HERA and the LHC

A Workshop on the implications on HERA for the LHC physics

15th International Topical Conference on Hadron Collider Physics, HCP2004

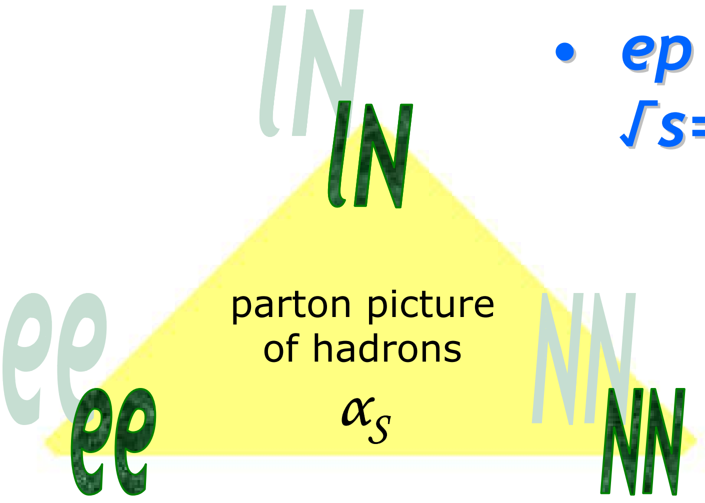
Michigan State University, June, 14-18, 2004

Uta Stösslein (DESY Hamburg)

From HERA to LHC …

Why?

variety of experiments probe universal properties of elementary processes&particles


lN

ee

NN

parton picture
of hadrons

α_S

- *ep @ HERA*
  $\sqrt{s}$=0.32TeV
  - *μN @ SPS*
  - *νN @ FNAL*

- *ee @ LEP*
- *B-factories*

- *$p\bar{p}$ @ TEVATRON*
- *AA @ RHIC*
- *pA @ HERA*

➔HERA is a unique machine for precise understanding of QCD at high energies
➔detailed study of the proton structure : essential for all HE processes involving a proton
and
➔HERA II is running! until 2007 ➔explore the potential of linking the communities

pp @ LHC

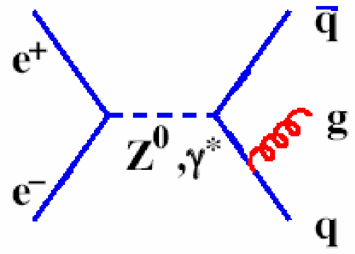
$\sqrt{s}$=14TeV

$m_h \leq \mathcal{O}$(1TeV)

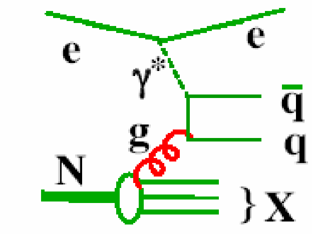
[S.Bethke, LL2004]

Experimental Determination of α_S

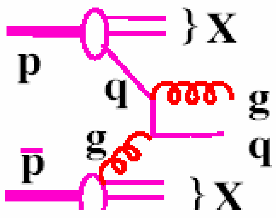
in all reactions which contain quark-gluon vertices



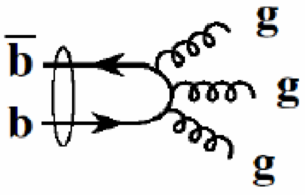
- e^+e^- annihilation
  - total hadronic cross section
  - hadronic decay width of Z bosons and τ leptons
  - jet rates and event shapes observables



- deep inelastic lepton-nucleon-scattering
  - scaling violations of structure functions
  - sum rules of structure functions
  - jet rates and event shapes observables



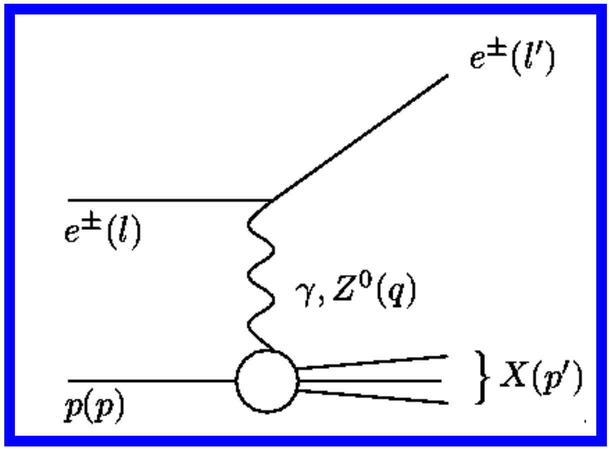
- proton-(anti-)proton collisions
  - jet rates
  - photoproduction
  - inklusive production of b-quarks

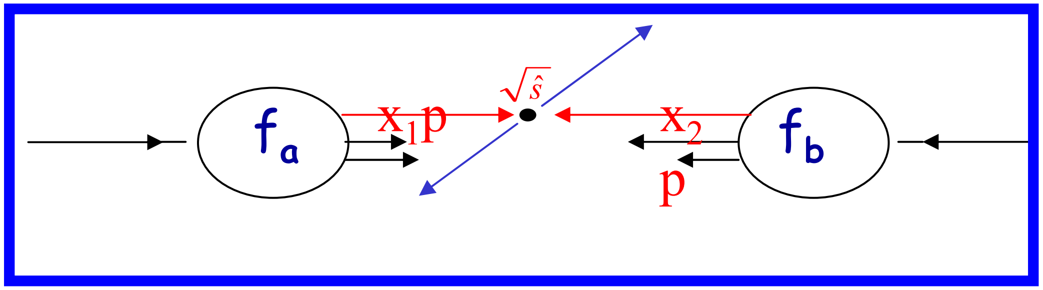


- heavy quarkonia decays

α_S least known of all couplings!

ep and pp Colliders





x = momentum fraction of quark in proton

$$\sigma = \sum_{a,b} \int dx_a \, dx_b \, f_a(x_a, Q^2) \, f_b(x_b, Q^2) \, \hat{\sigma}_{ab}(x_a, x_b)$$

ep collisions (HERA)

- Ideal tool to study the structure of hadrons via deep inelastic scattering

➔ structure functions/parton densities

- Can use the photon as a point-like or hadronic particle through its virtuality
- Main contributions are in the area of QCD: Small-x, diffraction, saturation, high densities, jets…
- Tests of new approaches/QCD

pp collisions (LHC)

- Highest energies reachable, can reach highest masses for new particles production
- Precision often limited by knowledge of quark/gluon structure of proton
- QCD effects need to be controlled to the best of our knowledge

[A.DeRoeck, Startup-WS]

HERA AND THE LHC

A workshop on the implications of HERA for LHC physics

March 2004 - January 2005

Parton density functions

Multijet final states and energy flow

Heavy quarks

Diffraction

Monte Carlo tools

Startup Meeting
March 26-27 2004
Midterm Meeting
11-13 October 2004
CERN, Geneva

Final Meeting
January 2005
DESY, Hamburg

www.desy.de/~heralhc

heralhc.workshop@cern.ch

- identify and quantify measurements to be made at HERA which have impact on LHC physics reach

- encourage and stimulate knowledge transfer between HERA and LHC communities

- examine and improve theoretical and experimental tools related to the goals

- 5 working groups with conveners from LHC and HERA experiments and theory

- framework:
startup at CERN,
March, 26-27, 2004
…working group meetings…
  DESY June, 1-4, 2004
midterm at CERN, Oct 11-13, 2004
finish at DESY, Jan, 17-21, 2005

Workshop Goals ⟺ Working Groups

- **Parton Density Functions (PDFs)**
  gluons and quarks at high and low x from HERA fits
  un-integrated PDFs (k_t factorization)
  parton luminosities and precision cross section
  measurements at LHC

- **Multi-jet final states and energy flows**
  underlying event and minimum bias
  rapidity gaps and survival probabilities
  multi-jet topologies and multi-scale QCD
  parton shower/ME matching

- **Heavy Quark (HQ) production: charm, beauty, quarkonia**
  production cross sections
  fragmentation
  charm and beauty in the proton distributions

Working Groups cont'd

- **Diffraction**
  - diffractive PDFs and (non)factorization
  - rapidity gaps and physics with forward proton tagging
  - forward physics and low-x dynamics
  - heavy ions and QCD at high parton density

- **Monte Carlo tools**
  - general Monte Carlos (Pythia, Herwig, Phojet)
  - new Monte Carlos with k_t factorization
  - NLO calculation (MC@NLO, NLOLIB...)
  - MC validation & tuning (JetWeb, HZTOOL)

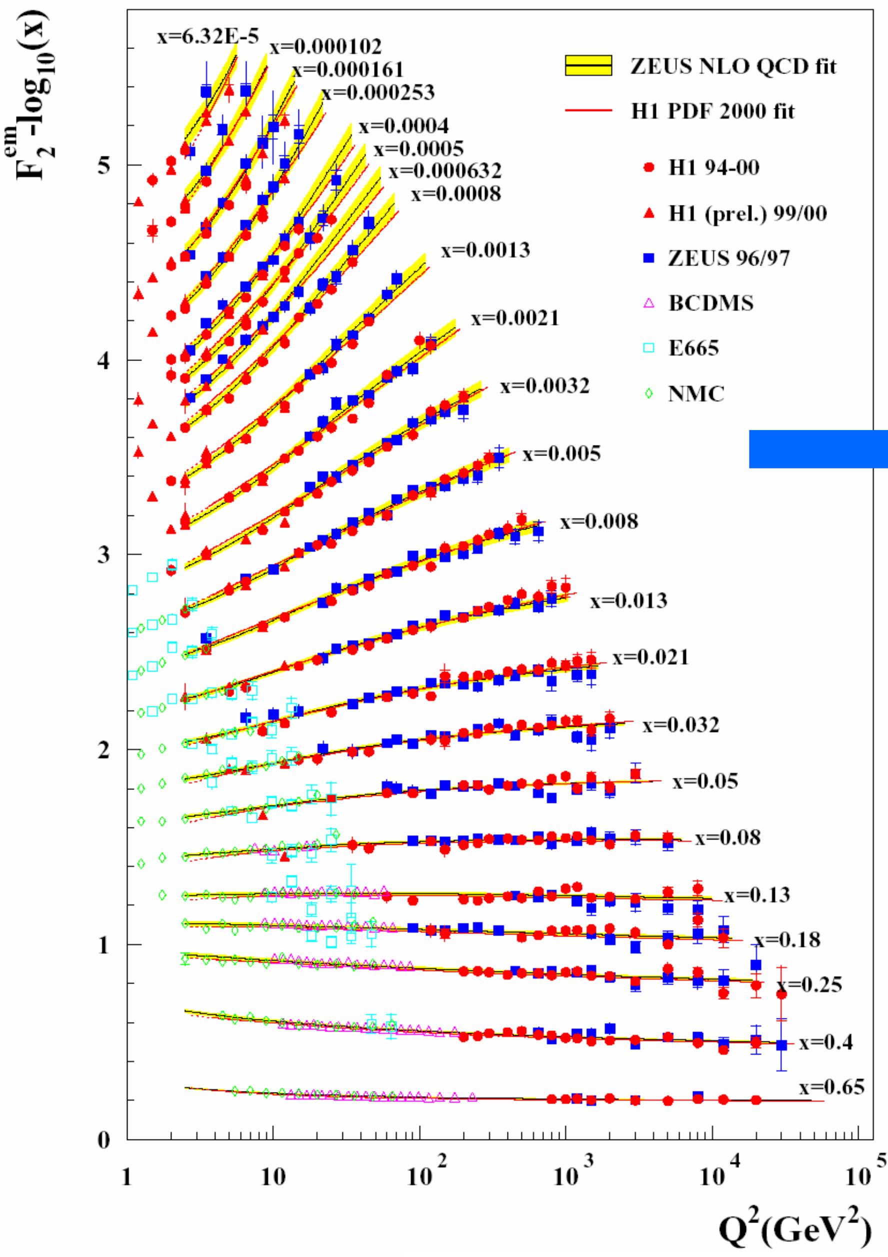
➔ illustrate workshop goals with my personal selected topics

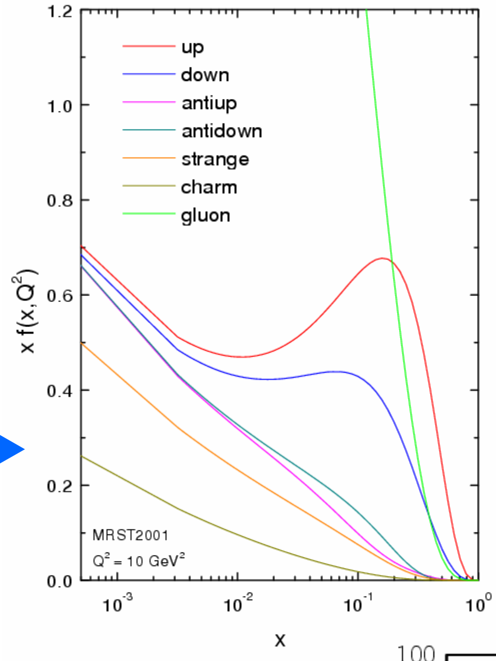
Outline

- **high precision PDF fits**
- **parton densities at high x**
- **Higgs and beauty**
- **multi-particle interactions and underlying events**
- **phenomena at low x**
- **Higgs and diffraction** (talk by B.Cox)
- **concluding remarks**

→many thanks to the speakers/conveners for delivering the work and material, see also at www.desy.de/~heralhc for further details

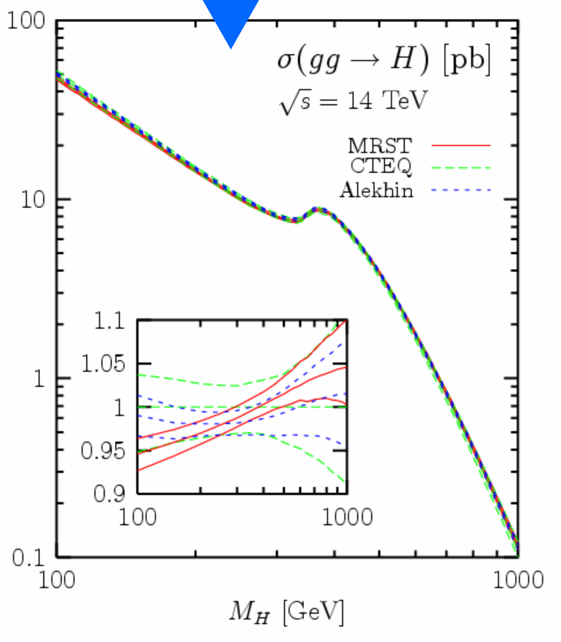
Structure of the Proton : PDFs from HERA





to

LHC



Parton Distributions at LHC

- interpretation of SM and BSM cross sections requires precision PDFs: $\delta\sigma_{th} = \delta\sigma_{pdf} + \ldots$
- ‘standard candle’ processes

$$\begin{array}{rl}
\text{associate production with } W/Z: & q\bar{q} \longrightarrow VH \\
\text{massive vector boson fusion}: & qq \longrightarrow Hqq \\
\text{the gluon gluon fusion mechanism}: & gg \longrightarrow H \\
\text{associate production with top quarks}: & gg, q\bar{q} \longrightarrow t\bar{t}H
\end{array}$$

➔ Higgs/new physics discovery requires to know PDFs

- measure luminosity to 1% using PDFs via Z and W production?

➔ How well do we know the current PDF uncertainties really?

How well do we know α_S?

- What we may learn more about PDFs from LHC measurements (e.g. high-E_T jets → gluon, W^+/W^- → sea quarks)?

… cont’d

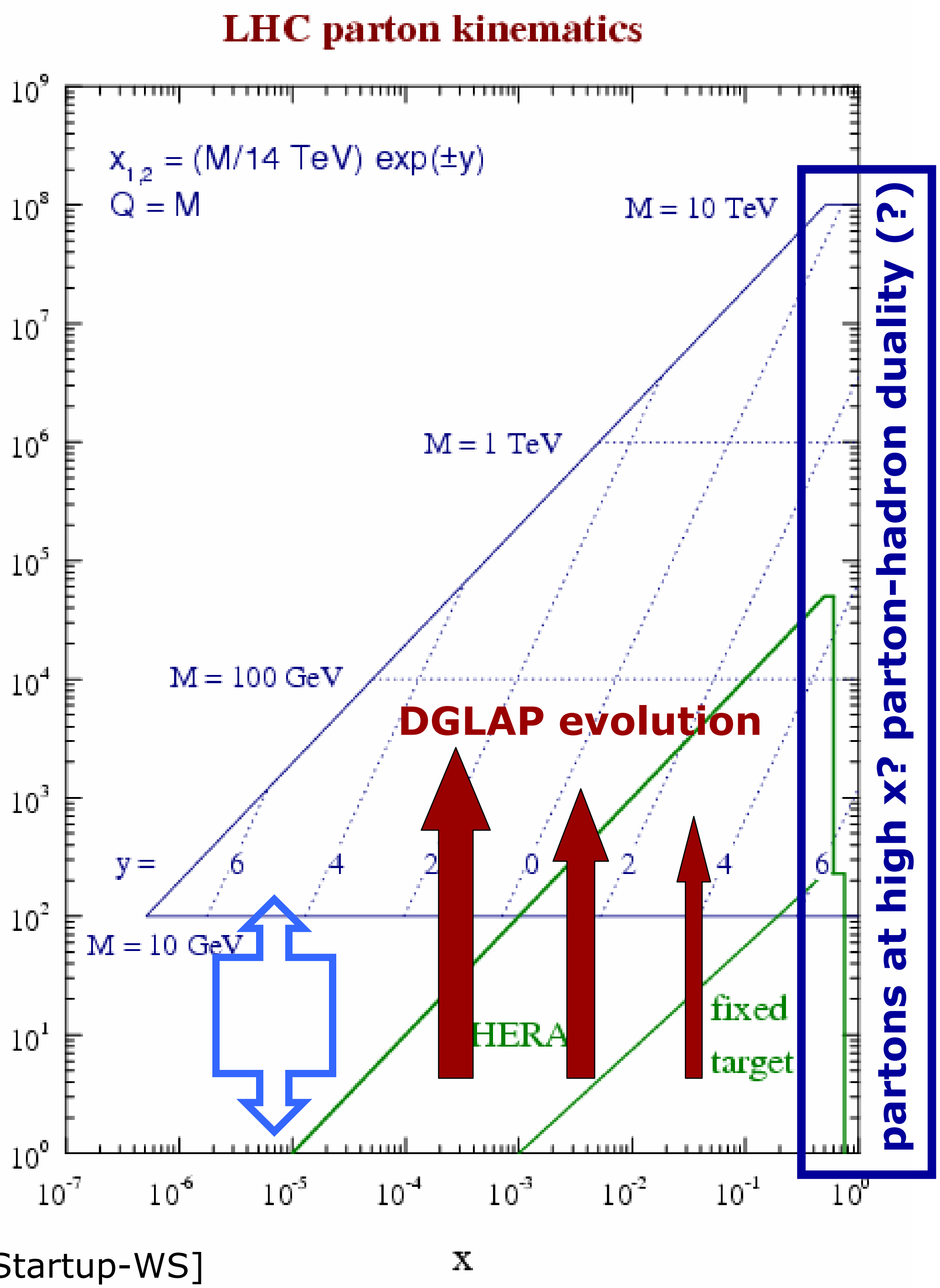
momentum fractions x_1 and x_2 determined by mass and rapidity of **X**

x dependence of $f(x,Q^2)$ determined by fit to ***eN*** data, Q^2 dependence determined by **DGLAP** equations:

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

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

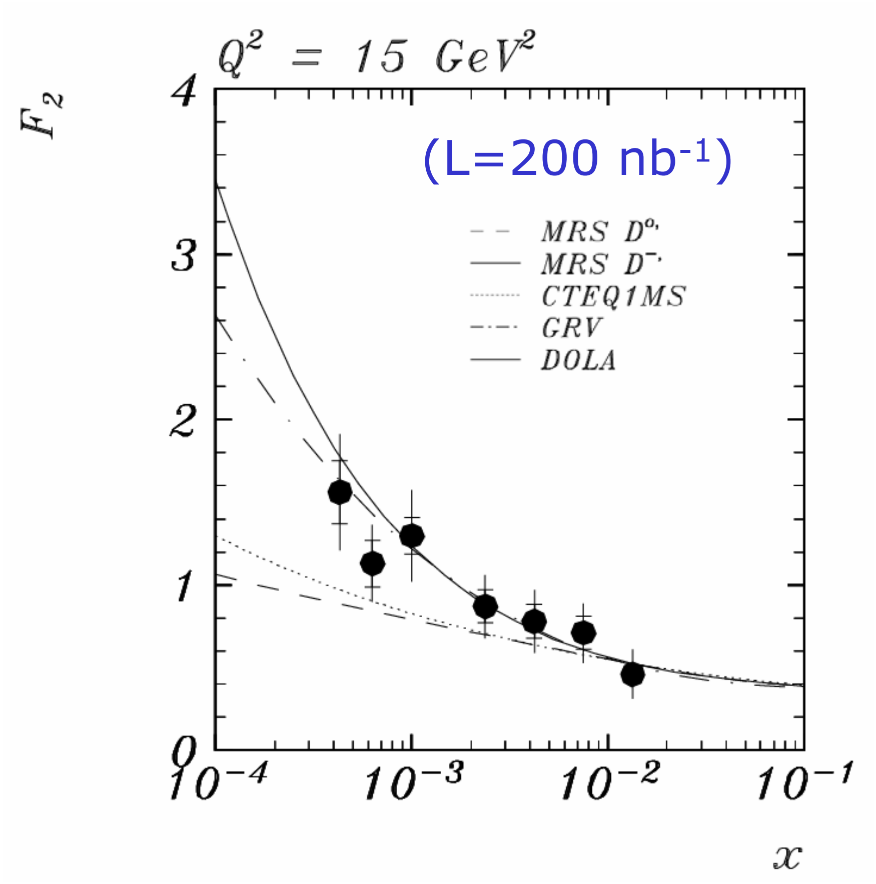
What is the validity range of NLO/NNLO DGLAP at small x? Are higher-orders $\sim \alpha_S^n \log^m x$ **important?**



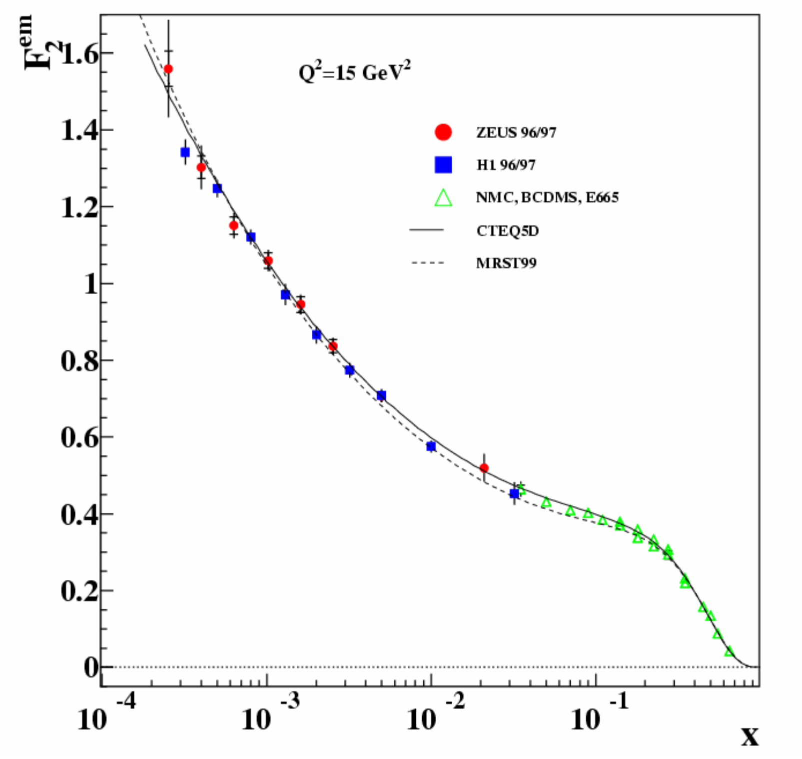
[J.Stirling, Startup-WS]

What HERA DIS Data taught us

DIS 1993



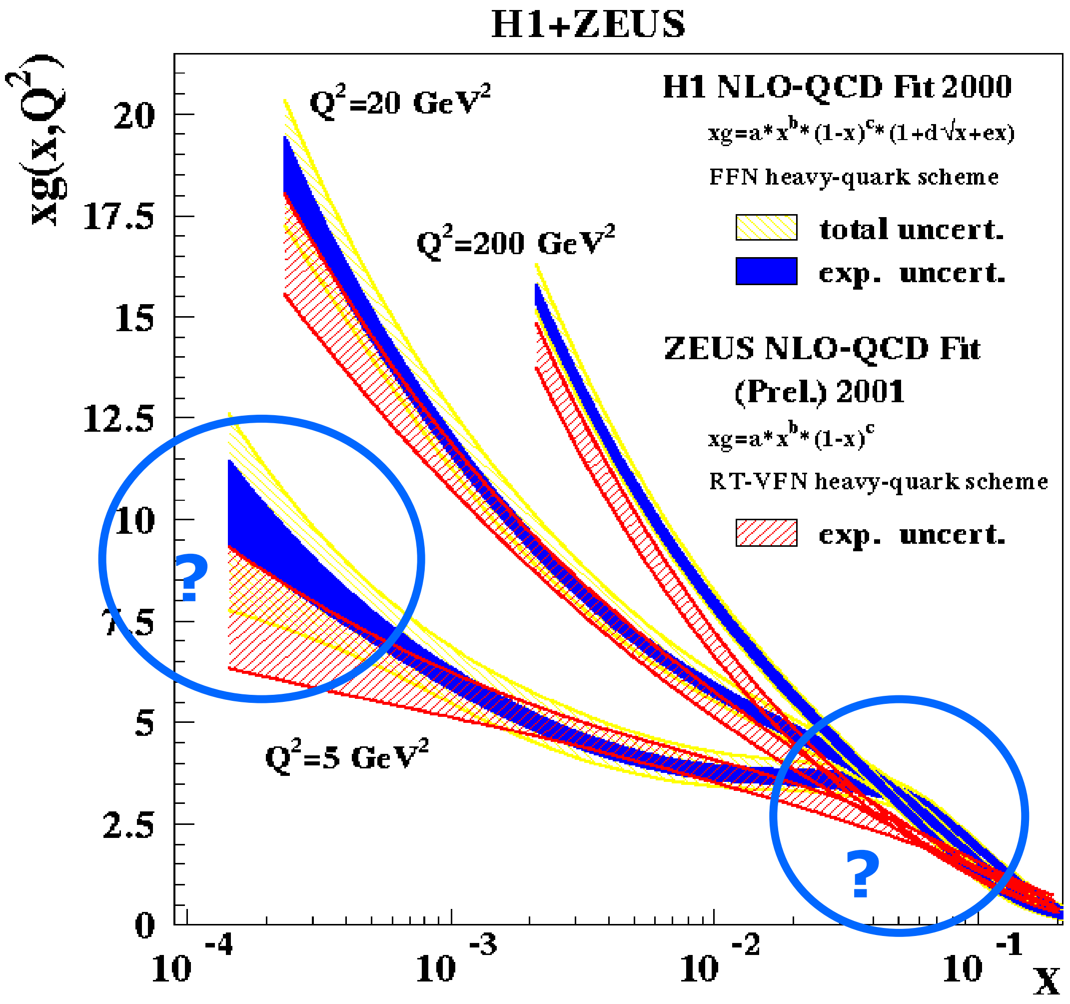
… and now



proton structure known to few %
in a large area of x and Q^2

Gluon from HERA

➔ large PDF uncertainties have potentially serious consequences for the determination of production rates at LHC



high x and low x partons are correlated by momentum sum rule

for gluon:
low-to-mid x: determined by F_2 scaling violations
→ HERA II
further constrained by F_L
mid-to-high x: better constraints possible by
→ Tevatron Run II data
may help here, but by how much ?
→ include HERA jet data

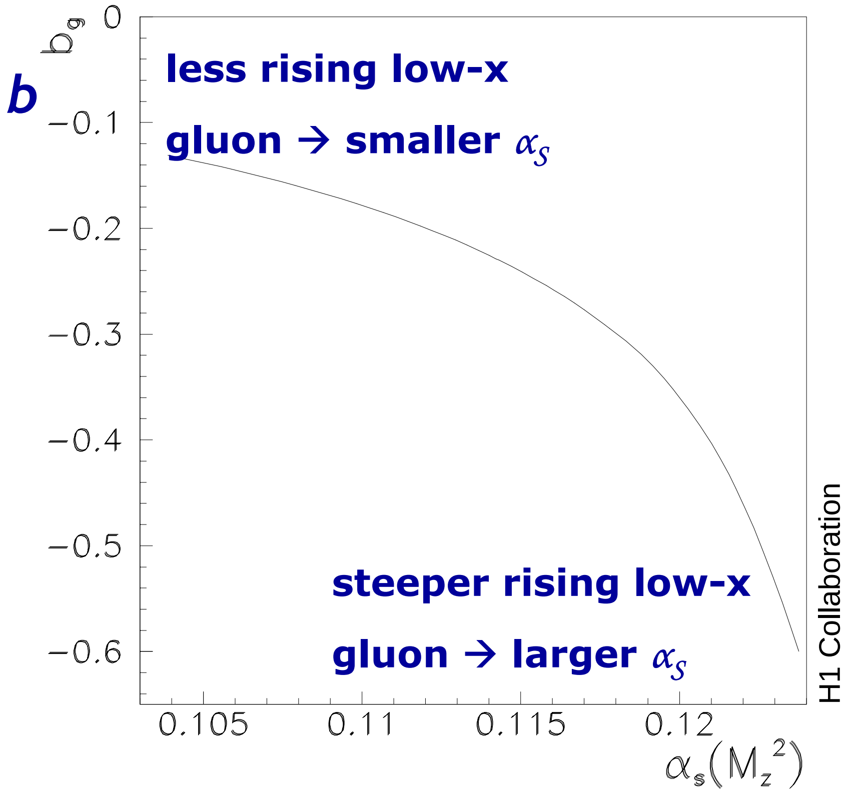
[H1 Collab., C. Adloff et al., EPJ **C19** (2001) 289]

[M.Klein, DESY-WS-04, R.Wallny, PhDThesis01]

Correlation of α_s and $xg=ax^b(1-x)^c$

as observed in QCD NLO fits of
H1 and BCDMS DIS data

low x (HERA near to x=0.002) → **F_L**



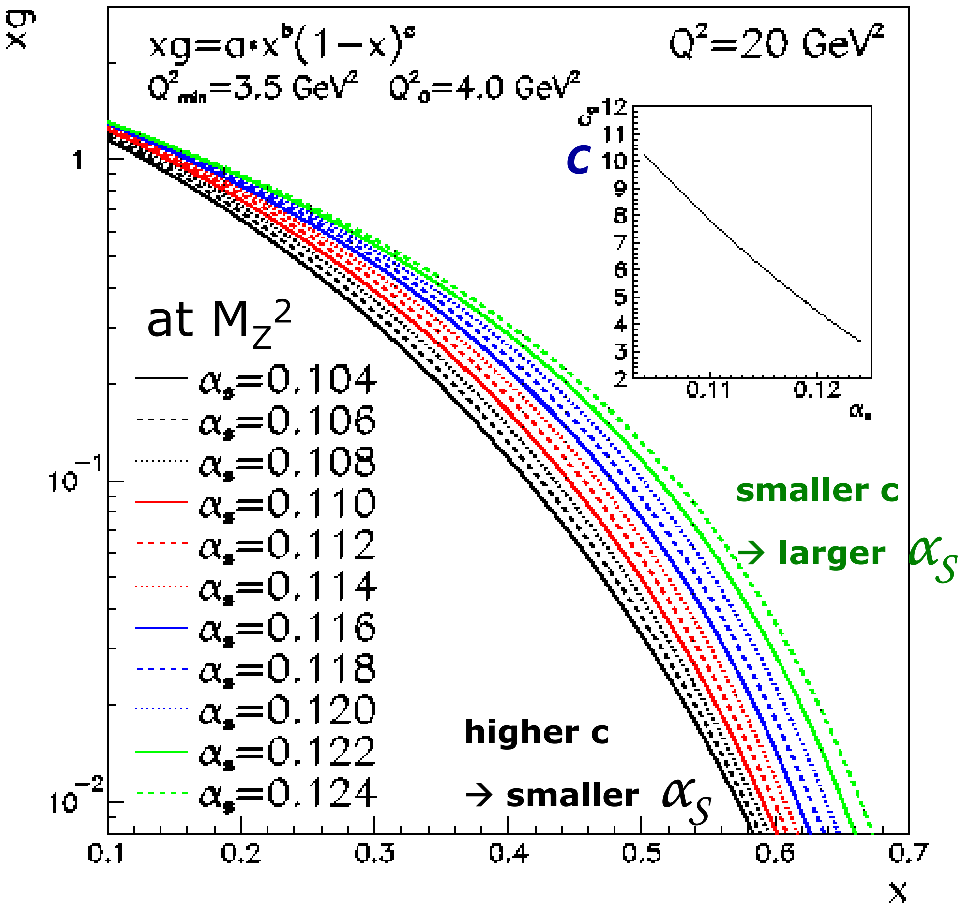
less rising low-x

gluon → smaller α_s

steeper rising low-x

gluon → larger α_s

high x (HERA near to x=0.1) → **jets?**



smaller c

→ larger α_s

higher c

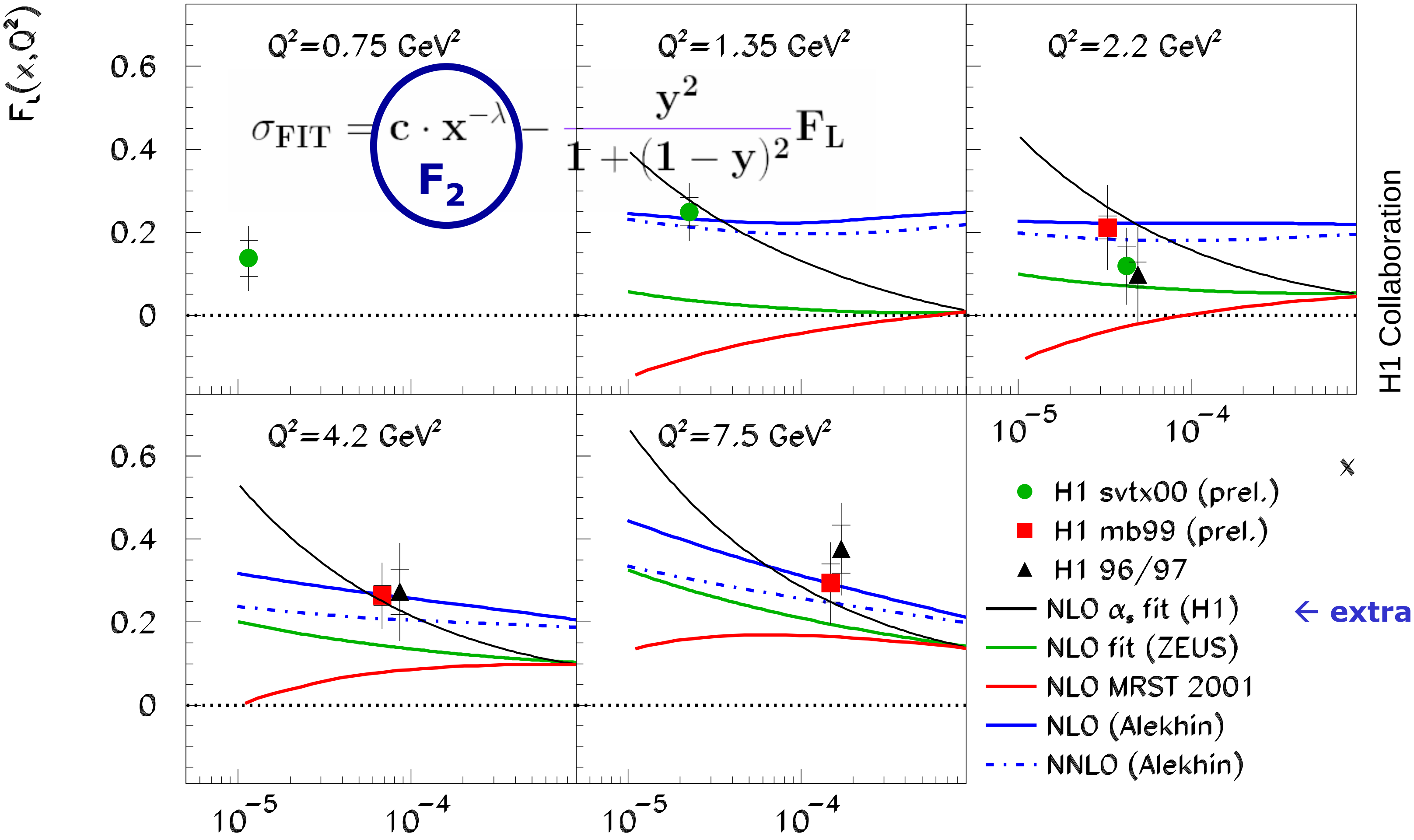
→ smaller α_s

The accurate determination of α_s will profit from the longitudinal structure function $F_L(x)$ at low x and from adding jets and more precise DIS data at mid-to-high x

➔ all will provide additional constraints on the gluon distribution

[E.Lobodzinska, DESY-WS-04]

F_L from reduced inclusive DIS cross section



$$\sigma_{\mathrm{FIT}} = \underbrace{c \cdot x^{-\lambda}}_{F_2} - \frac{y^2}{1+(1-y)^2} F_L$$

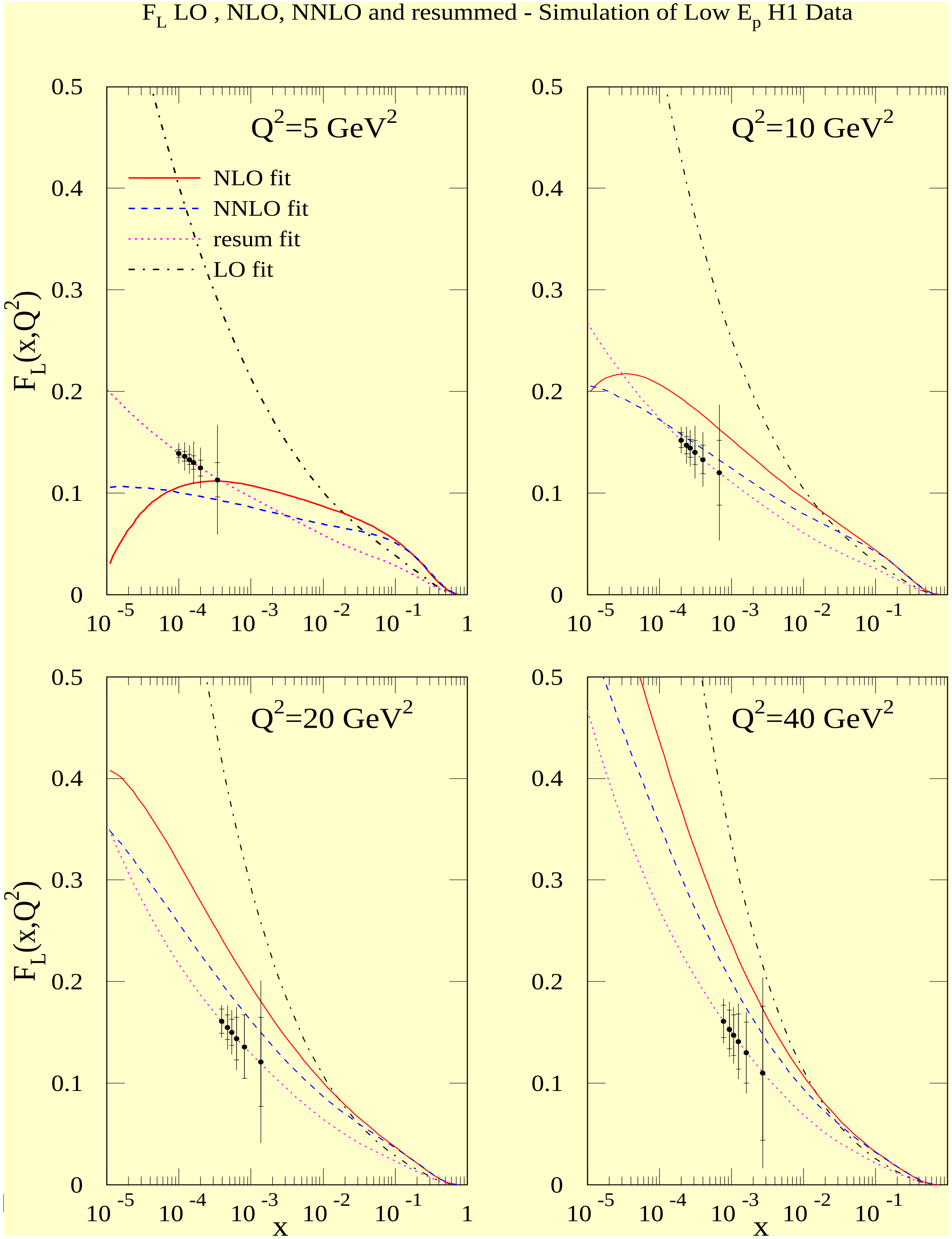
← extrapol < 3.5 GeV²

H1 determination of F_L has two limitations:

- small x & F_L extraction needs assumptions on F_2
- x-dependence of F_L can not be determined

Towards a F_L measurement

[R.Thorne, DIS04-WS,
M.Klein, DESY-WS-04]

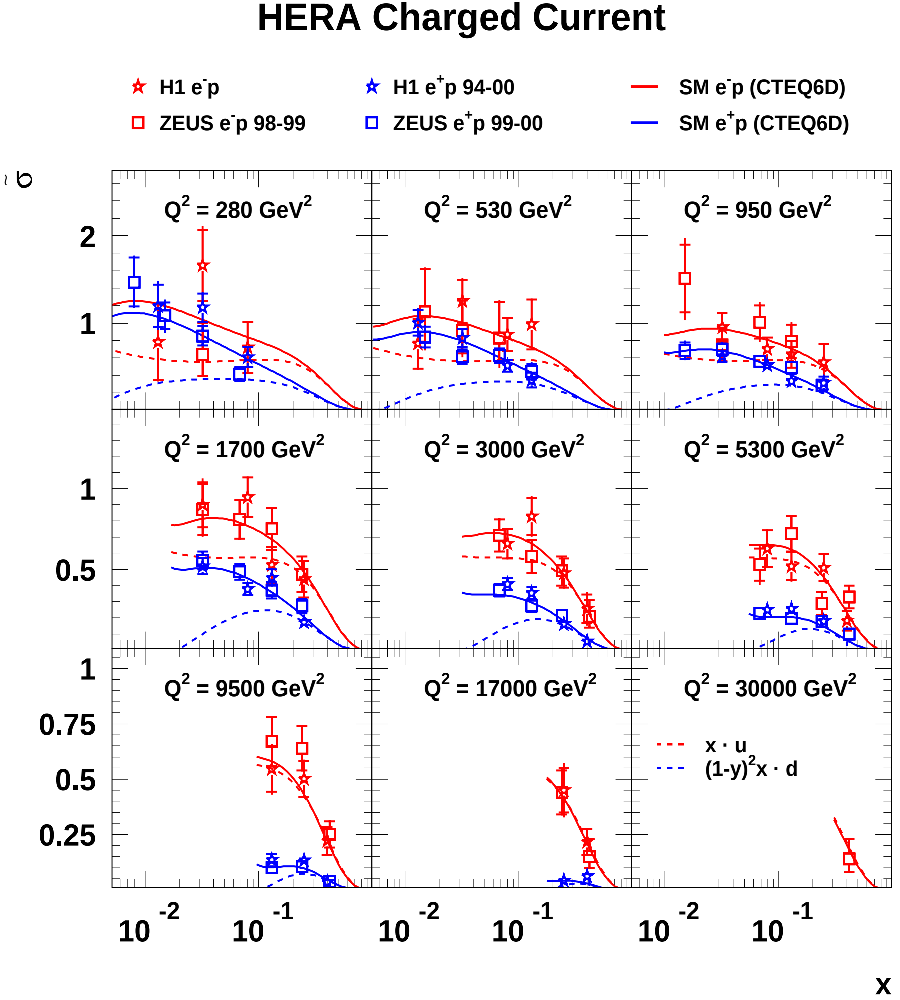


accurate F_L data
at low x and Q^2
are required to
test HO QCD and
pin down
$xg(x,Q^2)$ and α_S

such a measurement is
challenging but possible at HERA
via Rosenbluth separation
using protons at e.g.
400, 465, 575 in add. to 920 GeV

it delivers also data
at large x, medium Q2
besides measuring the
W,E dependence of
various cross sections, e.g.
for vector mesons

H1 and ZEUS - CC HERA I data



Charged Current Cross Sections

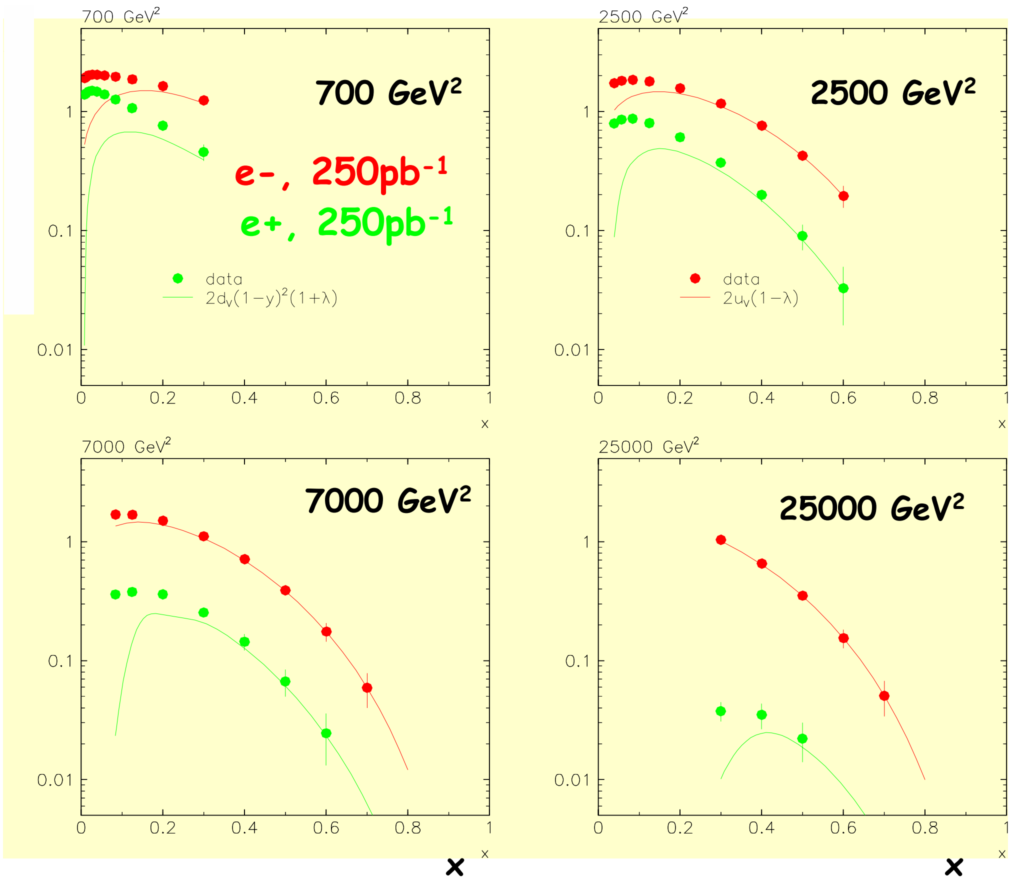
unfolding of parton distributions using CC and NC cross sections … important!

but difficult to reach very large x>0.7

--- $\sigma(e^-p) \sim x\,(u+c) + (1-y^2)\,x\,(\bar{d}+\bar{s})$

--- $\sigma(e^+p) \sim x\,(\bar{u}+\bar{c}) + (1-y^2)\,x\,(d+s)$

simulated reduced cc cross section

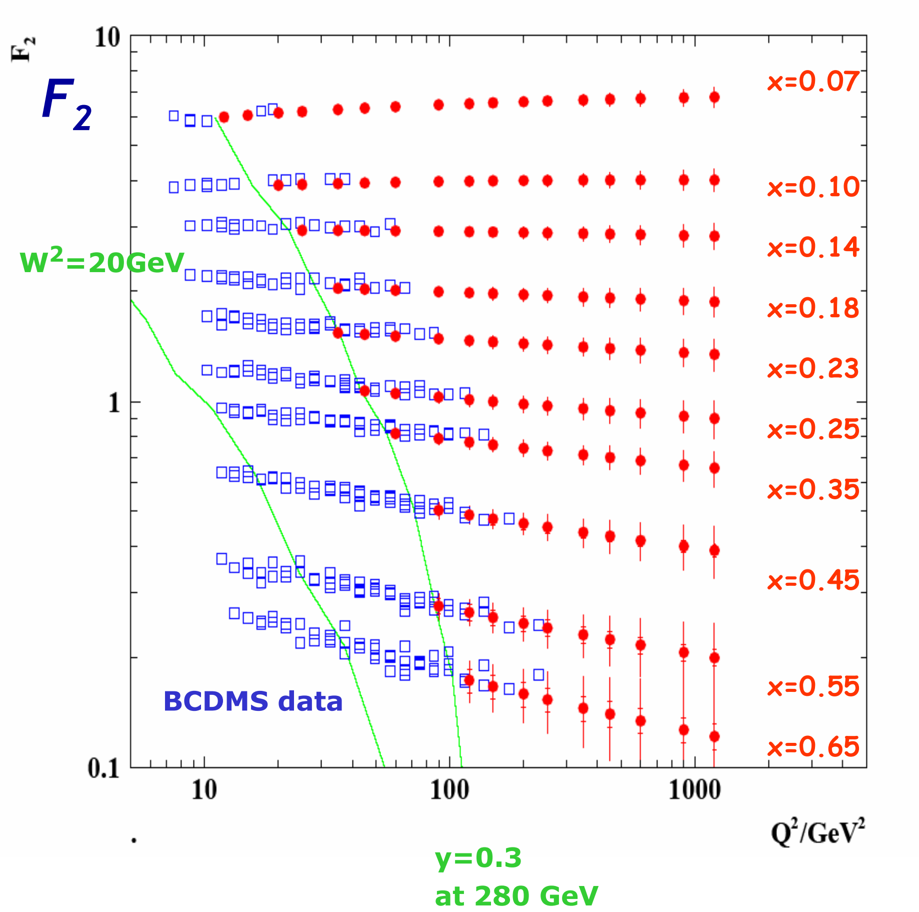


HCP 2004 ***Uta Stösslein*** **HERA and the LHC**

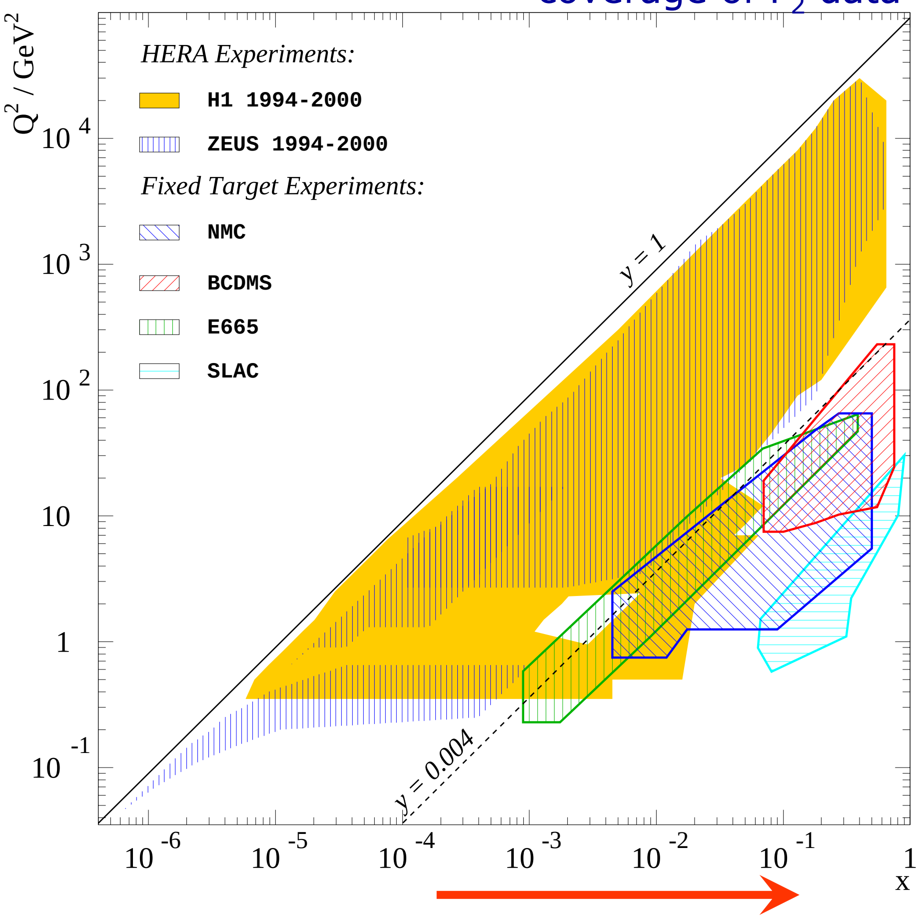
Access of Large x at Lower Q^2 using E_P=460 GeV

[M.Klein, DESY-WS-04]

H1 simulation 460 GeV*27.5 GeV L=30 pb^{-1}



coverage of F_2 data



extend measurements to lowest y with

- Simulation of resonance region (SOPHIA)
- Low noise calorimetry (upgraded electr.)
- Upgraded Forward tracking

[A.M.Cooper-Sarkar, C.Gwenlan,
DESY-WS-04]

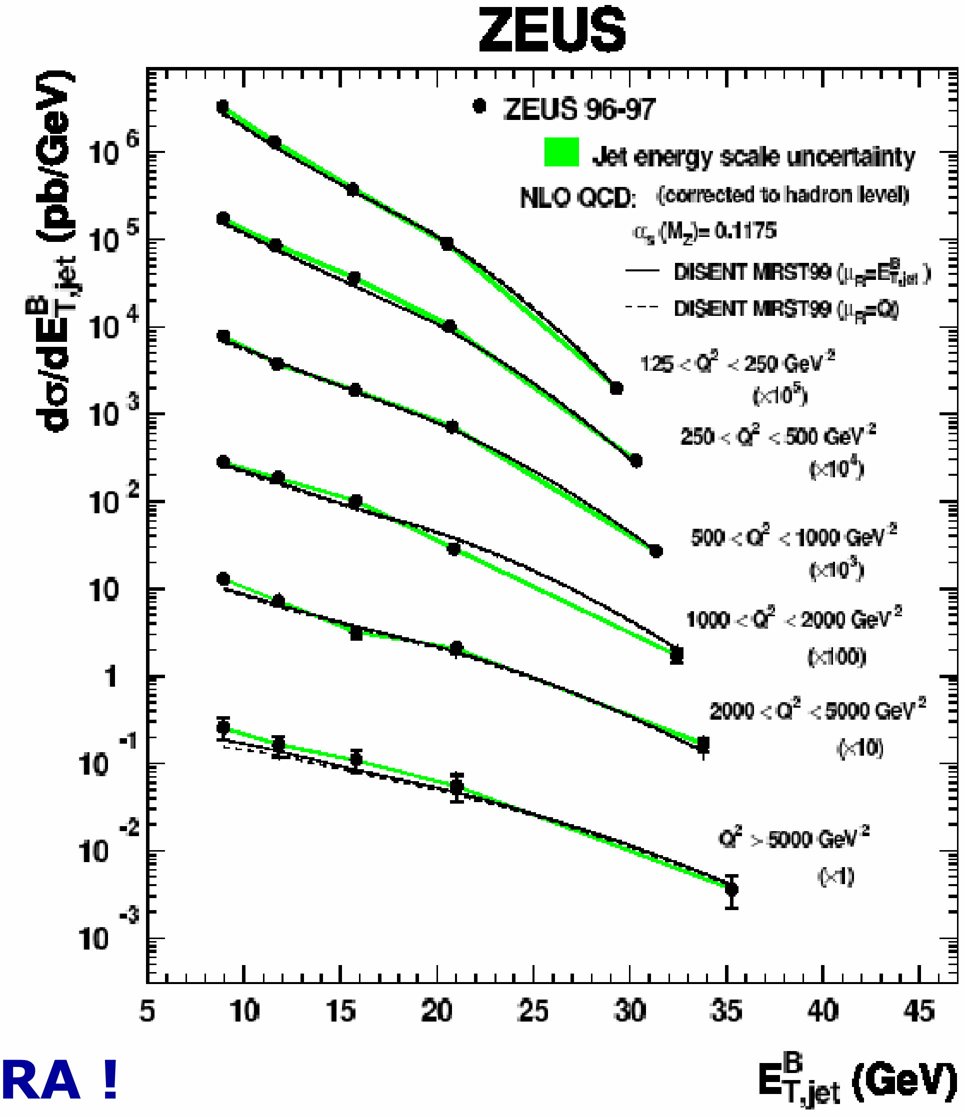
Add Inclusive DIS Jet Data

INCLUSIVE JET DEEP INELASTIC SCATTERING

(ZEUS Coll., Phys. Lett. B547 (2002) 164)

We have chosen to use only the 6 cross sections differential in E_T^B in bins of Q^2. This avoids correlations between cross sections with same events

30 NEW DATA POINTS ⟶



Precision jet data from HERA !

[A.M.Cooper-Sarkar, C.Gwenlan,
DESY-WS-04]

Add Photoproduction Dijet Data

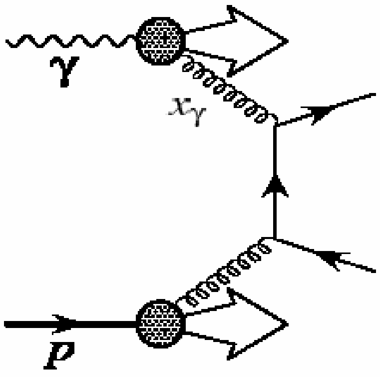
TWO-JET PHOTOPRODUCTION

AT HIGH-ET

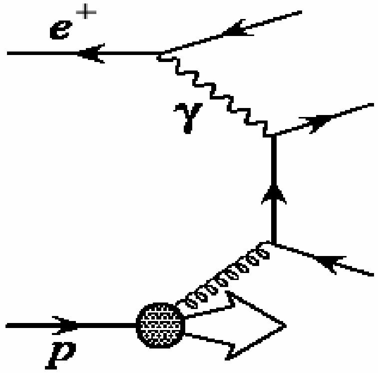
(ZEUS Coll., Eur. Phys. J C23 (2002) 4)

We have chosen only the 6 cross sections at high x_γ (to avoid complications from uncertainty in photon structure)

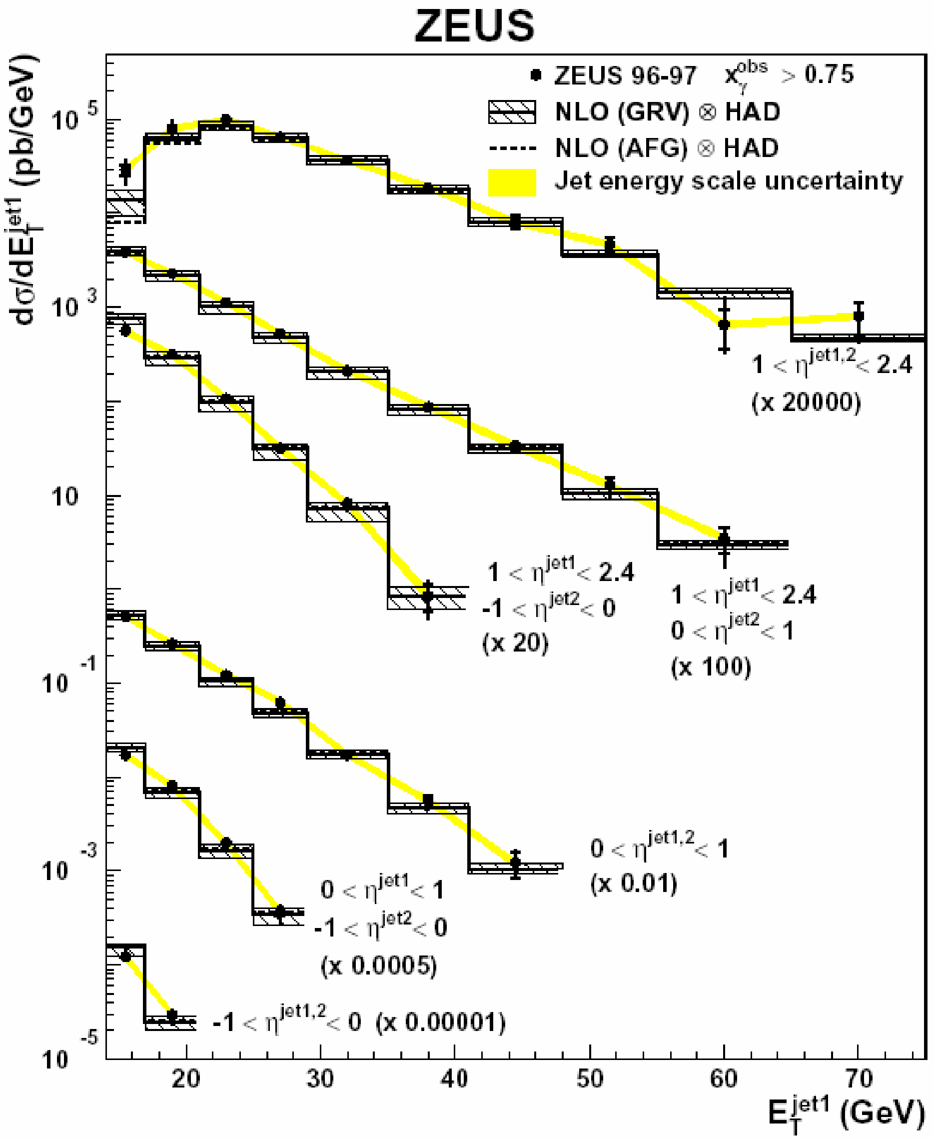
38 NEW DATA POINTS ⟶



$x_\gamma < 0.75$

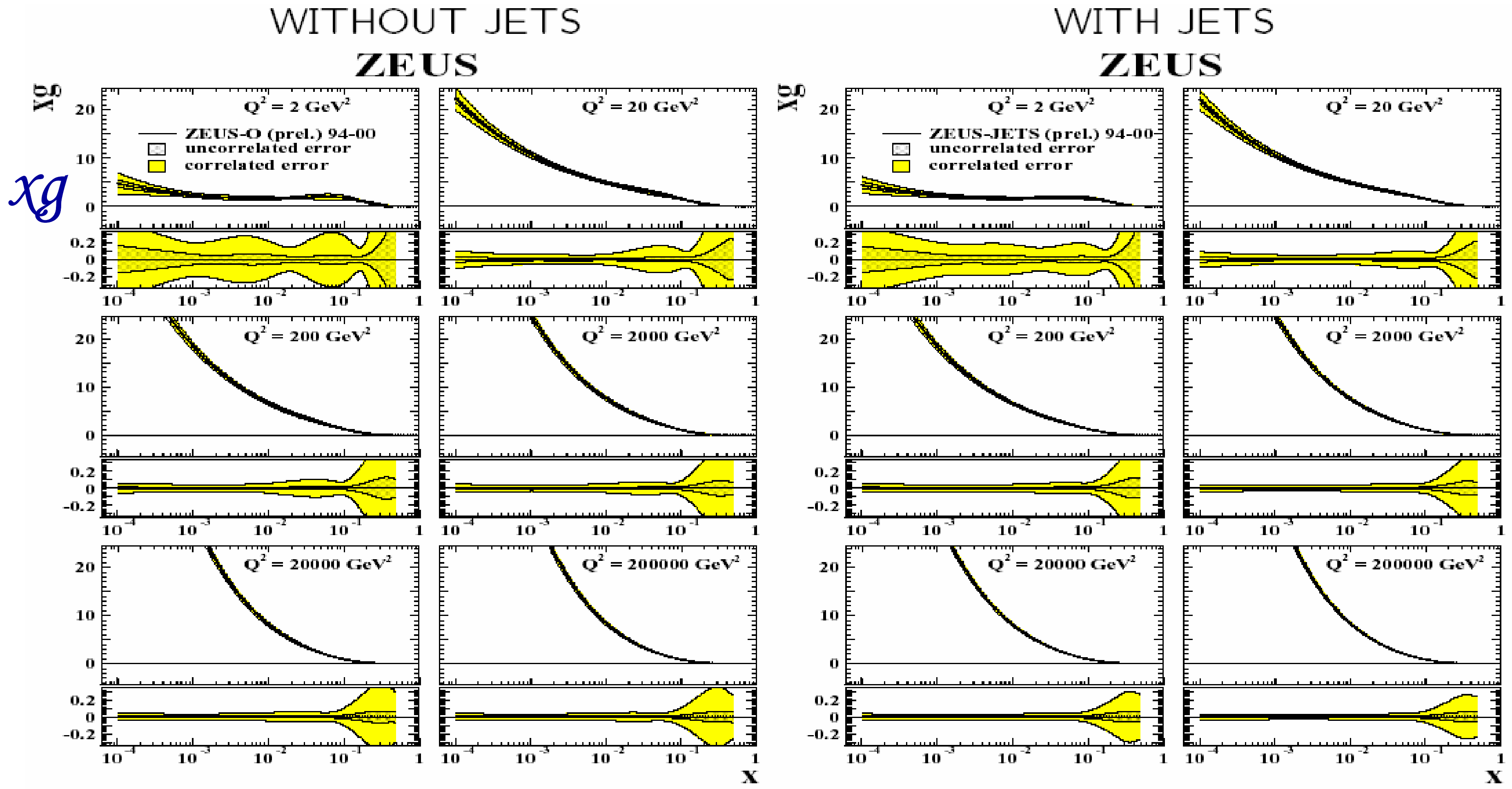


$x_\gamma > 0.75$



Extrapolation to LHC Energies

[A.M.Cooper-Sarkar, C.Gwenlan, DESY-WS-04]

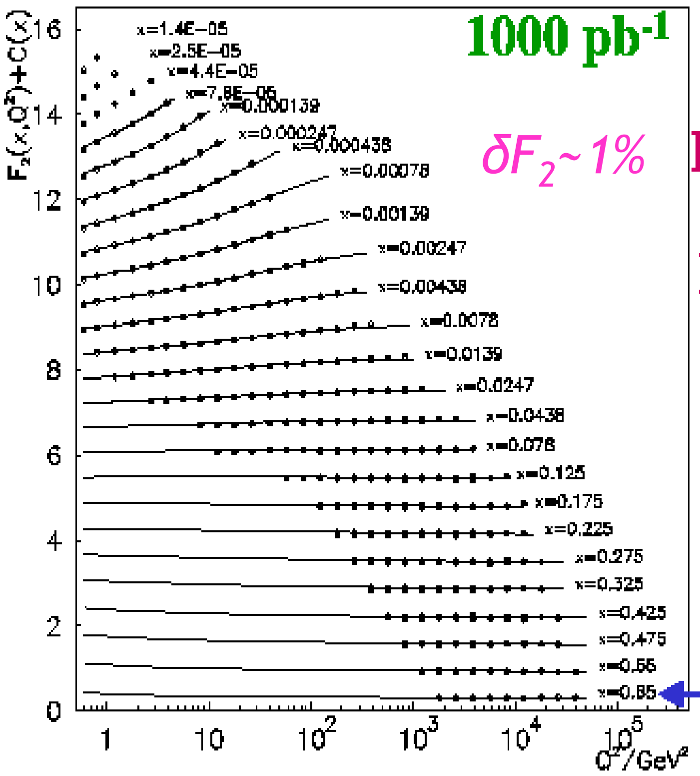


- Uncertainty in high-x (> 0.1) gluon can still be large, even at LHC scales
  → dominant uncertainty in production rates for many processes at LHC
- Addition of HERA jet data provides visible improvement even at LHC energies

HERA-II, now starting

[simulation:M.Botje,C.Pauscaud,
M.Klein,HERA-WS-97]

- The Structure Function F_2



High Precision F_2

Large x, Q^2 range

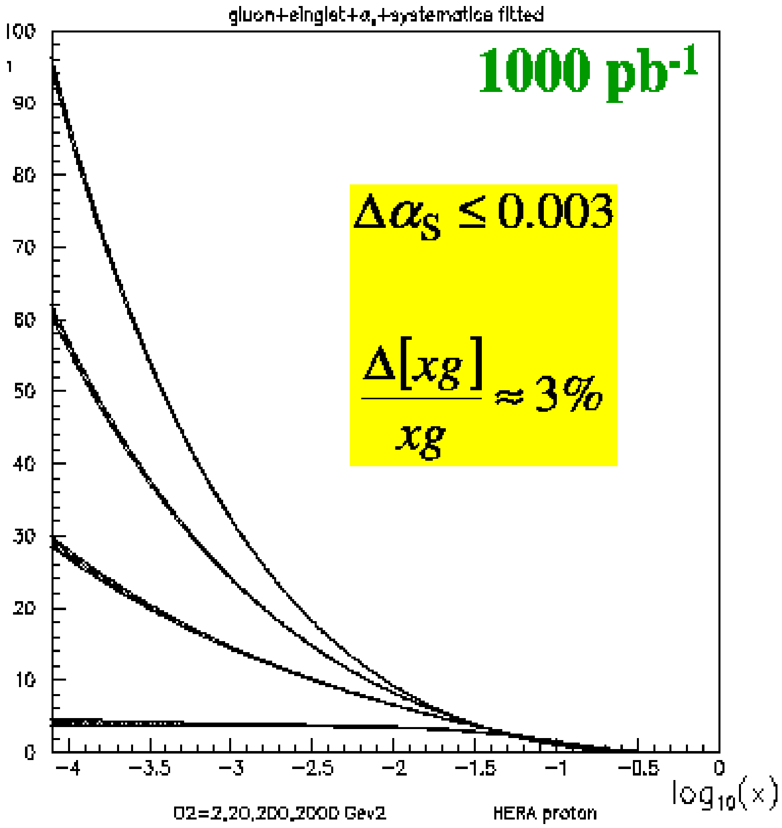
→

α_S and xg

$x = 0.65$

$Q^2 = 4 \times 10^4$

fit to HERA data only



High precision at large Q², precise determination of the gluon distribution, flavor separation (via CC), u(x)/d(x) for x→1,…

→ **but what will be the status of the theoretical uncertainties?**

NNLO singlet splitting functions

new

[S.Moch, DESY-WS-04]
[Moch,Vermaseren,Vogt
hep-ph/0403192 & 0404111]

NNLO singlet splitting functions

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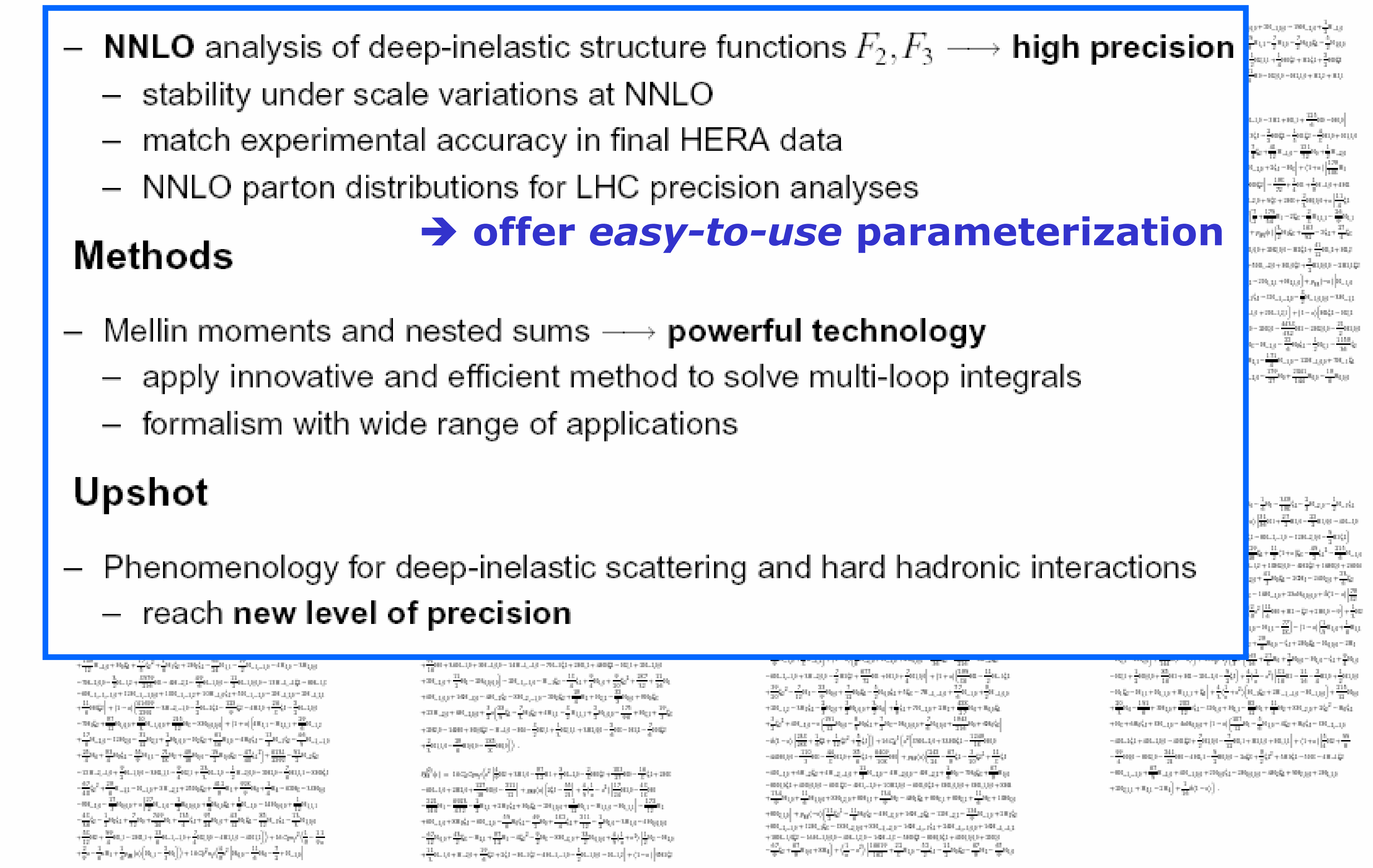


- **NNLO** analysis of deep-inelastic structure functions $F_2, F_3 \longrightarrow$ **high precision**
  - stability under scale variations at NNLO
  - match experimental accuracy in final HERA data
  - NNLO parton distributions for LHC precision analyses

➔ **offer *easy-to-use* parameterization**

Methods

- Mellin moments and nested sums $\longrightarrow$ **powerful technology**
  - apply innovative and efficient method to solve multi-loop integrals
  - formalism with wide range of applications

Upshot

- Phenomenology for deep-inelastic scattering and hard hadronic interactions
  - reach **new level of precision**

NNLO singlet splitting functions

[S.Moch, DESY-WS-04]
[Moch,Vermaseren,Vogt
hep-ph/0403192 & 0404111]

new

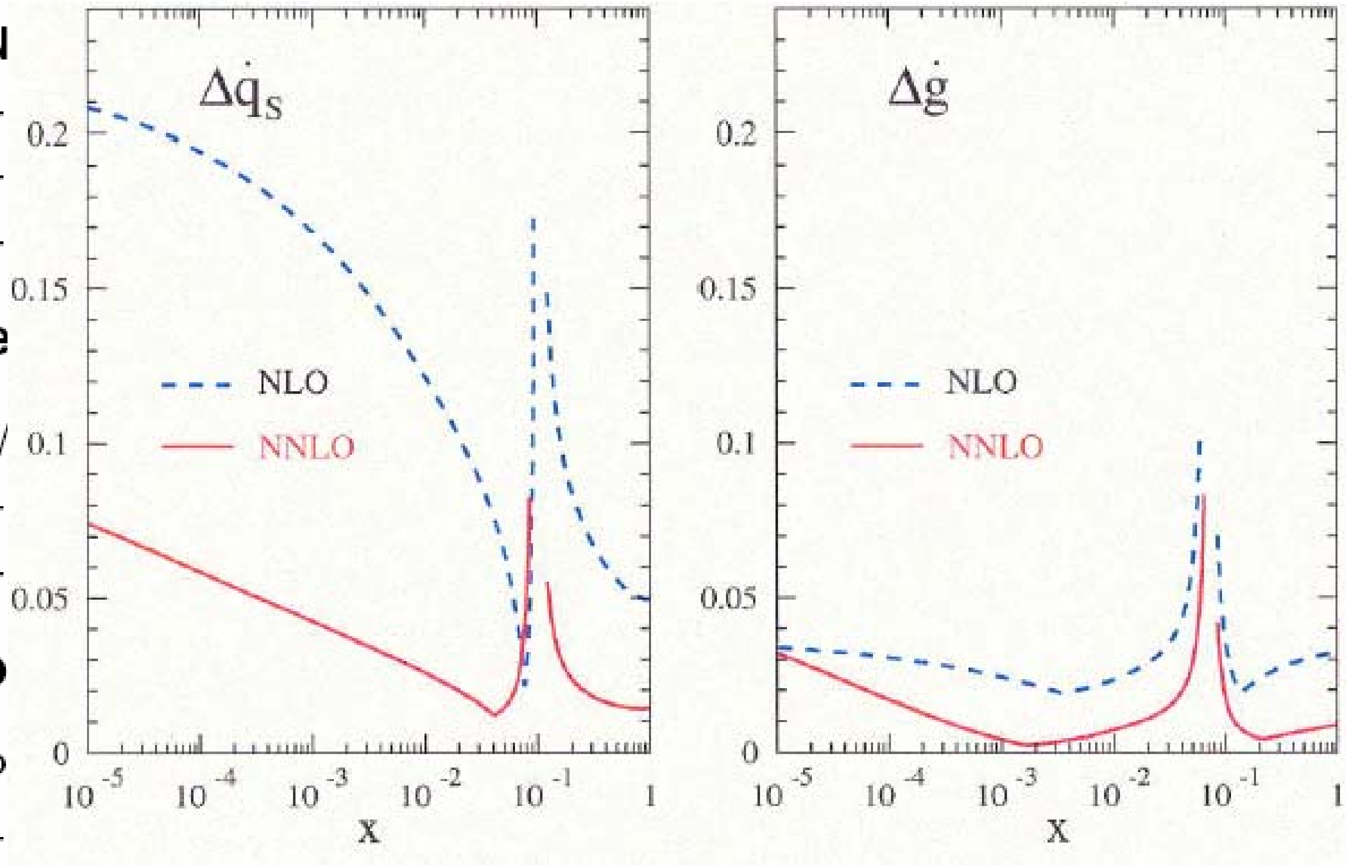
- N … precision

Me … ization

- M

Up

- P … ractions



NNLO singlet splitting functions

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[S.Moch, DESY-WS-04]
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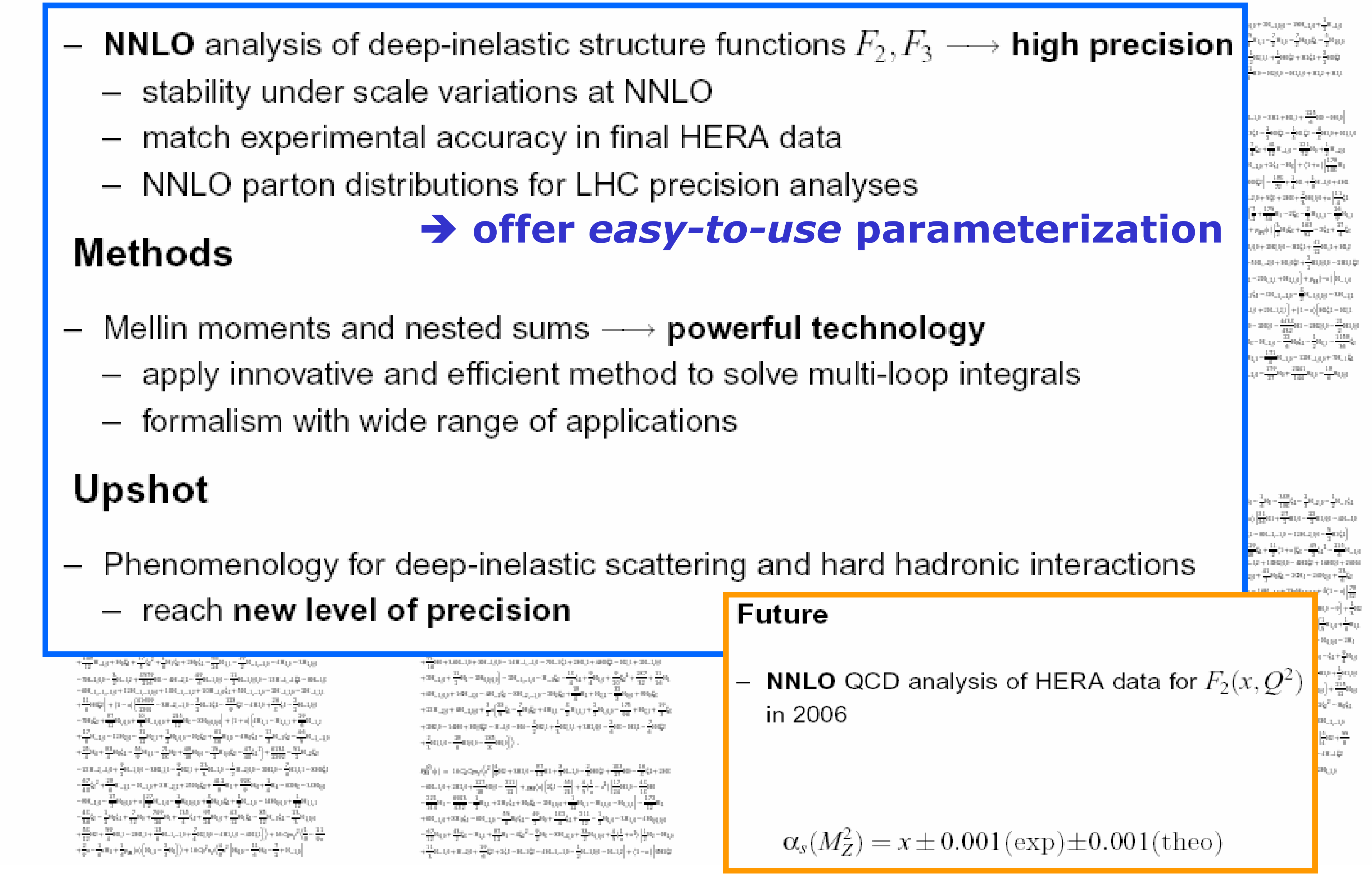
hep-ph/0403192 & 0404111]



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Future

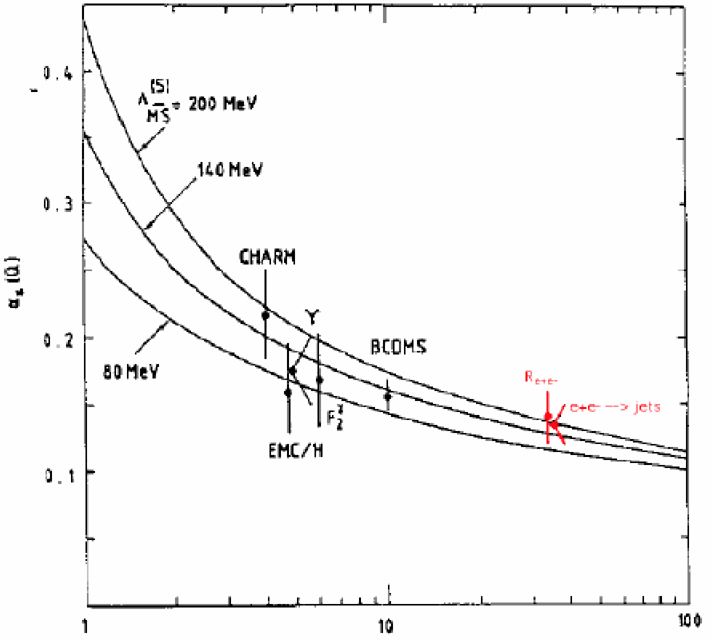
- **NNLO** QCD analysis of HERA data for $F_2(x, Q^2)$ in 2006

$$\alpha_s(M_Z^2) = x \pm 0.001(\text{exp}) \pm 0.001(\text{theo})$$

[S.Bethke, LL2004]

α_s World average

1989 NLO

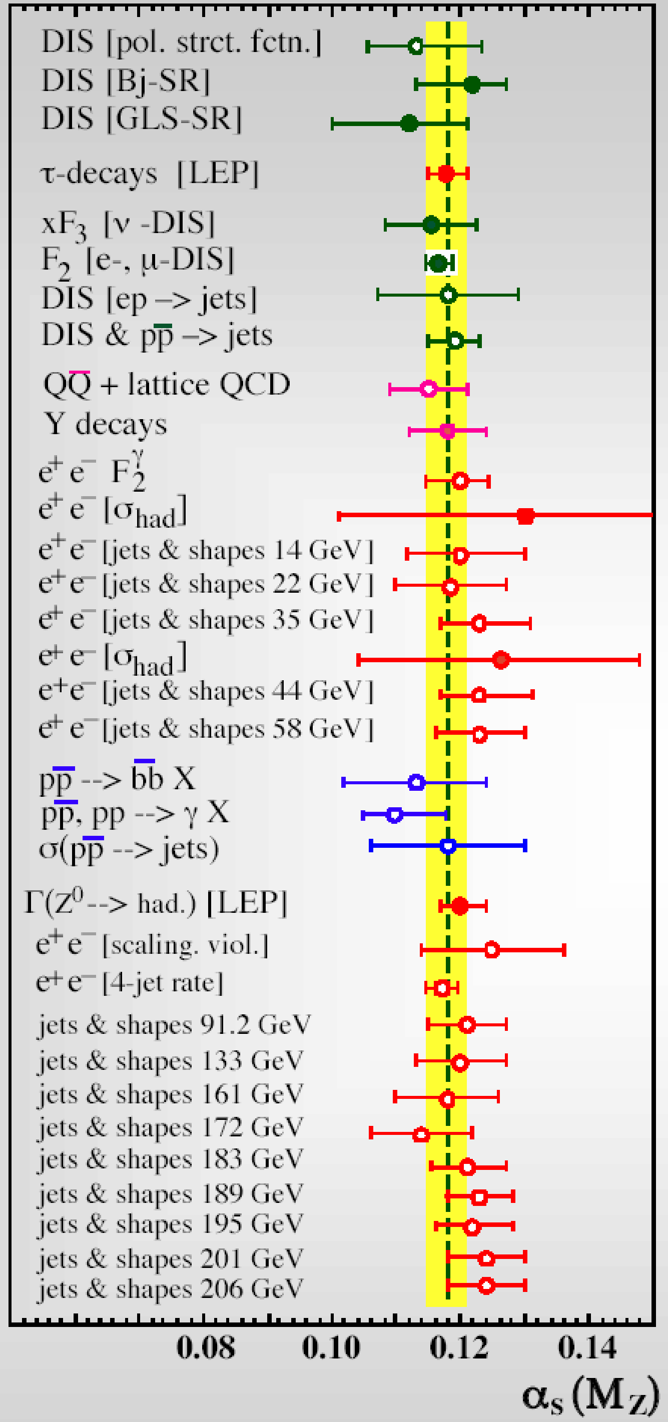


$$\alpha_S(M_Z) = 0.110^{+0.006}_{-0.008} \text{ (NLO)}$$

G. Altarelli, Ann. Rev. Nucl. Part. Sci. 39, 1989

2004 NNLO

$$\alpha_s(M_Z) = 0.1179 \pm 0.0031$$



- only results in completed NNLO with total error <0.008 used
- overall error adjusted to $\chi^2/dof = 1$

➔ theory:
more NNLO calculations!

➔exp:
more high precision collider data

➔consistent definitions and treatment of systematic uncertainties

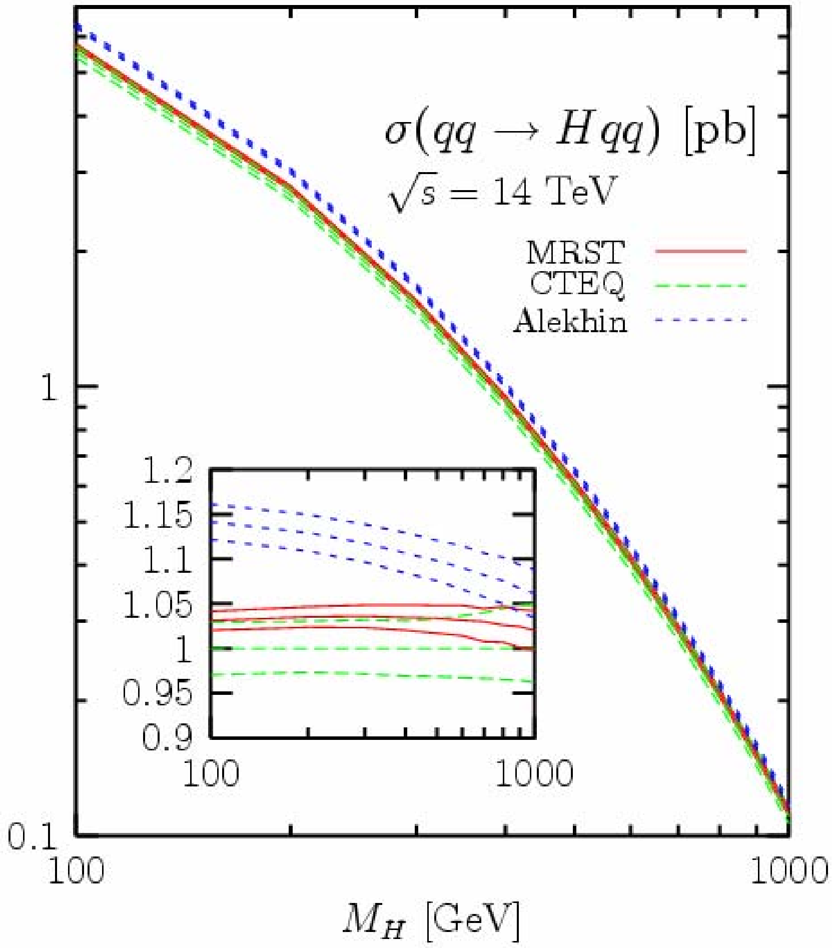
PDF : Goals and Roadmap

- study potential inclusion of HERA jet data in a rigorous manner in global QCD fits
- need improved understanding of error propagation and of consistency of experiments in order to assess relative size of exp. and theoretical uncertainties at LHC
- need to identify a list of 'reference' processes at HERA & LHC
- need to understand dependencies on rapidity and p_T → acceptance cut effects
- need to understand interplay of PDF uncertainties with MC
- need tools to access impact of resummation or non-DGLAP effects

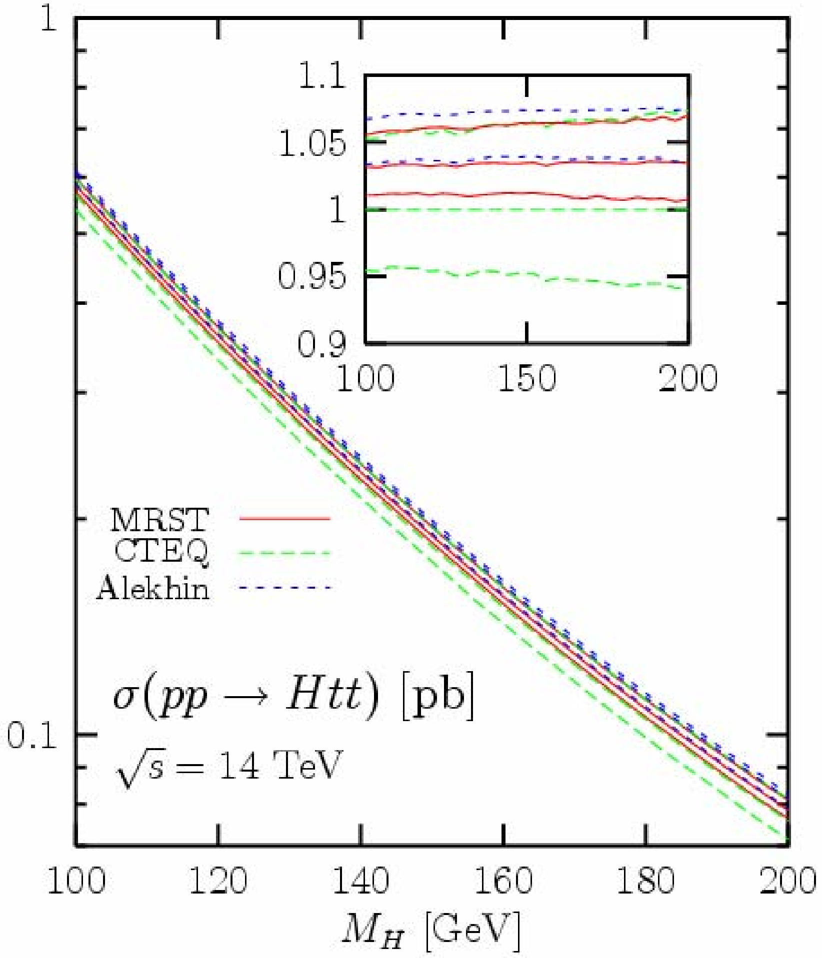
[A.Djouadi, S.Ferrag, hep-ph/0310209]

Higgs and Heavy Quarks

dominated by HERA: q,g@low-x



exclusive for TEVATRON: top



[M.Klein, BINN-LHC-04
B.Reisert, priv.comm.]

Charm and Bottom

at x=0.001

➔dominated by sea quarks

➔but valence quark PDFs although small also not well known

→xG_3 from HERA II

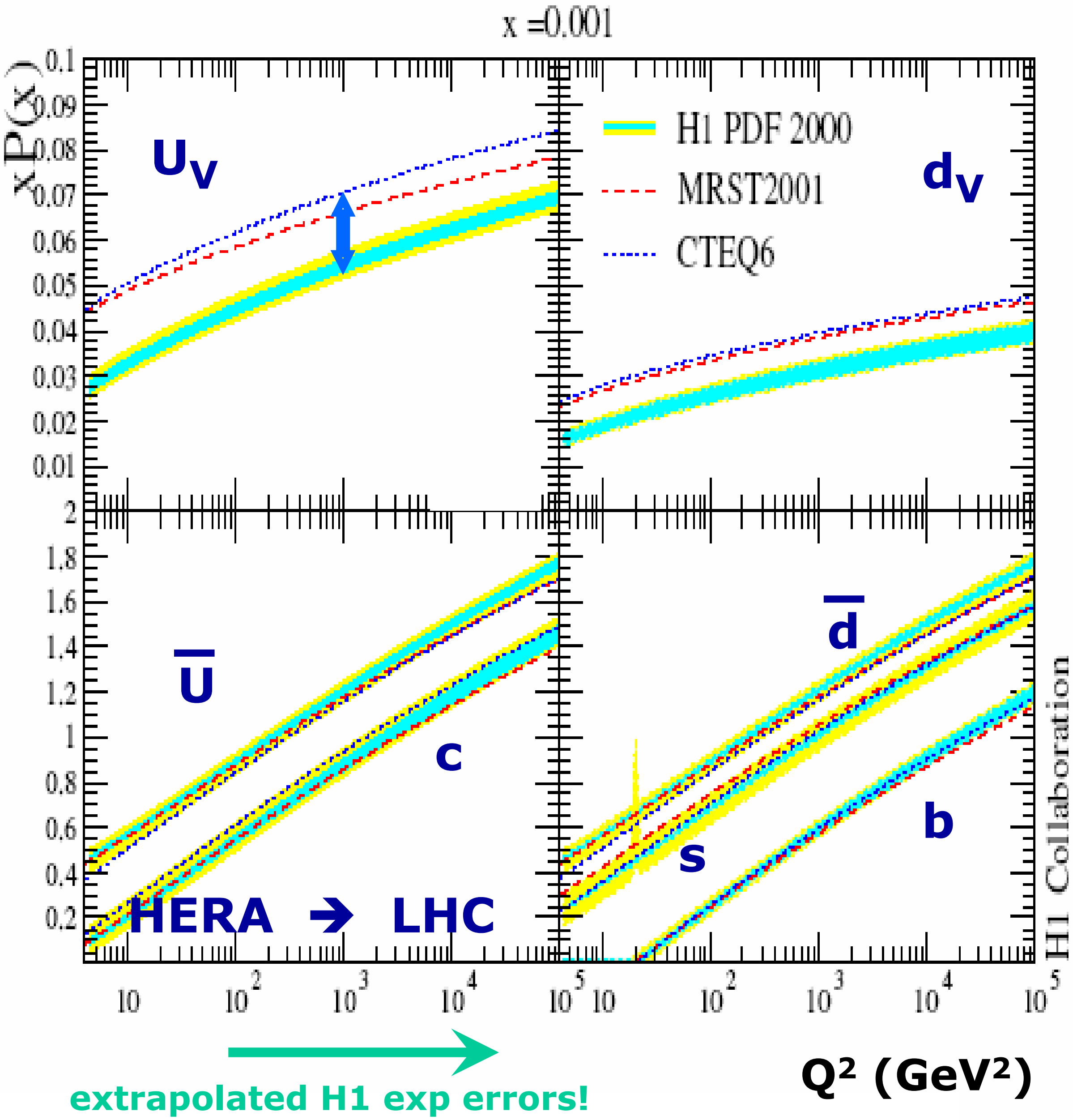
➔dramatic increase of sea PDFs towards high Q^2 :c,b dominant

➔ubar=dbar??

… ***ed*** at HERA!

➔how to improve knowledge on HQ PDFs?

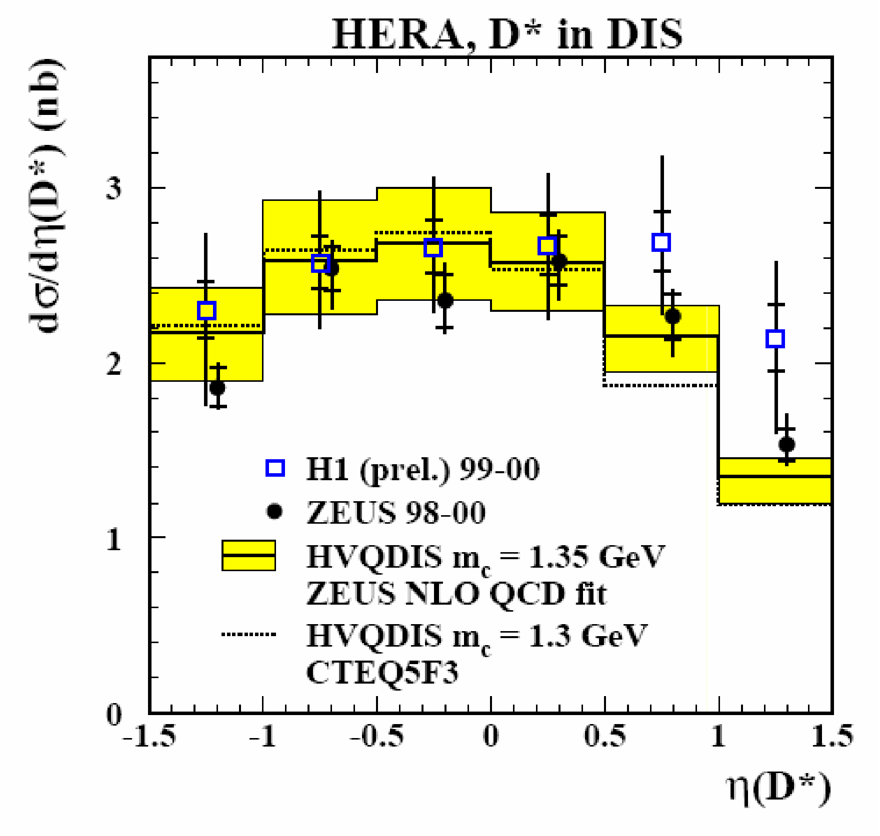
➔how well does evolution work?

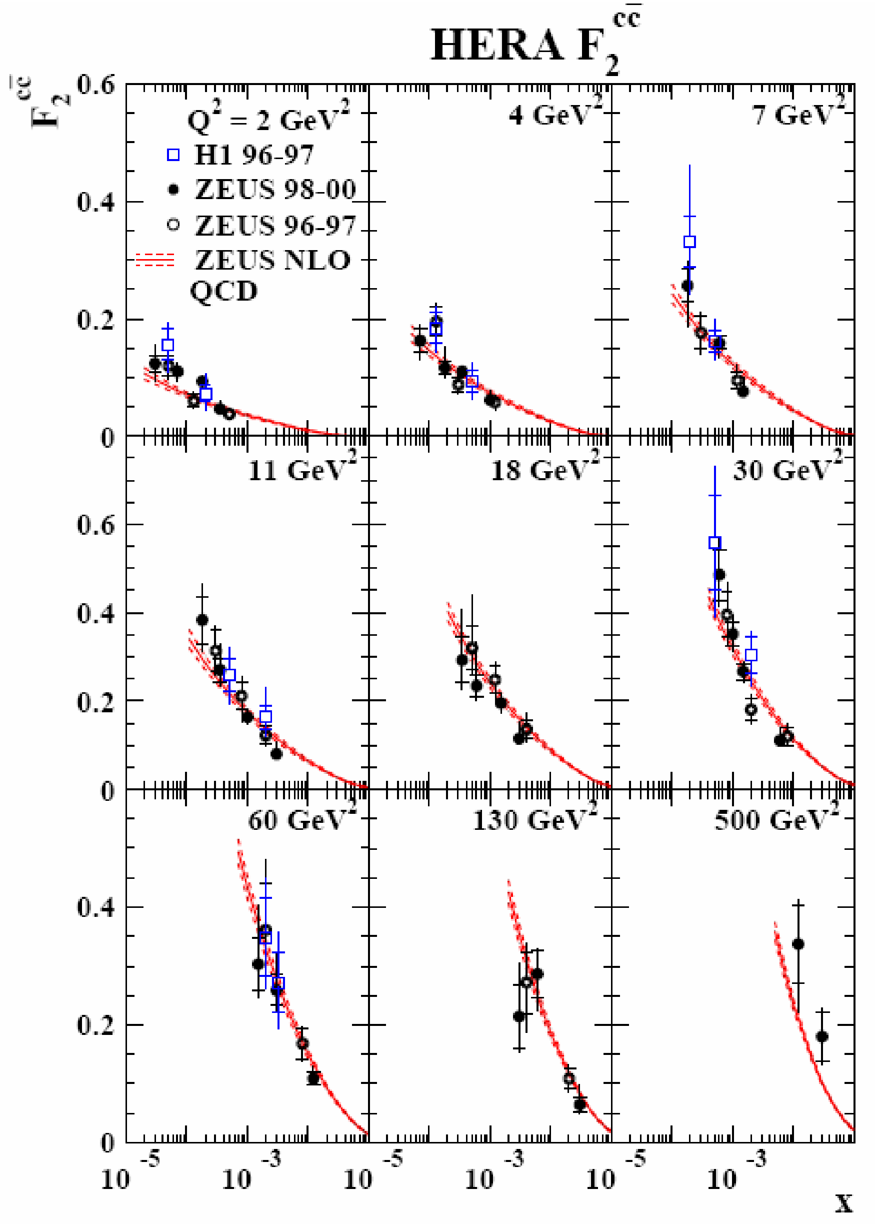


extrapolated H1 exp errors!

[M.Wing, DIS04-WS]

Charm in DIS





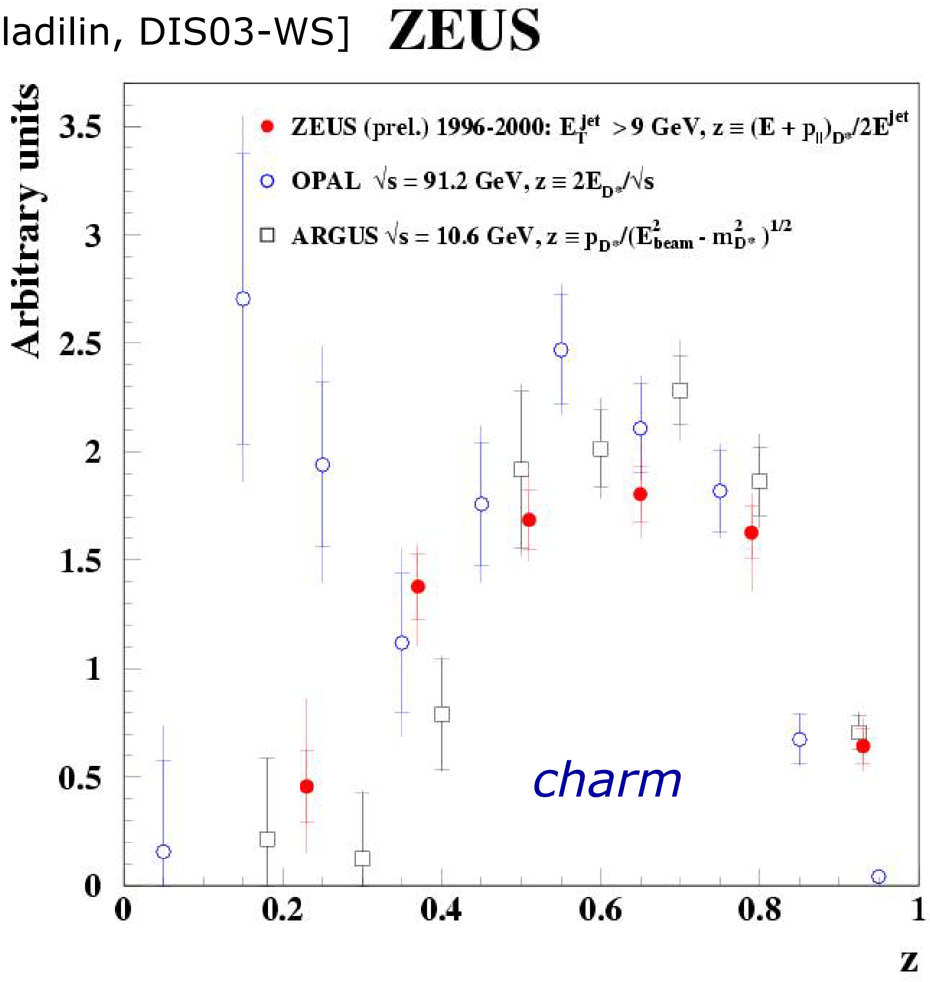
Good description of the data

by NLO QCD using a modern PDF

Fragmentation at HERA

- e.g. measure charm fragmentation function in *hadronic* events.
- needed for beauty jet rates; minimise extrapolation uncertainties.
- should be more precise after ugrade (CST, MVD).
- should also be done for beauty.
- also measured fragmentation fractions.

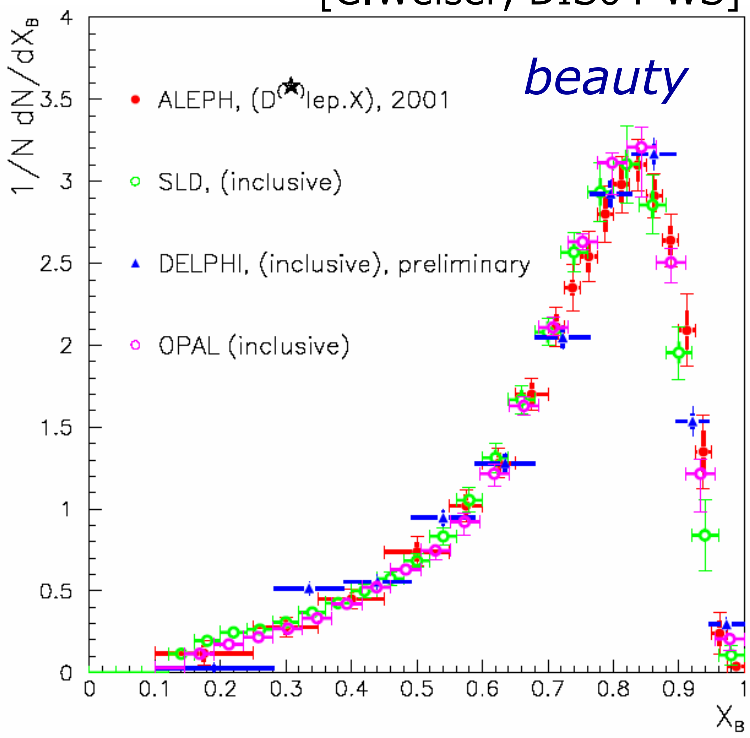
[L.Gladilin, DIS03-WS]



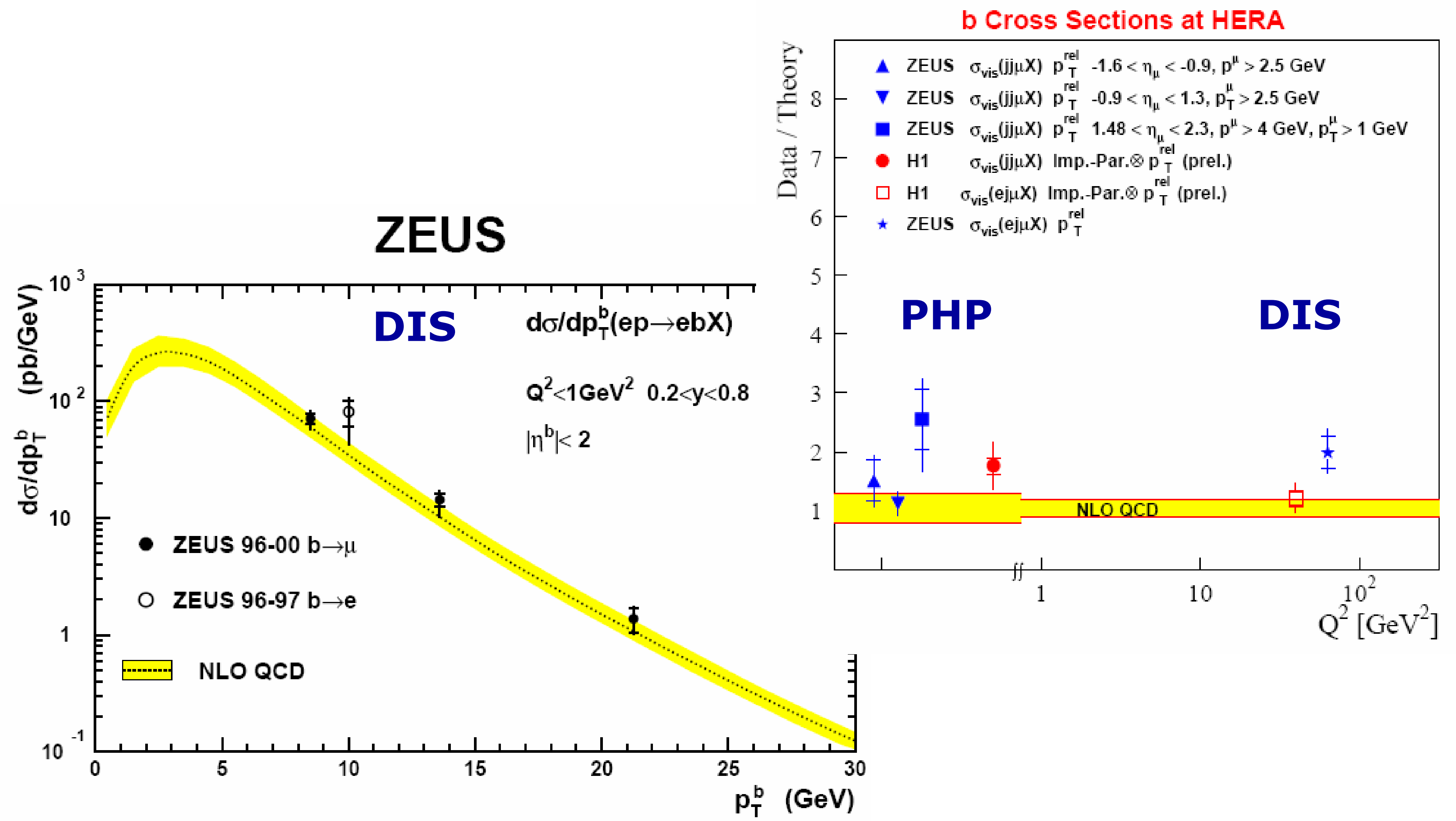
➔charm FF universal

...test also for b ➔

[C.Weiser, DIS04-WS]



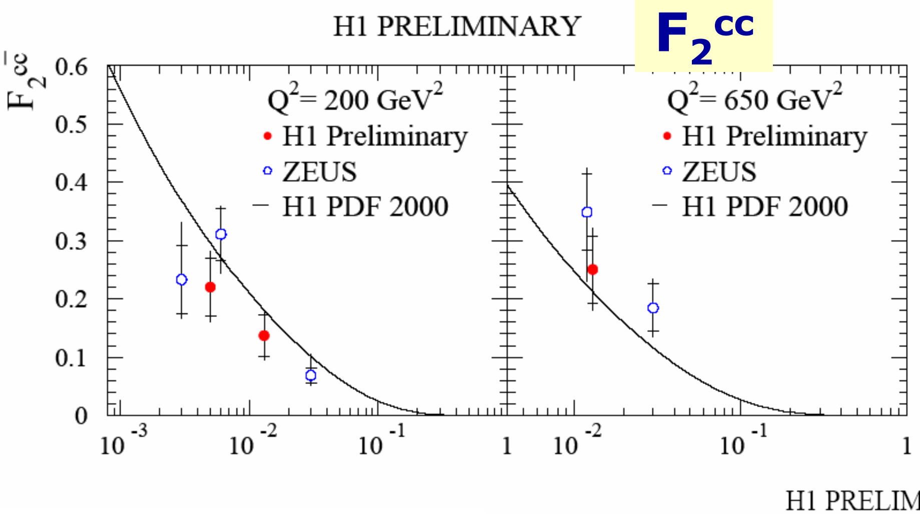
Beauty Production at HERA



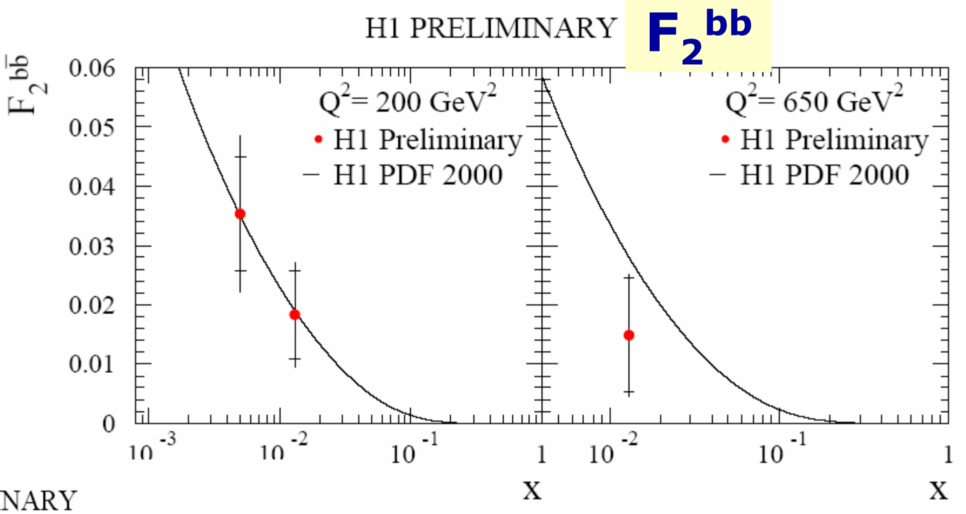
➔ fair agreement with NLO QCD

Charm and Beauty measurements using Si-Vertex-Detector : impact parameter analysis

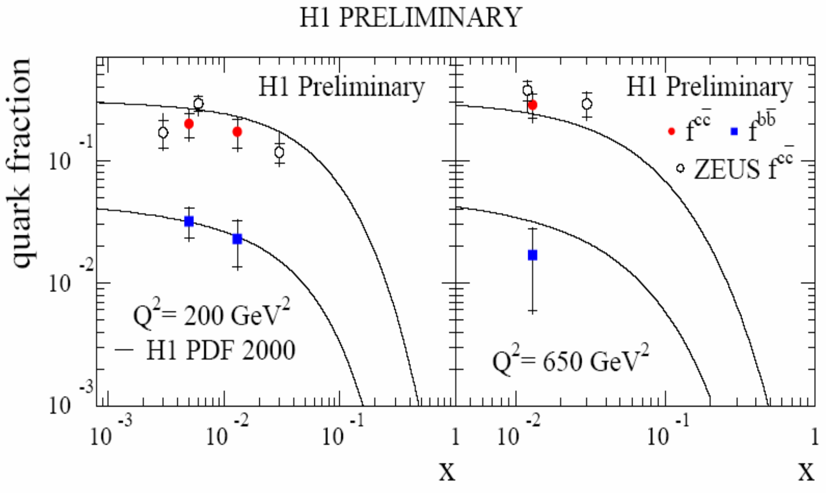
F_2^{cc}



F_2^{bb}



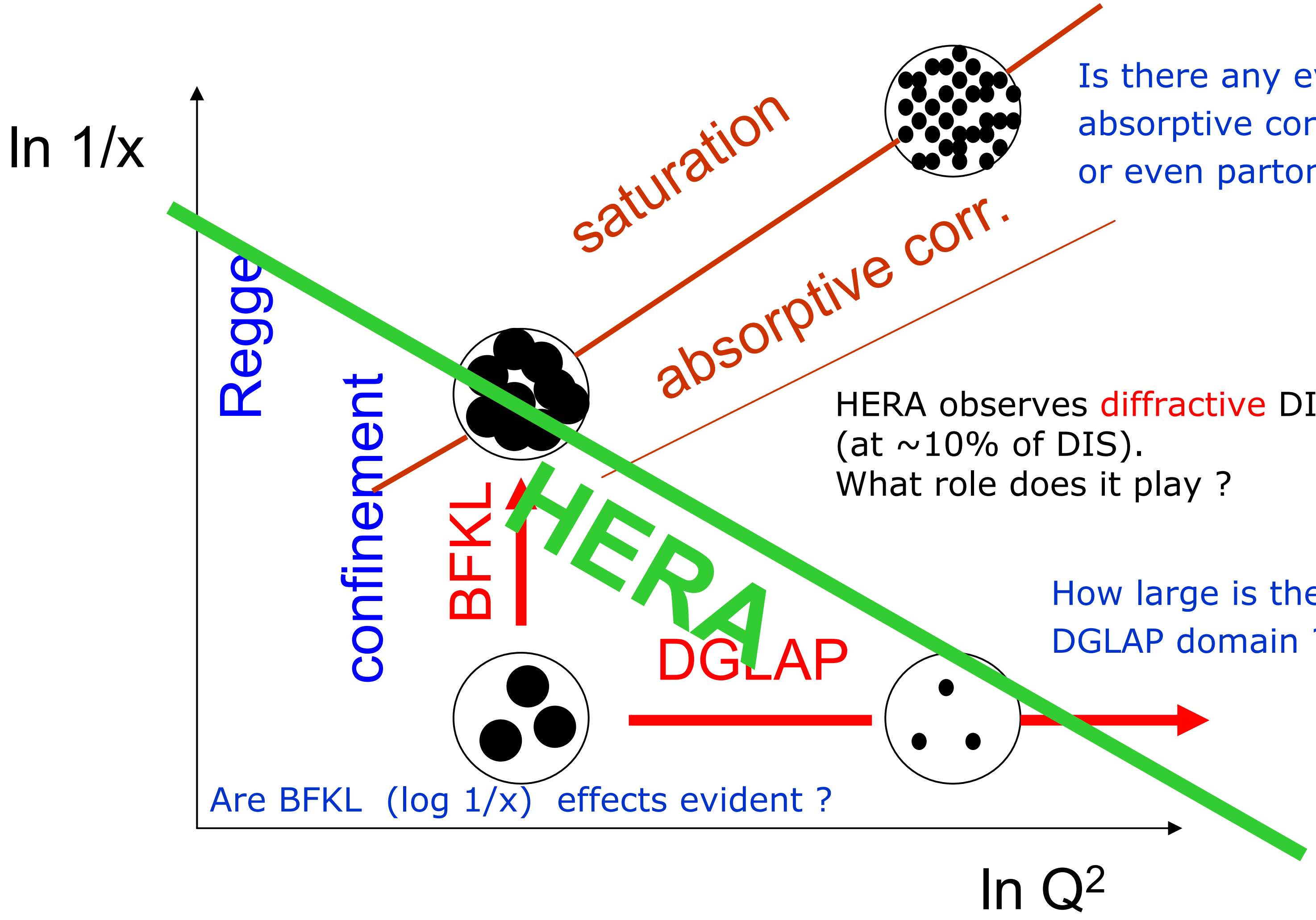
quark fractions



HERA II → '*b machine*' : much higher statistics anticipated
→ F_2^{cc}, F_2^{bb}, b-fragmentation functions…

[A.Martin, DIS04-WS-Summary]

A 'Map' of the Parton Dynamics



Is there any evidence of
absorptive corrections,
or even parton saturation ?

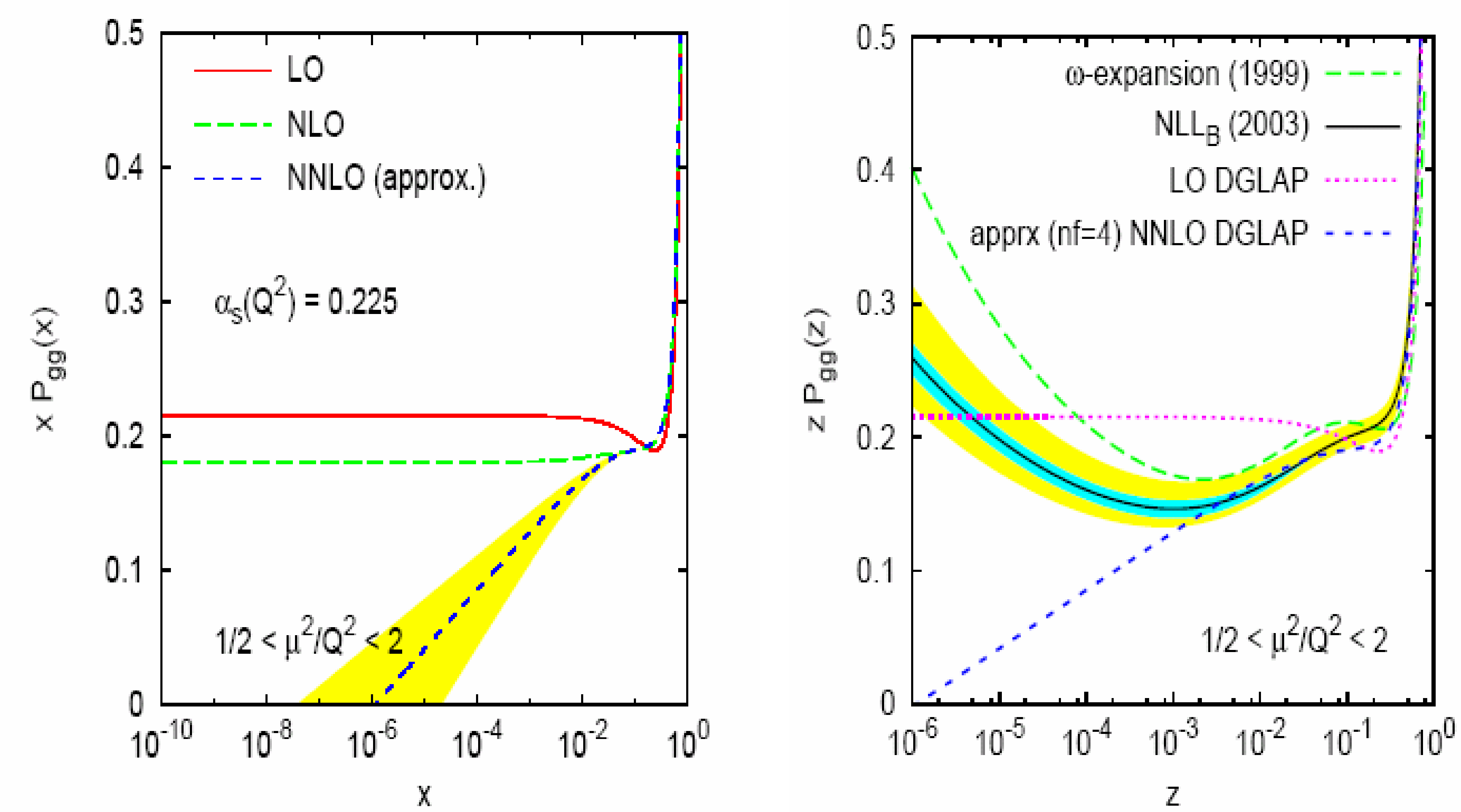
HERA observes diffractive DIS
(at ~10% of DIS).
What role does it play ?

How large is the
DGLAP domain ?

Are BFKL (log 1/x) effects evident ?

[G.Salam, DIS04-WS]

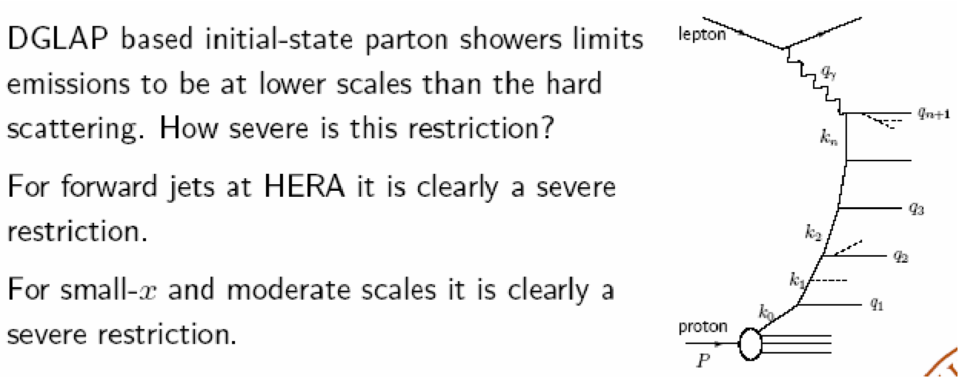
DGLAP at Low x?



- ➔ but splitting functions have to be convoluted with the gluon distribution
- ➔ exact NNLO trustable until $x \sim 10^{-4} - 10^{-5}$ …
- ➔ Gluon at low x needs experimental constraints

[L.Lönnblad,StartUp-WS]

Forward Activity



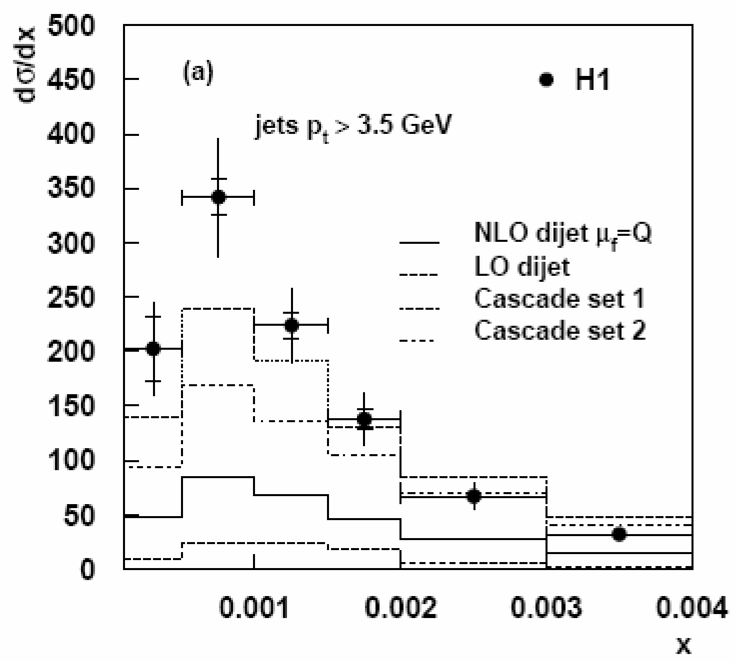
DGLAP based initial-state parton showers limits emissions to be at lower scales than the hard scattering. How severe is this restriction?

For forward jets at HERA it is clearly a severe restriction.

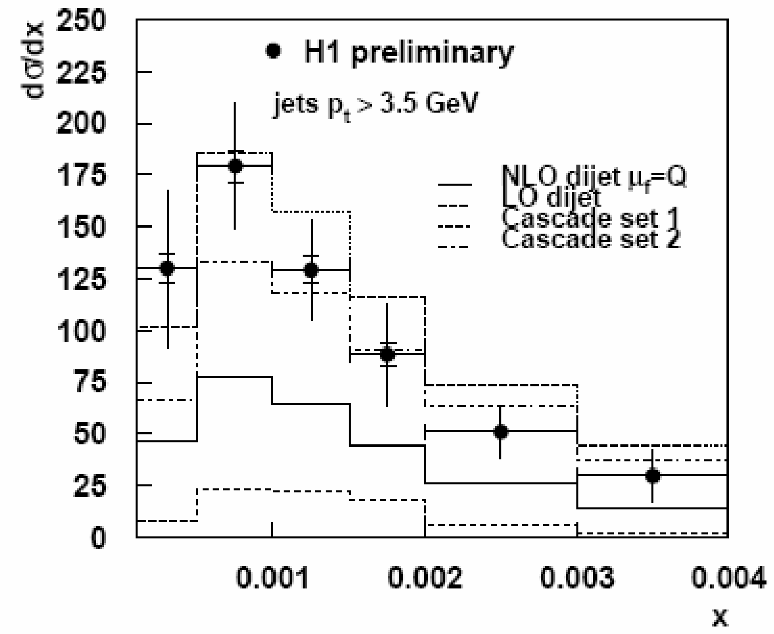
For small-x and moderate scales it is clearly a severe restriction.

$k_\perp$-factorized (BFKL/CCFM) generators

@TEVATRON x ~m_W/S~0.01-0.1
but @LHC x an order of mag. lower



Cone algorithm



$k_\perp$-algorithm

[L.Lönnblad,StartUp-WS]

Event Generator HERA → LHC

Who needs data when we have Pythia, Herwig and Ariadne?

LEP→ HERA :

At HERA we have a hadron in the initial state

There are initial-state parton showers, but they are not quite up to the task at small x

Not even in the current region of the Breit frame, where things should look like half an e^+e^- event. At small x the target region is very much larger and hard emissions there affect the current region (energy-momentum conservation).

HERA→ LHC :

All small-x problems at HERA are there at the LHC

In addition we have multiple scatterings and underlying events (also in photoproduction at HERA)

HERA has a lot to tell us about where to trust the current event generators at LHC

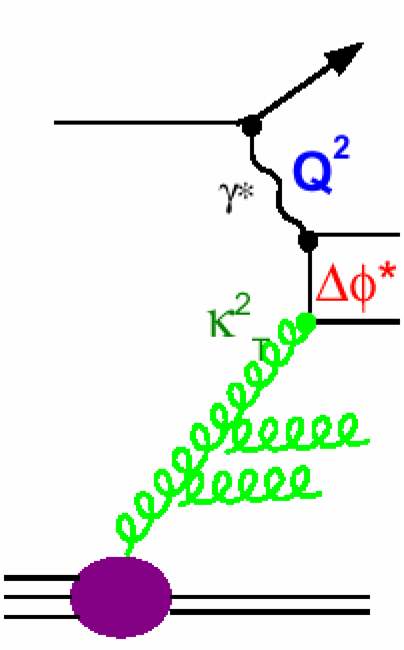
Forward activity

The second commandment of event generation:

Thou shalt never omit any part of phase space

Study of Azimuthal Correlations beteen two hardest jets

[Turnau,StartUp-WS]



DGLAP: $g(x, \kappa_T^2, Q^2) \rightarrow g(x,Q^2)$

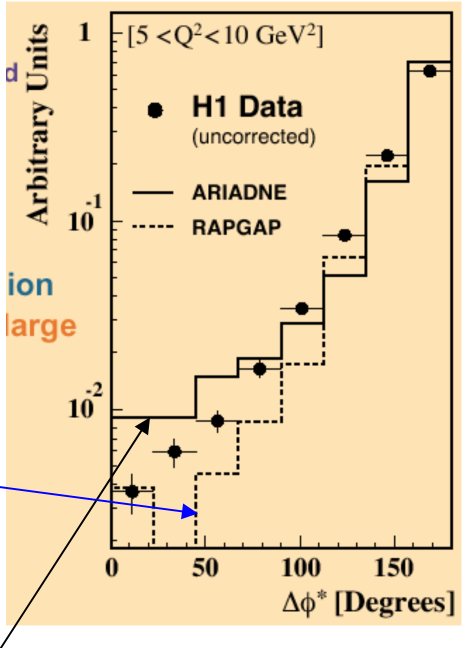
$$\rightarrow \kappa_t^2 \approx 0$$

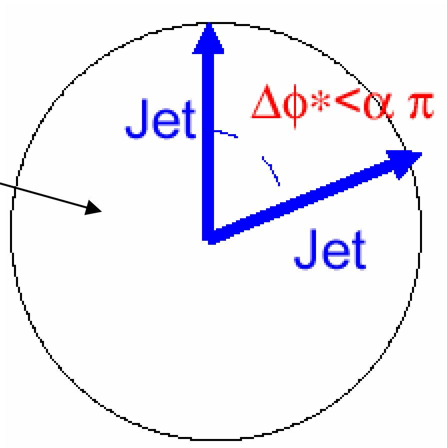
LO: $\Delta\phi^* = \pi$

HE (e.g. PS): $\Delta\phi^* \neq \pi$

NON-DGLAP e.g. ARIADNE

$$\kappa_t^2 \neq 0 \rightarrow \Delta\phi^* \neq \pi$$

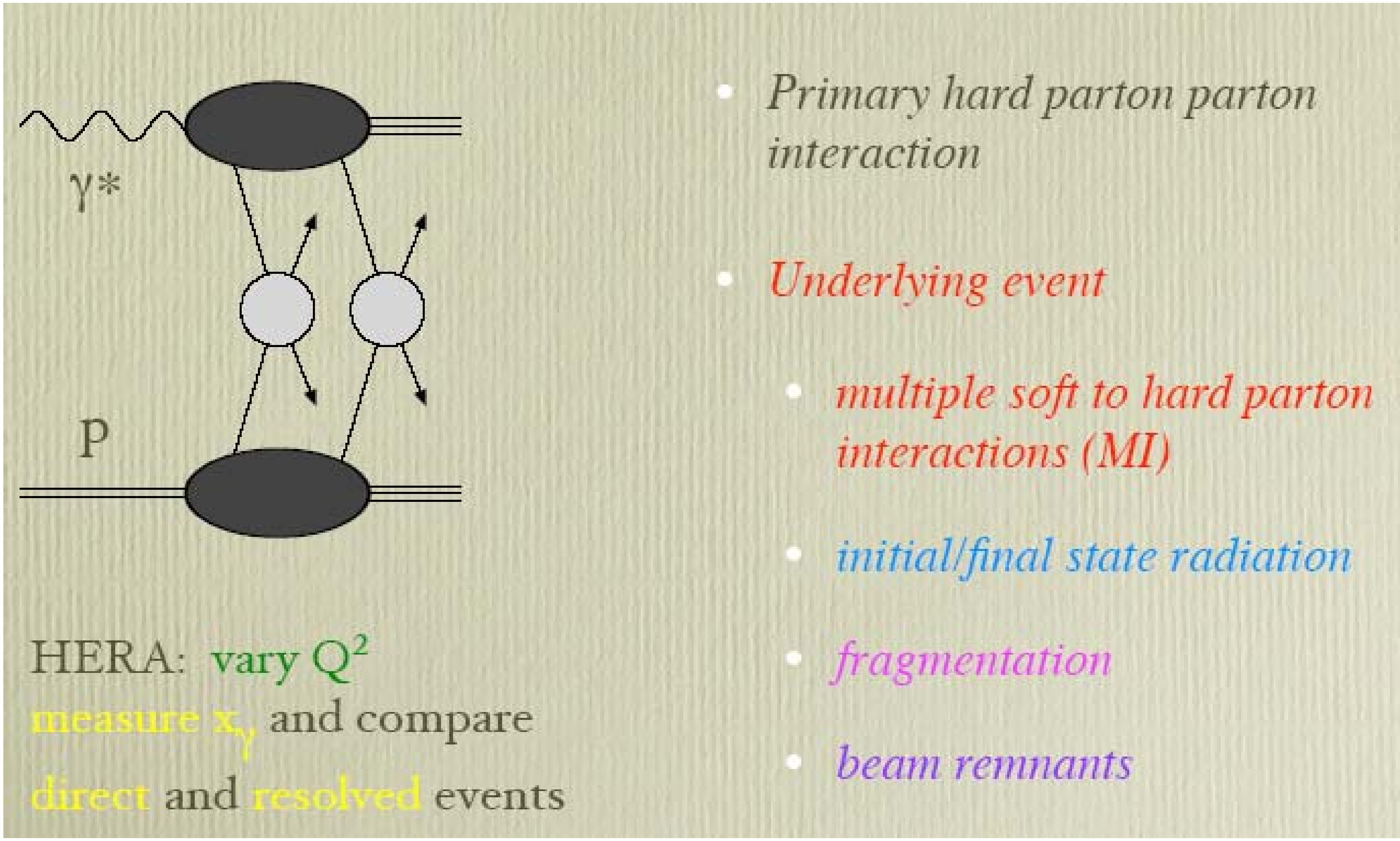




➔ **identify more channels sensitive to k_t effects!**

[G.Grindhammer, DESY-WS-04]

Underlying Event and resolved yp



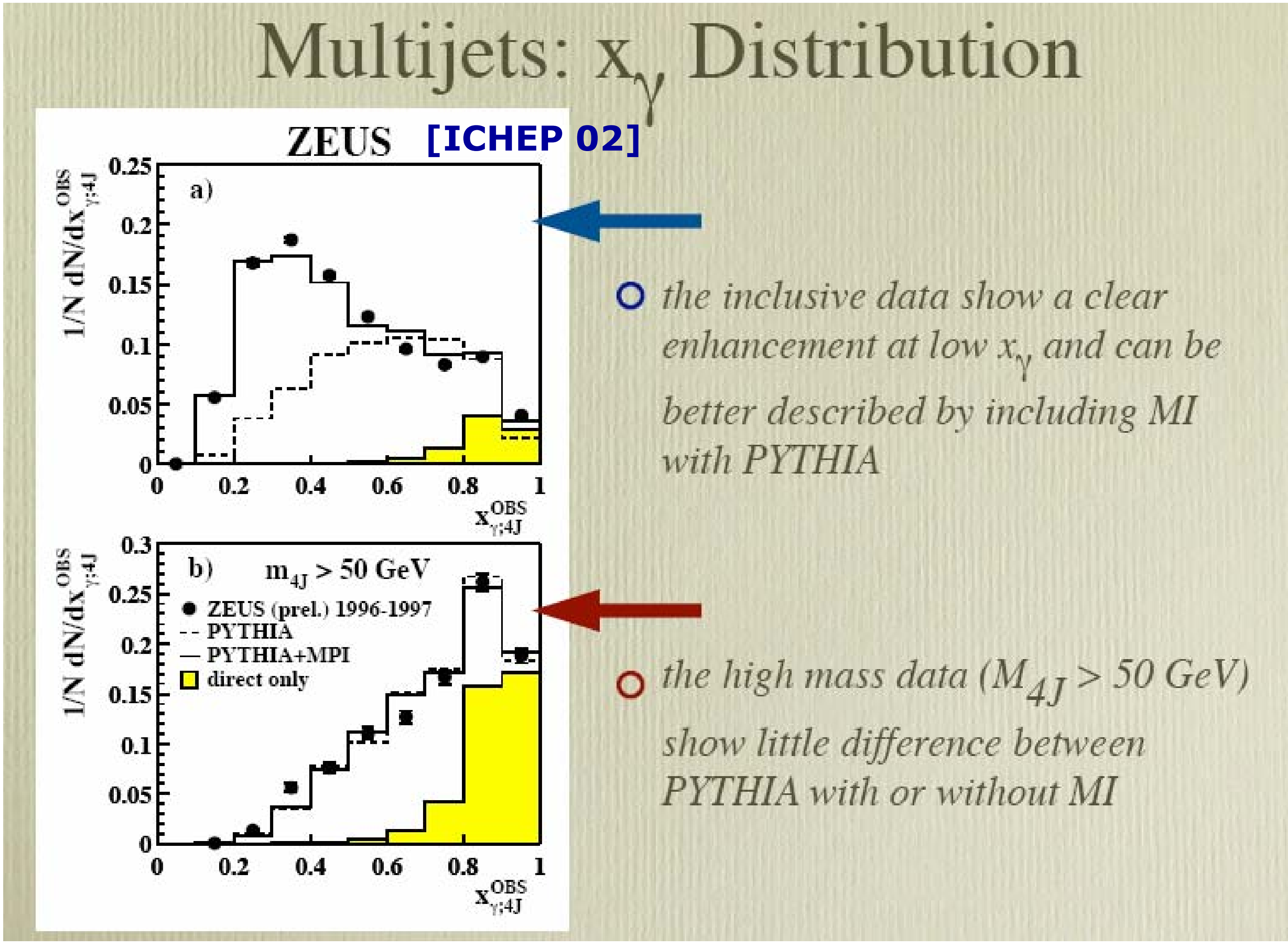
HERA: vary Q^2

measure x_γ and compare

direct and resolved events

- *Primary hard parton parton interaction*
- *Underlying event*
  - *multiple soft to hard parton interactions (MI)*
  - *initial/final state radiation*
  - *fragmentation*
  - *beam remnants*

[G.Grindhammer, DESY-WS-04]

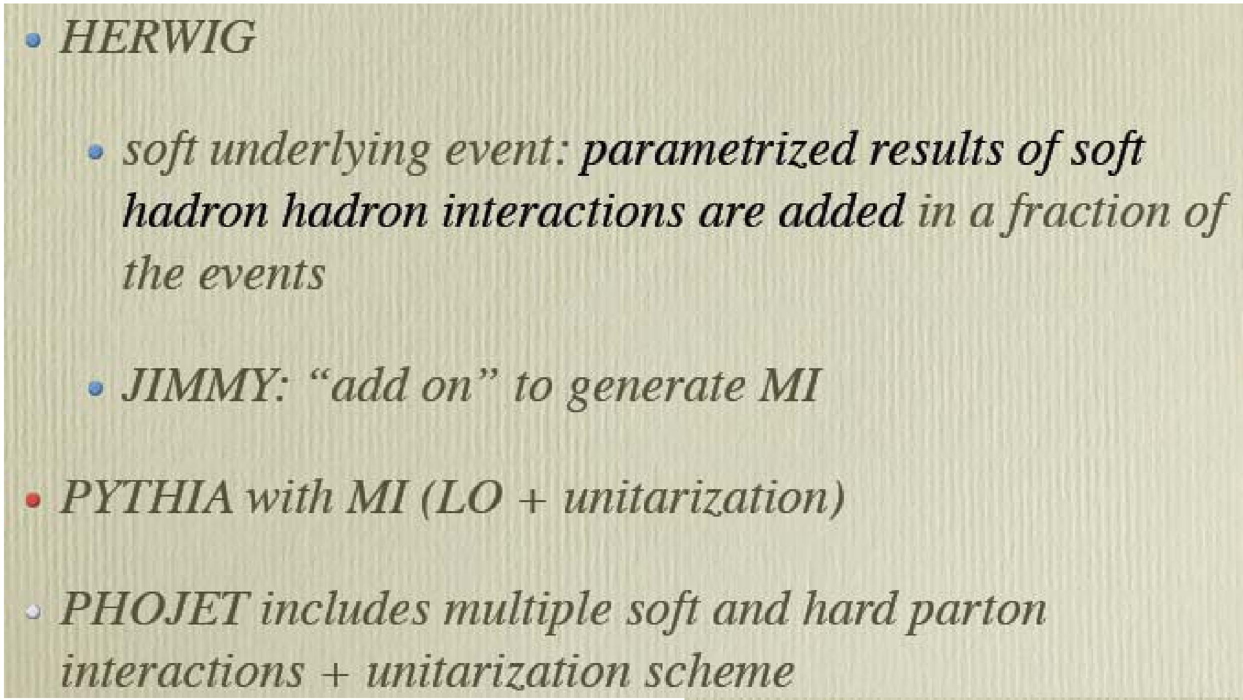


Multijets: x_γ Distribution

- ○ *the inclusive data show a clear enhancement at low x_γ and can be better described by including MI with PYTHIA*
- ○ *the high mass data ($M_{4J} > 50$ GeV) show little difference between PYTHIA with or without MI*

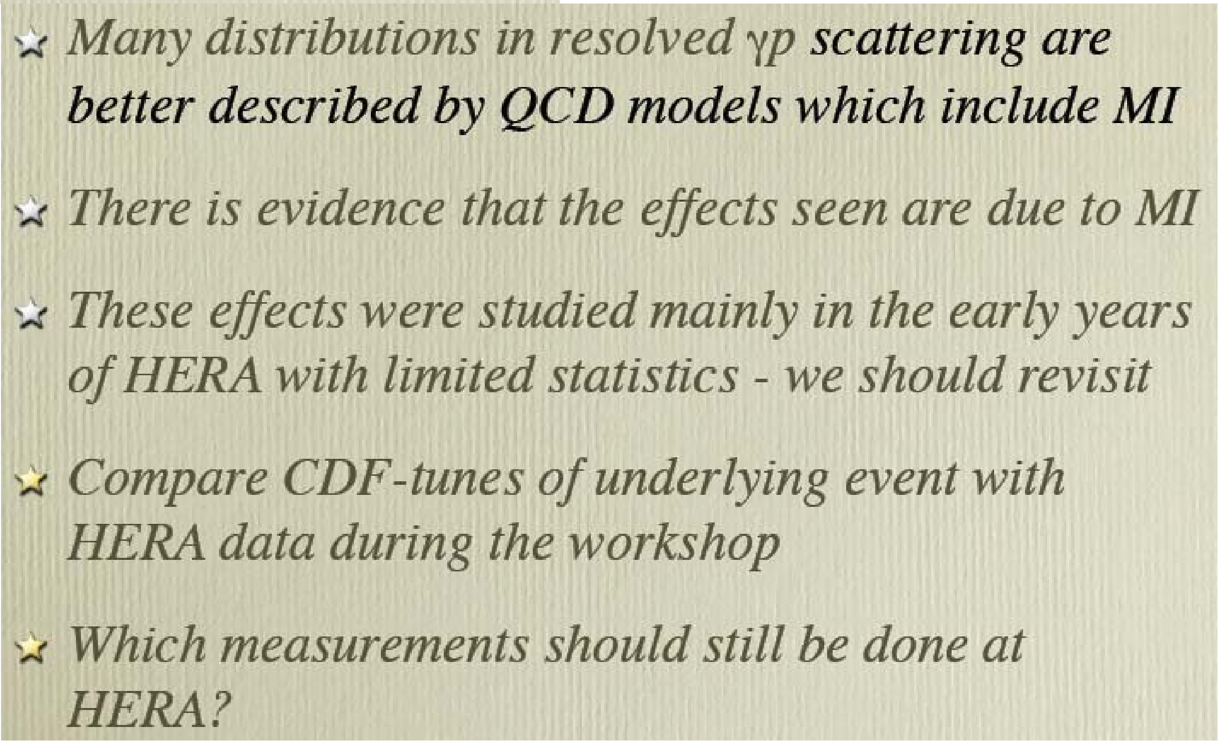
[G.Grindhammer, DESY-WS-04]

Models



- *HERWIG*
  - *soft underlying event:* ***parametrized results of soft hadron hadron interactions are added*** *in a fraction of the events*
  - *JIMMY: "add on" to generate MI*
- *PYTHIA with MI (LO + unitarization)*
- *PHOJET includes multiple soft and hard parton interactions + unitarization scheme*

Plans



- *Many distributions in resolved γp* ***scattering are better described by QCD models which include MI***
- *There is evidence that the effects seen are due to MI*
- *These effects were studied mainly in the early years of HERA with limited statistics - we should revisit*
- *Compare CDF-tunes of underlying event with HERA data during the workshop*
- *Which measurements should still be done at HERA?*

[P.Landshoff, DESY-WS-04]

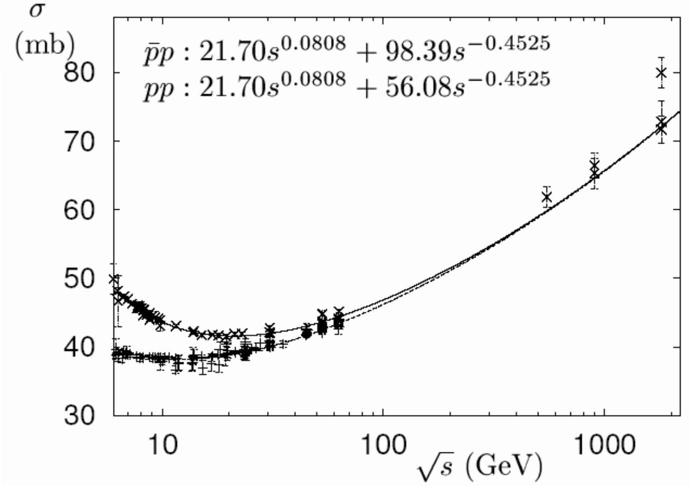
Regge Theory and Total Cross Section

1984: soft pomeron

Fit high-energy $\sigma(pp), \sigma(p\bar{p})$ with simple power s^{ϵ_1}
$\epsilon_1 \approx 0.08$

1998: hard pomeron

HERA data for $F_2(x, Q^2)$ at small x need also a term with
$\epsilon_1 \approx 0.4$



Use hardpom, softpom and reggeon exchange
Reggeon = ρ, ω, f_2, a_2

Approximate with a single term $\epsilon_R \approx 0.5$

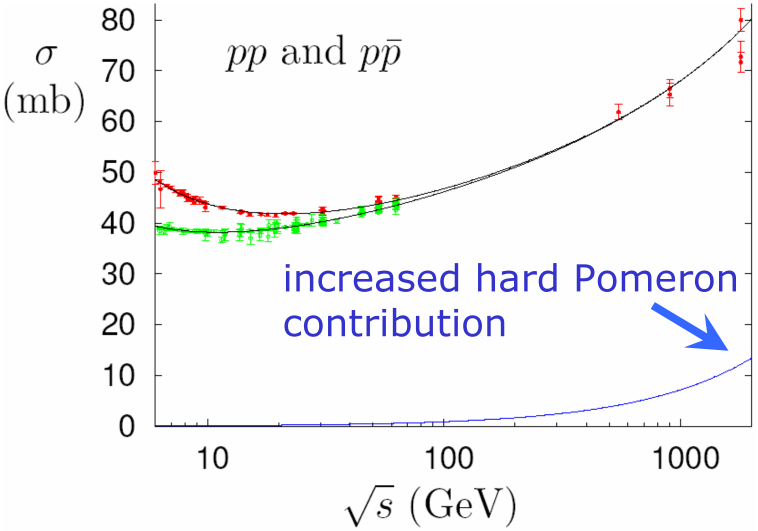
$\sigma(pp), \sigma(p\bar{p}), \sigma(\gamma p)$:

$$\sigma = X_0 s^{\epsilon_0} + X_1 s^{\epsilon_1} + Y s^{\epsilon_R}$$

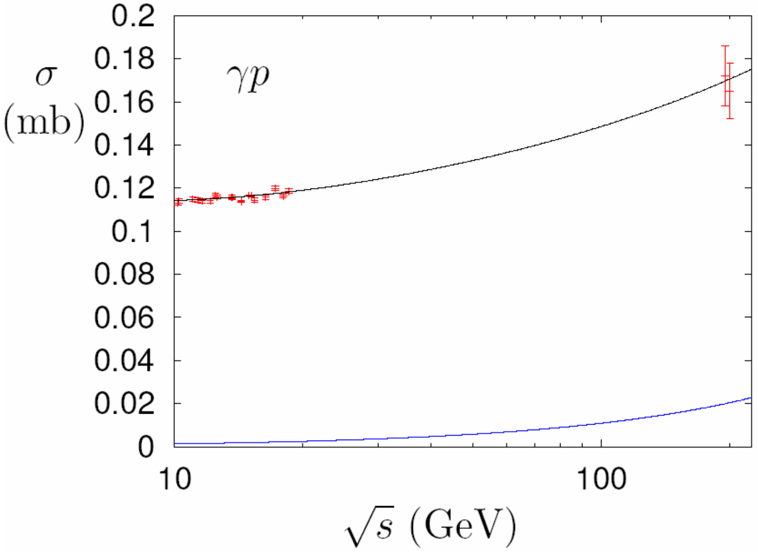
$F_2(x, Q^2)$:

$$x^{-\epsilon_0} f_0(Q^2) + x^{-\epsilon_1} f_1(Q^2) + x^{-\epsilon_R} f_R(Q^2)$$

NEW 2004 fit



increased hard Pomeron contribution



[P.Landshoff, DESY-WS-04]

Differential Cross Section

$$\frac{d\sigma^{pp}}{dt} \sim \frac{d\sigma^{\bar{p}p}}{dt} \sim \frac{(3\beta_{I\!P} F_1(t))^4}{4\pi} \left(\frac{s}{s_0}\right)^{2\alpha_{I\!P}(t)-2}$$

$$\alpha_{I\!P}(t) = 1.08 + \alpha' t \qquad s_0 = 1/\alpha'$$

$F_1(t)$=Dirac form factor

Old fit:

$$\alpha(t) = 1 + \epsilon + \alpha' t \qquad \epsilon = 0.08 \qquad \alpha' = 0.25$$

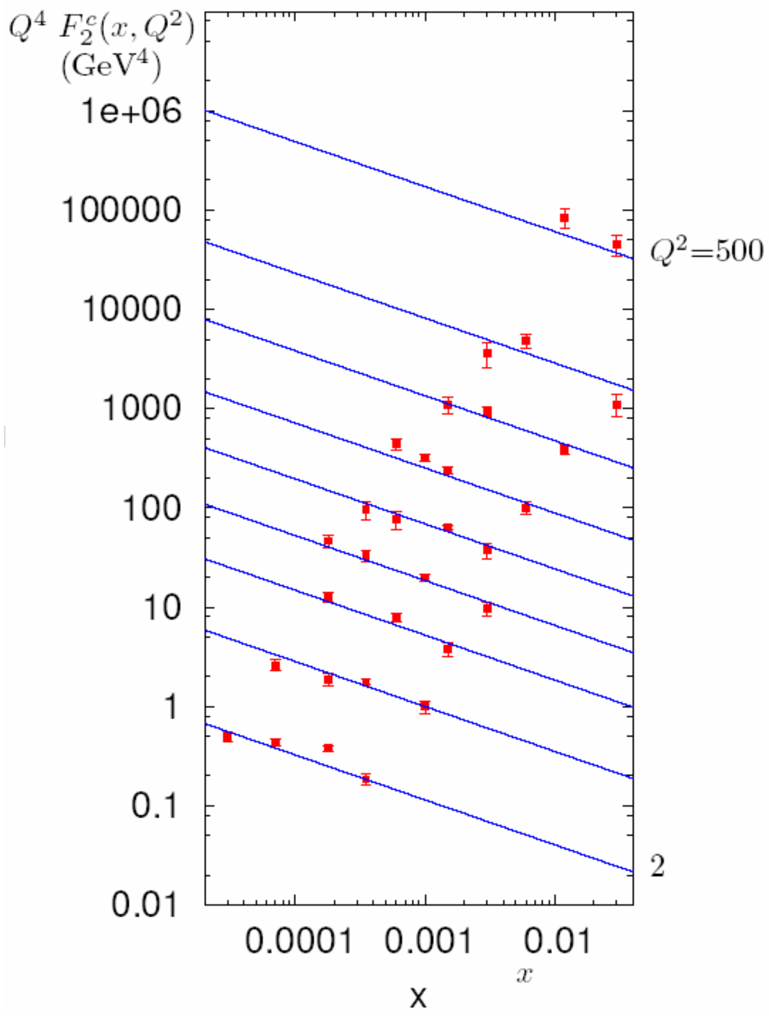
Replace with two trajectories:

$$\epsilon_0 = 0.45 \qquad \alpha'_0 \approx 0.1$$

$$\epsilon_1 = 0.067 \qquad \alpha'_1 \approx 0.3$$

$$F_2^c(x,Q^2) = \frac{\frac{4}{9}}{\frac{4}{9}+\frac{1}{9}+\frac{1}{9}+\frac{4}{9}} \; F_2(x,Q^2)\Big|_{\text{HARDPOM}}$$

$$= 0.4 \; F_2(x,Q^2)\Big|_{\text{HARDPOM}}$$



F_2^C is purely hard Pomeron exchange
hard Pomeron is flavor blind

[P.Landshoff, DESY-WS-04]

LHC Energies and Unitarity

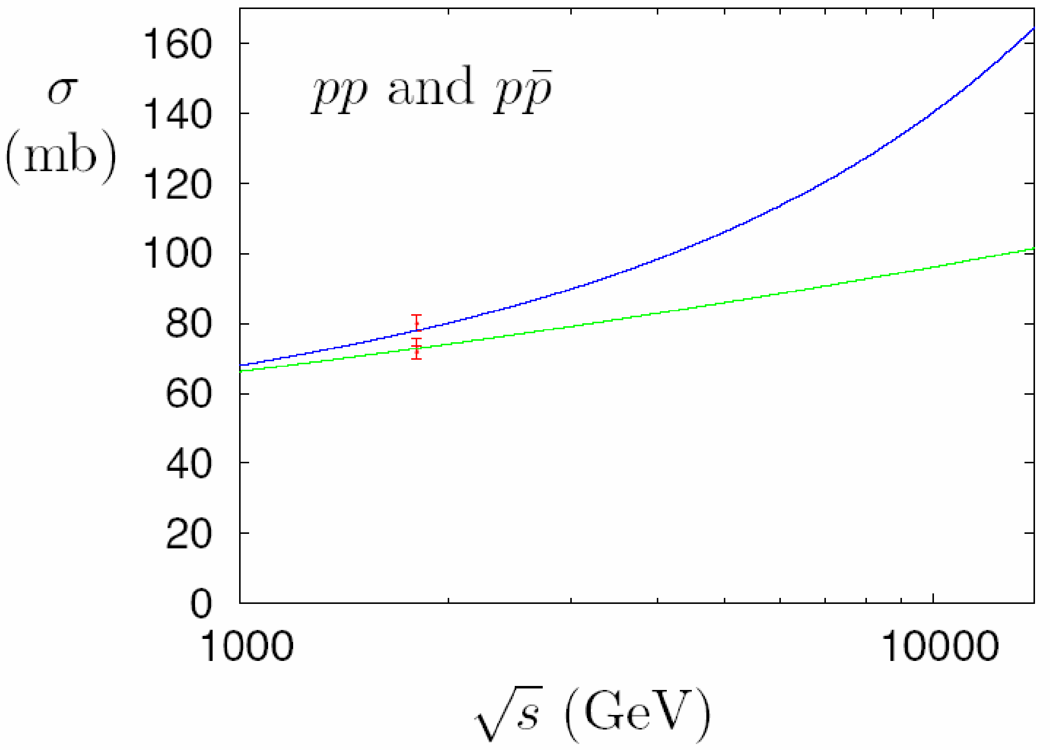
Froissart-Lukaszuk-Martin bound:

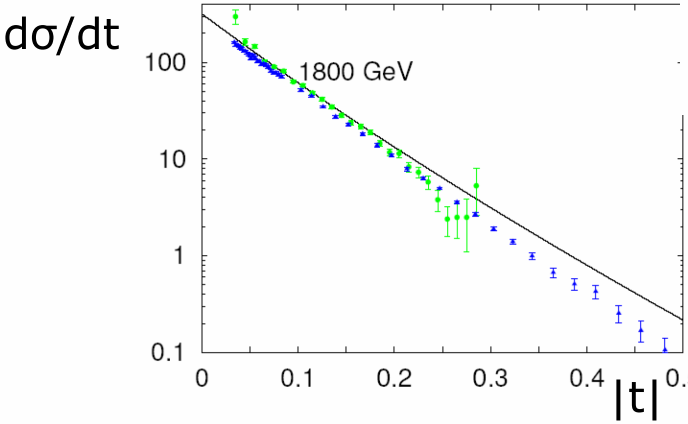
$$\sigma < \frac{\pi}{m_\pi^2}\log^2\left(\frac{s}{s_0}\right) \approx 22\ \textbf{barns}$$

$$A(s,b) = \frac{1}{16\pi^2}\int d^2q\ e^{i\mathbf{q}.\mathbf{b}} A(s,t=-\mathbf{q}$$

$$\mathrm{Im}\ A(s,b) = 1.1$$

It should be < 1 **but** . . .

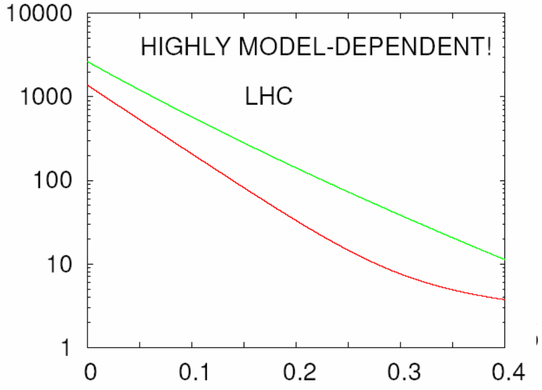




$I\!P I\!P$ exchange pulls $d\sigma/dt$ down at larger t.

But nobody knows how to calculate it!

At 14 TeV:



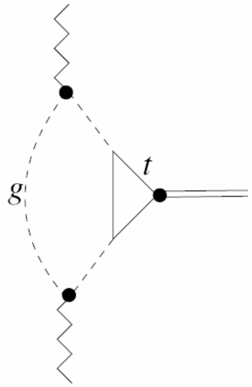
[P.Landshoff, DESY-WS-04]

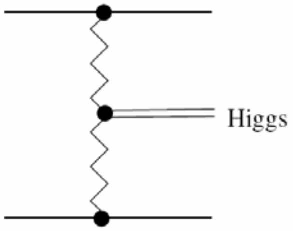
Diffractive Higgs pp →pHp

A good way to discover the Higgs: the background is relatively small - Albrow

Big disagreement about size of cross section

Bialas + PVL (1991):





[C.Royon, DIS04-WS]

"Exclusive" production at the LHC

- Survival probability: estimated to be ~ 0.03
- Exclusive $b\bar{b}$ cross section (for jets with $p_T > 25$ GeV): 70.1 pb * 0.03 = 2.1 pb
- Exclusive Higgs production (in fb) after applying the gap survival probability

M_{Higgs}	σ (fb)
120	3.9
125	3.5
130	3.1
135	2.5
140	2.0

Peter Landshoff: $pp \to p$ Higgs p anywhere between 3 and 300 fb

LHC should teach us a lot

Areas of Impact & Concluding Remarks

Precision measurement of QCD inputs

α_S : from jet rates, jet substructure, event shapes, global fits...

Parton distributions from structure functions, jets and charm

Fragmentation parameters: strange, charm, beauty, leading particles

Testing ground for non- or semi-perturbative models

Underlying events; minijets, multiparton interactions, saturation

Soft underlying events, rescattering, forward neutrons & protons

Diffractive structure functions, gaps between jets, survival probability

Testing ground for calculational techniques

Very forward jets, low x
Multijets, matrix element/parton showers
Evaluation of theoretical uncertainties
Beauty & charm production cross sections and dynamics
DIS/photoproduction transition; multiscale QCD
“Intrinsic” transverse momentum, k_T factorization

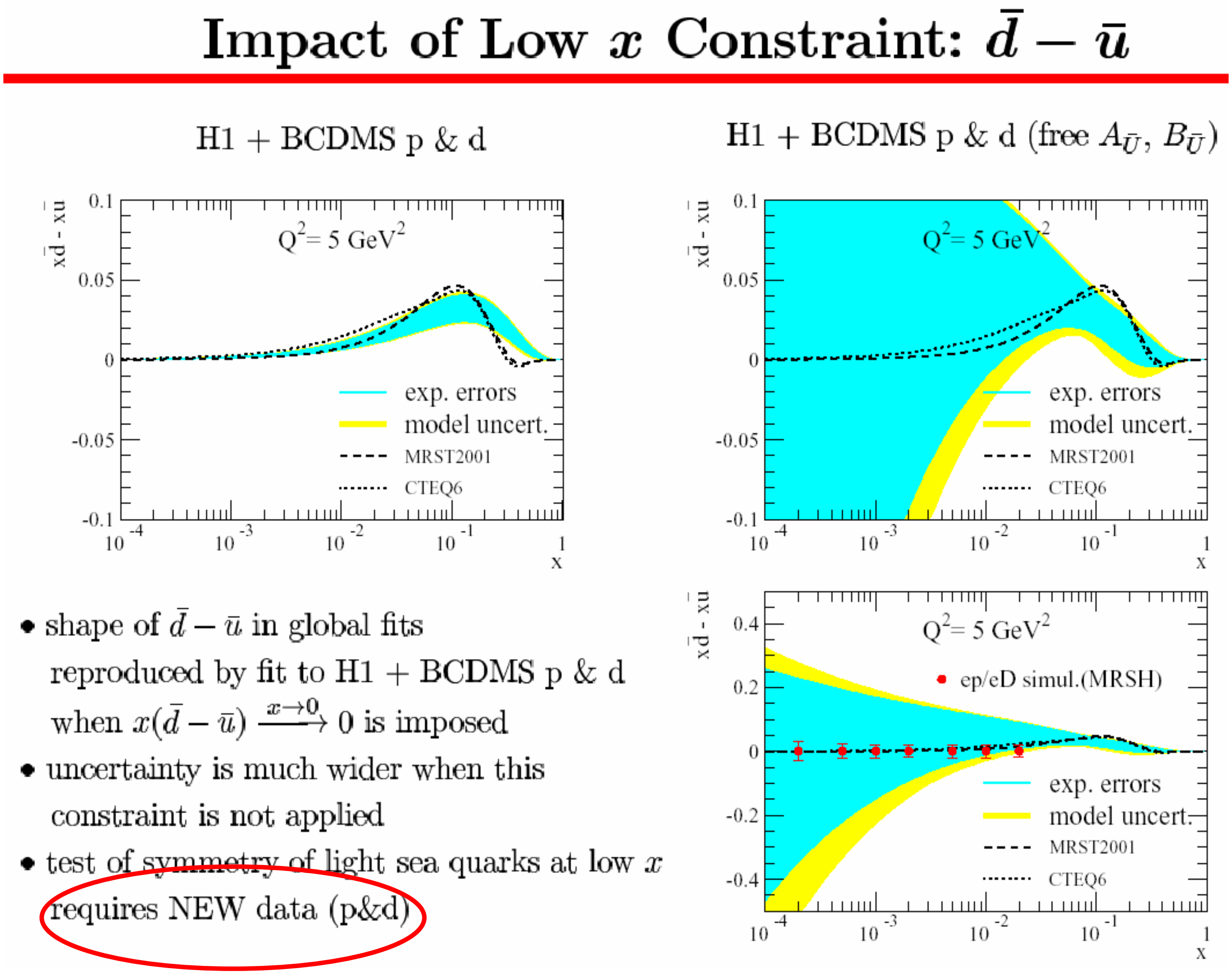
Gain a *quantitative* understanding of hadronic production mechanisms at high energies.

Join the effort !

Many thanks to the organizers for the invitation and the fruitful workshop

Shown Backup Slide

[B.Reisert, DIS03-WS]



Impact of Low x Constraint: $\bar{d} - \bar{u}$

H1 + BCDMS p & d

H1 + BCDMS p & d (free $A_{\bar{U}}$, $B_{\bar{U}}$)

- shape of $\bar{d} - \bar{u}$ in global fits reproduced by fit to H1 + BCDMS p & d when $x(\bar{d} - \bar{u}) \xrightarrow{x \to 0} 0$ is imposed
- uncertainty is much wider when this constraint is not applied
- test of symmetry of light sea quarks at low x requires NEW data (p&d)