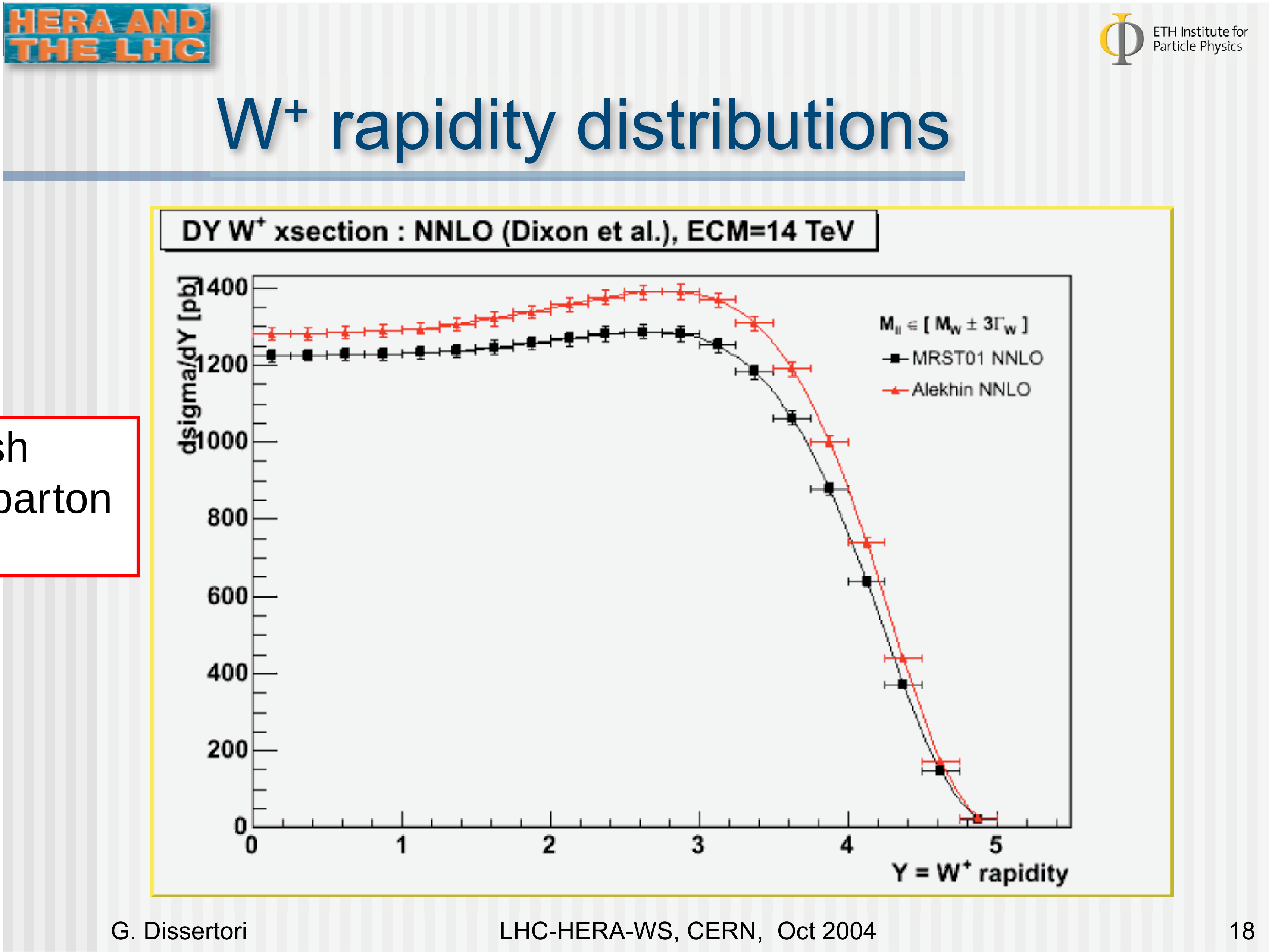
Veto on events with jets $p_t^{\rm jet} > 40{\rm GeV}$
Sensitive to clustering algorithm at NNLO
Two partons form one jet if $R_{ij} < R$

$$R_{ij} = \sqrt{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}$$



- Cut affects more severely the NNLO than the NLO cross-section.
- NLO: $< P_t^H > \sim 38\,{\rm GeV}$
- NNLO: $< P_t^H > \sim 45\,{\rm GeV}$

Dissertori


HERA AND THE LHC

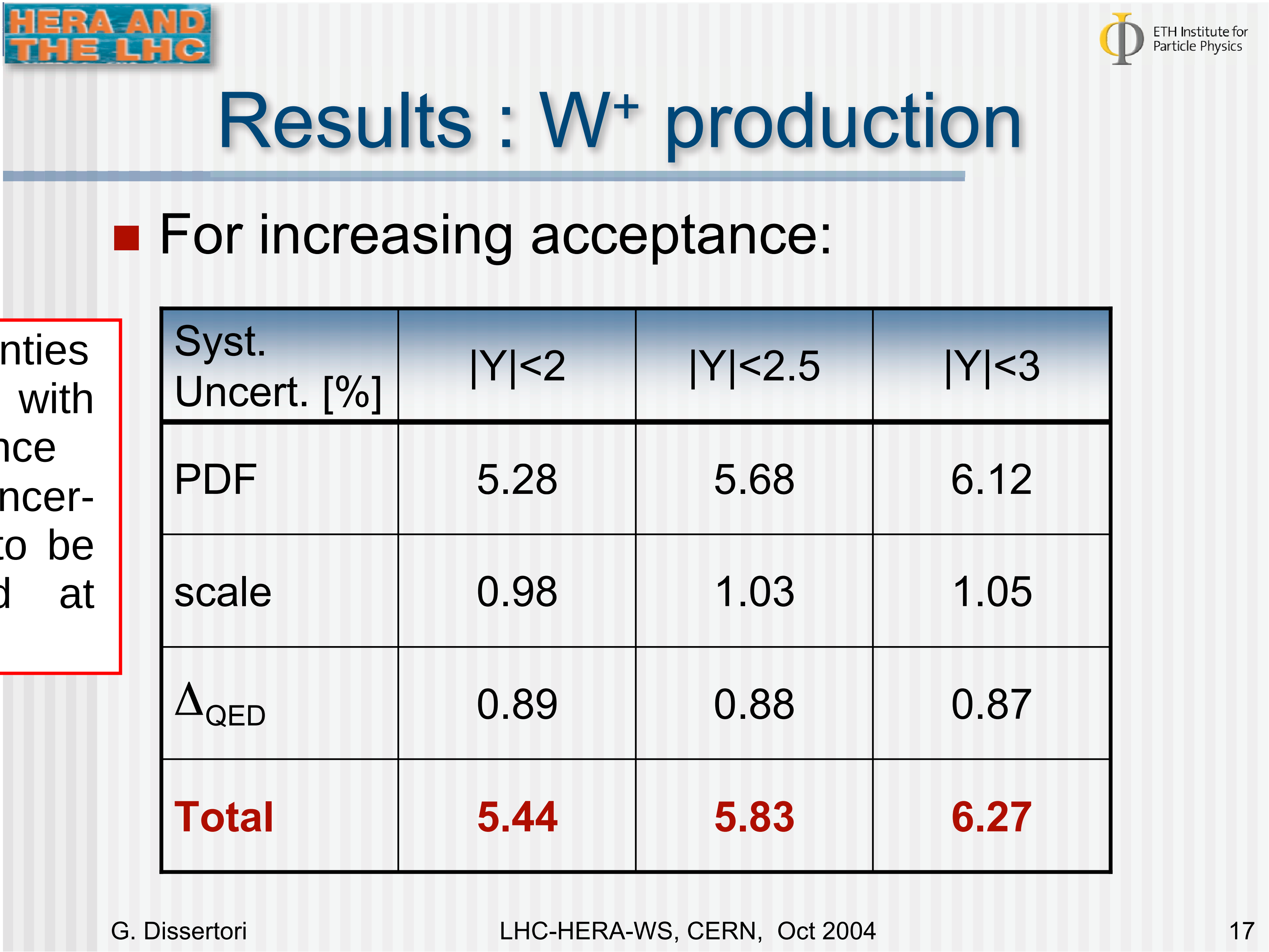
ETH Institute for Particle Physics

W$^+$ rapidity distributions

G. Dissertori LHC-HERA-WS, CERN, Oct 2004 18

Distinguish different parton sets

Dissertori



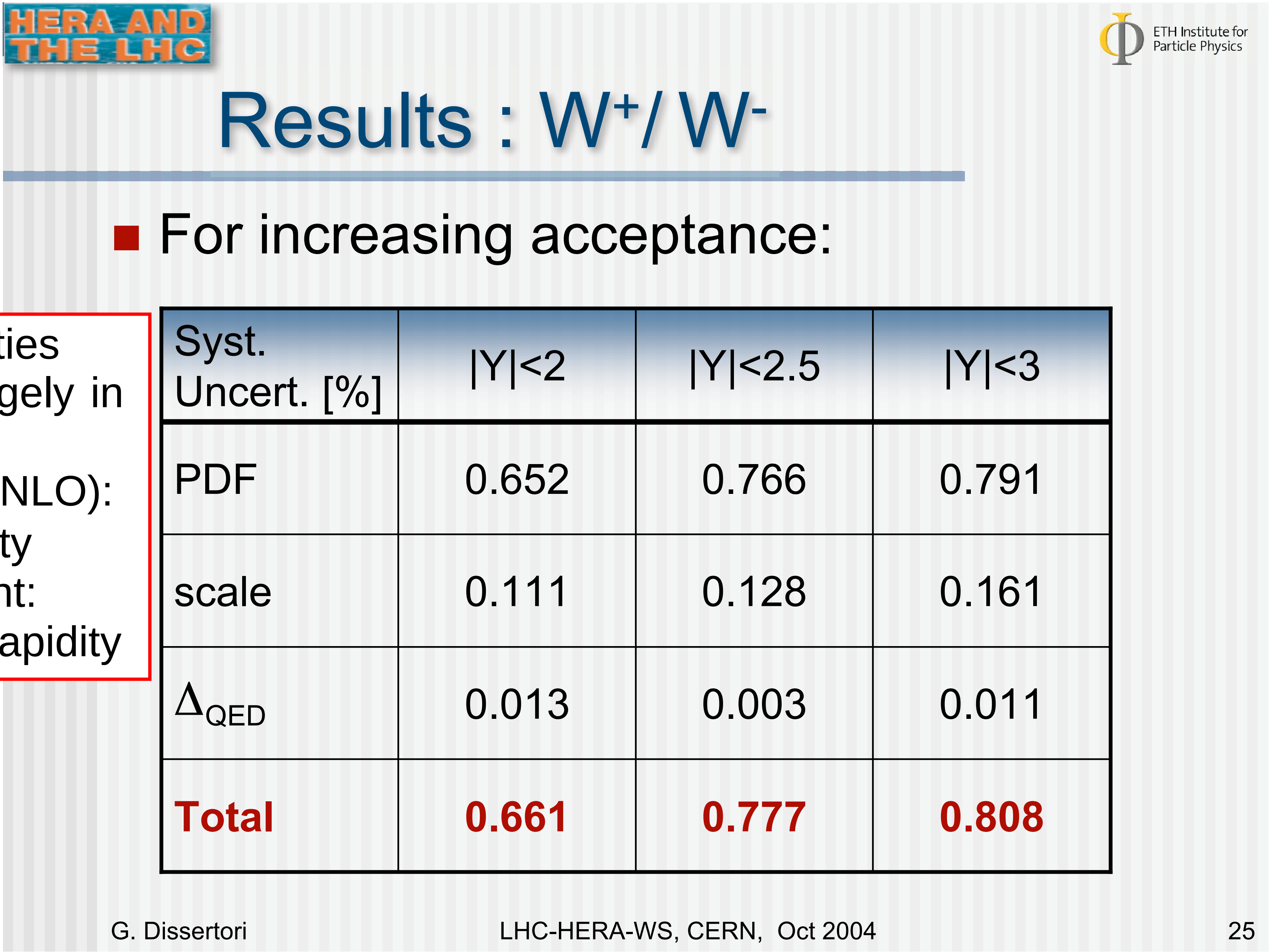
Results : W^+ production

- For increasing acceptance:

Syst. Uncert. [%]	|Y|<2	|Y|<2.5	|Y|<3
PDF	5.28	5.68	6.12
scale	0.98	1.03	1.05
Δ_{QED}	0.89	0.88	0.87
Total	**5.44**	**5.83**	**6.27**

Uncertainties vary with acceptance PDF uncertainties to be improved at NNLO

Dissertori



ETH Institute for Particle Physics

Results : W^+/W^-

- For increasing acceptance:

Syst. Uncert. [%]	|Y|<2	|Y|<2.5	|Y|<3
PDF	0.652	0.766	0.791
scale	0.111	0.128	0.161
Δ_{QED}	0.013	0.003	0.011
Total	**0.661**	**0.777**	**0.808**

G. Dissertori LHC-HERA-WS, CERN, Oct 2004 25

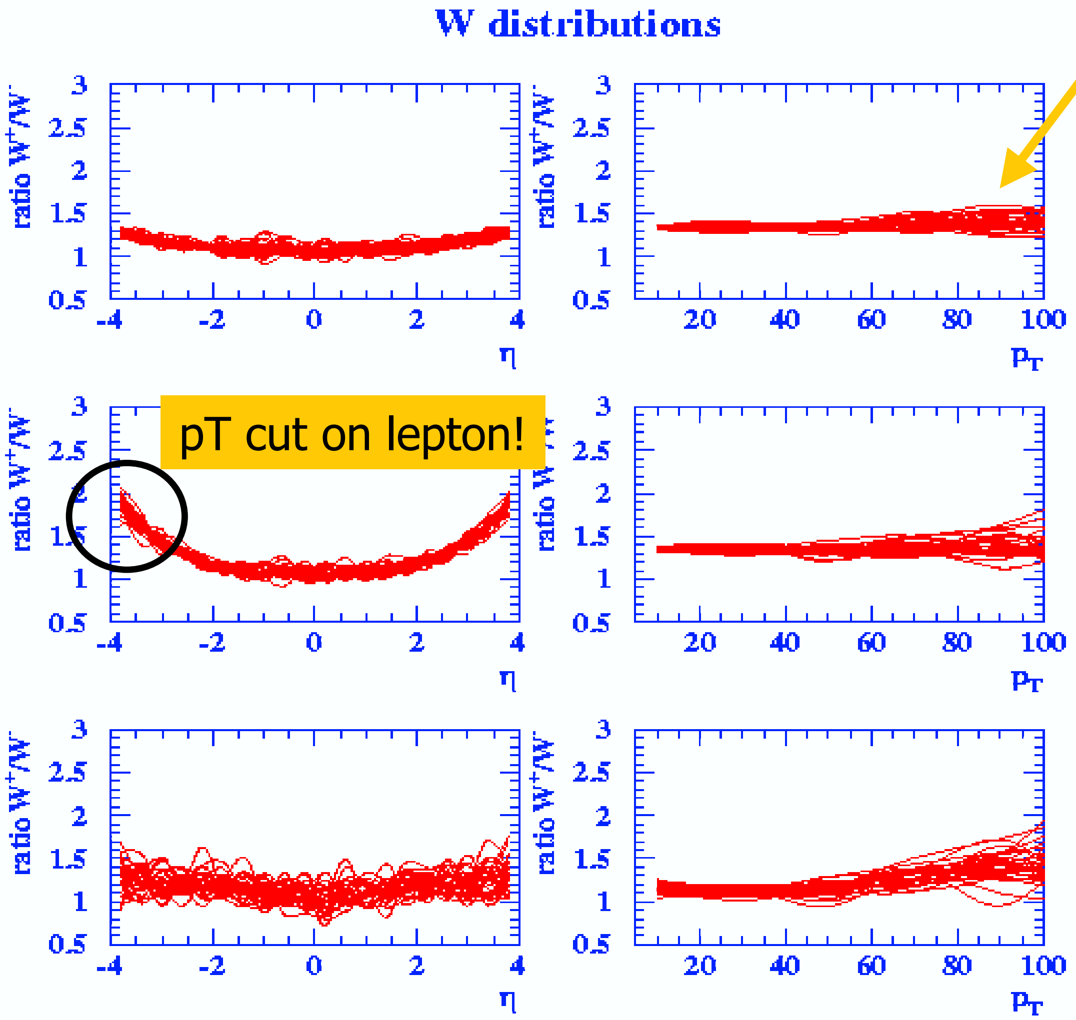
Uncertainties cancel largely in ratios
Theory (NNLO): W^+-rapidity
Experiment: di-lepton rapidity

Schörner

Effects of lepton cuts with MC@NLO

Results: W^+/W^- ratios

Not taking any fake rate effects etc. into account



pT cut on lepton!

CTEQ6m plus 40 error PDFs!

All semileptonic W without any sigificant lepton selection.

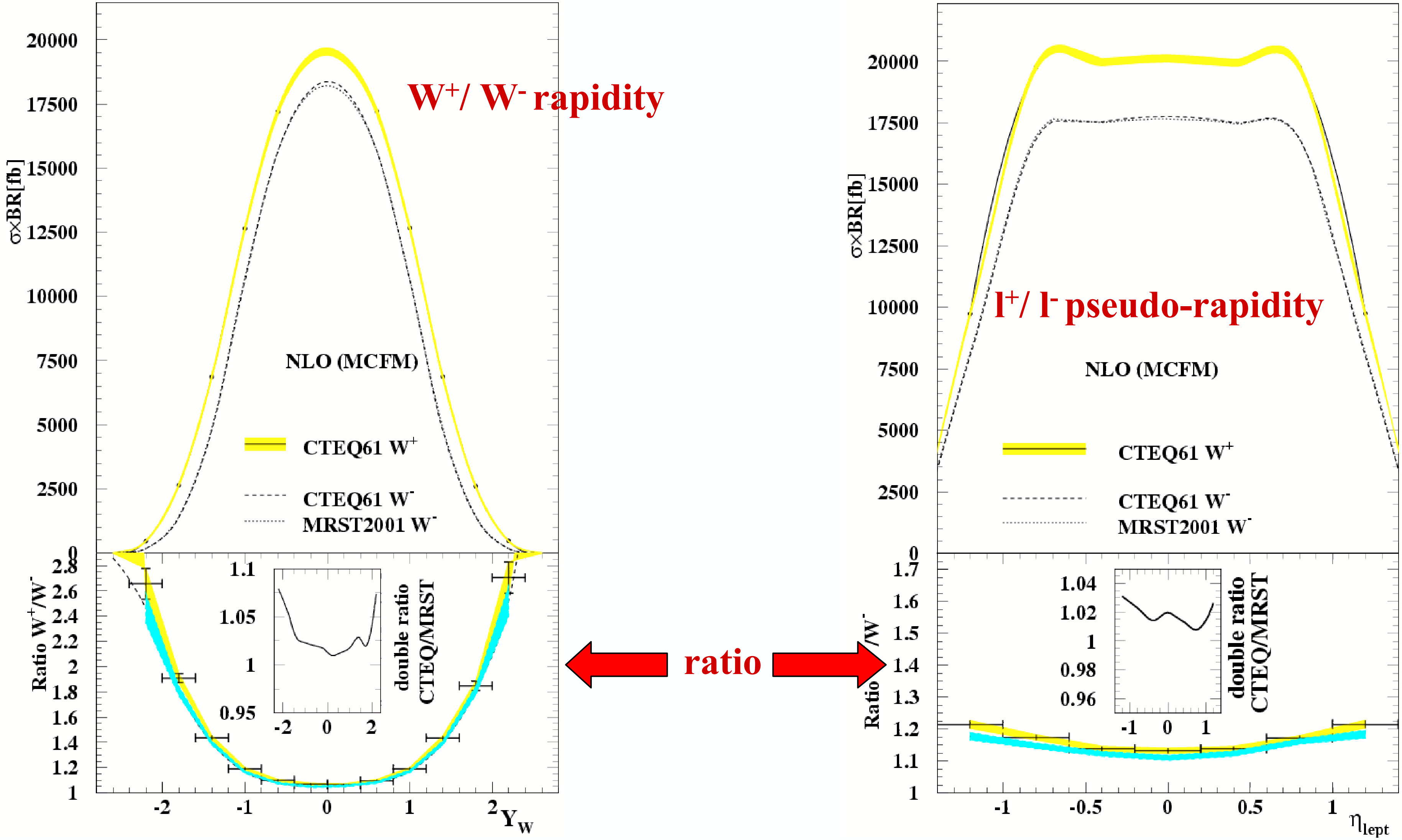
Soft lepton selection:
p_T > 20 GeV, |eta|<2.5

Hard lepton selection:
p_T > 40 GeV, |eta|<2.5
(and $E_{T,miss}$ > 20 GeV)

Similar study for $W^+/W^- + 1\text{jet}$ with MCFM, sensitive to PDFs

Stenzel

Comparison W⁺/ W⁻ + jet



HERA-LHC Workshop October 11-13, 2004 H. Stenzel - W/Z+jet production at LHC 7

2. Comparison of ZEUS/H1 public analyses

Cooper-Sarkar

Both ZEUS (2004) and H1 (2003) now make PDF fits to their own data. Where does the information come from in a HERA only fit compared to a global fit ?

	Global	HERA Only
Valence	Predominantly fixed target data (ν-Fe and $\mu D/\mu p$)	High Q^2 NC/CC $e^\pm$ cross sections
Sea	Low-x from NC DIS High-x from fixed target Flavour from fixed target	Low-x from NC DIS High-x less precise Flavour ?(need assumptions
Gluon	Low-x from HERA $dF_2/d\ln Q^2$ High-x from momentum sum	Low-x from HERA $dF_2/d\ln Q^2$ High-x from momentum sum

Mostly uv

some dv

Tevatron jet data?

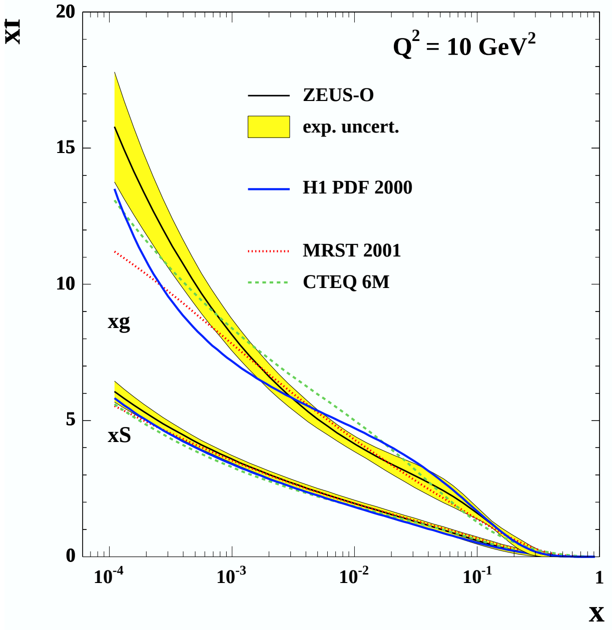
HERA jet data?

ANALYSES FROM HERA ONLY …

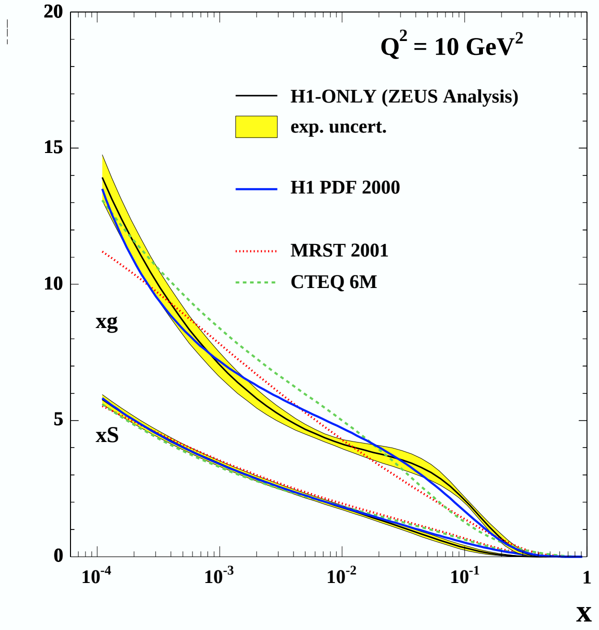
— Systematics well understood
  - measurements from our own experiments !!!

— No complications from heavy target Fe or D corrections

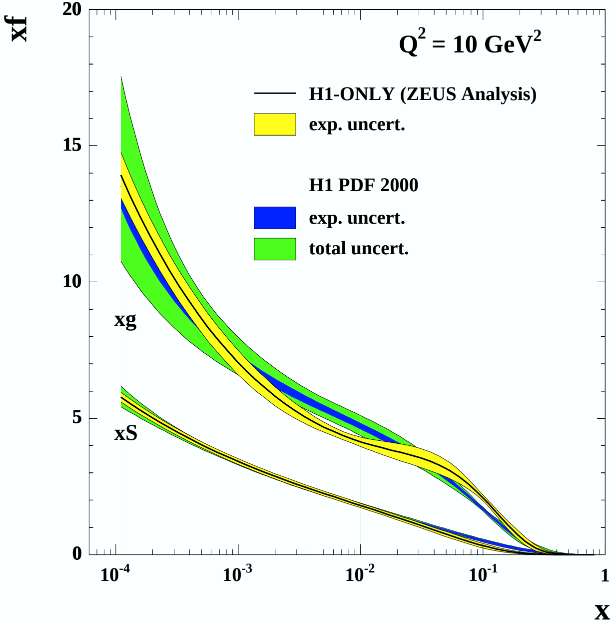
Cooper-Sarkar



ZEUS analysis/ZEUS data



ZEUS analysis/H1 data



ZEUS analysis/H1 data compared to

H1 analysis/H1 data

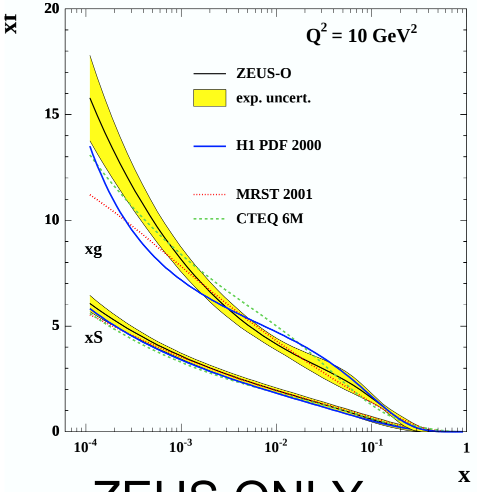
Here we see the effect of differences in the data, recall that the gluon is not directly measured (no jets)

The data differences are most notable in the large 96/97 NC samples at low-Q2 The data are NOT incompatible, but seem to 'pull against each other'

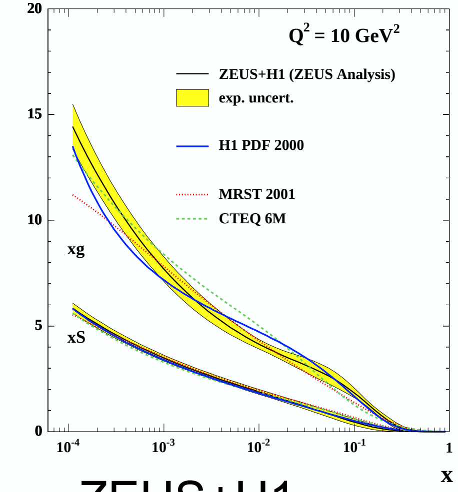
IF a fit is done to ZEUS and H1 together the $\chi2$ for both these data sets rise compared to when they are fitted separately………..

Here we see the effect of differences of analysis choice - form of parametrization at Q2_0 etc

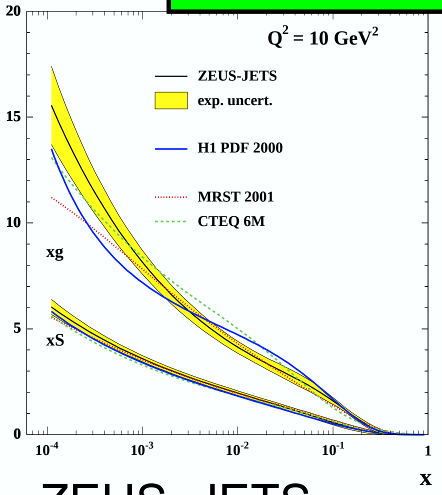
Cooper-Sarkar



ZEUS ONLY

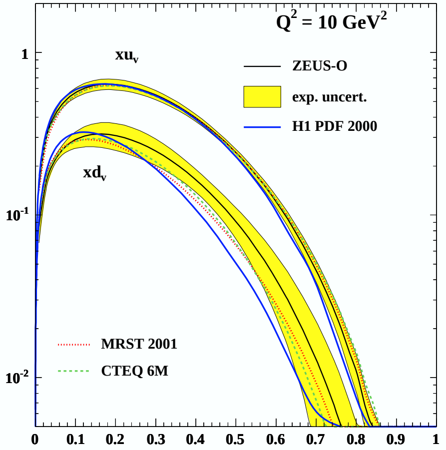


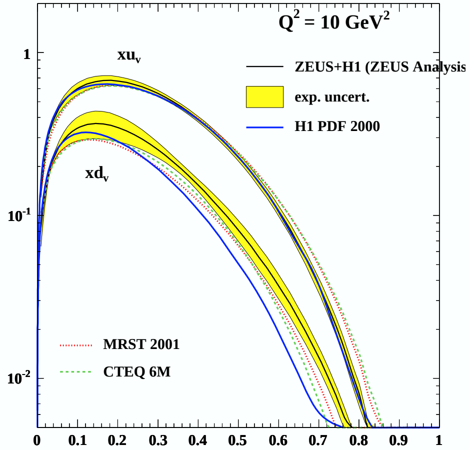
ZEUS+H1

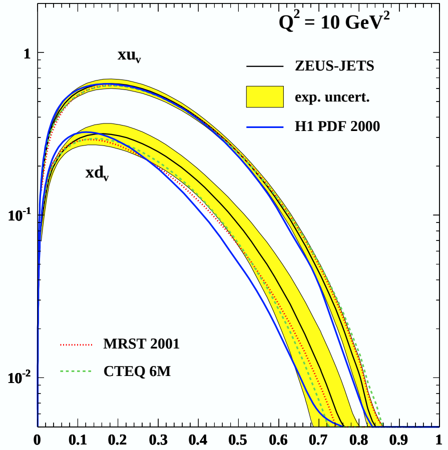


ZEUS_JETS

Whereas adding H1 to ZEUS data brings no significant improvement for the low/mid-x sea and glue determination, where systematic uncertainties already dominate statistical uncertainties, it does bring improvement to the high-x valence distributions where statistical uncertainties dominate







The ZEUS and H1 high-Q2 data are also more compatible –again need the joint H1/ZEUS data set?

Motivation for the averaging of the data

Glazov

The mentioned above drawbacks can be significantly reduced by *averaging* of the world structure function data:

- One combined world structure function dataset (or even χ^2 function with complete systematic uncertainties) is much easier to handle. No more mainstream global QCD fits only, hard-core low-x theorist can also become experts in QCD fitting !
- The averaging procedure is unique (will be discussed next), it removes the drawback of the offset method – systematic errors are floated (reduced) in the averaging procedure.
- χ^2/dof of the average allows model independent consistency check between experiments.

HERA structure function data dominant in global PDF fits

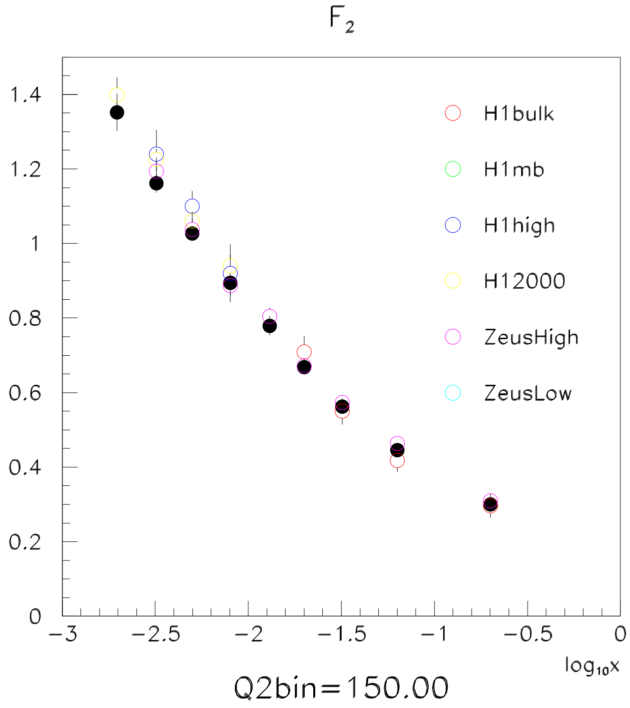
Average of all published HERA NC/CC data

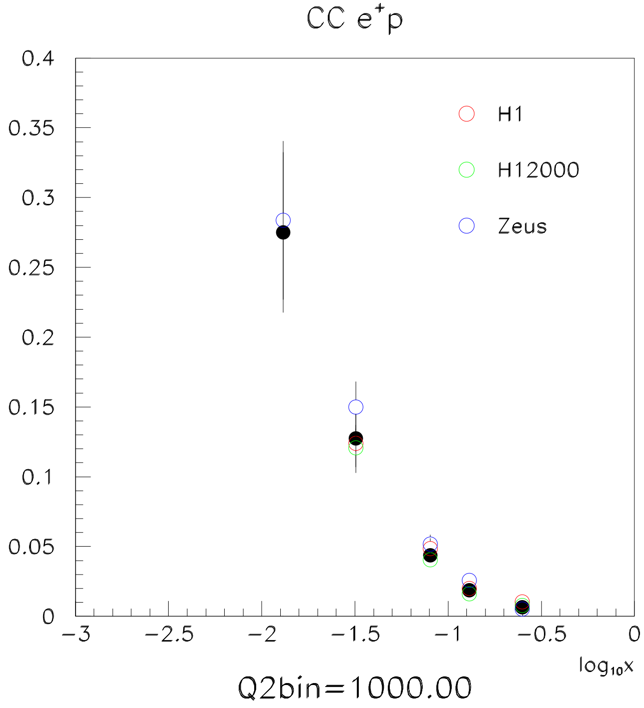
Glazov

Input data sets (separate for e^+p and e^-p):

- H1: low Q^2 96-97, NC/CC 94-97, NC/CC 98 NC/CC 00
- Zeus: NC 96-97, CC/NC e^-p 98-99, e^+p 99-00

Averaging works well



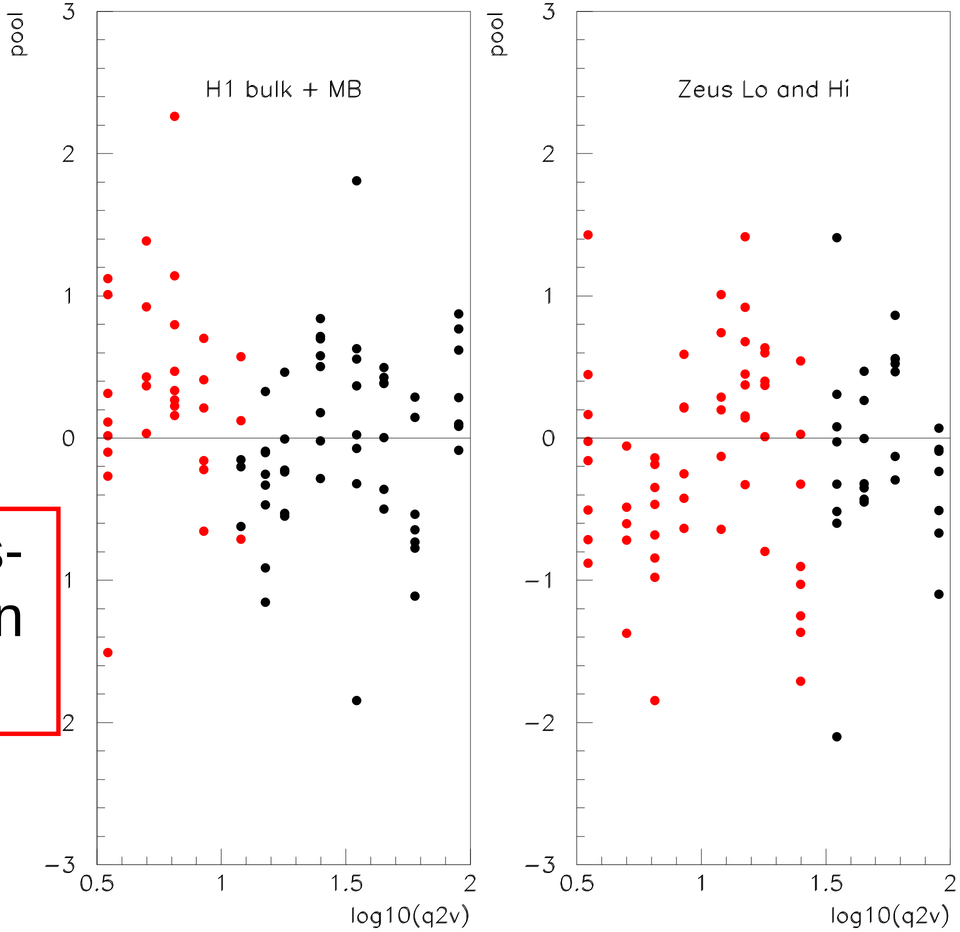


(Too) Good global $\chi^2/dof = 394/491$

Low Q^2 pool distribution

Glazov

Study potential discrepancies in certain kinematical regions



Indication of some differences at low Q^2.
New H1 result for low Q^2 will be published soon.

W cross section predictions: CTEQ and MRST studies

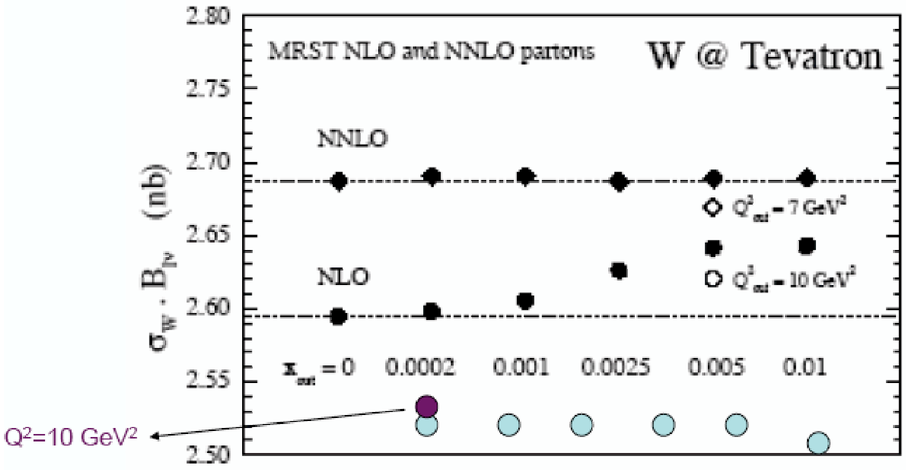
Huston

CTEQ conclusion is that the W cross section seems
respect to cuts in x and Q^2. Aside from an overall K-fa
needed to lend stability to the calculations.

with positive-definite gluon

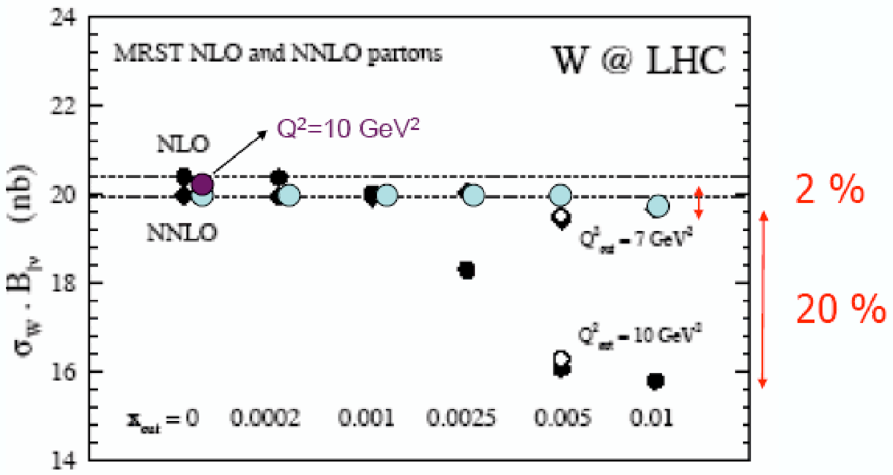
Importance of PDF shapes (MRST large negative gluon)
Stabilize NLO, then improve with NNLO

σ_W at the Tevatron



○ shows the results of applying x cuts to the CTEQ6 data set and performing a NLO fit

W total cross section at the LHC

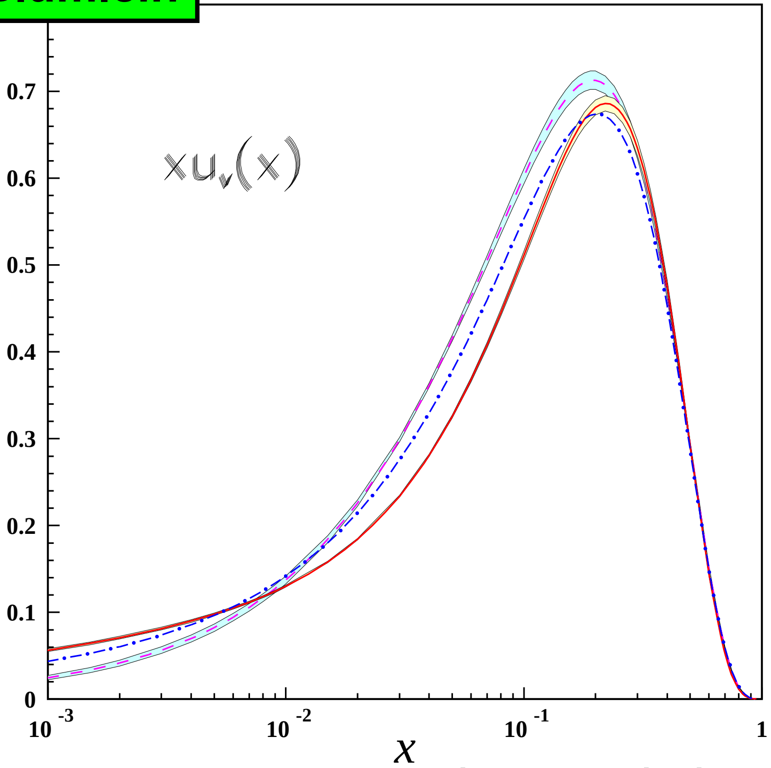


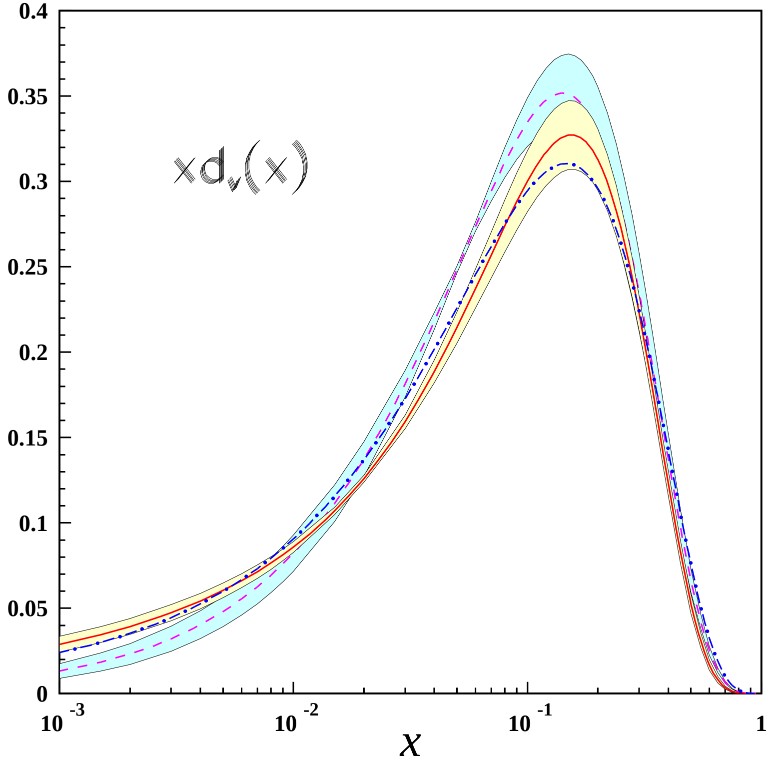
○ shows the results of applying x cuts to the CTEQ6 data set and performing a NLO fit.

Stability of global analysis change Q^2, x cuts → “conservative partons”

NNLO non-singlet QCD analysis of structure function data

Blümlein



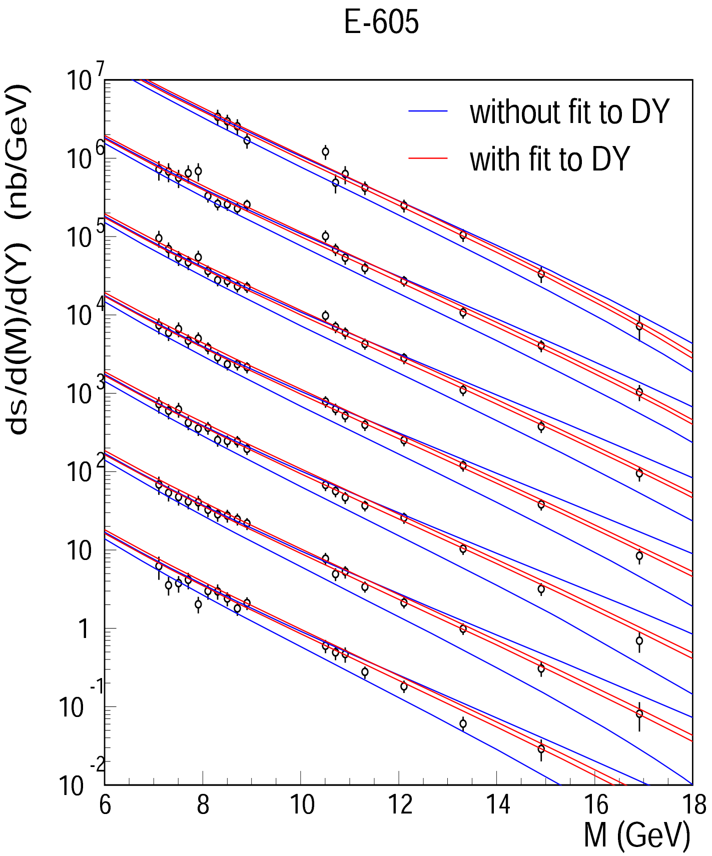


- Fully correlated 1σ statistical error bands for xu_v and xd_v at $Q_0^2 = 4.0\ \mathrm{GeV}^2$
  - extracted values (solid) Blümlein, Böttcher, Guffanti `hep-ph/0407089` with $\alpha_s = 0.1135^{+0.0023}_{-0.0026}(\mathrm{exp})$
- Comparision with combined singlet/non-singlet fits
  - (dashed) Alekhin `hep-ph/0211096` with $\alpha_s = 0.1143 \pm 0.0014(\mathrm{exp}) \pm 0.0009(\mathrm{th})$
  - (dashed–dotted) Martin, Roberts, Stirling, Thorne `hep-ph/0307262` with $\alpha_s = 0.1153 \pm 0.0020(\mathrm{exp}) \pm 0.0030(\mathrm{th})$

Update of NNLO analysis based on DIS data extending to Drell-Yan data

NNLO fit using a code by Anastasiou-Dixon-Melnikov-Petriello

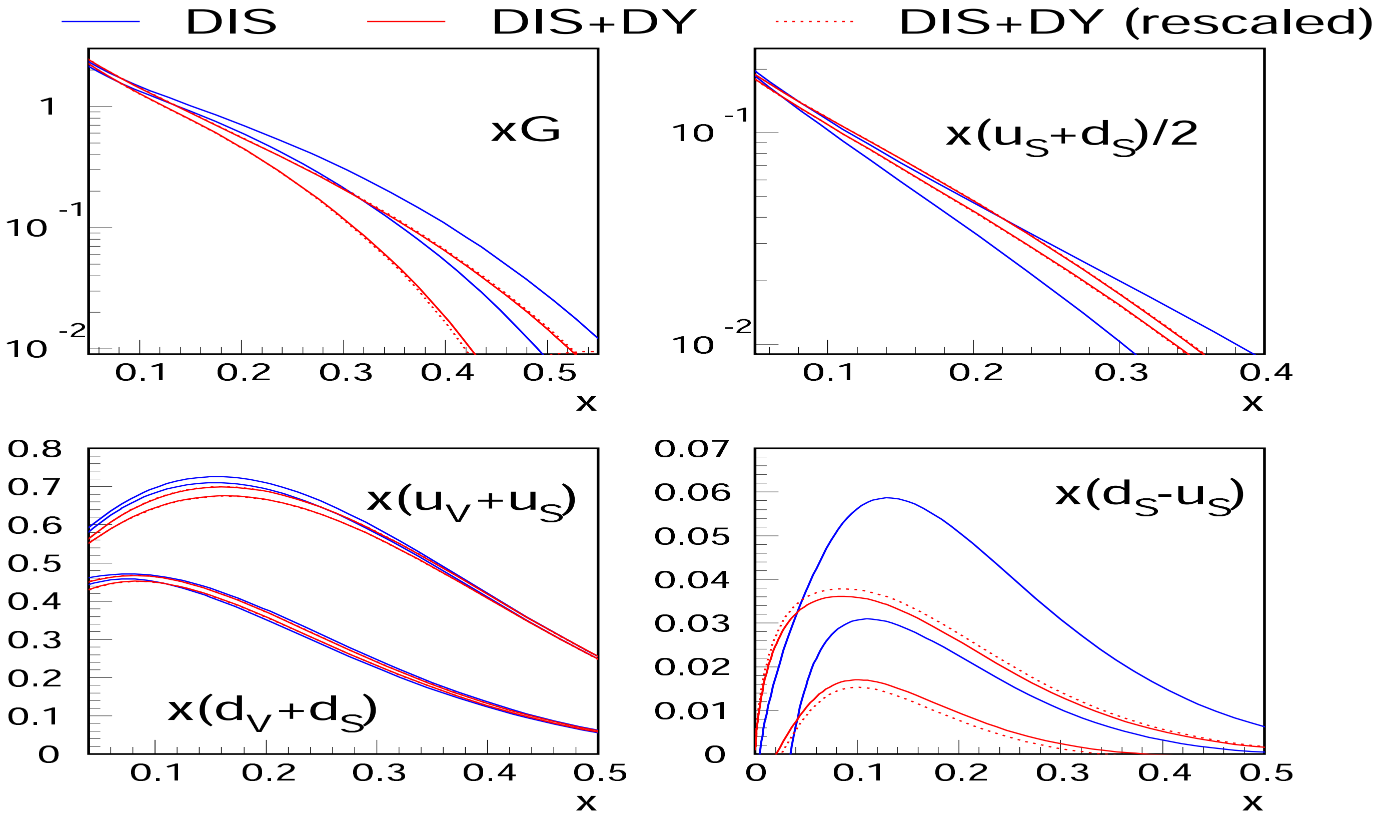
Alekhin



New fit is within the error bands of the previous fit: determination of the errors is not inconsistent

Impact of the DY data on the PDFs

Alekhin



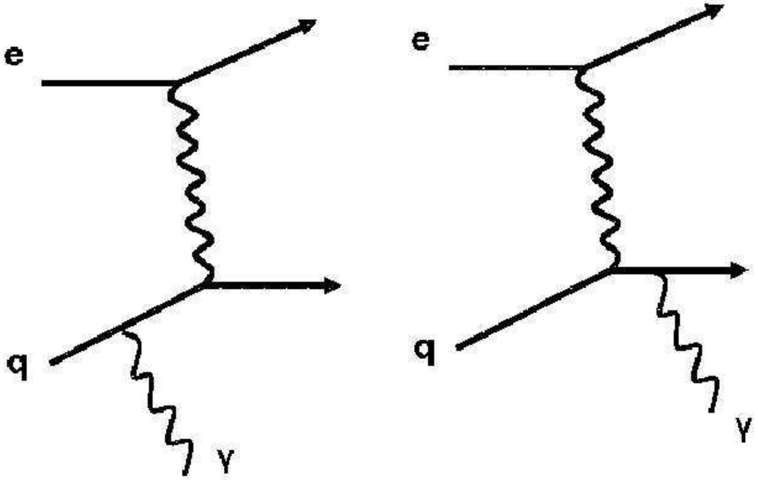
Changes in flavour composition of PDFs
e.g. $d - u$

Stirling

QED effects in pdfs

De Rujula, Petronzio, Savoy-Navarro 1979
Krifganz, Perlt 1988
Bluemlein 1990
Spiesberger 1994
Roth, Weinzierl 2004

QED corrections to DIS include:

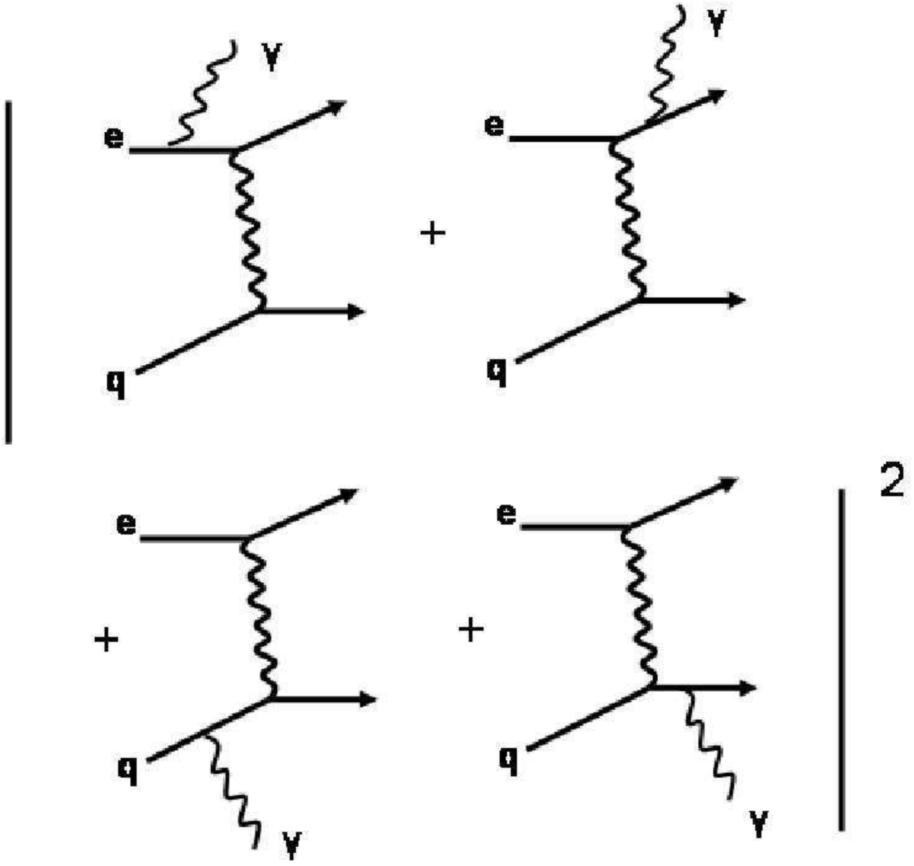


⇒ mass singularity when $\gamma \parallel q$

$$\frac{\alpha}{2\pi}\langle e_q^2\rangle \ln\left(\frac{Q^2}{m_q^2}\right) \simeq 0.01$$

for $Q = 100$ GeV, $m_q = 10$ MeV, $\langle e_q^2\rangle = 5/18$.

included in standard radiative correction packages (HECTOR, HERACLES)



+ loop corrections

$$\Rightarrow \quad \frac{\alpha}{\pi}\left[\,\mathcal{C}_{\rm lept} + e_q^2\,\mathcal{C}_{\rm quark} + e_q\,\mathcal{C}_{\rm int}\,\right]$$

Note: C_{int} finite as $m_q \to 0$

QED-improved DGLAP equations

Stirling

- at leading order in Ä and Ä$_S$

$$
\begin{aligned}
\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{qq}(y)\; q_i(\frac{x}{y},\mu^2) + P_{qg}(y,\alpha_S)\; g(\frac{x}{y},\mu^2)\Big\} \\
&+ \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{\tilde{P}_{qq}(y)\; e_i^2 q_i(\frac{x}{y},\mu^2) + P_{q\gamma}(y)\; e_i^2 \gamma(\frac{x}{y},\mu^2)\Big\} \\
\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{gq}(y)\; \sum_j q_j(\frac{x}{y},\mu^2) \\
&+ P_{gg}(y)\; g(\frac{x}{y},\mu^2)\Big\} \\
\frac{\partial \gamma(x,\mu^2)}{\partial \log \mu^2} &= \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{\gamma q}(y)\; \sum_j e_j^2\; q_j(\frac{x}{y},\mu^2) \\
&+ P_{\gamma\gamma}(y)\; \gamma(\frac{x}{y},\mu^2)\Big\}
\end{aligned}
$$

where

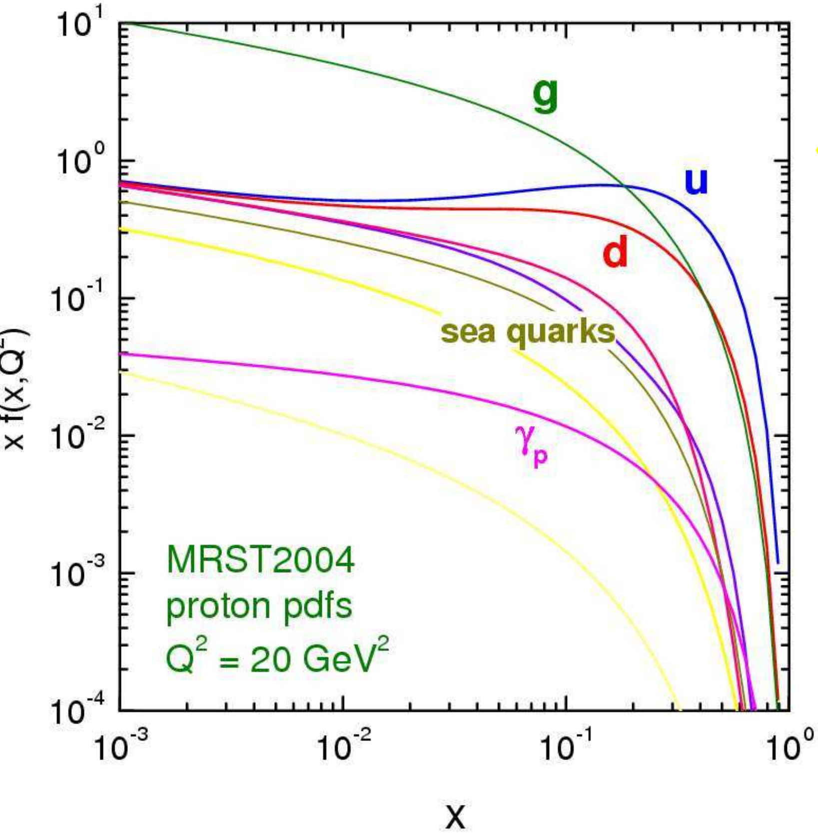
$$
\begin{aligned}
\tilde{P}_{qq} &= C_F^{-1} P_{qq}, & P_{\gamma q} &= C_F^{-1} P_{gq}, \\
P_{q\gamma} &= T_R^{-1} P_{qg}, & P_{\gamma\gamma} &= -\frac{2}{3}\sum_i e_i^2\; \delta(1-x)
\end{aligned}
$$

- momentum conservation:

$$
\int_0^1 dx\; x\left\{\sum_i q_i(x,\mu^2) + g(x,\mu^2) + \gamma(x,\mu^2)\right\} = 1
$$

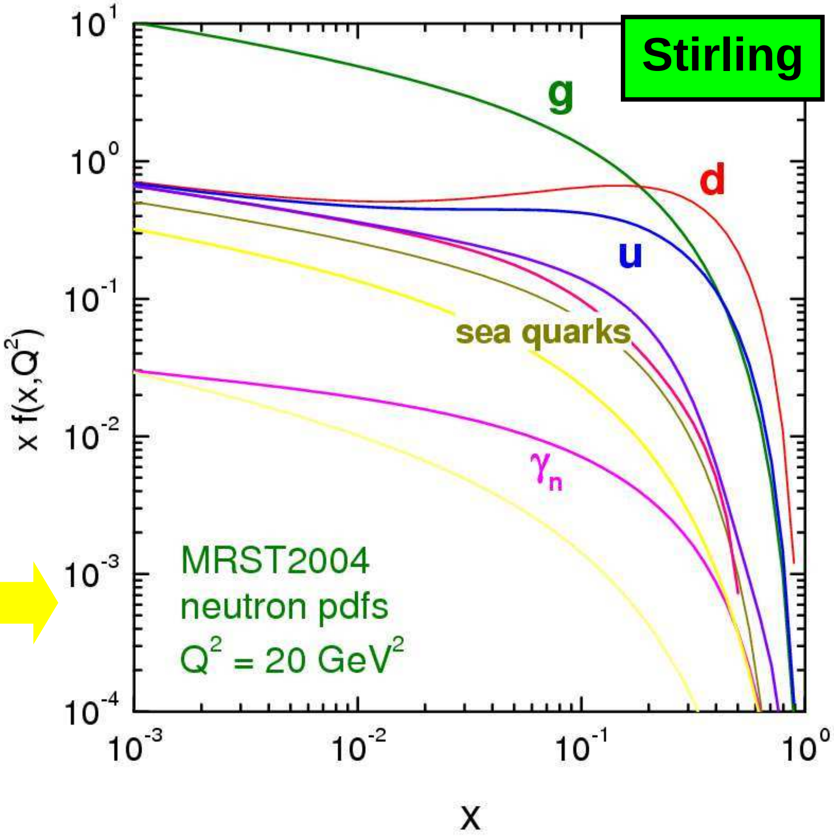
S. Moch

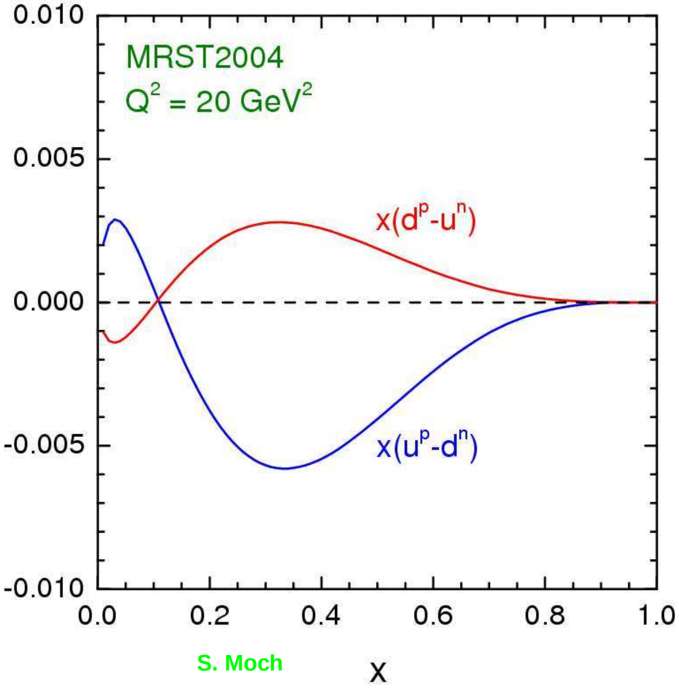
Stirling



proton

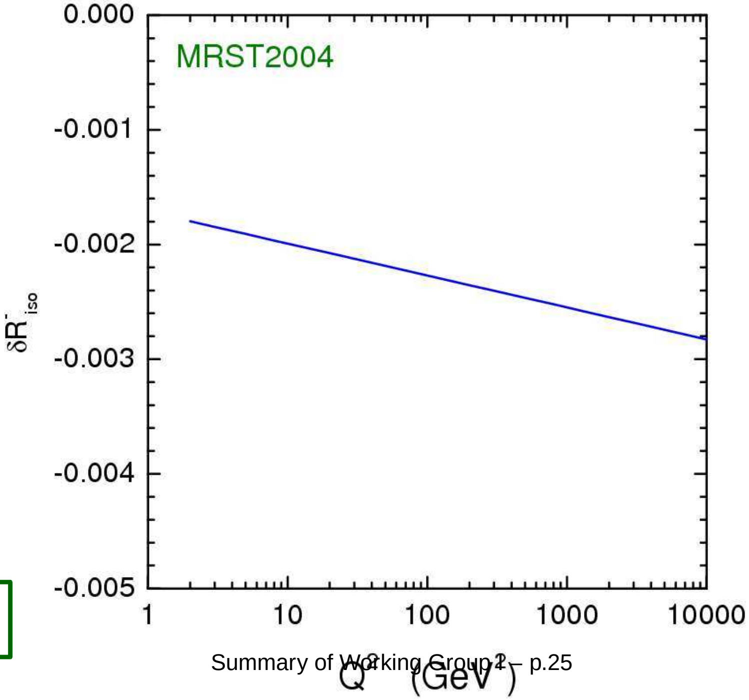
neutron





valence difference

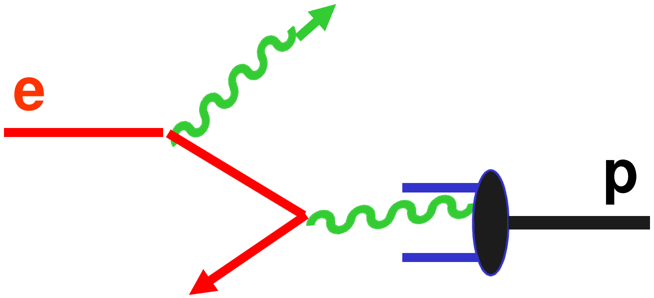
δR^-_{iso}



MRST2004QED(NLO)

Stirling

first measurement of $\gamma_p(x,Q^2)$?



ZEUS: “Observation of high E_T photons in deep inelastic scattering”, hep-ex/0402019

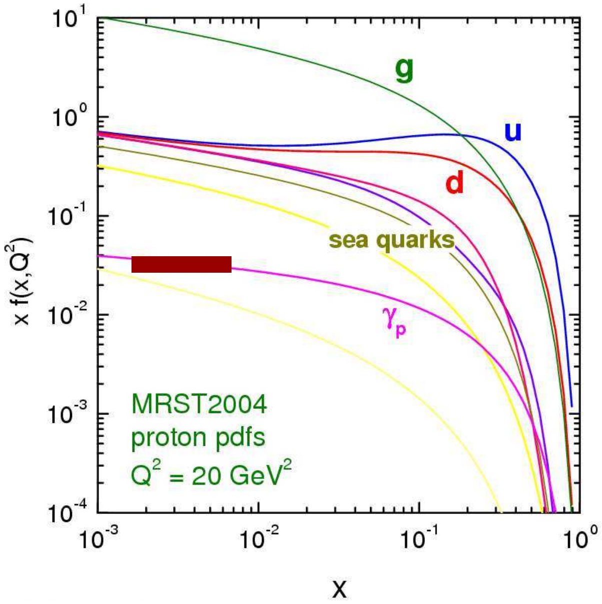
$\sqrt{s}$ = 318 GeV, $Q^2 > 35$ GeV², $E_e > 10$ GeV
$139.8^o < \theta_e < 171.8^o$
$5 < E_T^\gamma < 10$ GeV, $-0.7 < \eta^\gamma < 0.9$

$\sigma(ep \to e\gamma X) = 5.64 \pm 0.58\ (\text{stat.}) \pm^{0.47}_{0.72}\ (\text{syst.})$ pb

prediction using MRST2004 QEDpdfs:

$\sigma(ep \to e\gamma X) = 6.2 \pm 1.2$ pb

scale dependence



Future:
extract γ_p from data

a new look at the high-x gluon distribution

Stirling

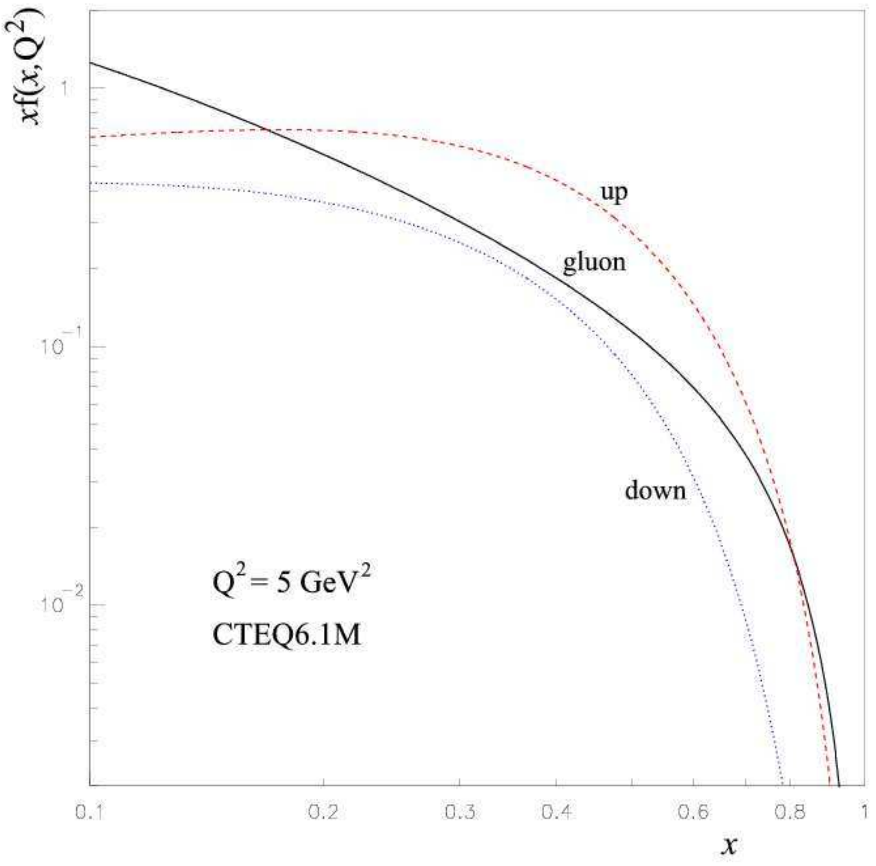
- good fit to Tevatron high E_T jet data requires 'hard' gluon distribution

- MRST use traditional parametrisation *$Ax^a(1-x)^n[1+b\sqrt{x}+cx]$* , not quite as good a fit as CTEQ; note that *$n_g = 2.98$* for the MSbar NLO global fit

- but recall dimensional counting arguments for x →1 behaviour of parton distributions

$$q_{\mathrm{val}} \sim (1-x)^3, \quad g(x) \sim (1-x)^5$$

(but in what factorisation scheme, and at what Q^2 scale?)



Study parametrization bias of PDFs through choice of scheme

QCD Evolution Equations

- Evolution Equations of DIS Structure Functions do exhibit factorization and renormalization scheme dependencies
- Renormalization scheme dependence is removed only if the perturbative series is summed to all orders
- When considering factorization scheme dependence we have two viable approaches
  - Consider process-independent scheme-dependent evolution equations for PDFs (Standard QCD analysis)
  - Consider process-dependent scheme-independent evolution equations for observables (Scheme Invariant analysis)

Guffanti

Possible choices for two independent observables for α_s:
F_2, $d/d\ln Q^2 F_2$
F_2, F_L

Physical observables factorization scheme independent

The goal of our recent work is to use these results to construct a relatively simple, closed form, improved anom. dim. $\Delta(\Delta,N)$ or splitting funct.n $P_I(\Delta,x)$

G.A., R. Ball, S.Forte, hep-ph/ 0306156 (NPB 674,459), 0310016

Altarelli

$P_I(\Delta,x)$ should

- reduce to pert. result at large x
- contain BFKL corr's at small x
- include running coupling effects (Airy)
- be sufficiently simple to be included in fitting codes

and of course

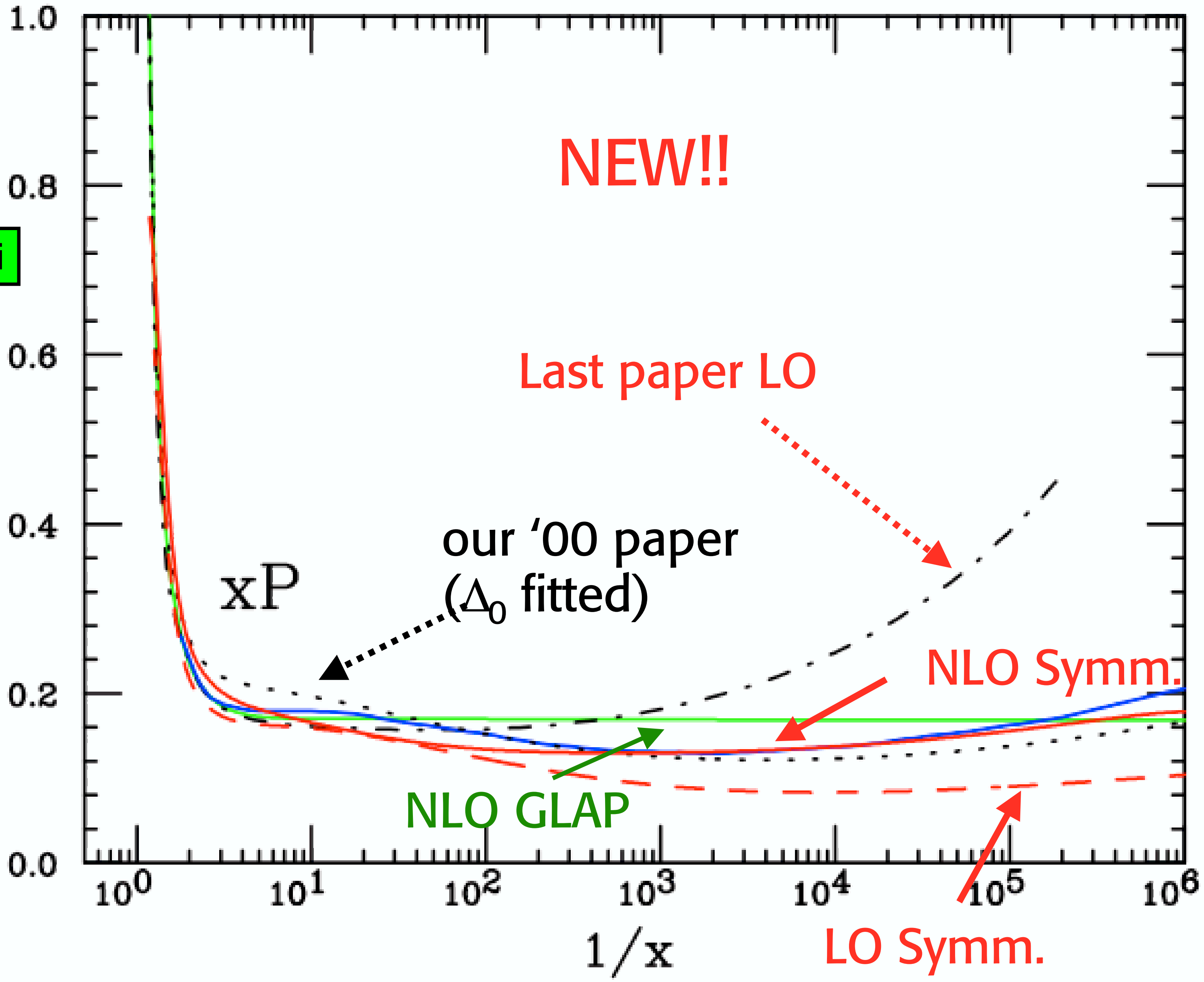
Small-x resummation

- closely follow the trend of the data

G. Altarelli

Here are the results for splitting functions (n_f=0)

Altarelli



NEW!!

Last paper LO

our ‘00 paper (Δ_0 fitted)

NLO Symm.

NLO GLAP

LO Symm.

G. A

Conclusions

Heavy-quark production at large rapidities

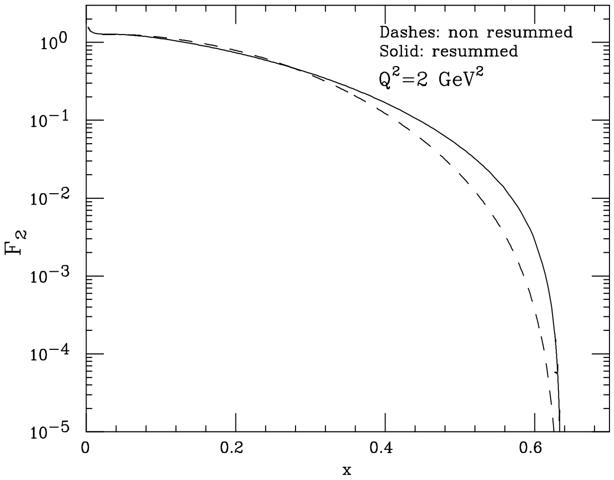
Maltoni

- Various studies for the "detection" of BFKL dynamics have been proposed
- No clear evidence of the need to resum BFKL logs yet
- We have studied various signatures involving heavy quarks at large rapidities
- Can something similar, ie with HF, be done at HERA?

Search for small-x effects in heavy quarks (bottom) final states

Inclusive structure functions

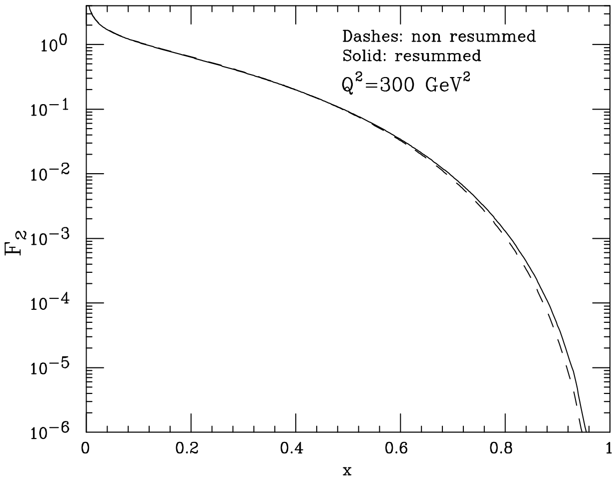
Corcella



$x = 0.5$: **factor of 2**; $x = 0.6$: **factor of 8**

Resum large logarithms $\ln N \leftrightarrow \ln^l(1-x)/1-x$

Effects visible, but large experimental uncertainties



$x = 0.8$: 20%; $x = 0.9$: 60%

Summary of the Summary

- Strong participation, new ideas
- Study precision for reference processes
- Quantify impact of HERA PDFs
- Investigate kinematical limits, resum where required

Summary of the Summary

- Strong participation, new ideas
- Study precision for reference processes
- Quantify impact of HERA PDFs
- Investigate kinematical limits, resum where required

On track to meet the workshop goals

- Subgroups established
- Preparation for proceedings under way

Summary of the Summary

- Strong participation, new ideas
- Study precision for reference processes
- Quantify impact of HERA PDFs
- Investigate kinematical limits, resum where required

On track to meet the workshop goals

- Subgroups established
- Preparation for proceedings under way

Thanks all participants of WG1