DIS 2009, Madrid, 30 April '09

Concluding Talk: Outlook and Perspective

Guido Altarelli

Universita' di Roma Tre
and CERN

Dedicated to Wu-Ki Tung

DIS is 40 years old!

VOLUME 23, NUMBER 16 PHYSICAL REVIEW LETTERS 20 OCTOBER 1969

OBSERVED BEHAVIOR OF HIGHLY INELASTIC ELECTRON-PROTON SCATTERING

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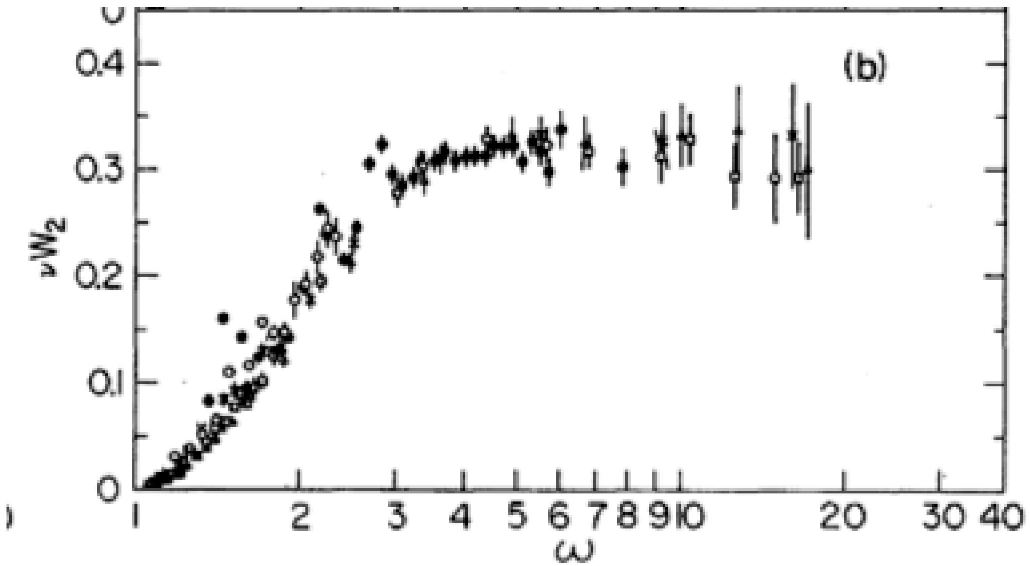
Department of Physics and Laboratory for Nuclear Science,*
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, L. W. Mo, and R. E. Taylor
Stanford Linear Accelerator Center,† Stanford, California 94305
(Received 22 August 1969)

Results of electron-proton inelastic scattering at 6° and 10° are discussed, and values of the structure function W_2 are estimated. If the interaction is dominated by transverse virtual photons, νW_2 can be expressed as a function of $\omega = 2M\nu/q^2$ within experimental errors for $q^2 > 1$ $(\mathrm{GeV}/c)^2$ and $\omega > 4$, where ν is the invariant energy transfer and q^2 is the invariant momentum transfer of the electron. Various theoretical models and sum rules are briefly discussed.

1969: first evidence of approximate Bjorken scaling

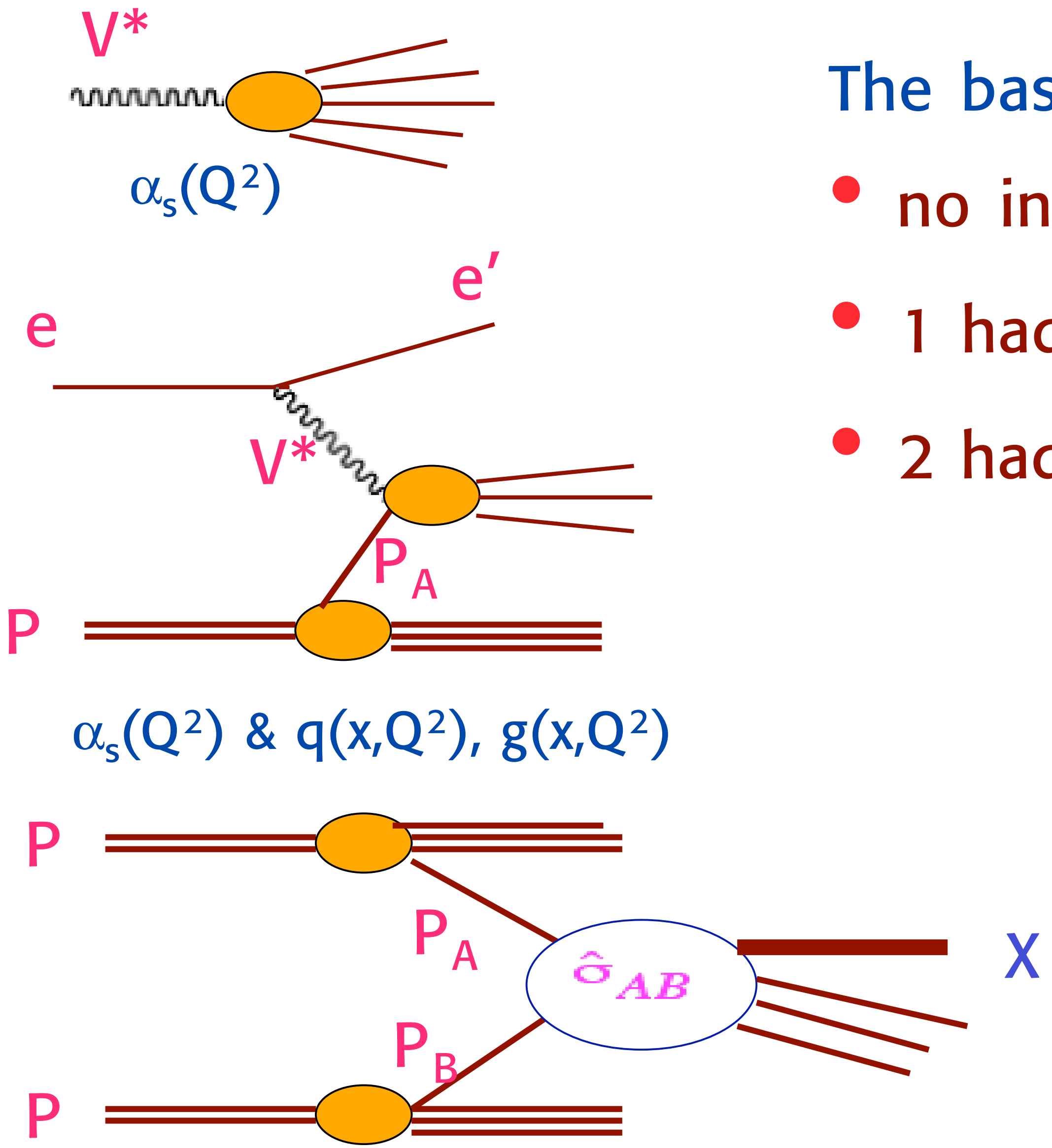


Deep Inelastic Scattering has played a capital role in the development of QCD

$l + N \to l' + X, \quad l = e, \mu, \nu$

- Many structure functions
- $F_i(x,Q^2)$: two variables
- Neutral currents, charged currents
- Different beams and targets
- Different polarization

From the beginning: Establishing quarks and gluons as partons
Constructing a field theory of strong int.ns
and along the years: Quantitative testing of QCD
Totally inclusive
QCD theory of scaling violations crystal clear
(based on ren. group and operator exp.)
Q^2 dependence tested at each x value)
Measuring q and g densities in the nucleon
Instrumental to compute all hard processes
Measuring α_s
Always presenting new challenges, e g:
Structure functions at small x; heavy flavour structure functions;
polarized parton densities, g_1, g_2, h_1...; non forward pdf's
Diffraction



The basic experimental set ups:

- no initial hadron (....LEP, ILC, CLIC)
- 1 hadron (....HERA, ... LHeC)
- 2 hadrons (....SppS, Tevatron, LHC)

Progress in particle physics needs their continuous interplay to take full advantage of their complementarity

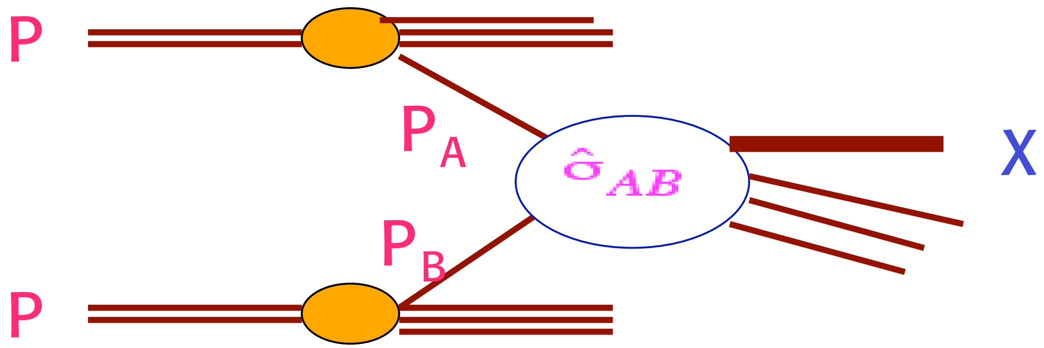
Parton densities extracted from DIS are used to compute hard processes, via the Factorisation Theorem:

x times density of parton A

$$\sigma(s) = \sum_{A,B} \int \frac{dx_1}{x_1} \frac{dx_2}{x_2} p_A(x_1, Q^2) p_B(x_2, Q^2) \hat{\sigma}_{AB}(x_1 x_2 s, Q^2)$$

reduced X-section

For example, at hadron colliders



V=γ*,W,Z

X=V, jets, QQ, H.....

Q=b,c,t

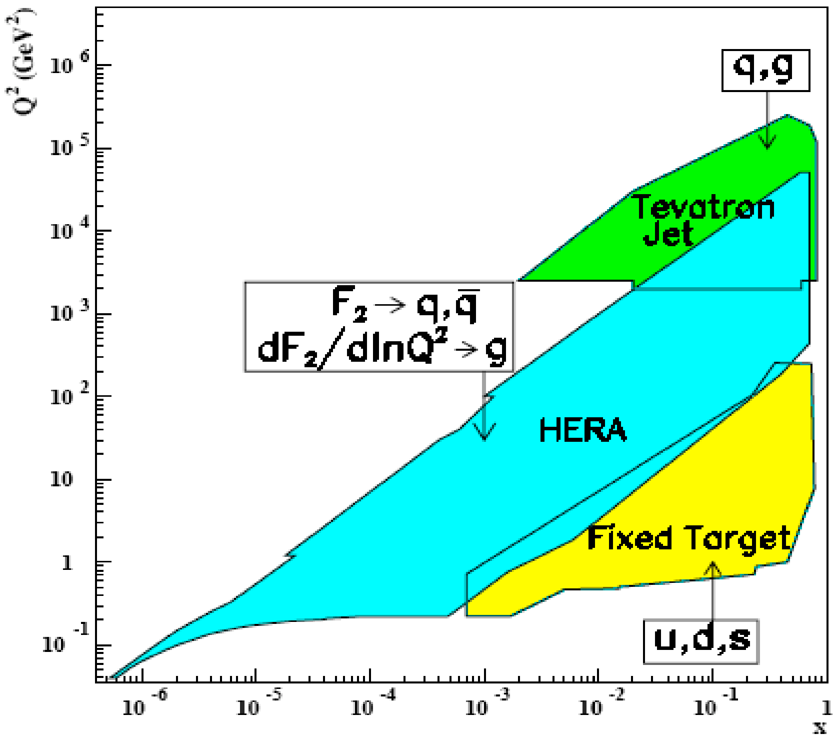
•Very stringent tests of QCD
•Feedback on constraining parton densities

Over the years a magnificent work both experimental and theoretical

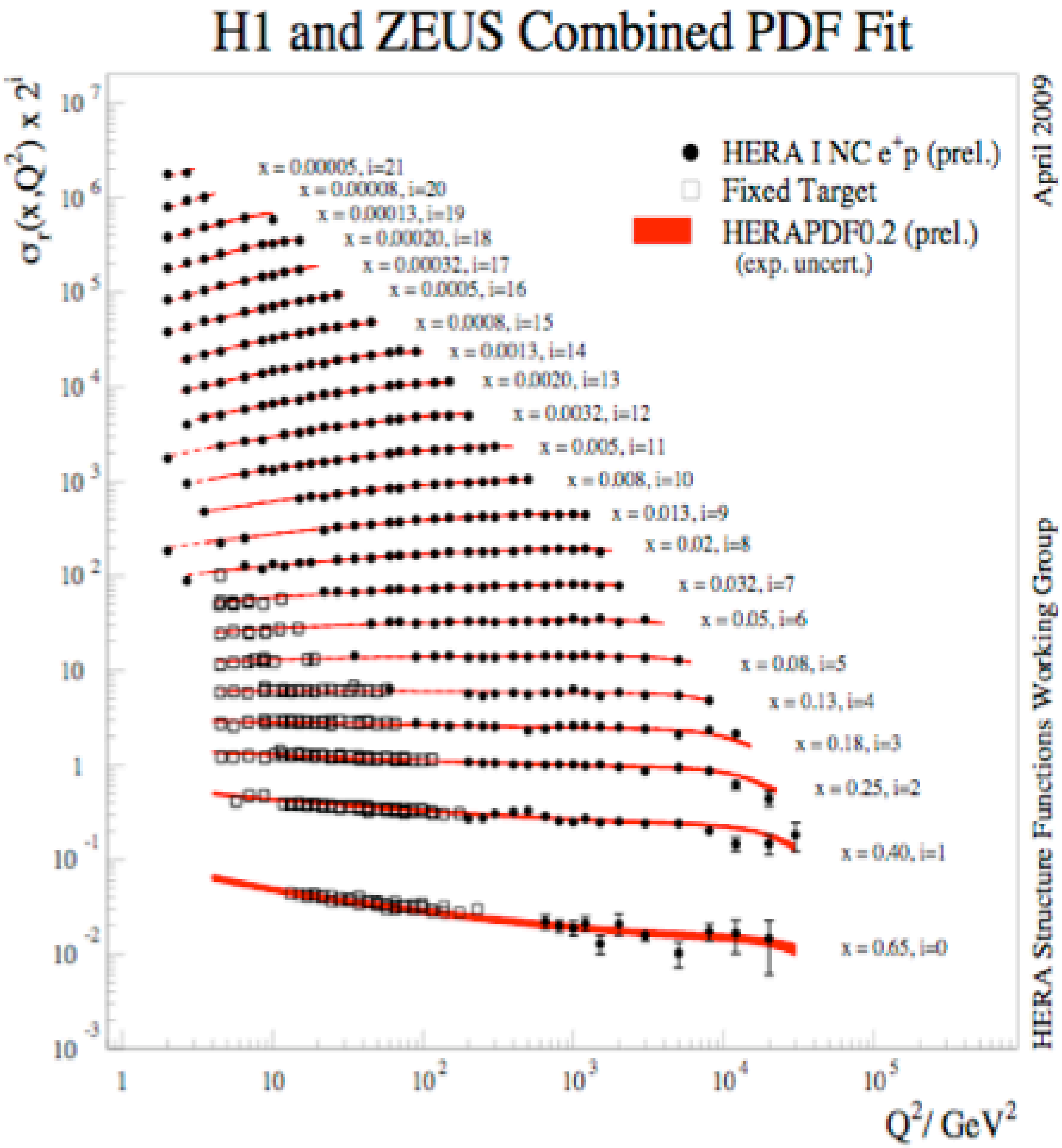
For experiment some examples follow also from this Workshop

Great progress in the DIS data culminated at HERA

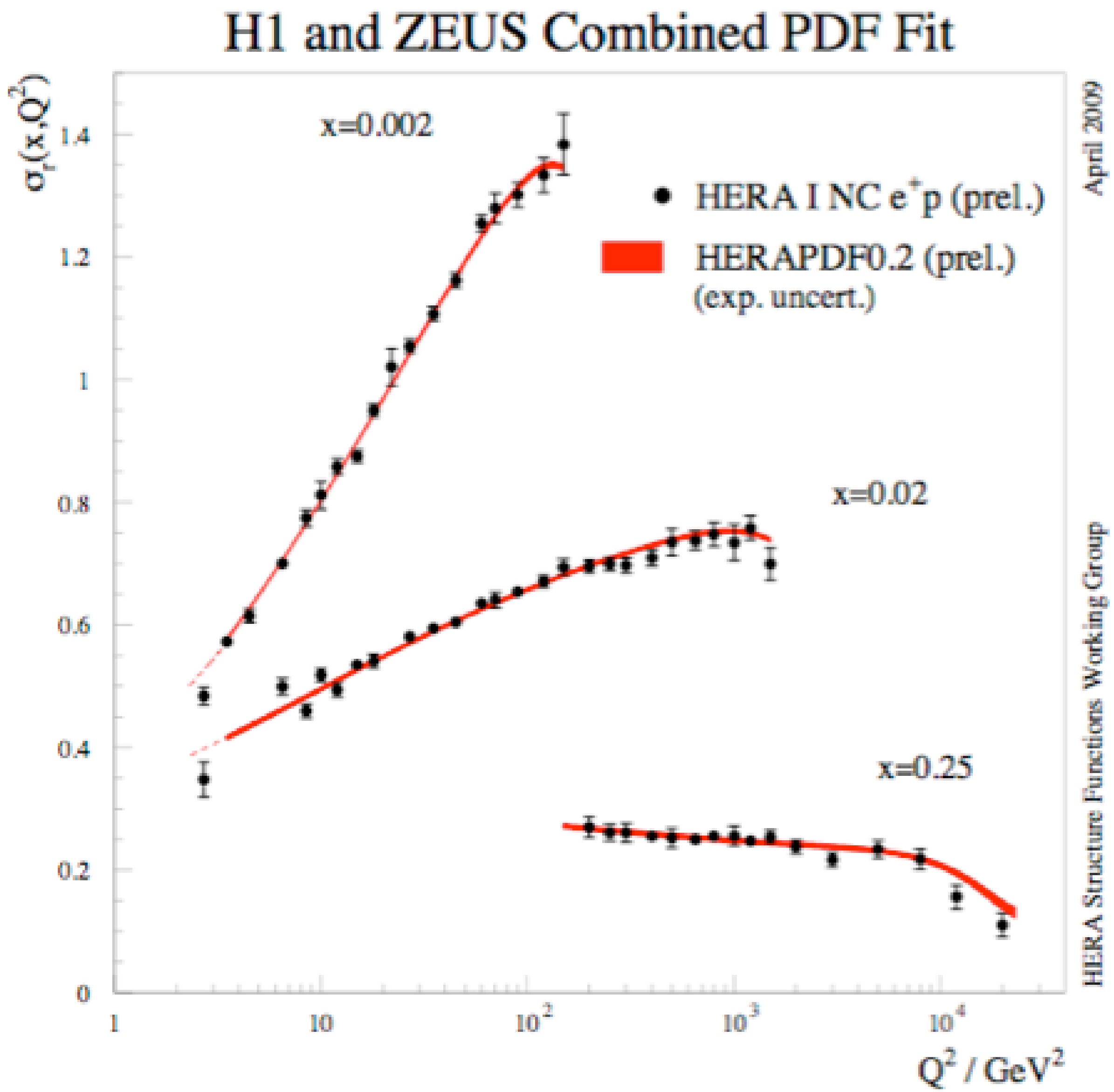
Proton Structure Function $F_2(x,Q^2)$



V. Radescu, E. Tassi, A. Cooper-Sarkar

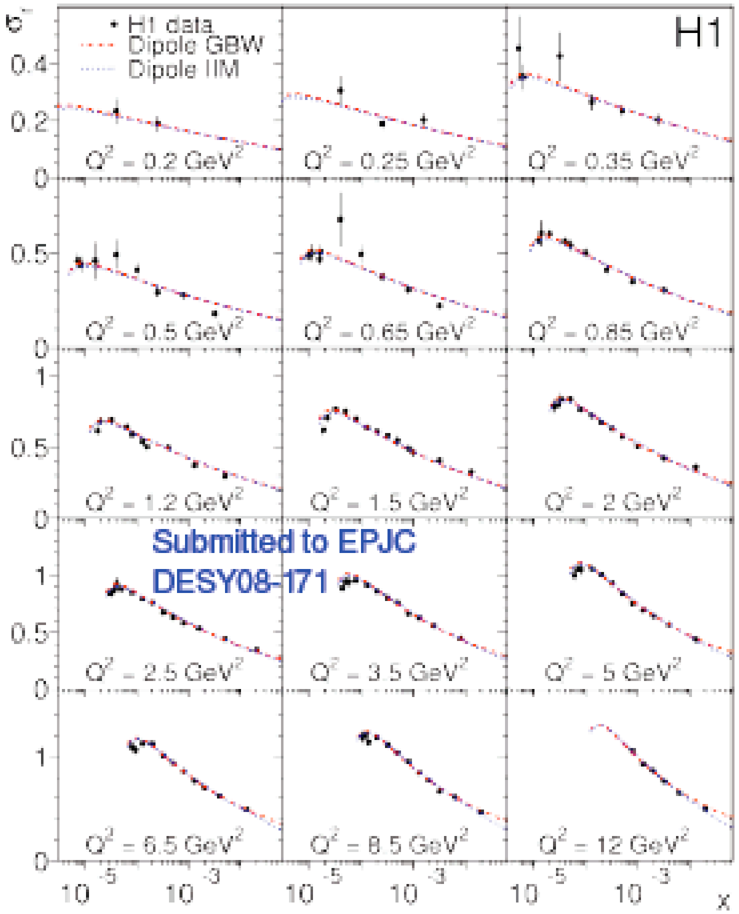


This is how the scaling violations appear in 2009 after 40 years

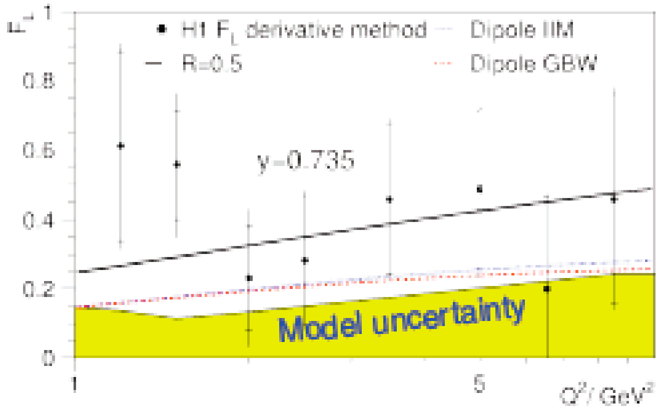


New data

DIS at low Q^2 and low x



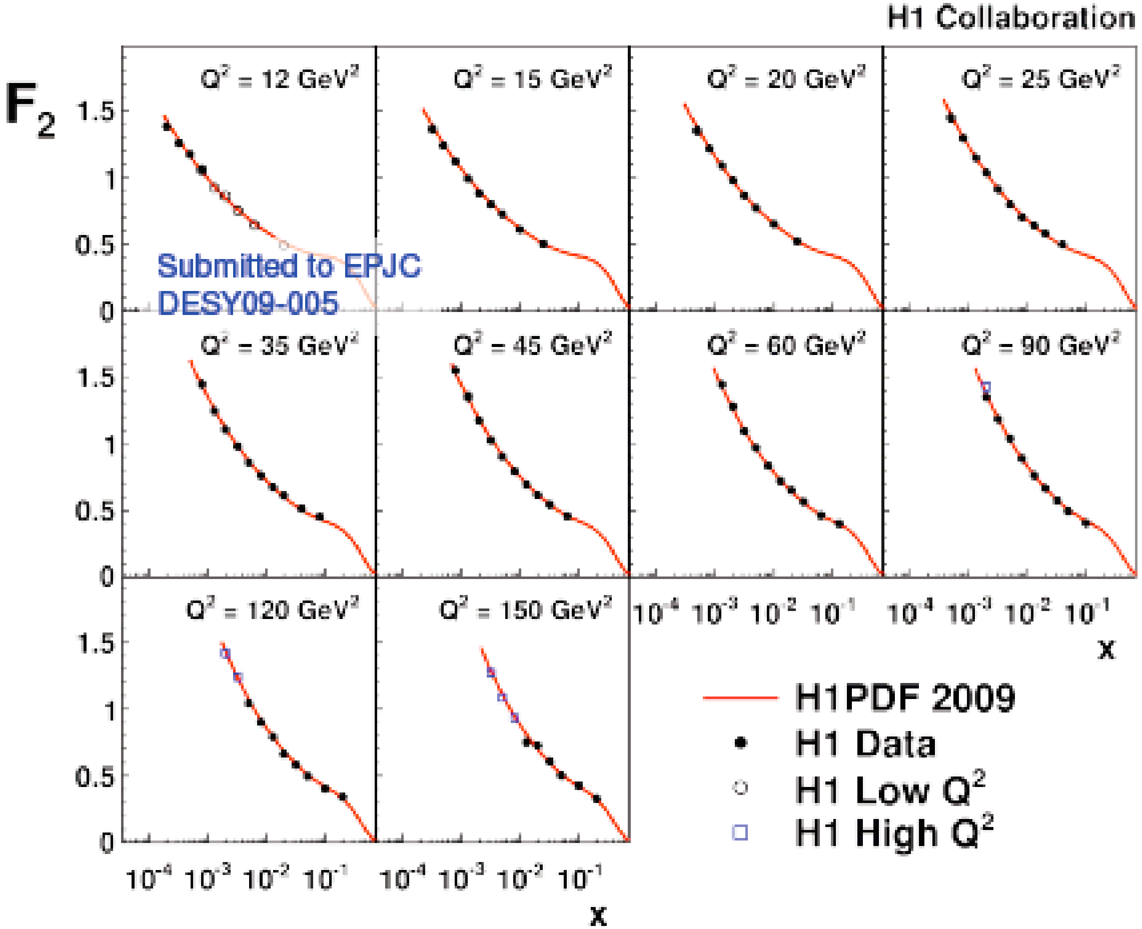
- Full H1 data for low Q^2 published
- Precision 2–3%
- Combination of several H1 datasets
- Fits to power-law, fractal and dipole models
- F_L extracted using indirect methods, consistent with models



→ A. Petrukhin [54]

New example of NLO QCD evolution fit

F_2 precision data



- Full HERA I data for $12<Q^2<150$ GeV^2
- Most precise F_2 data in this Q^2 range, uncertainty 1.3–2%
- Combination of two independent datasets
- New QCD fit, very good consistency with DGLAP prediction

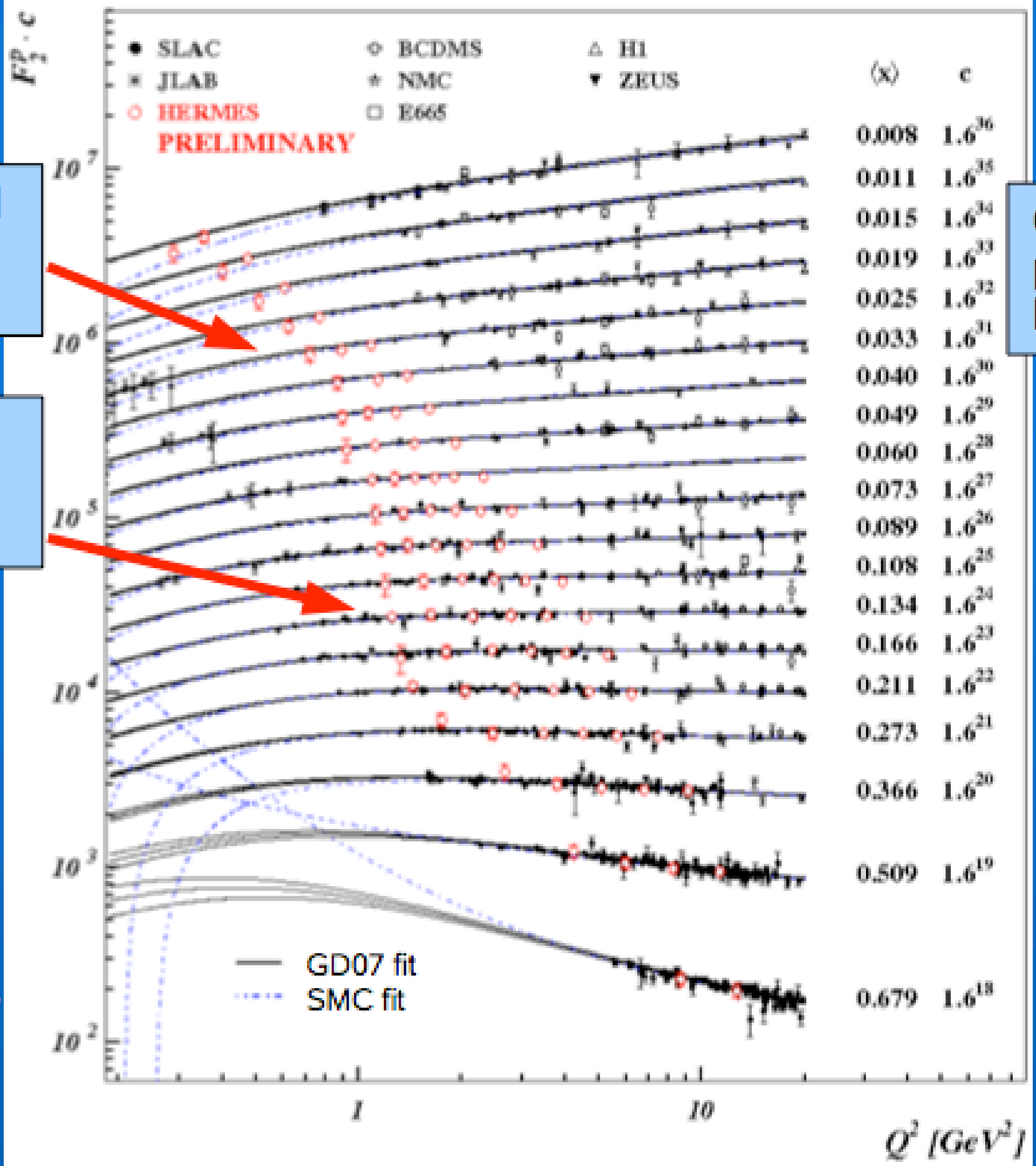
→ J. Kretzschmar [56]
Combination with ZEUS:
→ E. Tassi [63]

D.Gabbert

Proton

New region covered by HERMES

Agreement with world data in the overlap region



Comparison with parameterization by SMC and GD07

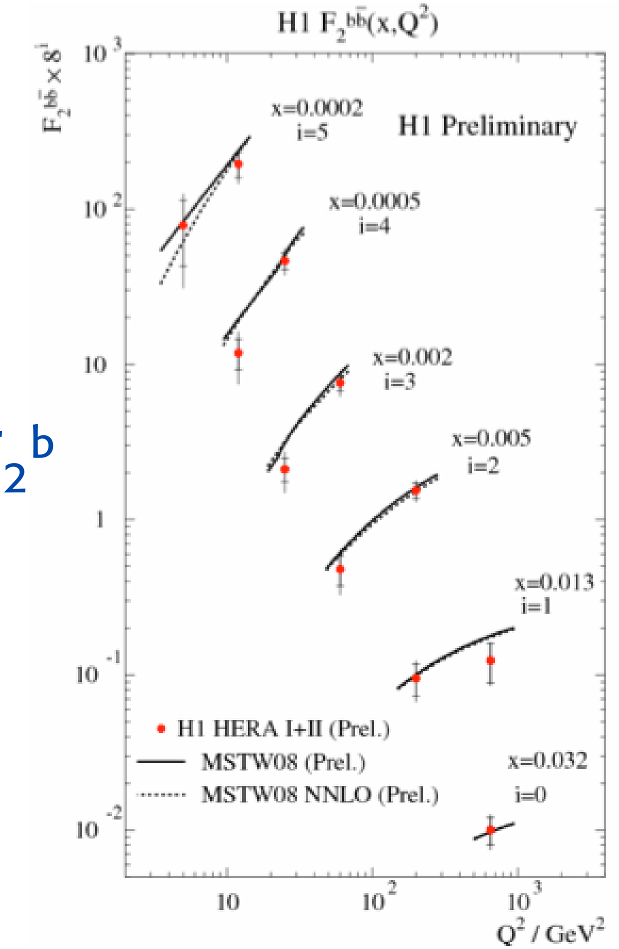
GD07 fit hep-ph 0708.3196
SMC fit Phys. Rev. D, Vol. 58, 112001

Heavy flavoured structure functions

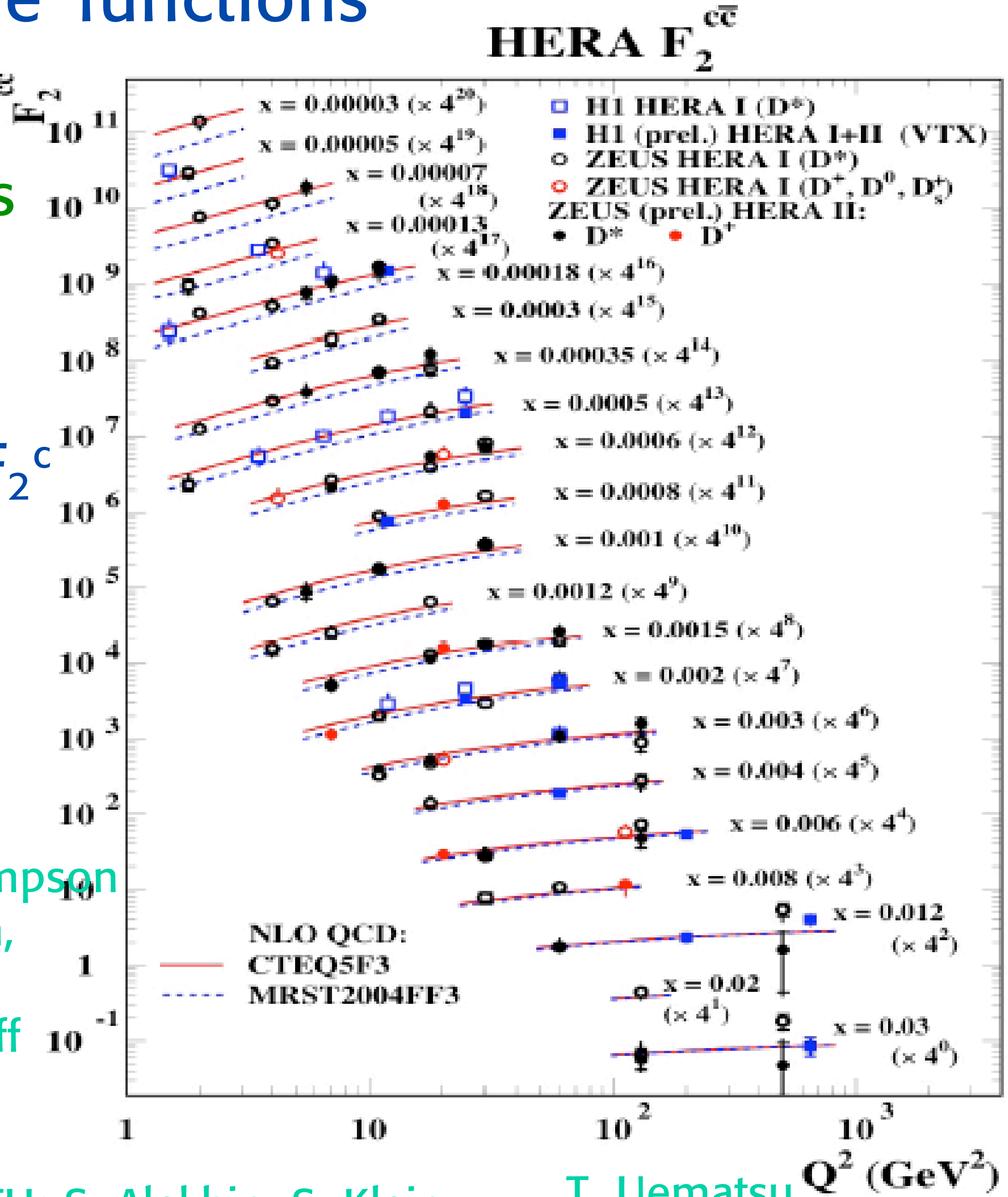
Another kind of gluon
sensitive structure functions

A great job at HERA!

F_2^b



F_2^c

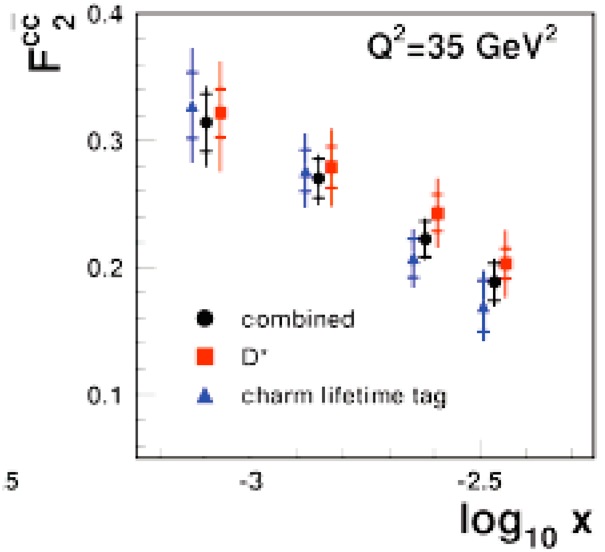


P. Thompson
K. Lipka,
A Jung,
P. Roloff

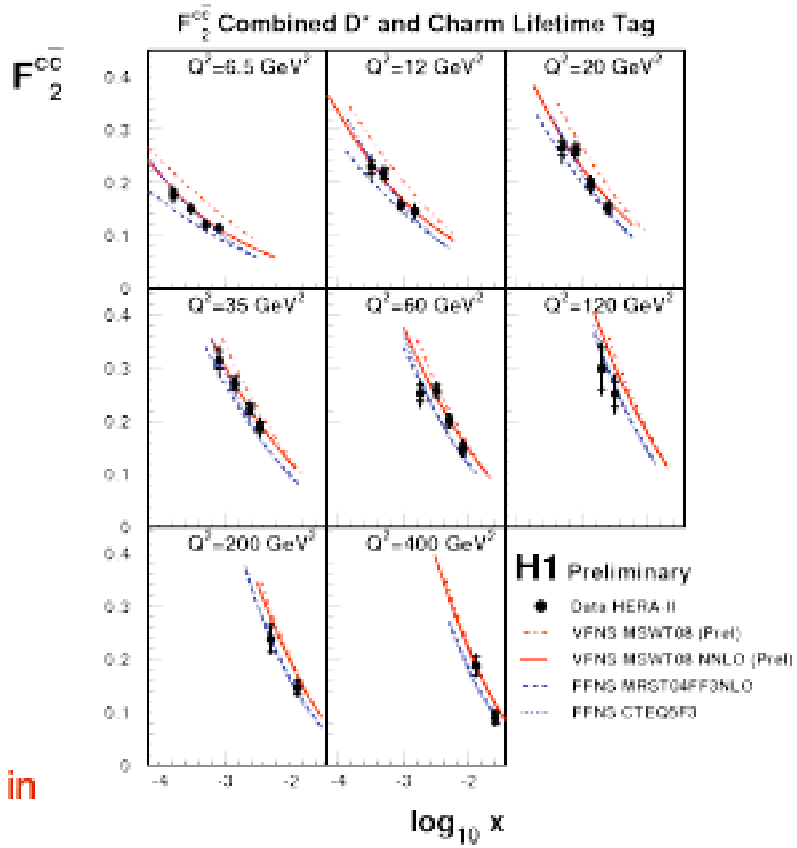
TH: S. Alekhin, S. Klein

T. Uematsu

Combined F_2^c



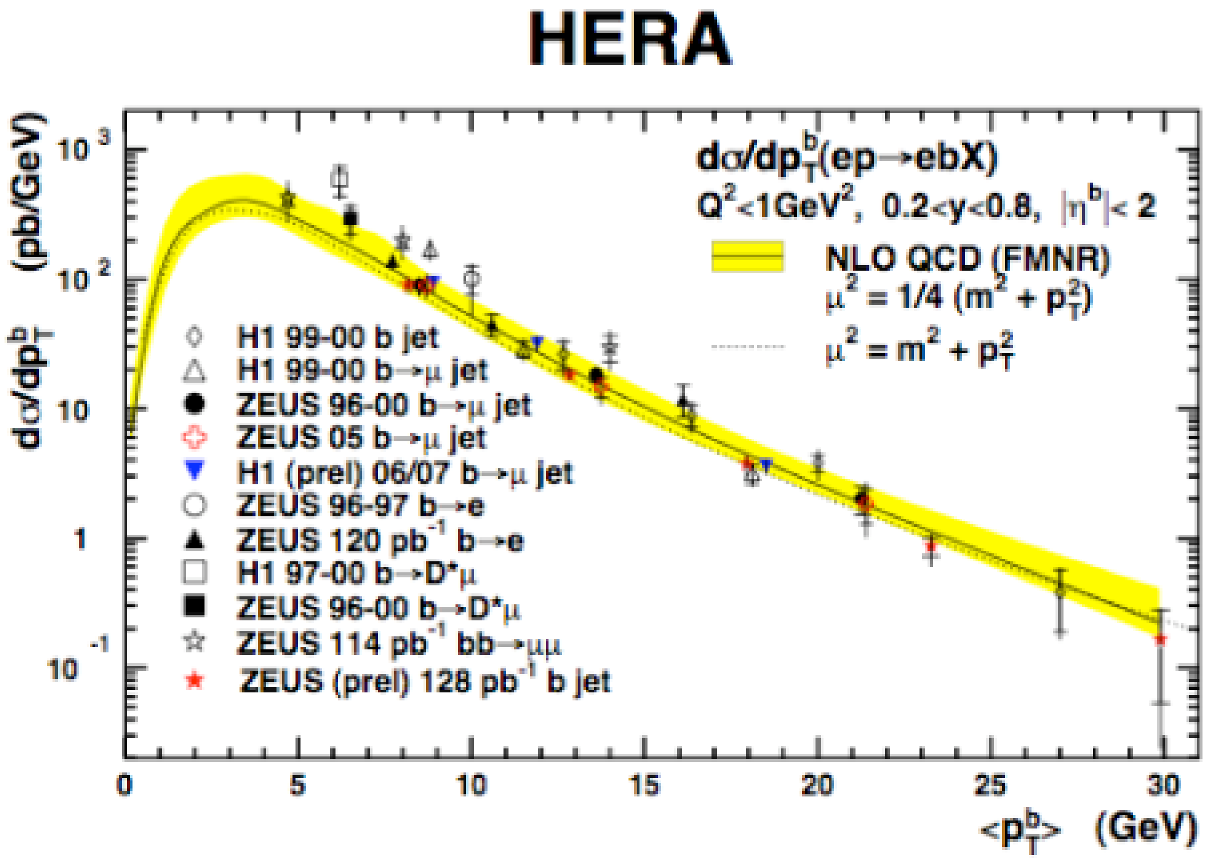
Extract F_2^c from D* cross sections and combine with lifetime-tag F_2^c



- Consistent results from lifetime and D* analyses
- Combine the two measurements
- Significant improvement in precision
- Data constrain PDFs and heavy quark treatment in QCD fits

→ P. Thompson [177]

b photoproduction



E. Tassi

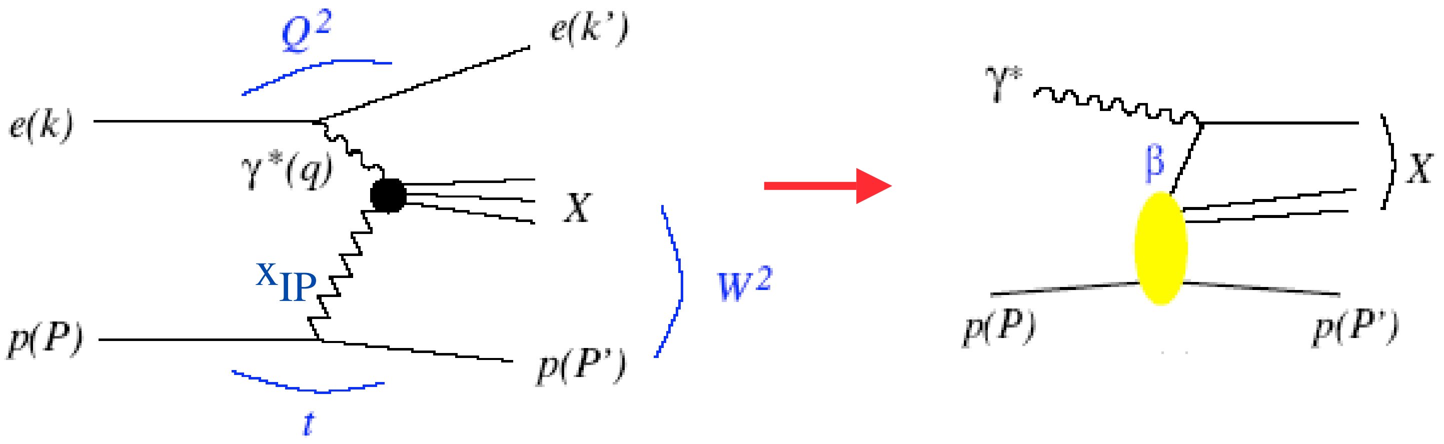
B. List
S. Miglioranzi

MC@NLO
T. Toll

Fair agreement with NLO QCD

Diffractive structure functions

QCD partons and Pomeron phenomenology



Arneodo, Diehl '06

$$x_{I\!P} = \frac{(P - P') \cdot q}{P \cdot q} \qquad \beta = \frac{Q^2}{2(P - P') \cdot q} \qquad \beta x_{I\!P} = x$$

x_{IP} ~0.001-0.02

$$\frac{d\sigma^{ep \to eXp}}{d\beta\, dQ^2\, dx_{I\!P}\, dt} = \frac{4\pi \alpha_{\rm em}^2}{\beta Q^4} \left[\left(1 - y + \frac{y^2}{2}\right) F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) - \frac{y^2}{2} F_L^{D(4)}(\beta, Q^2, x_{I\!P}, t) \right]$$

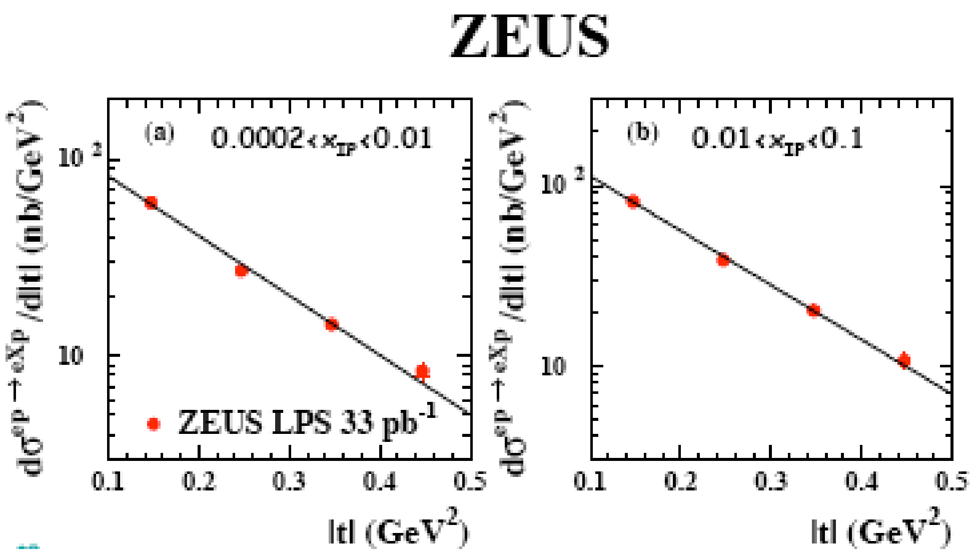
QCD evolution

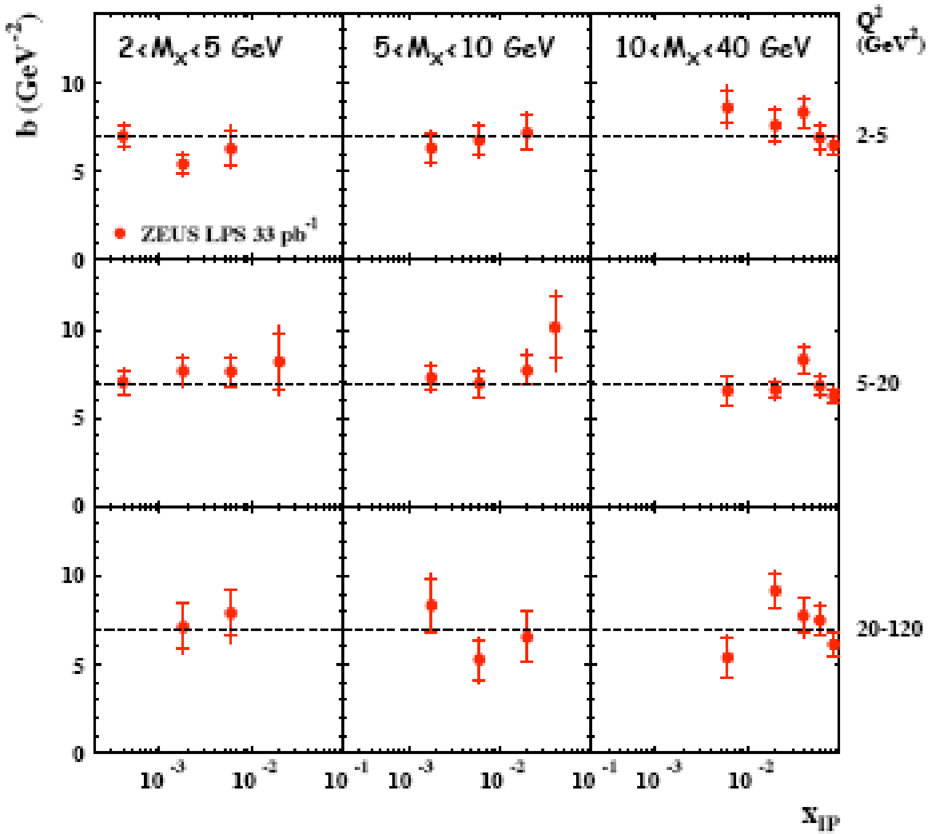
factorization

$$F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) = \sum_i \int_\beta^1 \frac{dz}{z} C_i\left(\frac{\beta}{z}\right) f_i^D(z, x_{I\!P}, t; Q^2)$$

t dependence is exponential (typical of diffraction)

M. Ruspa





Fit to $e^{-b|t|}$ → $b = 7.0 \pm 0.4\ GeV^{-2}$

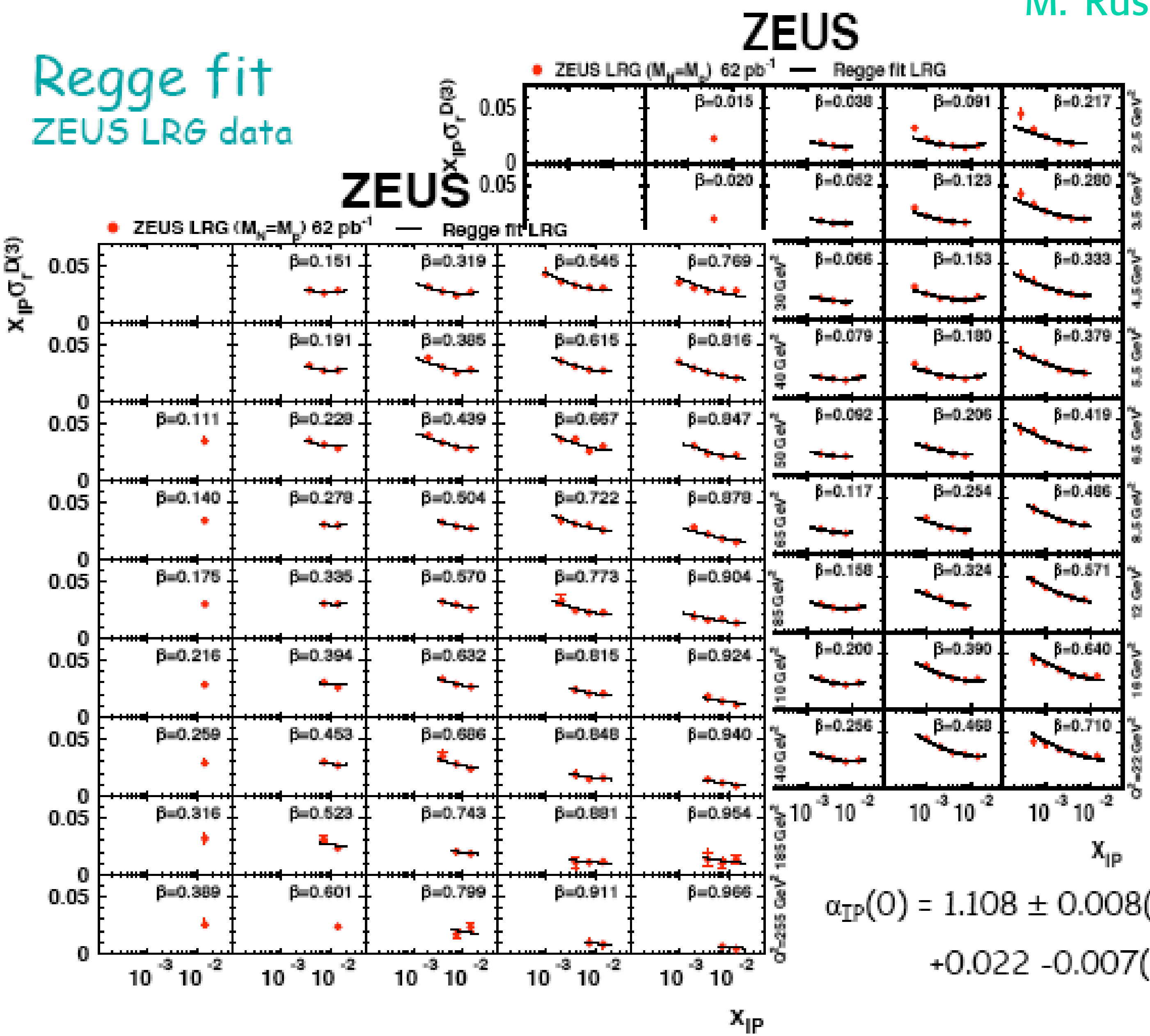
Regge fit

ZEUS LRG data

M. Ruspa

W. Slominski

Theory:
A. Luszczak
L. Schoeffel



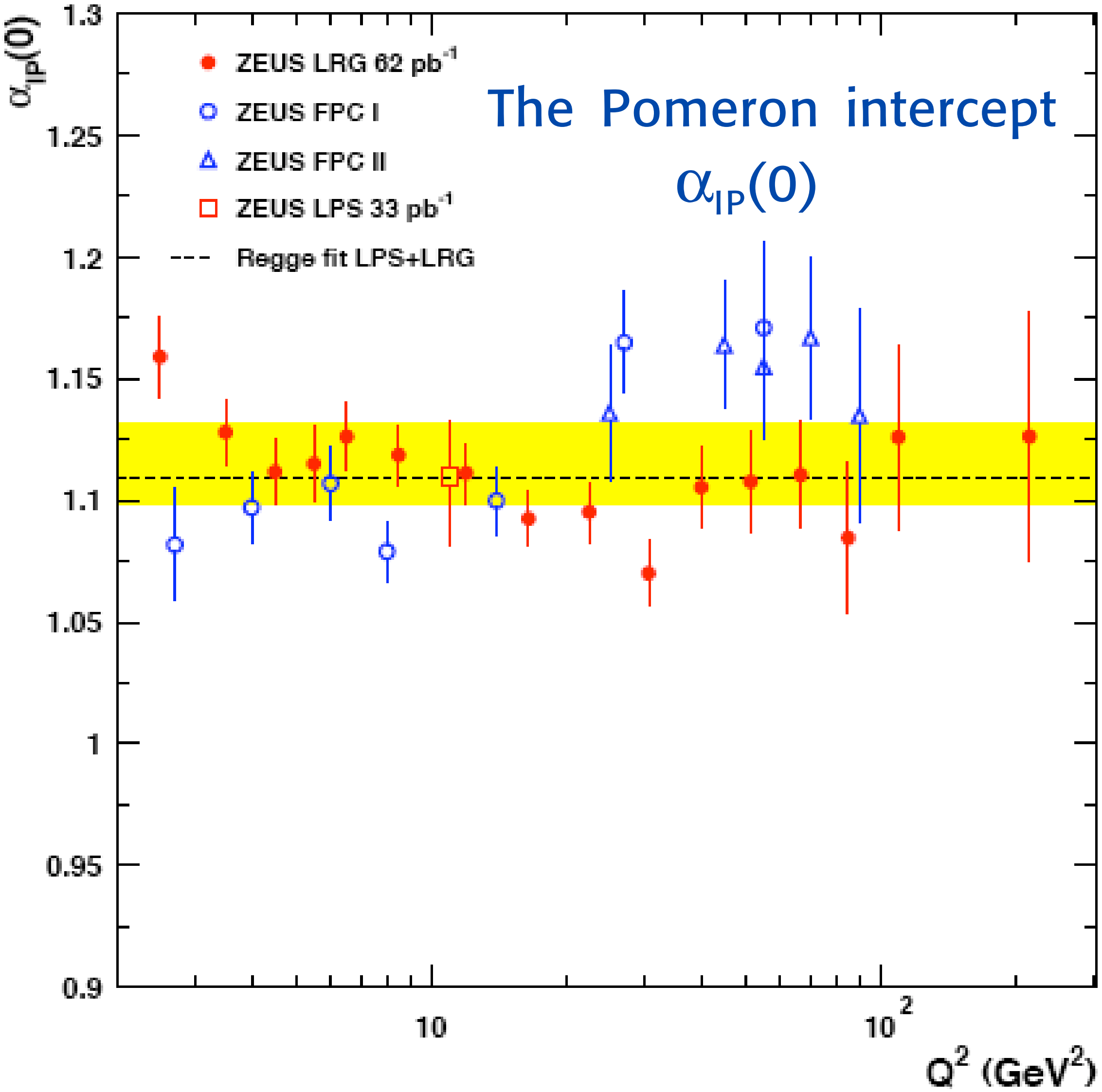
$\alpha_{IP}(0) = 1.108 \pm 0.008(stat{+}syst)$

$+0.022\ -0.007(model)$

→ Assumption of Regge factorisation works

M. Ruspa '08

The Pomeron intercept $\alpha_{IP}(0)$



constant in Q^2

$\alpha_{IP}(0)>1$

(maybe 1 modulo logs)

F_L^D Results

- F_L^D measured in the kinematic region:

  $7 < Q^2 < 32\ GeV^2$

  $0.001 < x_{IP} < 0.01$

- measurement corrected to:

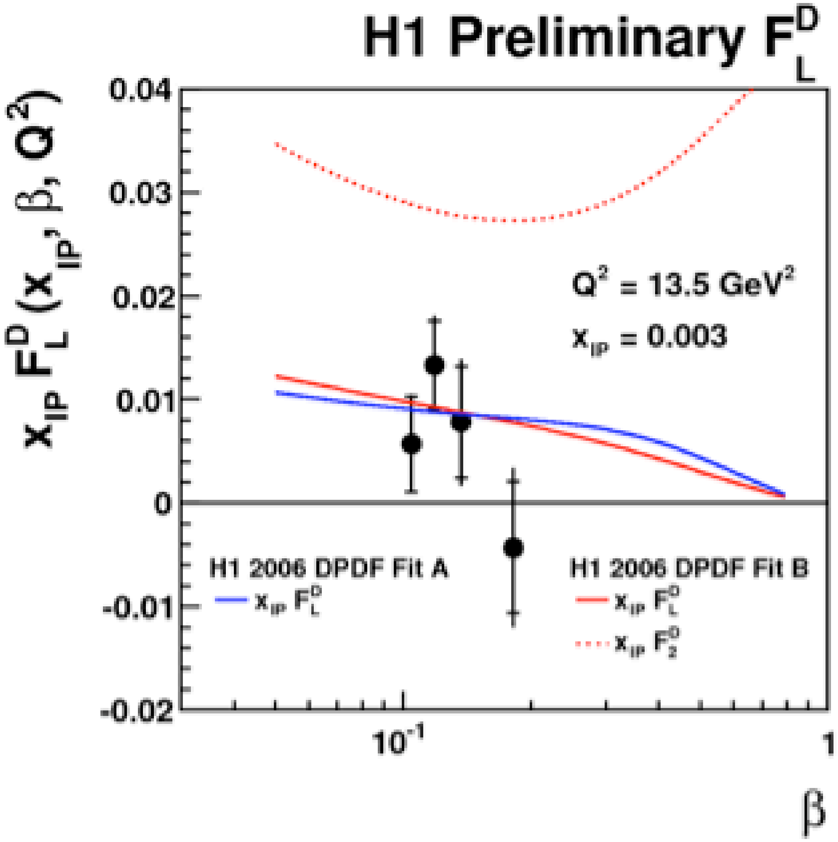
  $Q^2 = 13.5\ GeV^2$

  $x_{IP} = 0.003$

- the measurement represents a significant non-zero value (more than 4σ)

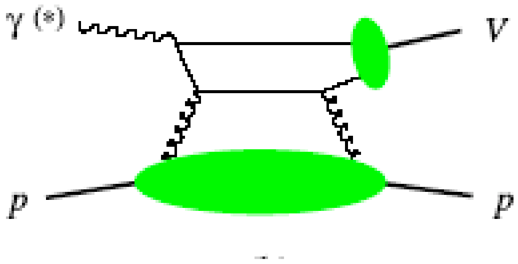
- results consistent with the H1 2006 DPDF Fits (based on DPDF's and factorisation)

D. Salek



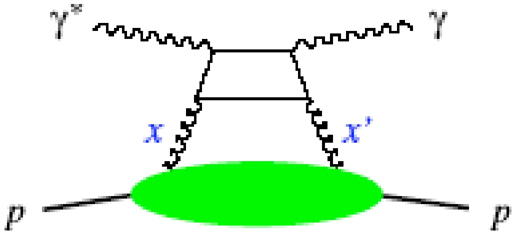
Exclusive diffractive processes

Vector meson production

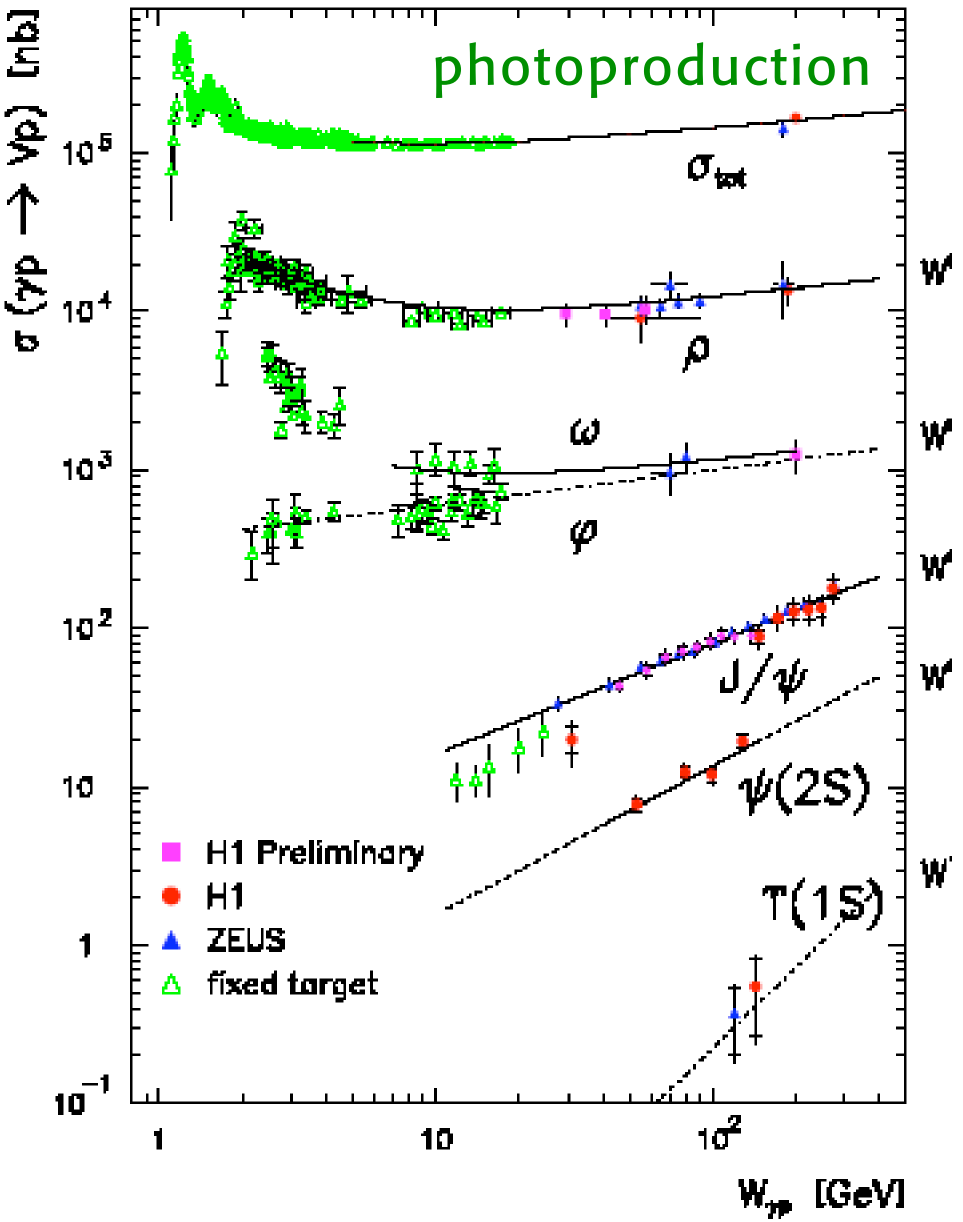


Deeply virtual Compton Scattering

Generalized Parton Distributions



G. Moreno, S. Liuti, A. Mukherjee.
A. Movsisyan, M. Polyakov



- A lot of physics still in the making

A. Levy, P. Marage, S. Yashenko,

More on experiment later

Now some theory highlights

Progress in experiment has been matched by impressive achievements in theory

For example in the theory of scaling violations

$$\frac{\partial q_i(x,Q^2)}{\partial \log Q^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{q_i q_j}(y,\alpha_S)q_j(\frac{x}{y},Q^2)\ +\ P_{q_i g}(y,\alpha_S)g(\frac{x}{y},Q^2)\right\}$$

$$\frac{\partial g(x,Q^2)}{\partial \log Q^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\left\{P_{g q_j}(y,\alpha_S)q_j(\frac{x}{y},Q^2)\ +\ P_{gg}(y,\alpha_S)g(\frac{x}{y},Q^2)\right\}$$

Splitting functions stimulated the development of the most advanced computational techniques over the years

For nearly 20 years all splitting funct.s P have been known to only NLO accuracy: $\alpha_s P \sim \alpha_s P_1 + \alpha_s^2 P_2 + \ldots\ldots$

Floratos et al; Gonzales-Arroyo et al; Curci et al; Furmanski et al

Then the complete, analytic NNLO results have been derived for the first few moments (N<13,14).

Larin, van Ritbergen, Vermaseren+Nogueira

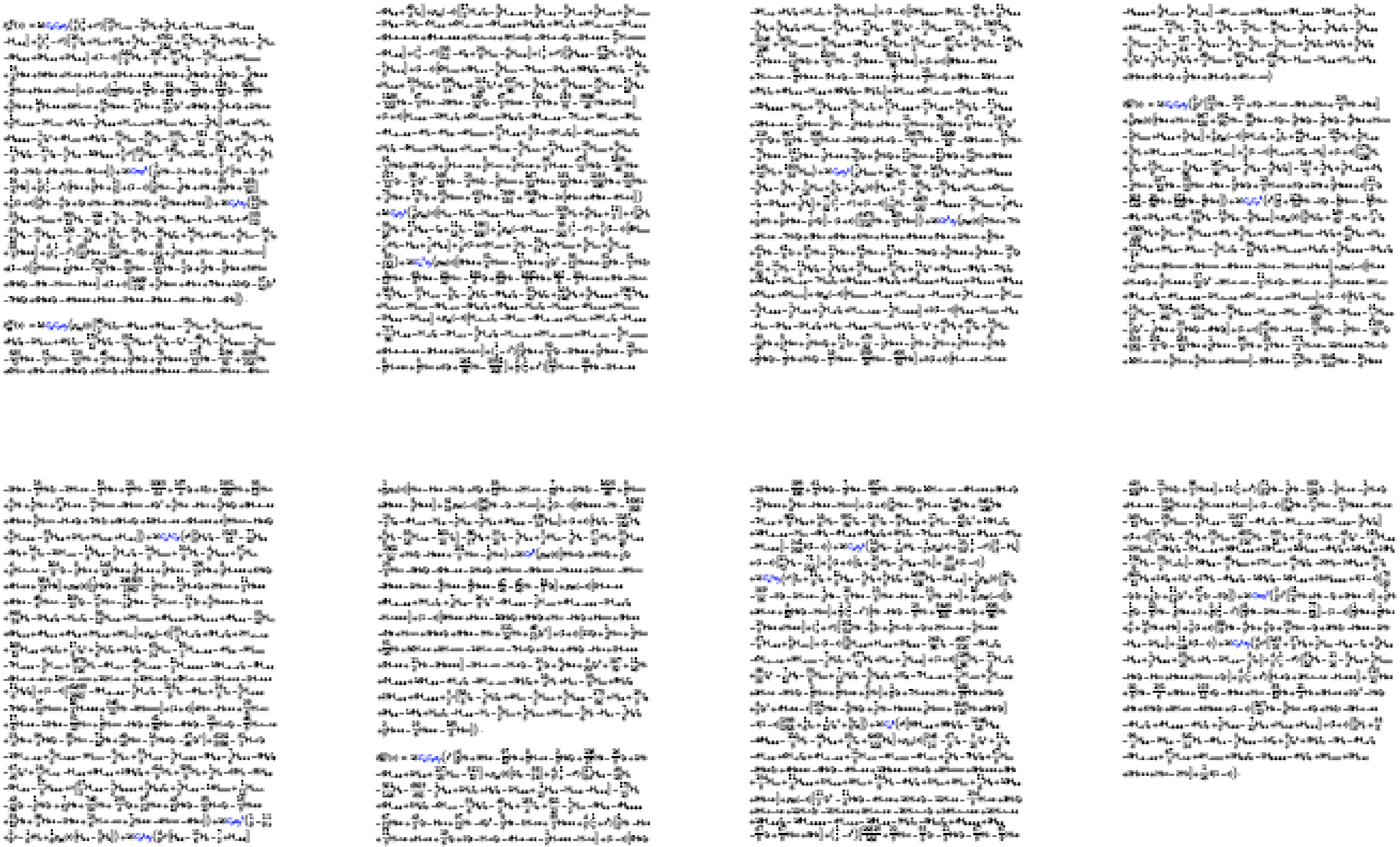
Finally, in 2004, the calculation of the NNLO splitting functions has been totally completed $\alpha_s P \sim \alpha_s P_1 + \alpha_s^2 P_2 + \alpha_s^3 P_3 + \ldots\ldots$

Moch, Vermaseren, Vogt '04

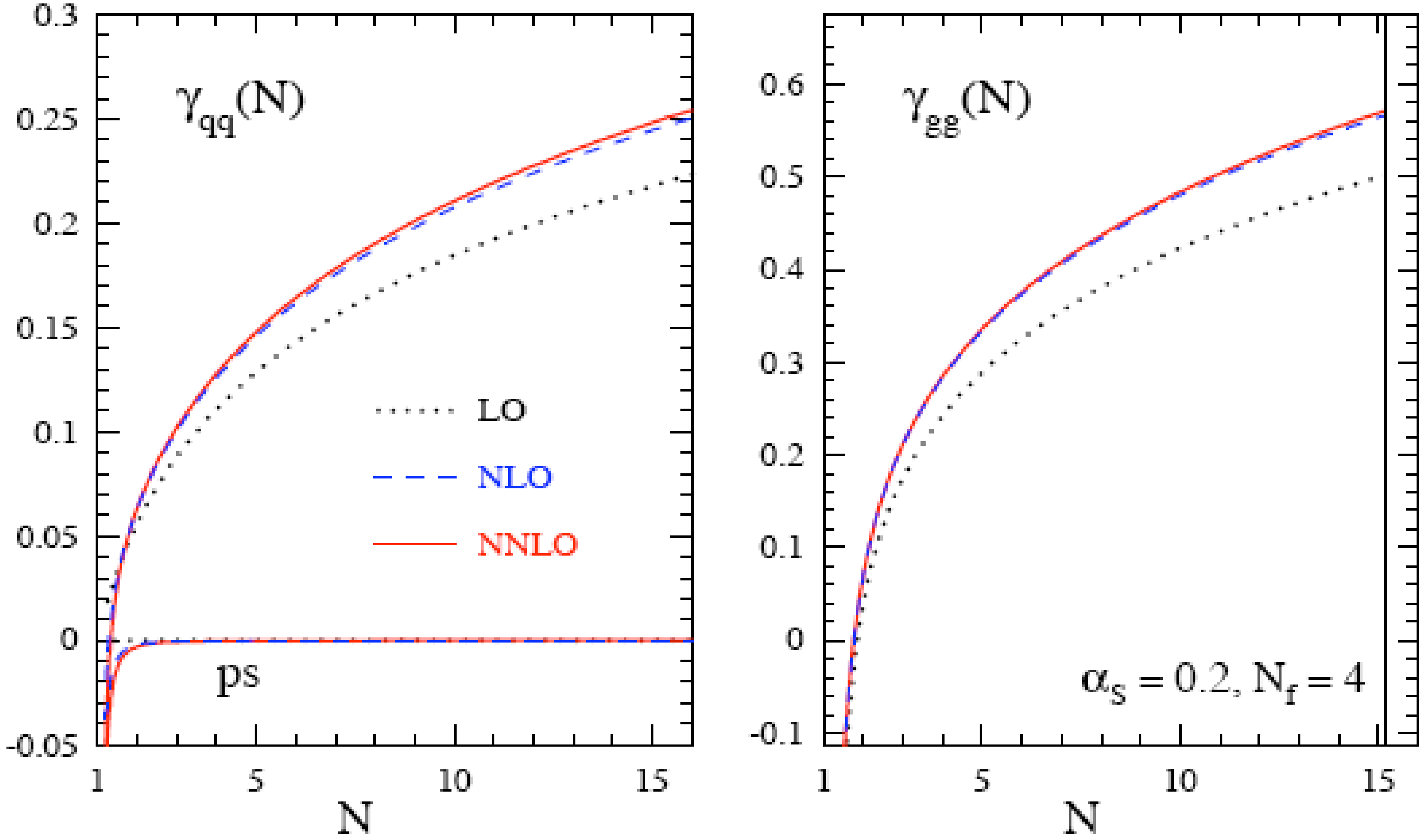
⊕ A really monumental, fully analytic, computation

NNLO singlet splitting functions   A completely analytical result

Moch, Vermaseren, Vogt '04



Anomalous dimensions vs N, the Mellin index

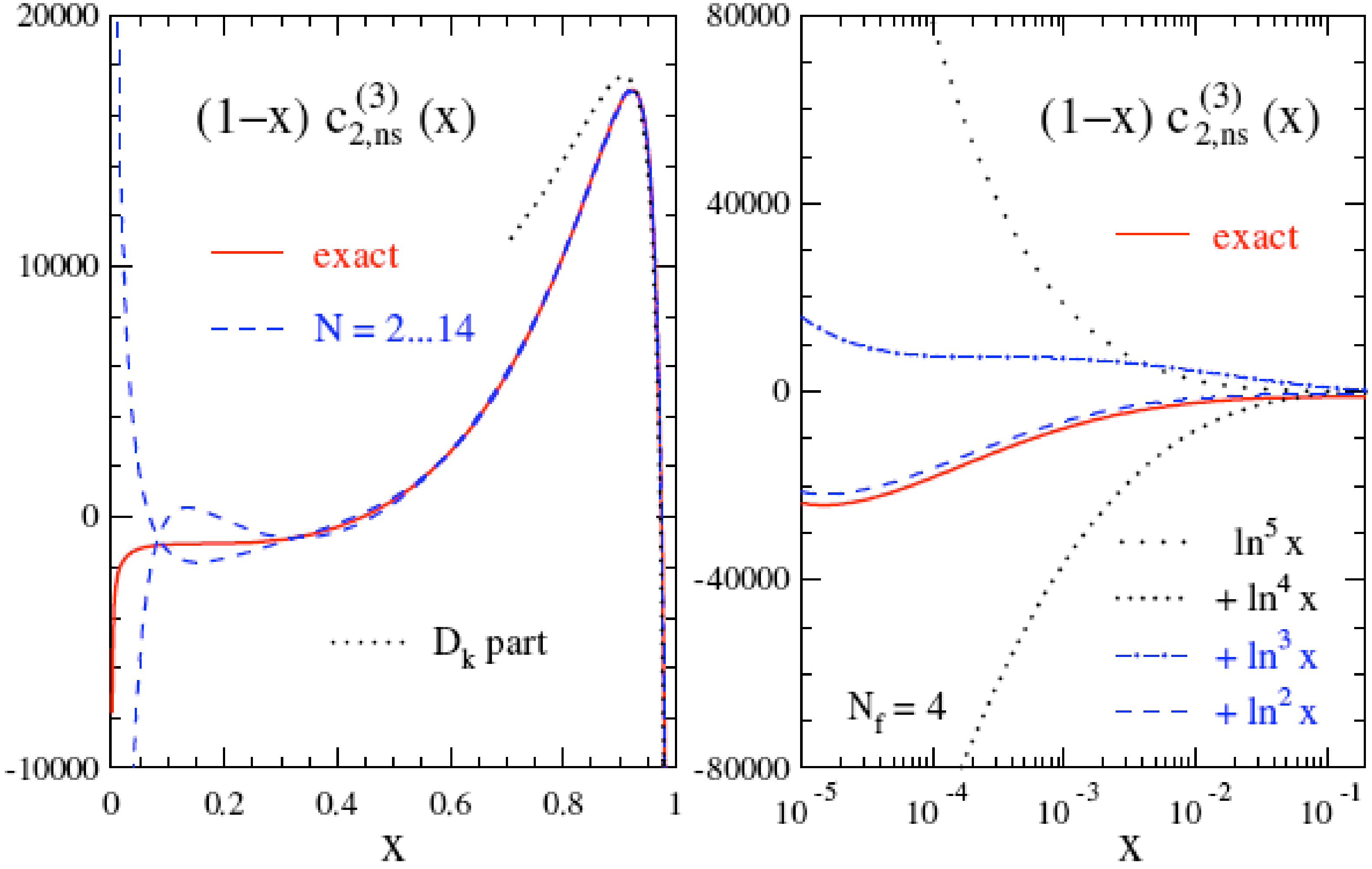


Good convergence is apparent

Now also the α_s^3 coefficient functions are known

(eg the NNLO calculation of F_L completed)

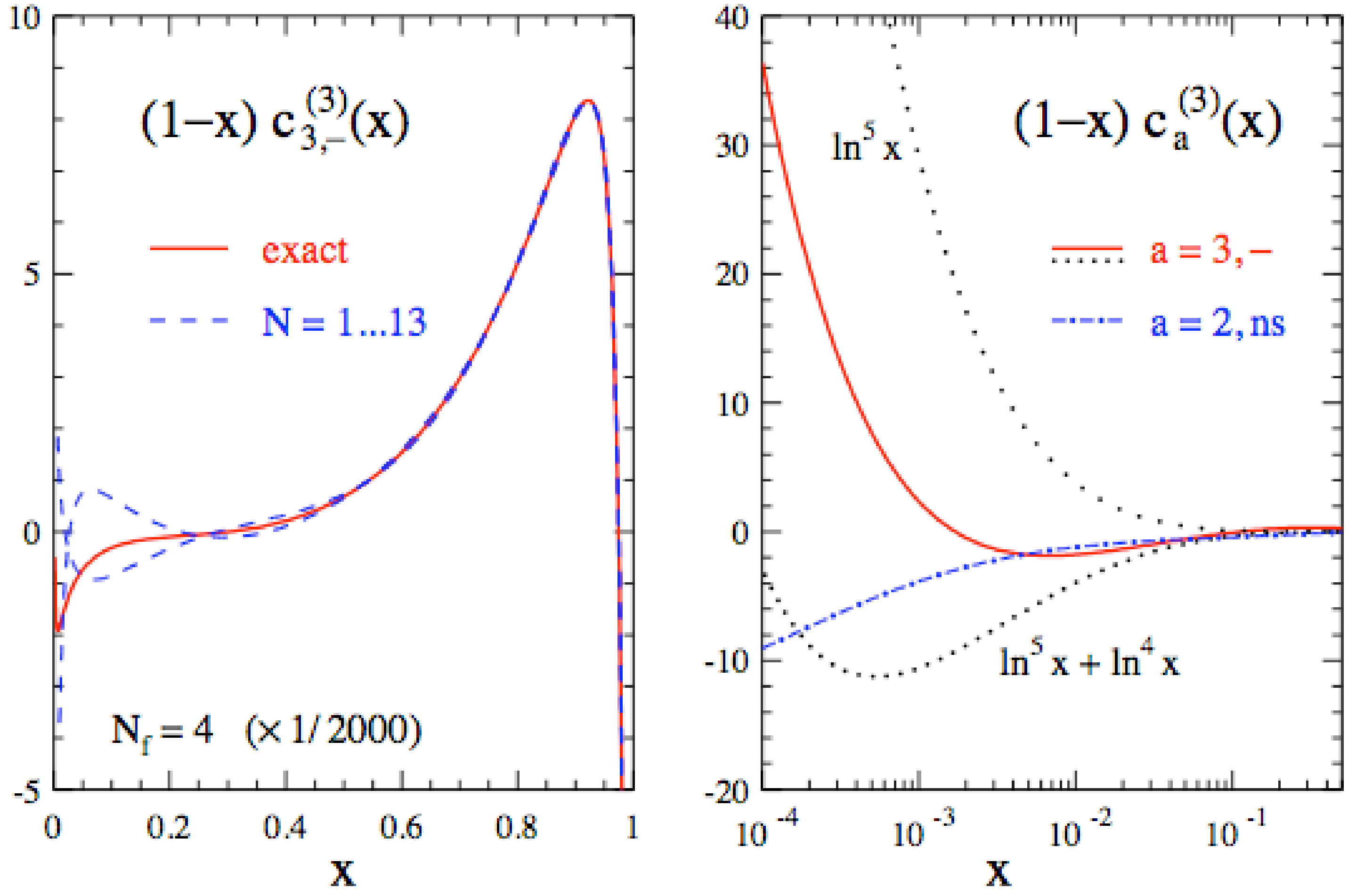
Moch, Vermaseren, Vogt '05



Talks by Vermaseren, Bluemlein, Vogt

Structure function $F_3^{W^+ + W^-}$: N^3LO coefficient function computed

Moch, Vogt, Vermaseren



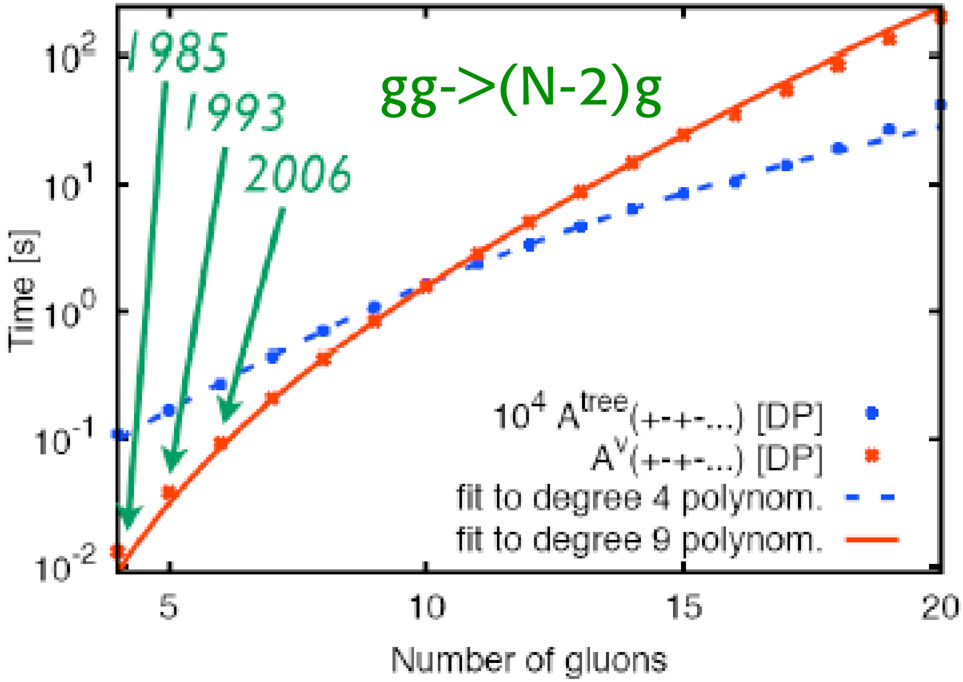
* MVV, arXiv: 0812.4168 (NPB); MV, arXiv: 0902.2342 (JHEP); MV, to appear

Great computational advances: from N. Glover talk

remarkable development pace in QCD for higher order calculations in past few years

- ✓ first signs of automated mutiparticle NLO cross sections
- ✓ many new ideas for sophisticated jet definitions
- ✓ high precision NNLO calculations for standard candle processes on the way
- ✓ glimpses of more structure in higher loop gauge theory amplitudes

link to massive progress in multiparticle multi-loop N=4 Super Yang Mills



Giele, Zanderighi

Singlet splitting function at small x

Resum $(\alpha_s \log 1/x)^n$

The problem of correctly including BFKL at small x has been solved

Ciafaloni, Colferai, Salam, Stasto (CCSS)
Altarelli, Ball, Forte (ABF); White, Thorne

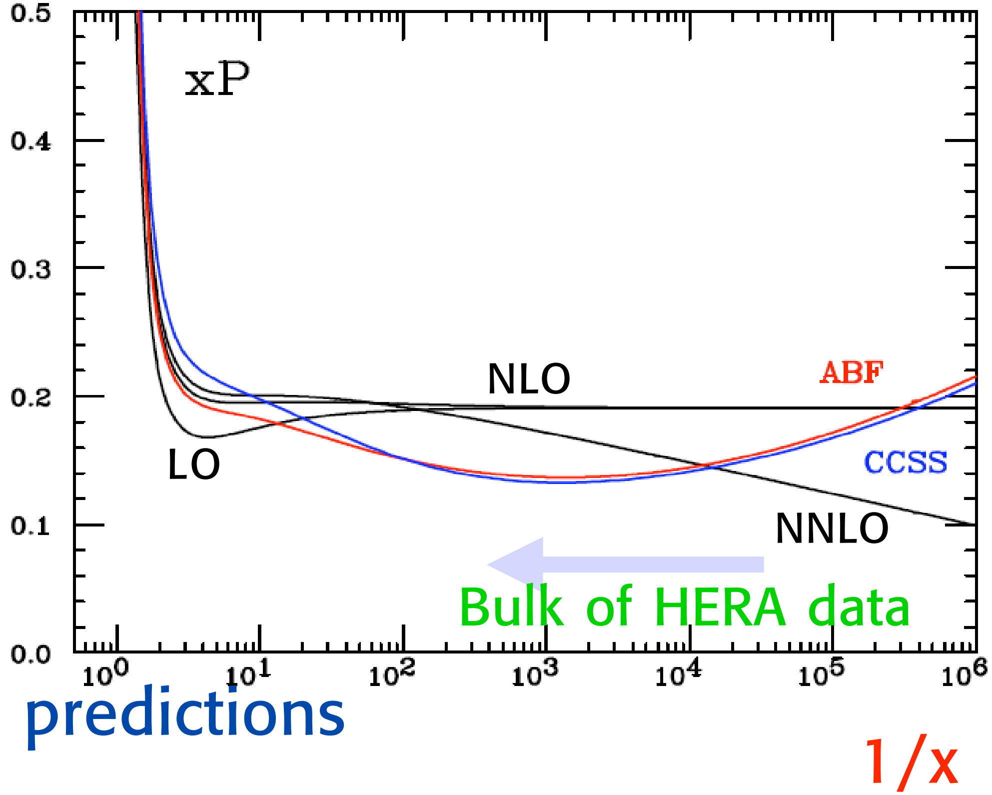
Momentum cons.+ symmetry + running coupling effect

→ soft simple pole in anom. dim

- BFKL sharp rise tamed

- resummed result close to NLO in HERA region

- new expansion stable



Makes the ground solid for LHC predictions (eg b production)

$$x_1 x_2 s = (2m_b)^2 \Rightarrow \bar{x} = \sqrt{x_1 x_2} \sim \frac{2m_b}{\sqrt{s}} \sim 0.7 \cdot 10^{-3}$$

Due to the dip there is less scaling violations at HERA than from NLO

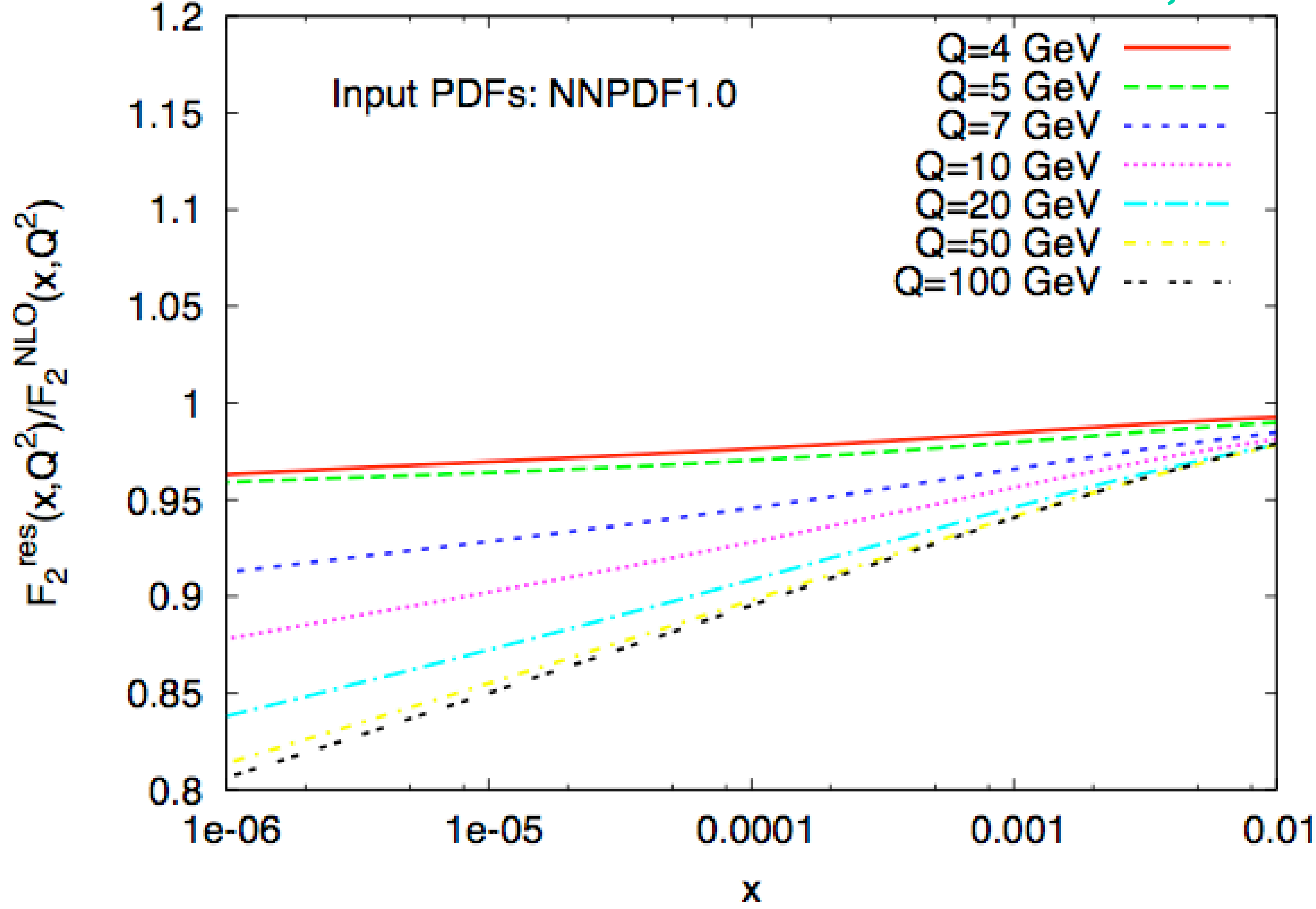
Fitting α_s from NLO one would obtain a smaller value than the true value (for the same gluon).

Theoretical contributions on BFKL and related topics:

J. Bartels
H.P Kowalski
D. Colferai
V. Fadin
I. Balitsky

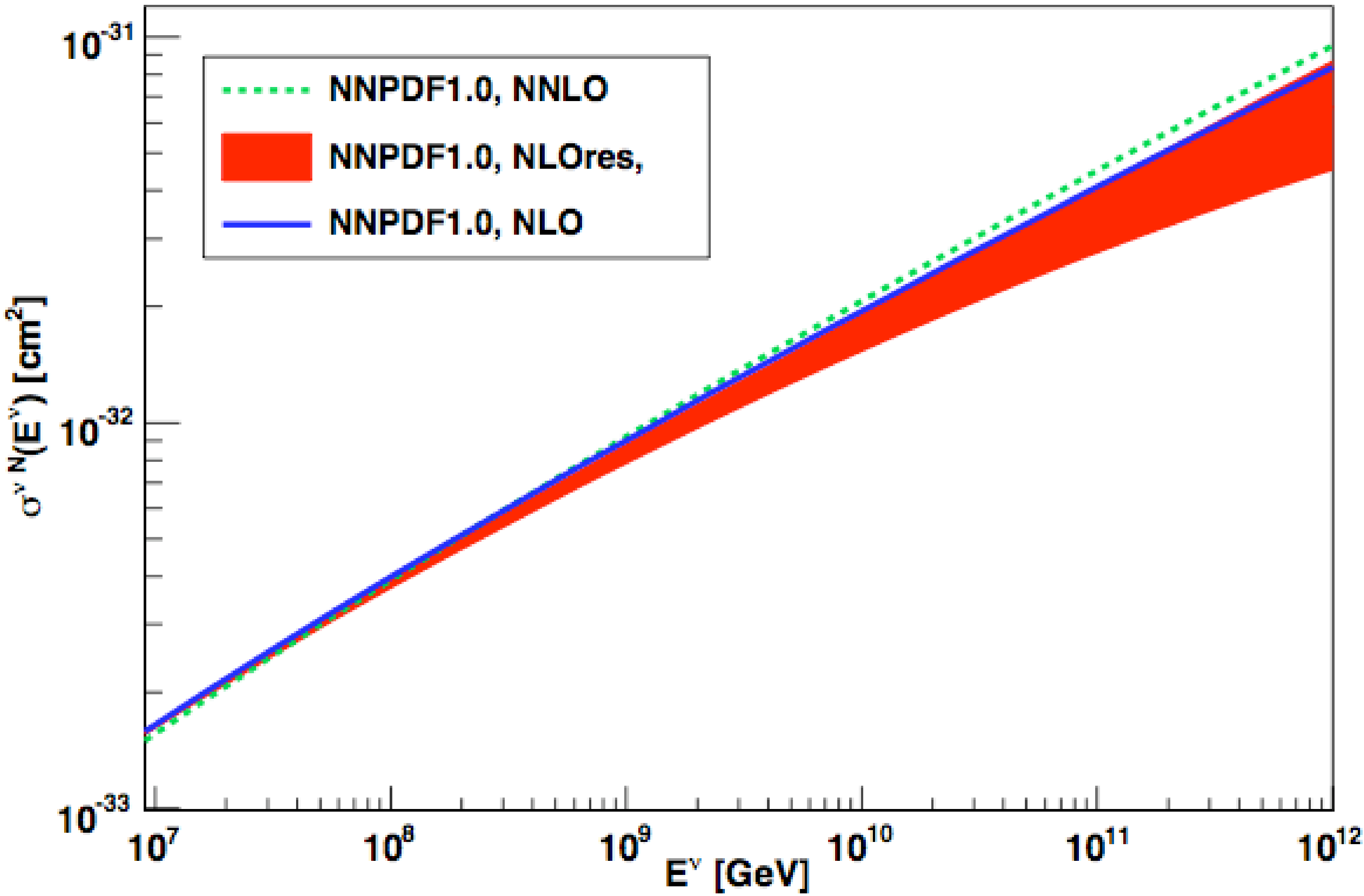
Resummed K-factors

J. Rojo



Small-x resummation of UHE neutrinos

J. Rojo



- Small x resummation also completed for Drell-Yan Ball, Marzani

In spite of the large effort in theory and experiment over ~40 years still our knowledge is in many respects surprisingly not satisfactory

Some examples:

- The determination of α_s from DIS
- Ambiguities on the pdf's
- Neutrino structure functions not good enough
- ONLY NOW (!) some reasonable data on F_L are been obtained (H1 and ZEUS)
- Polarized DIS

What is the value of α_s from DIS?

From LEP we have the best values to compare with:

- Z inclusive decay: $\alpha_s(m_Z)=0.1191\pm0.0027$ (N^3LO)
- τ inclusive decay: $\alpha_s(m_Z)=0.1212\pm0.0011$ (N^3LO)

Davier et al '08

(I do not believe this small error, but this is not an issue here)

- Event shapes: $\alpha_s(m_Z)=0.1240\pm0.0034$ (N^3LO)

Dissertori et al '08

DIS is the next "golden" channel to consider

α_s from DIS

The scaling violations of non-singlet str. functs. would be ideal: less dependence on input parton densities

$$\frac{d}{dt}\log F(x,t) = \frac{\alpha_s(t)}{2\pi}\int_x^1 dy \frac{F(y,t)}{yF(x,t)} P_{qq}\left(\frac{x}{y}\right)$$

But for F_p-F_n exp. errors add up in the difference, and $F_{3\nu N}$ is not terribly precise
(ν data only from CCFR, NuTeV)

Neutrinos. For xF_3 at NNLO:

Using Bernstein moments

A combination of Mellin moments which emphasizes a value of x and a given spread in order to be sensitive to the interval where the measured points are

- $\alpha_s(m_Z)=0.1153\pm0.0063$

  Santiago, Yndurain '01

- $\alpha_s(m_Z)=0.1174\pm0.0043$

  Maxwell, Mirjalili '02

Here the error from scale dep. not included (a model dep. scale fixing is chosen)

Using Mellin moments

- $\alpha_s(m_Z)=0.1190\pm0.0060$

  Kataev, Parente, Sidorov '02

Good overall agreement. Not very precise: (as expected from ν's) Total error $\sim\pm0.006$

electron/muon production

From a recent analysis of eP and eD data, neglecting sea and gluons at $x > 0.3$

- Non singlet DIS: $\alpha_s(m_Z)=0.1148\pm0.0019$ (exp)+? (NLO)

  $\alpha_s(m_Z)=0.1134\pm0.0020$ (exp)+? (NNLO)

Bluemlein et al '06

- a rather small central value
- not much difference between NLO and NNLO

When one measures α_s from scaling viols. in F_2 from e or μ beams, data are abundant, exp. errors small but:

$\alpha_s \longleftrightarrow$ gluon correlation $dF/d\log Q^2 \dashrightarrow \alpha_s g$

- Using data on P from SLAC, BCDMS, E665 and HERA, NNLO [Bernstein moments] :

$\alpha_s(m_Z)=0.1166\pm0.0013$ (!!th error?)

Santiago, Yndurain '01

- Or using data on p from SLAC, BCDMS, NMC and HERA, NNLO [Mellin moments]:

$\alpha_s(m_Z)=0.1143\pm0.0014\ (\mathrm{exp})\ \pm0.0013\ (\mathrm{th})$

Alekhin '02

The difference in central values between these nominally most precise determinations suggests a total error $\sim\pm0.003$

Other analyses (NLO vs NNLO generally close) based on different methods and data sets offer a spread of central values suggesting larger errors

- Using data on p from BCDMS and NMC, NLO kernels, truncated moments

Moments from x_0 to 1 in measured range, coupled eqs.

$$\alpha_s(m_Z)=0.122\pm0.006$$

Forte, Latorre, Magnea, Piccione '02

- H1 only or H1+BCDMS, NLO

$$\alpha_s(m_Z)=0.1185\pm0.002\ (\mathrm{exp})\ \pm0.005$$
$$\alpha_s(m_Z)=0.1150\pm0.002\ (\mathrm{exp})$$

- ZEUS, NLO $\alpha_s(m_Z)=0.1166\pm0.0049\ (\mathrm{exp})\ \pm0.0018$

- Proton data, Nachtmann moments including soft gluon resumm. at large x and estimate of higher twist

$$\alpha_s(m_Z)=0.1188\pm0.0017\ (\mathrm{exp})$$ Simula, Osipenko '03

Summary

- Z inclusive decay: $\alpha_s(m_Z)=0.1191\pm0.0027$ (N^3LO)
- τ inclusive decay: $\alpha_s(m_Z)=0.1212\pm0.0011$ (N^3LO)

  Davier et al '08

  (I do not believe this error, but this is not an issue here)
- Event shapes: $\alpha_s(m_Z)=0.1240\pm0.0034$ (N^3LO)

  Dissertori et al '08

- Non singlet DIS: $\alpha_s(m_Z)=0.1148\pm0.0019$ (exp)+? (NLO)

  $\alpha_s(m_Z)=0.1134\pm0.0020$ (exp)+? (NNLO)

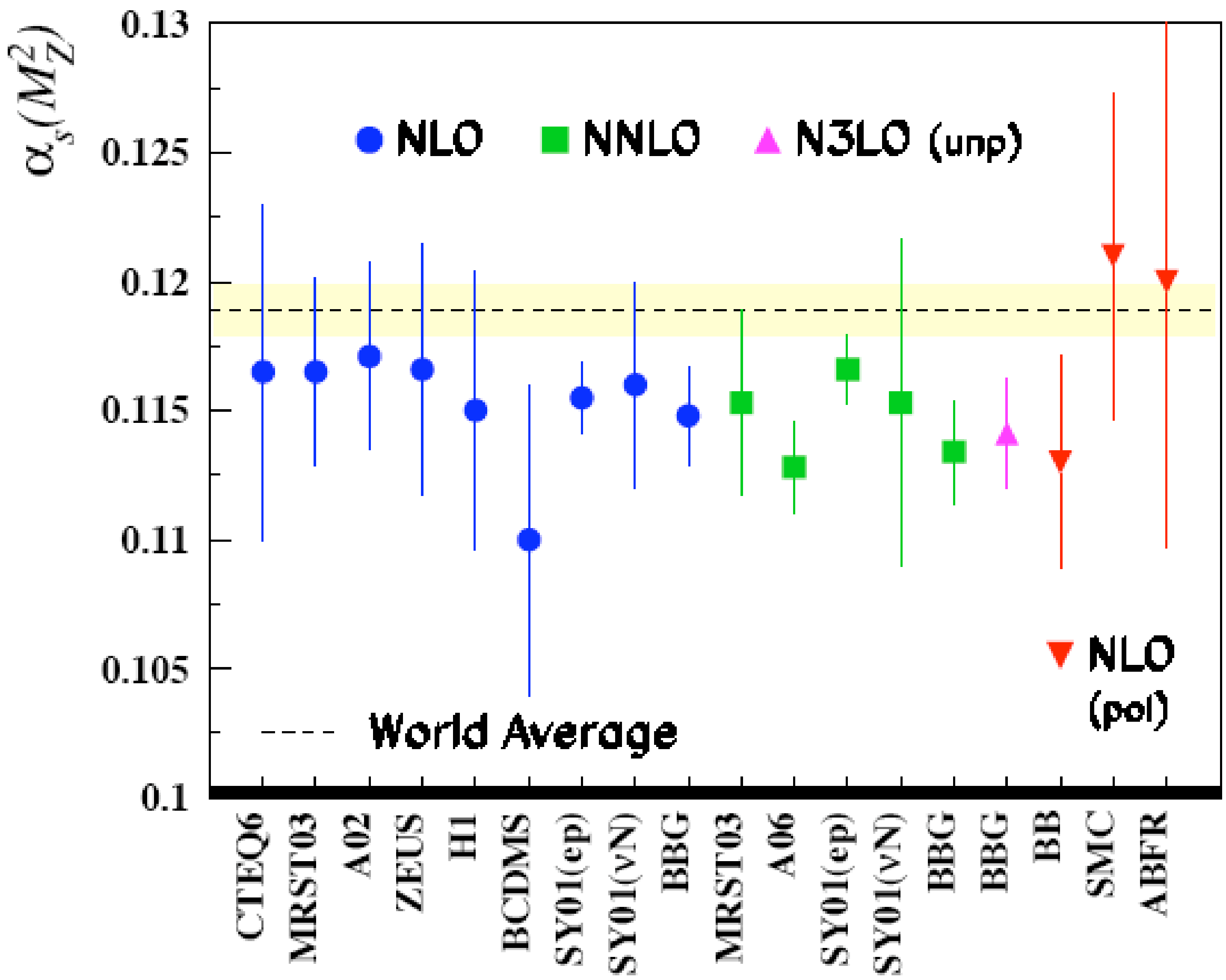
  Bluemlein et al '06
- All DIS eP: $\alpha_s(m_Z)=0.1166\pm0.0013$ (th error?) (NNLO)

  Santiago, Yndurain '01

  $\alpha_s(m_Z)=0.1143\pm0.0014$ (exp) ±0.0013 (th) (NNLO)

  Alekhin '02

Bluemlein et al '06

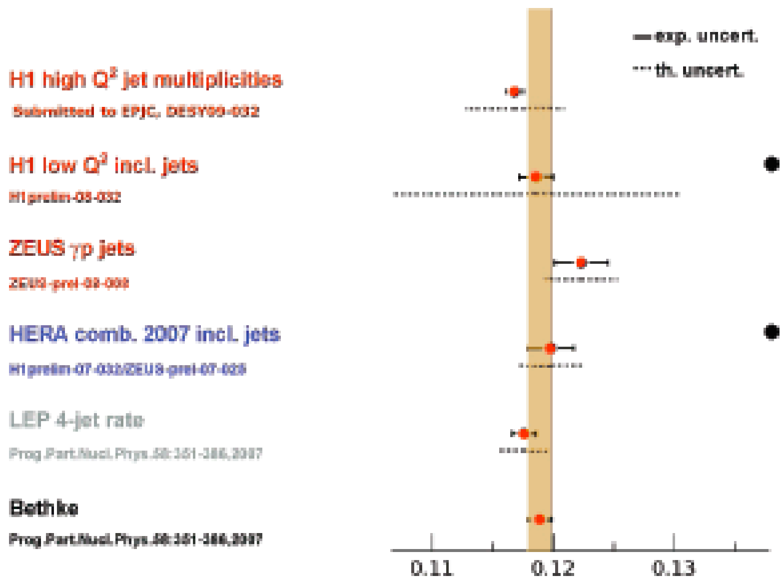


- DIS results tend to be on the low side.

Result on α_s

- Result: strong coupling extracted from H1 jet data

$$\alpha_s = 0.1168 \pm 0.0007\,(\mathrm{exp}) \pm^{0.0046}_{0.0030}\,(\mathrm{theo}) \pm 0.0016\,(\mathrm{PDF})$$



- Experimentally most precise single measurement of α_s (0.6%)
- Theory (NLO) error dominated by scale uncertainties (3-4%)

→ A. Specka [237]

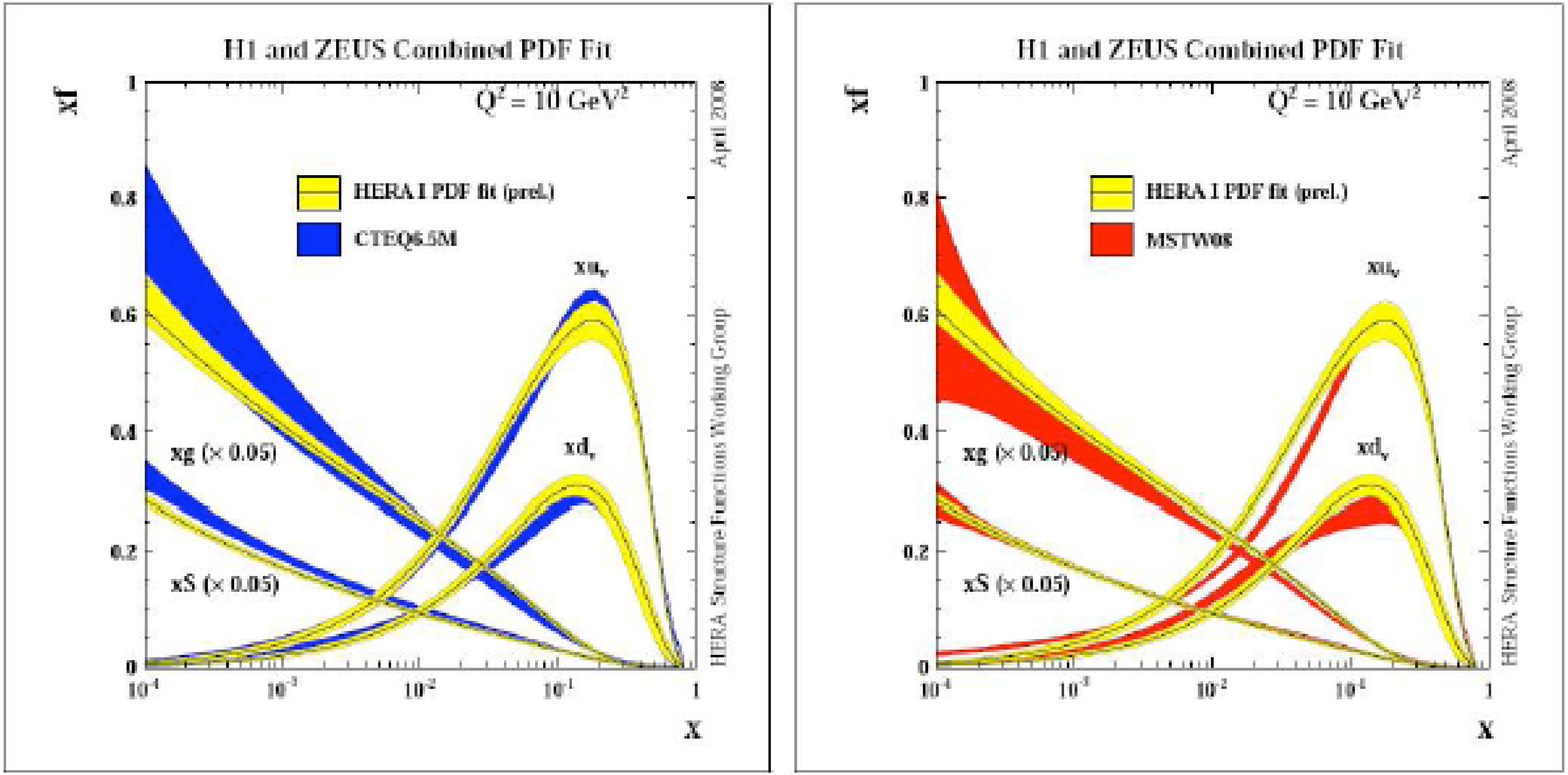
Jets ZEUS: C. Gwenlan, E. Ron

New and updated PDF analyses at DIS'2009

PDF analysis group	Talk(s) by
Alekhin and collaborators	*S. Alekhin*
CTEQ *(MSU/SMU/Taiwan/Washington)*	*H.-L. Lai, P. N.*
CTEQ *(JLab)*	*C. Keppel*
EPS nuclear PDFs	*H. Paukkunen*
H1	*J. Kretzschmar, A. Petrukhin*
HERAPDF (H1+ZEUS)	*V. Radescu*
MSTW	*R. Thorne*
Neural Network PDF	*J. Rojo, M. Ubiali*
ZEUS	*A. Cooper-Sarkar*

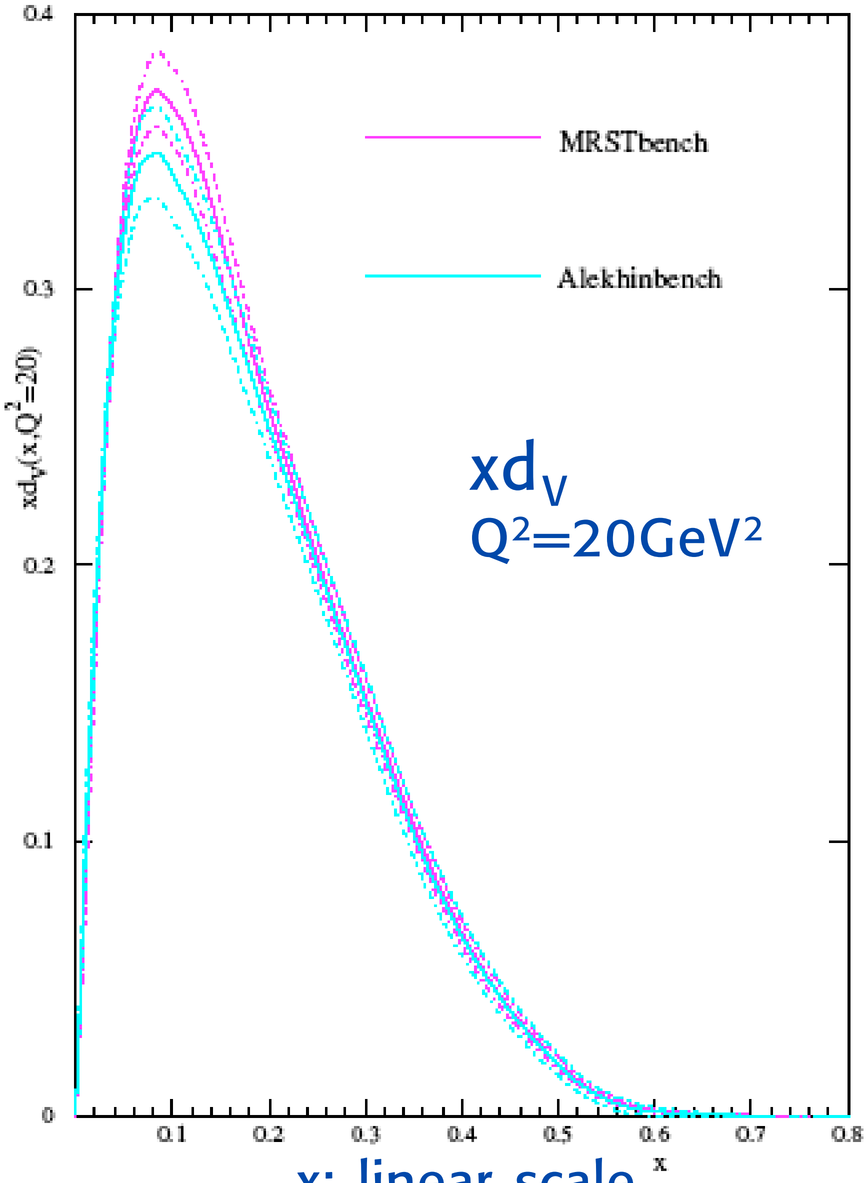
DIS2009

Are the parton densities known well enough?

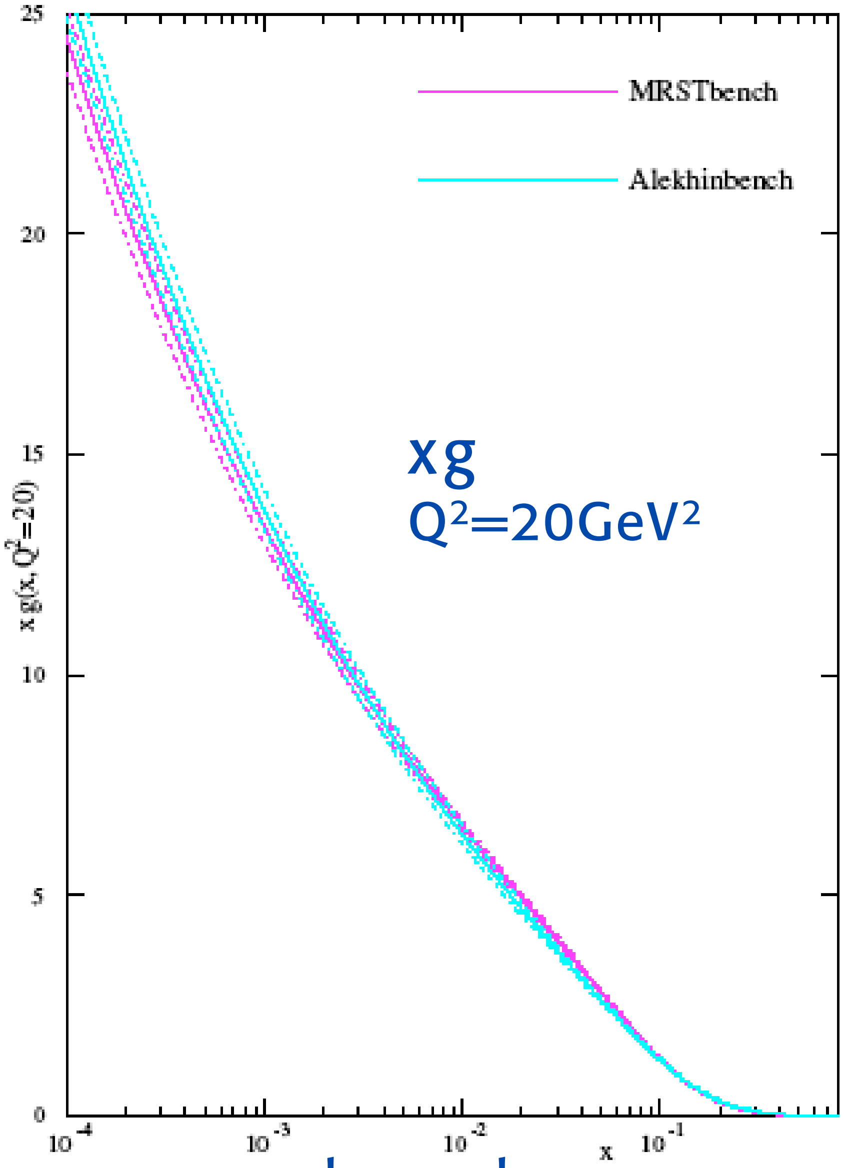


Different fits to same DIS data are comparable

HERA LHC Workshop '06

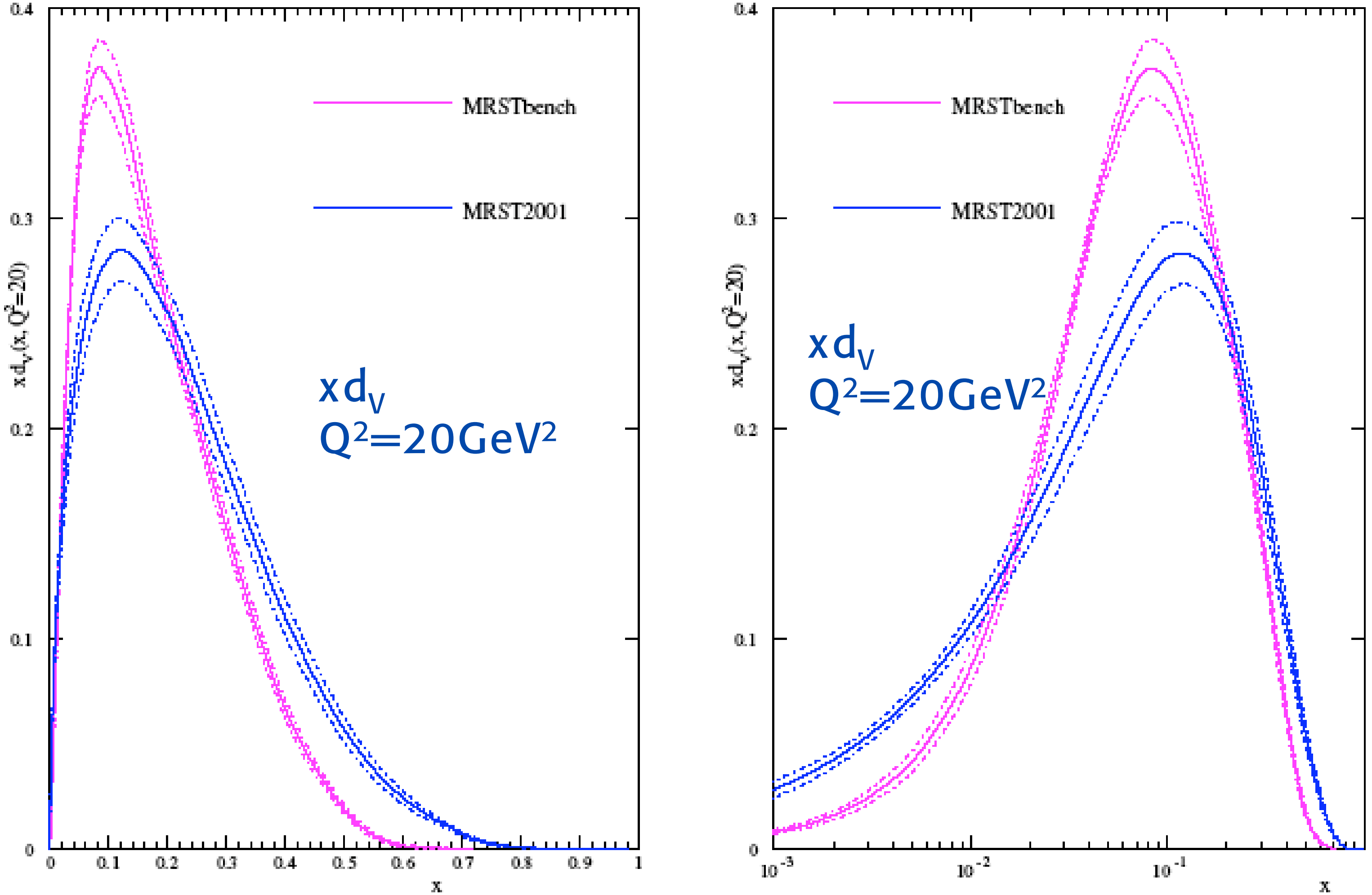


x: linear scale



x: log scale

But differ from those obtained from all the data



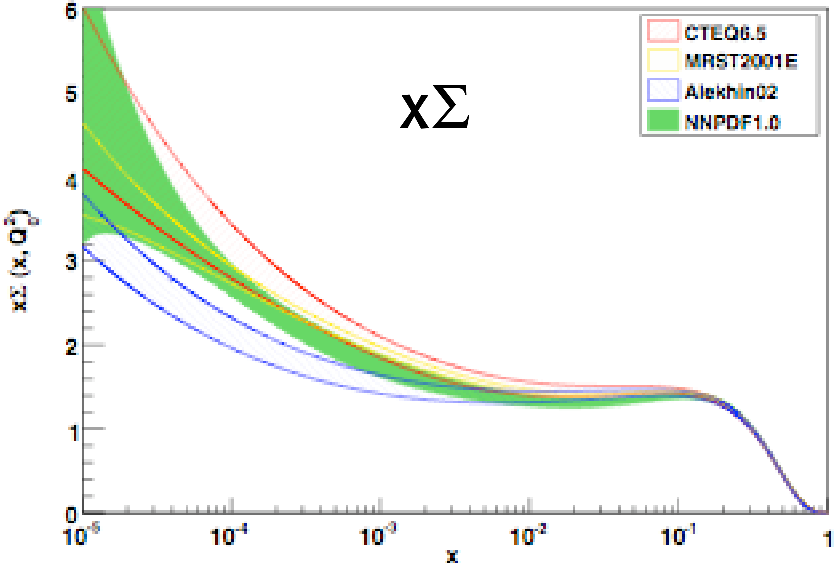
x: linear scale

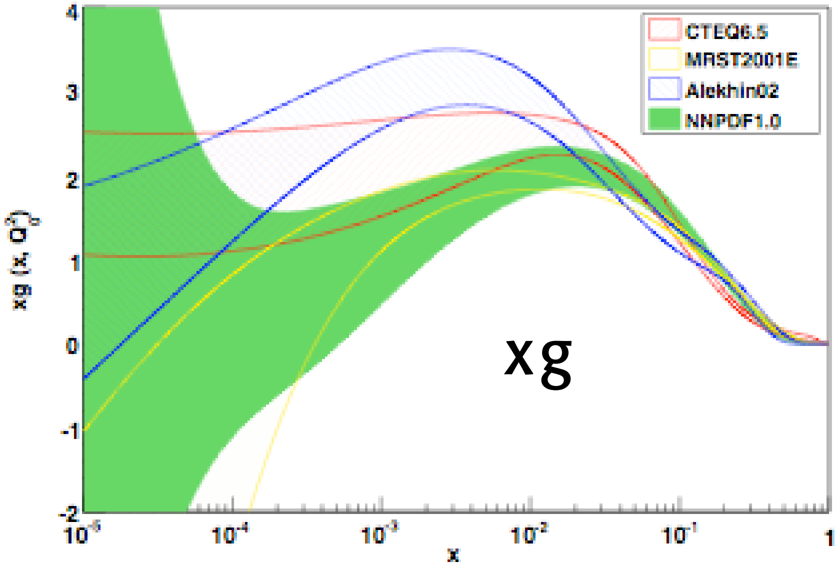
x: log scale

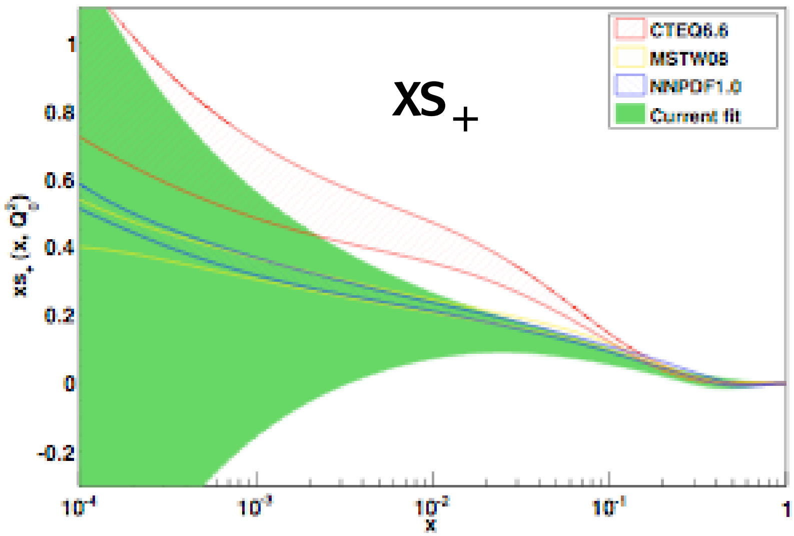
- This shows that extrapolation from one data set to another is dangerous

NNPDF: R. Ball et al '08

M. Ubiali







J. Rojo

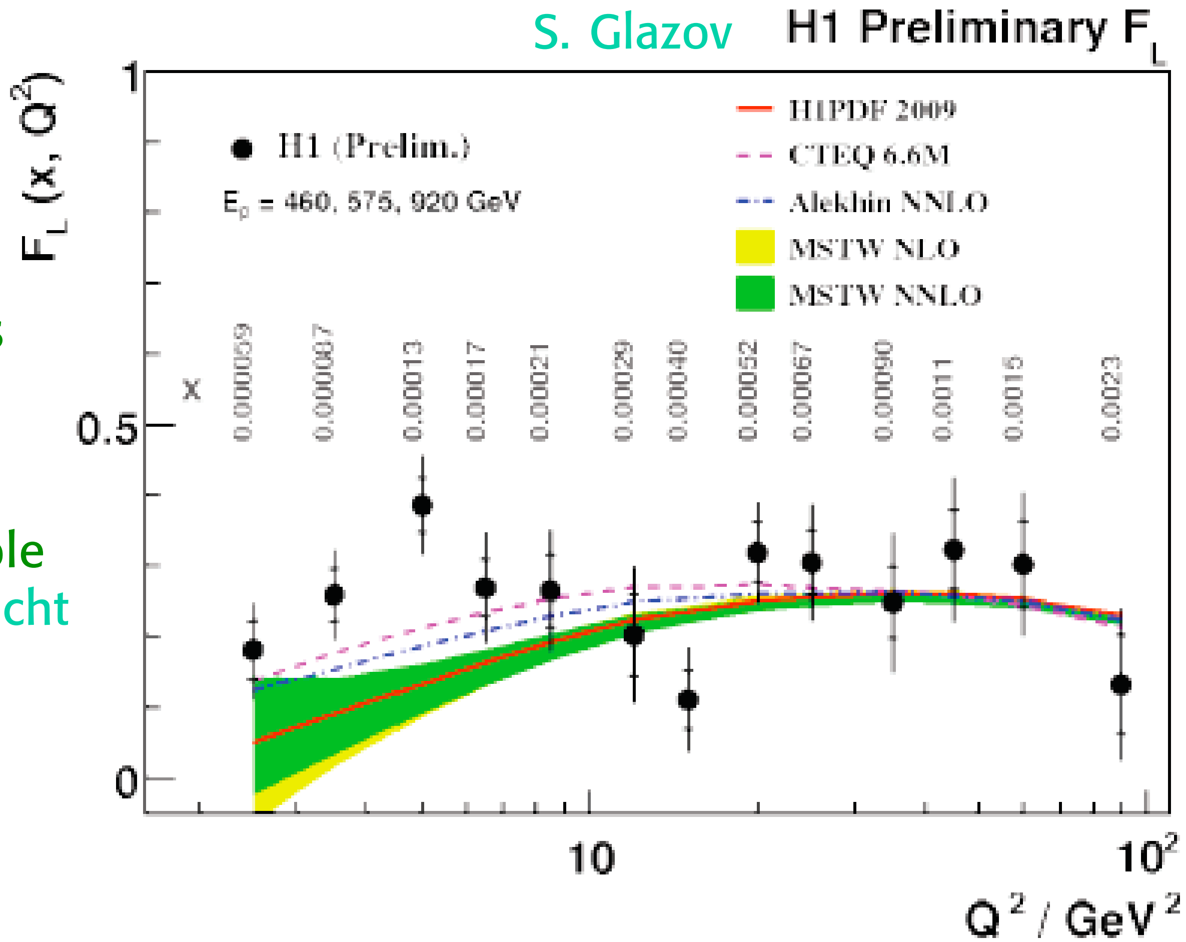
Neural Network pdf
less dep on parametrization.

a large ensemble of pdf allowed

Uncertainties larger than for
CTEQ, MRST, Alekhin
in unmeasured region

It took ~40 years to get meaningful data on the longitudinal structure function!!

S. Schmitt
S. Glazov



Theory

BFKL corr's at small x

A. Stasto

Colour dipole

D. Schldknecht

Another experimental highlight!

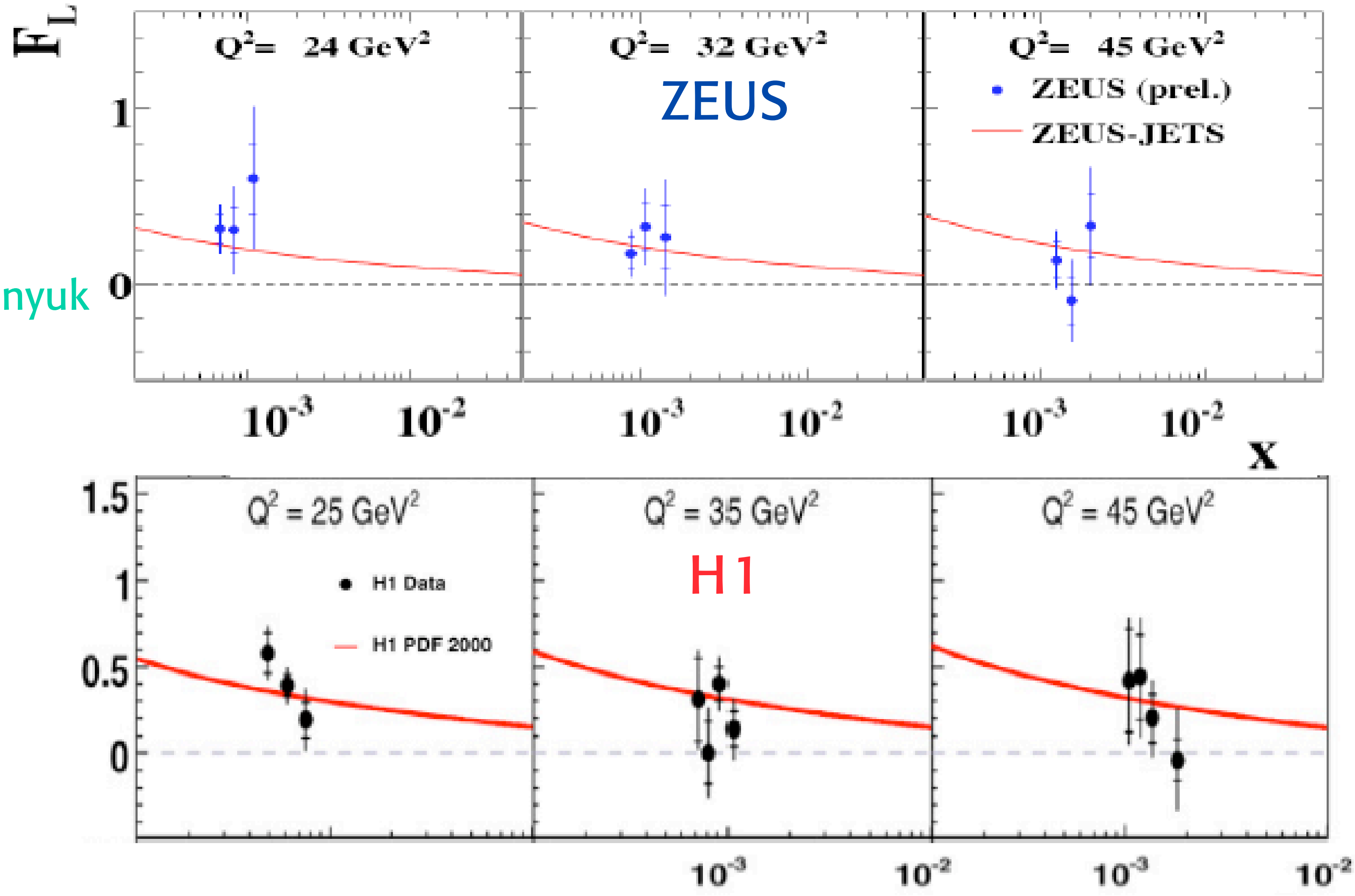
But better data would be highly desirable

Altarelli, Martinelli '78

$$F_L(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi} x^2 \int_x^1 \frac{dy}{y^3} \left[\frac{8}{3} F_2(y,Q^2) + \frac{40}{9} yg(y,Q^2)(1-\frac{x}{y}) \right]_{n_f=4}$$

New data on F_L at small x presented here

J. Grebenyuk



Polarized Structure Functions

A subject where our knowledge is still far from satisfactory

Who carries the proton spin?

$$\frac{1}{2}\Delta\Sigma + \Delta g + \Delta L_z = \frac{1}{2}$$

typically $\Delta\Sigma_{exp} \sim 0.24$

What is missing must be either $\Delta g + \Delta L_z$ or $\Delta\Sigma$ terms at small x (below the measured range)

E-C. Aschenauer
M. Stratmann

F. Taghavi

First moments

$$\Delta q \equiv \Delta q + \Delta \bar{q}$$

$$a_3 = \Delta u - \Delta d = (F + D)(1 + \varepsilon_2) = 1.269 \pm 0.003$$

SU(2) breaking

$$a_8 = \Delta u + \Delta d - 2\Delta s = (3F - D)(1 + \varepsilon_3) = 0.586 \pm 0.031$$

SU(3) breaking

$$\Gamma_1 = \int dx g_1(x) = \frac{1}{12}[a_3 + \frac{1}{3}(a_8 + 4a_0)]$$

From Γ_1 we get a_0

$$a_0 \equiv \Delta\Sigma = \Delta u + \Delta d + \Delta s = a_8 + 3\Delta s \approx 0.24$$

at Q^2= 1 GeV^2

$\Rightarrow$ for $\varepsilon_2, \varepsilon_3=0$

$$\Delta u \simeq 0.81$$

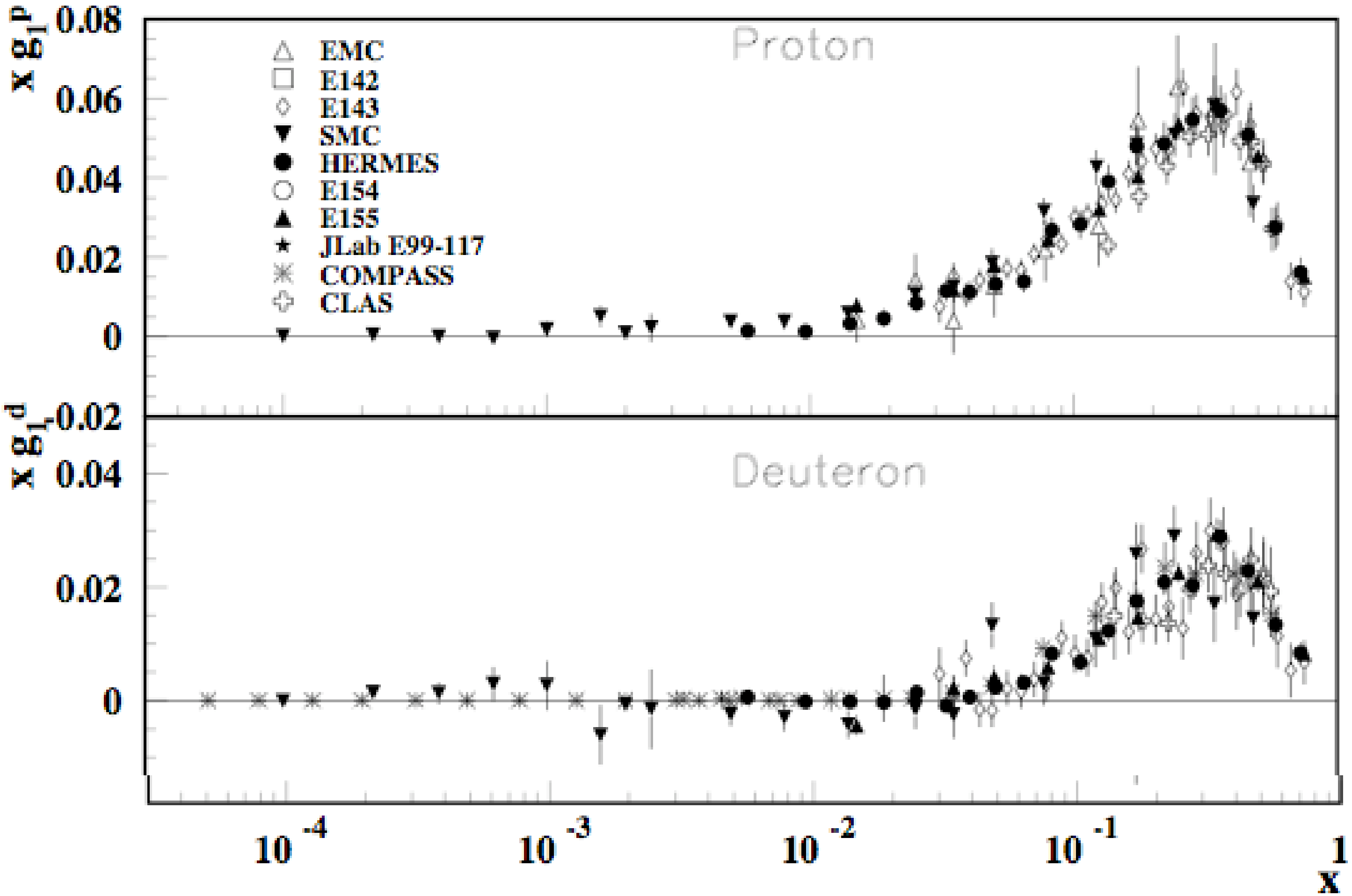
$$\Delta d \simeq -0.46$$

$$\Delta s \simeq -0.12$$

This is a strong result!
Given F, D and Γ_1 we know Δu, Δd, Δs, $\Delta\Sigma$ in the SU(3) limit

The 1st moment of g_1 does not seem to get much at small x

Theory: Ermolaev, Greco, Troyan



From Γ_1 on deuterium COMPASS finds $\Delta s = -0.09 \pm 0.01 \pm 0.02$
while from SIDIS $\Delta s = -0.02 \pm 0.02 \pm 0.02$

H. Santos

In massless QCD in perturbation theory at LO:

- $\Delta\Sigma$ is conserved
- $\Delta g \sim 1/\alpha_s(Q^2) \sim \log Q^2$
- $\Delta g + \Delta L_z$ is conserved

$$\underset{\substack{\text{const}\\ \sim 0.12}}{\frac{1}{2}\Delta\Sigma} + \underbrace{\underset{\log Q^2}{\Delta g} + \underset{\log Q^2}{\Delta L_z}}_{\text{const}} = \frac{1}{2}$$

while at NLO

- $\Delta\Sigma'$ is conserved: $$\Delta\Sigma = \Delta\Sigma' - N_f \frac{\alpha_s(Q^2)}{2\pi}\Delta g$$

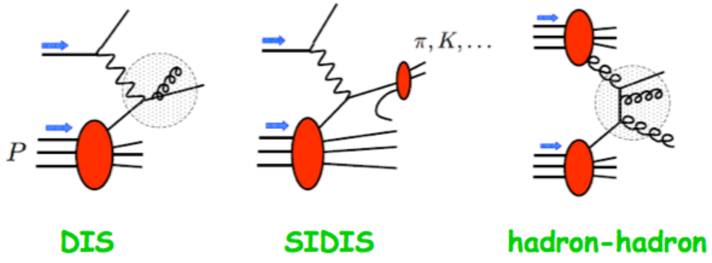
In principle the gluon could explain the smallness of $\Delta\Sigma$

Δg measured indirectly from scaling violations, directly from asymmetries, e.g. in cc production

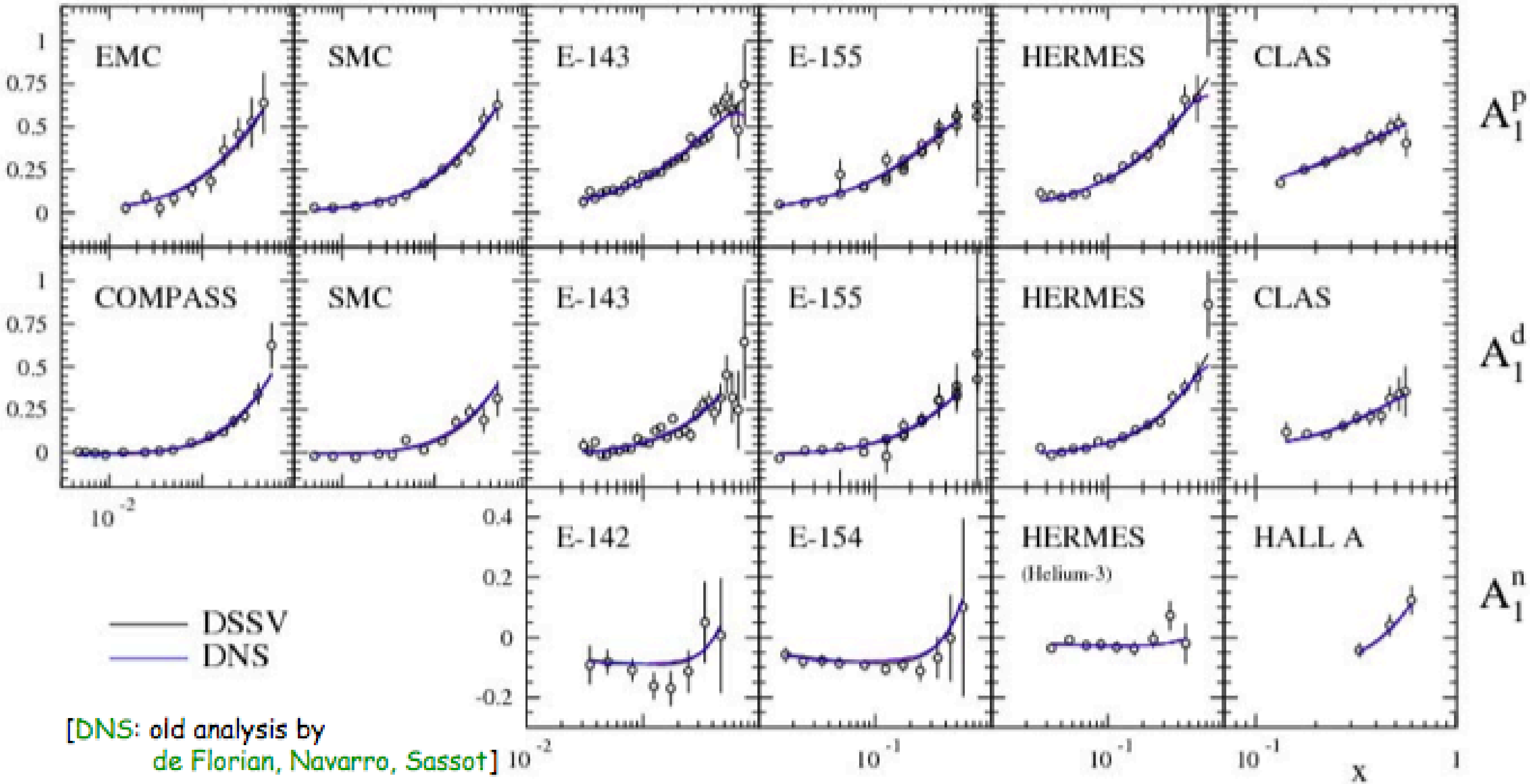
Existing direct measurements HERMES, COMPASS, CLAS, RHIC still very crude. No hint of large Δg at large x.

Note that it is unnatural that $\Delta g <\sim 0.2$

A beautiful set of data



spin asymmetries in inclusive DIS

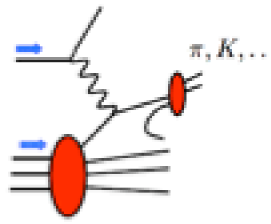


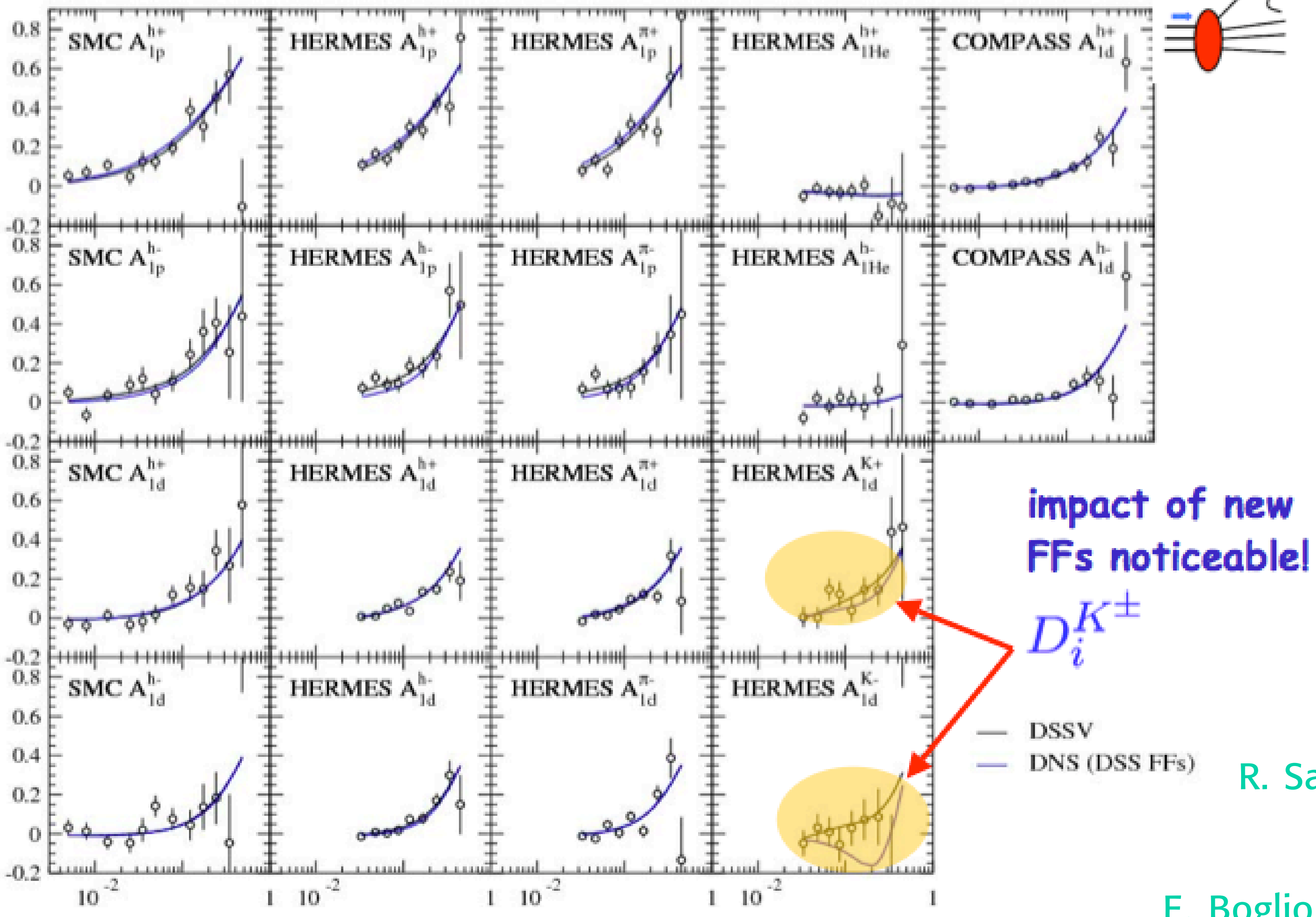
[DNS: old analysis by
de Florian, Navarro, Sassot]

U. D'Alesio

M. Stratmann
E-C. Aschenauer

spin asymmetries in semi-inclusive DIS





R. Sassot

E. Boglione

The fit to all data leads to puzzling results

Tension between the 1st moments from SU(3) and from fitting the actual data (x>0.001) which fix the moments only thru a possibly too rigid parametrization assumed

de Florian et al '08

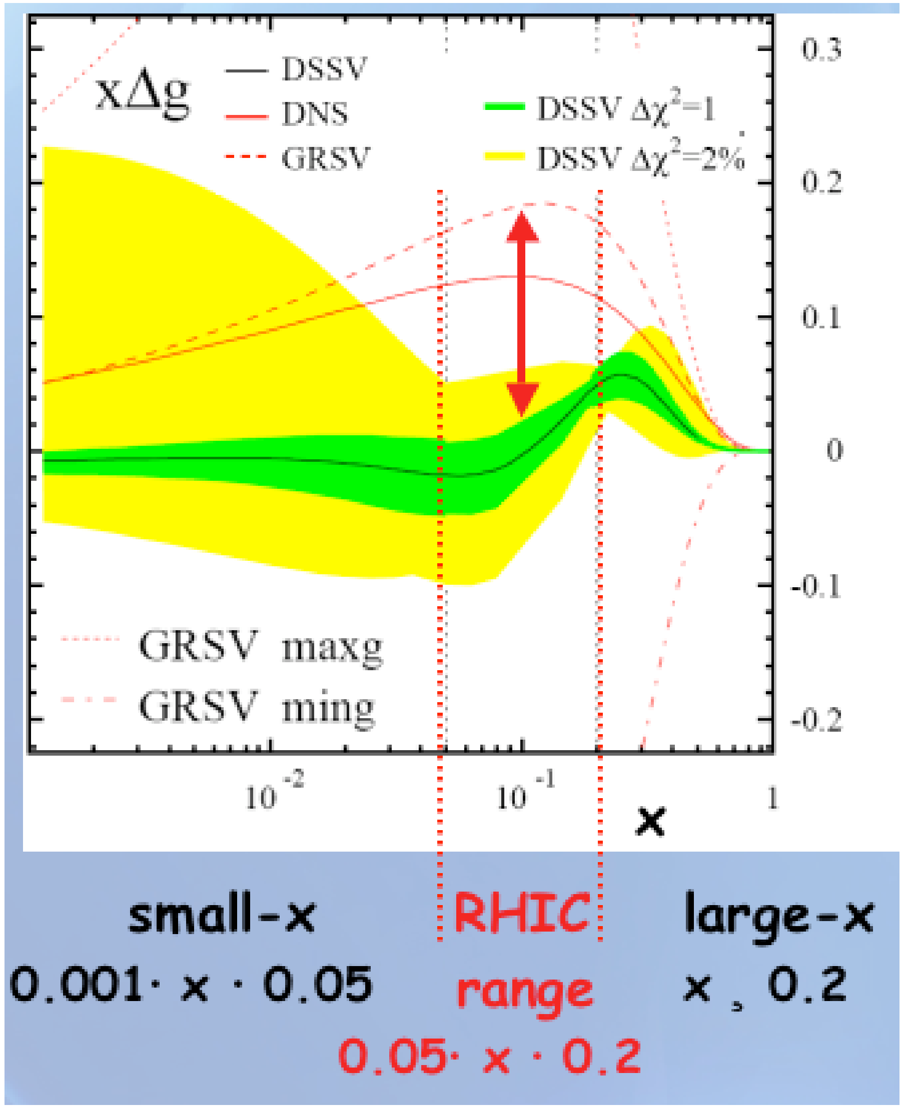
TABLE II: First moments $\Delta f_j^{1,[x_{\min}-1]}$ at $Q^2 = 10\,\mathrm{GeV}^2$.

	$x_{\min} = 0$ best fit	$x_{\min} = 0.001$ $\Delta\chi^2 = 1$	$\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta\bar{u}$	0.813	$0.793\ ^{+0.011}_{-0.012}$	$0.793\ ^{+0.028}_{-0.034}$
$\Delta d + \Delta\bar{d}$	-0.458	$-0.416\ ^{+0.011}_{-0.009}$	$-0.416\ ^{+0.035}_{-0.025}$
$\Delta\bar{u}$	0.036	$0.028\ ^{+0.021}_{-0.020}$	$0.028\ ^{+0.059}_{-0.059}$
$\Delta\bar{d}$	-0.115	$-0.089\ ^{+0.029}_{-0.029}$	$-0.089\ ^{+0.090}_{-0.080}$
$\Delta\bar{s}$	-0.057	$-0.006\ ^{+0.010}_{-0.012}$	$-0.006\ ^{+0.028}_{-0.031}$
Δg	-0.084	$0.013\ ^{+0.106}_{-0.120}$	$0.013\ ^{+0.702}_{-0.314}$
$\Delta\Sigma$	0.242	$0.366\ ^{+0.015}_{-0.018}$	$0.366\ ^{+0.042}_{-0.062}$

SU(3)

Parametrization?
Recall NNPDF s_+
The error from small x probably large

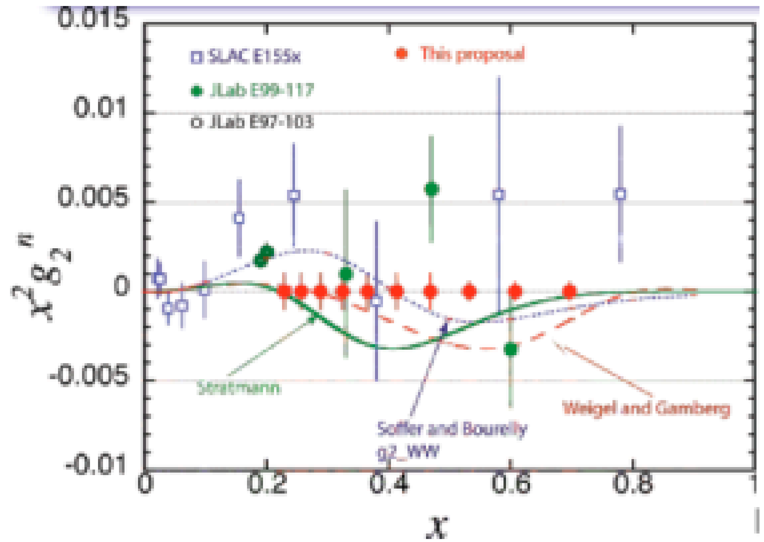
Kaon SIDIS fixes Δs but is questionable

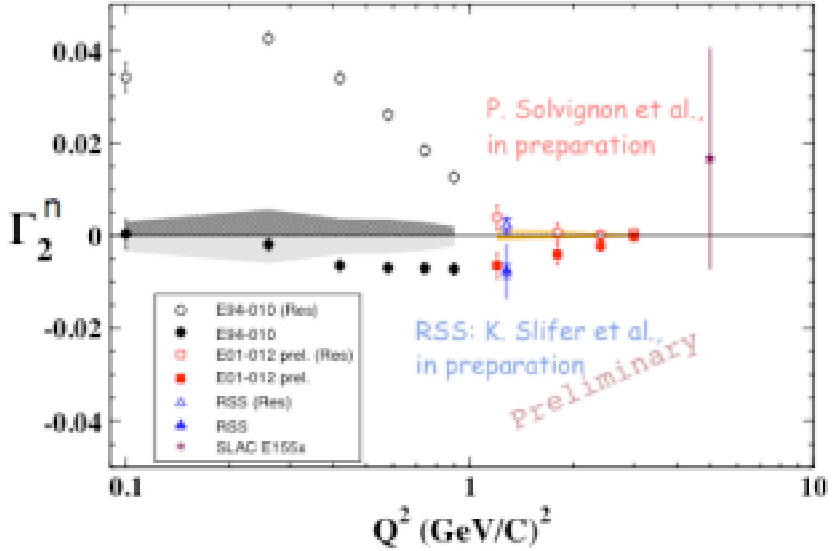


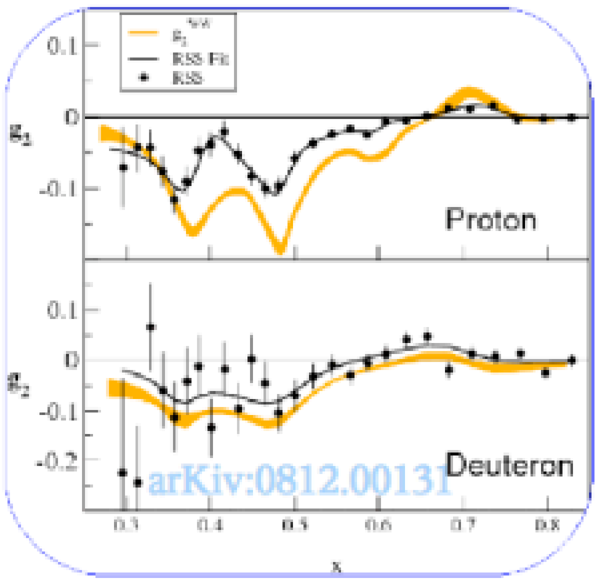
xΔg
DSSV
DNS
GRSV
DSSV Δχ²=1
DSSV Δχ²=2%
GRSV maxg
GRSV ming
0.3
0.2
0.1
0
-0.1
-0.2
10⁻²
10⁻¹
1
x
small-x
0.001· x · 0.05
RHIC
range
0.05· x · 0.2
large-x
x ¸ 0.2

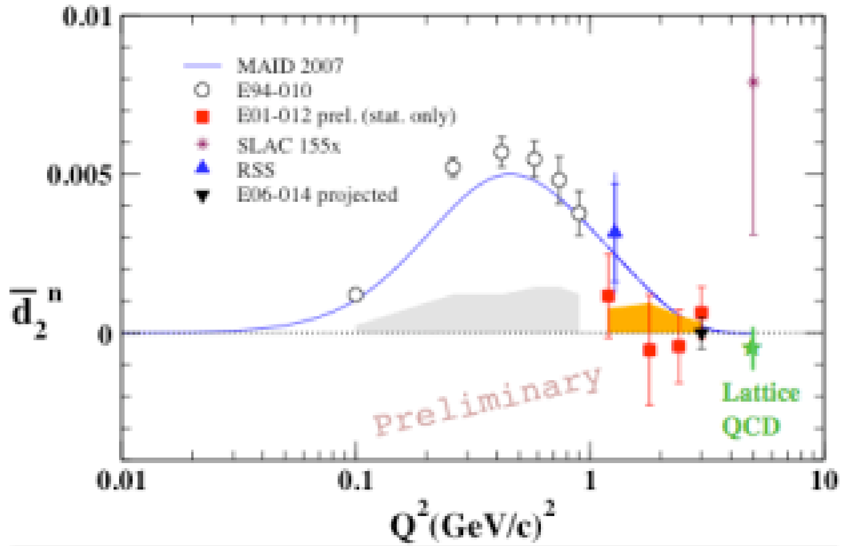
Data on g_2 support the BC sum rule and show departures from the WW sum rule

S. Kuhn







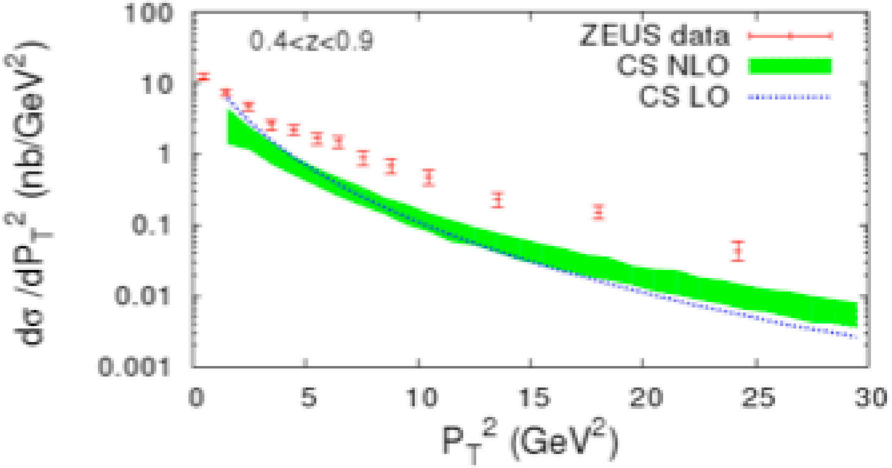


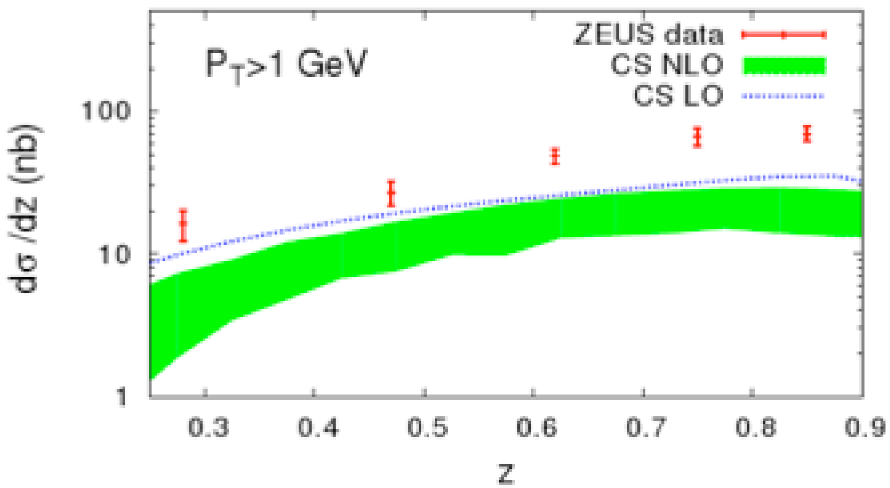
J/Ψ production at HERA. NLO QCD colour singlet model fails

Should we worry? Probably not
but interesting

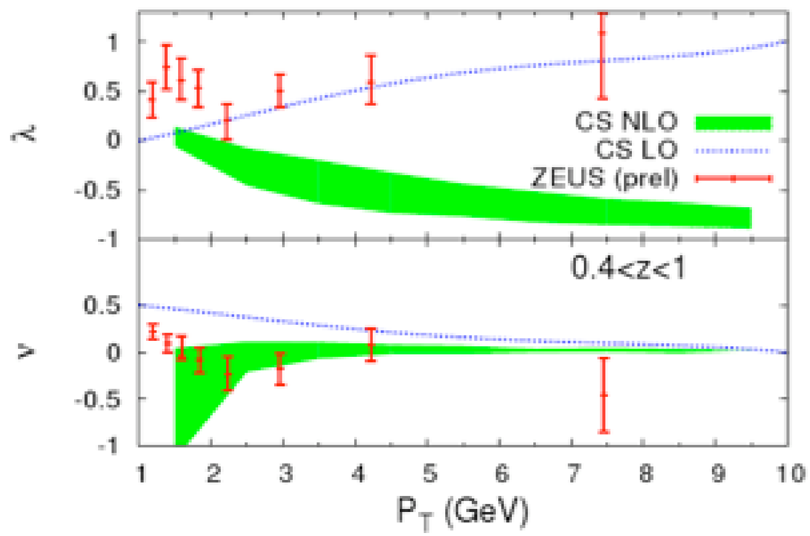
P. Artoisenet, A. Bertolin
P. Faccioli

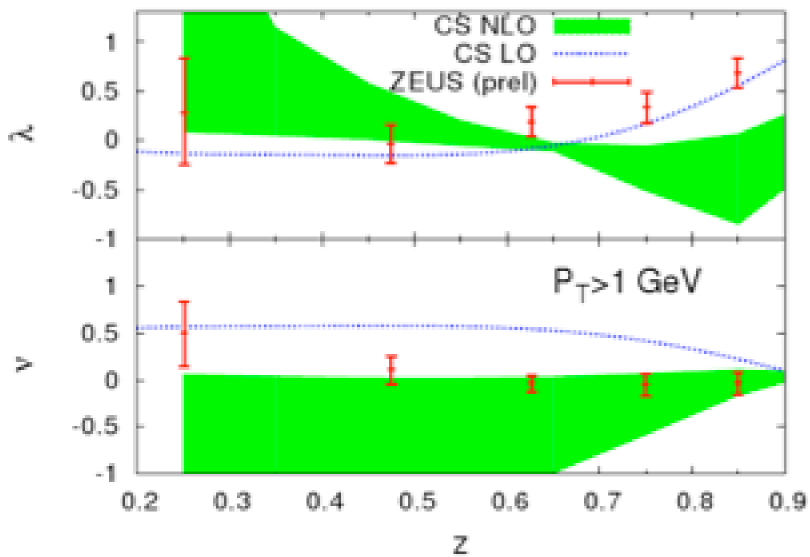
Rate





Polarization





What future for DIS and PDF's?

A. De Roeck

STAR&PHENIX W spin
T. Kempel, J. Balewski

R. Ent, M. Guidal, C. Keppel, S. Liuti

- Jefferson Lab (12 GeV, ELIC?)
- Brookhaven (RHIC, eRHIC?)
- CERN (COMPASS, LHeC?)

A. Magnon

EIC

eRHIC ELIC

A. Deshpande

Electron Ion Collider	Large Hadron e-Collider
• Lumi > 10^{33} cm^{-2} sec^{-1}	• Lumi ~ 10^{33} cm^{-2} sec^{-1}
• CM Energy 30-100 GeV	• CM Energy 1.4 TeV
• Polarized protons & heavy ions (A=p-U)	• Un-polarized protons and heavy ions (A=p-Pb)
• Science focus: QCD, EW(?) & Nucleon Spin	• Science Focus: QCD , EW and BSM Physics

A. Caldwell
M. Lamont
E. Kinney
C. Weiss

LHeC

70 GeV $e^{\pm}$ <--> 7 TeV p -----> $2E_{CM} \sim 1.4$ TeV

compare with HERA $2E_{CM} \sim 0.3$ TeV

Luminosity $\sim 10^{33}\ cm^{-2}s^{-1}$ (3-30 fb^{-1} per year)

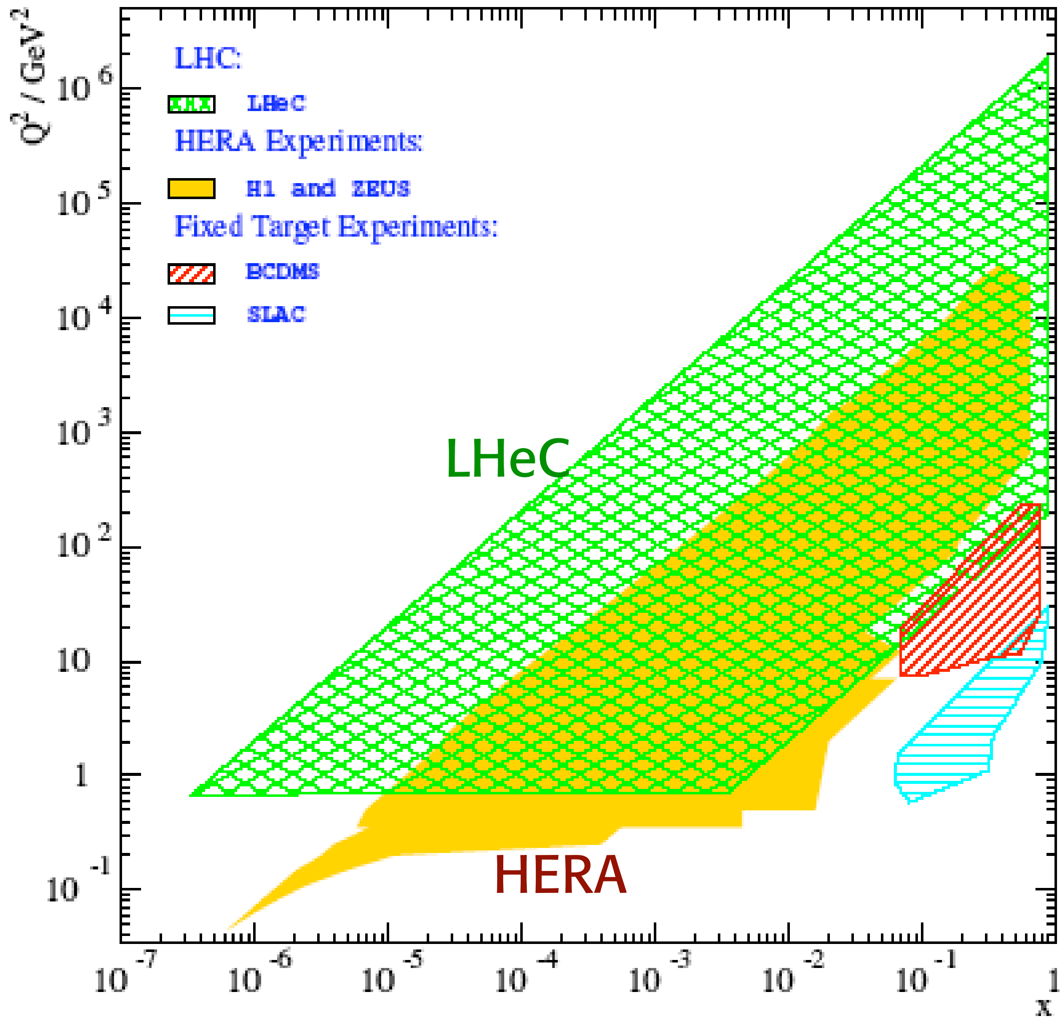
HERA $\sim$ 0.12-0.3 fb^{-1} per year

γ of eP system: $\gamma \sim E/m_{eP} \sim 5$

HERA $\sim \gamma \sim 2.7$

$e^{\pm}$ polarization possible

$\oplus$ Simultaneous running of eP with PP or eA with AA



LHC:
LHeC
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
BCDMS
SLAC
LHeC
HERA
Q^2 / GeV^2
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

Broad physics goals

A. Stasto
O. Behnke, C. Gwenlan
U. Klein
J. Rojo

- Proton structure and precision QCD physics in the domain of x and Q^2 of LHC experiments

- Small-x physics in eP and eA collisions

- Probing the $e^{\pm}$-quark system at ~TeV energy

  eg leptoquarks, excited e*'s, mirror e, SUSY with no R-parity......

- Searching for new EW currents

  eg RH W's,
  effective eeqq contact interactions...

M. Klein

ACCELERATORS

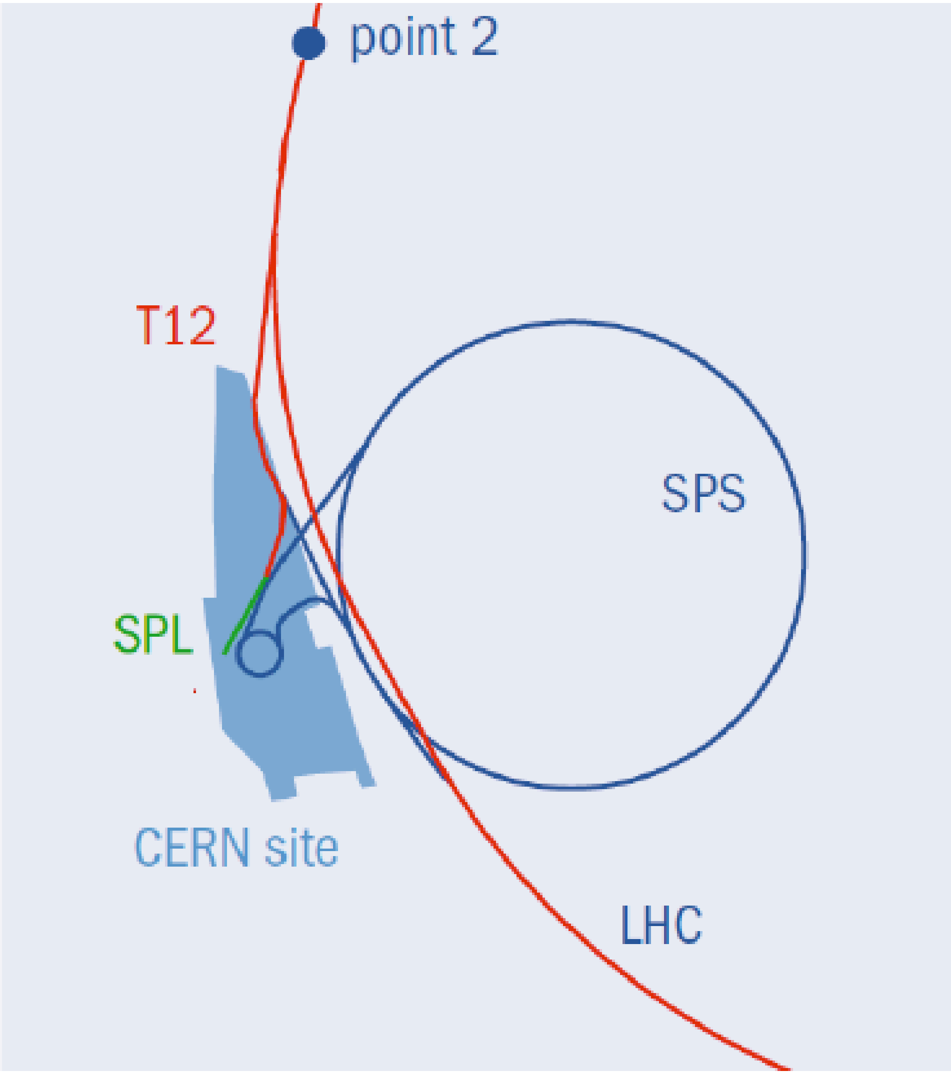


Fig. 4. Sketch of a possible layout to inject an electron beam into the LHC ring, using the SPL and the TI2 connection to the LHC tunnel.

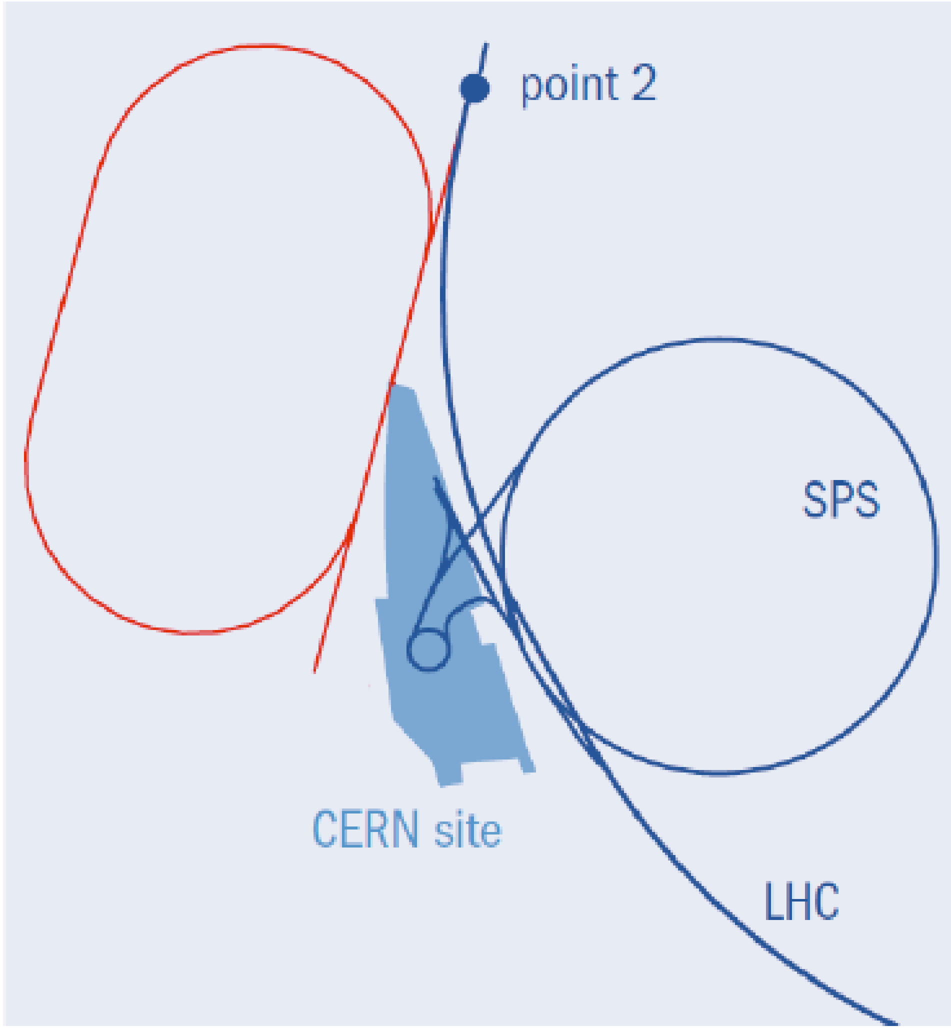


Fig. 5. A possible layout in which an electron linac arrives tangentially to the LHC, after multiple passes around a "racetrack" that makes full use of the linac accelerating structures.

Conceptual Design Report
Large Hadron Electron Collider (LHeC) at CERN

M. Klein

DRAFT - February 2009

1. Introduction

2. Particle Physics and Deep Inelastic Lepton-Nucleon Scattering

1. DIS from 1 to 100 GeV
2. Status of the Exploration of Nucleon Structure
3. Tera Scale Physics

3. The Physics Programme of the LHeC

1. New Physics at Large Scales
2. Precision QCD and Electroweak Physics
3. Physics at High Parton Densities

4. Design Considerations

1. Acceptance and Kinematics
2. A Series of Measurements
3. Compatibility with the LHC
4. Proton, Deuteron and Ion Beams

5. A Ring-Ring Collider Concept

1. Injector
2. Lepton Ring
3. Synchrotron Radiation
4. Interaction Region
5. Installation
6. Infrastructure and Cost

6. A Linac-Ring Collider Concept

1. Electron and Positron Sources, Polarisation
2. Linac
3. Interaction Region
4. Beam Dump
5. Infrastructure and Cost

7. A Detector for the LHeC

1. Dimensions and General Requirements
2. Coil
3. Calorimeters
4. Tracking
5. Options for the Inner Detector Region
6. Detector Simulation and Performance

8. Summary

1. Physics Highlights
2. Parameters
3. Concluding Remarks

Appendix

1. Tasks for a TDR
2. Building and Operating the LHeC

Conclusion

- Very interesting data are still coming out from DIS experiments
- Many problems and challenging goals remain
- The continuation of experiment and theory in this domain is well motivated also in view of the LHC

Conclusion

- Very interesting data are still coming out from DIS experiments
- Many problems and challenging goals remain
- The continuation of experiment and theory in this domain is well motivated also in view of the LHC

It is with great pleasure that, on behalf of all participants,
I thank the Organizers who have done a really great job.
This very efficient Palacio de Congresos is
an ideal venue and the splendid town of Madrid a very
exciting background