Highlights from

DIS 2003

XI International Workshop on Deep Inelastic Scattering

St. Petersburg, 23-27 April 2003

Part III

Uta Stösslein (DESY Hamburg)

Structure Functions, low-x and Diffraction

WG A. Convenors: R. Devenish, V.S. Fadin

- inclusive DIS data and QCD partons
- low x signals
- vector mesons and DVCS
- diffractive phenomena

→ experimental talks : about 1/3 out of 63 talks

introductory talk: M. Ryskin, PNPI

Heavy Flavours

WG D. Convenors: F. Sefkow, B. Kniehl

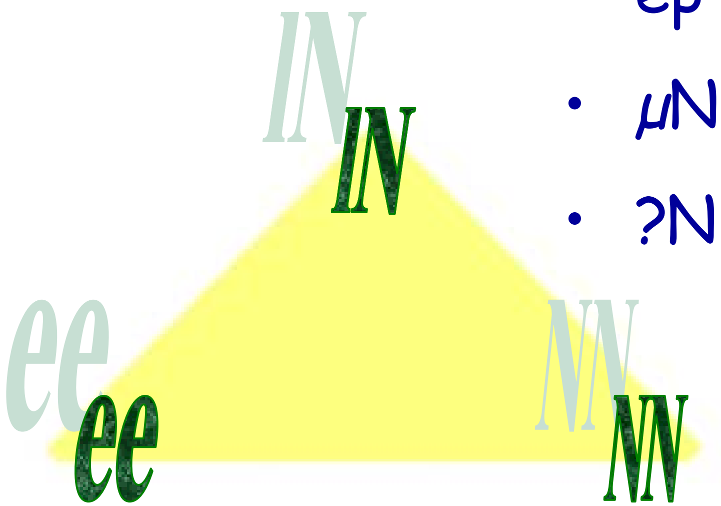
- charm in DIS and γp, fragmentation
- beauty in DIS and γp
- … and more …
- [theory and models → summary by B. Kniehl]

→ experimental talks : about 2/3 out of 34 talks

introductory talk: B. Naroska, Uni Hamburg

Recent results mainly from

- ep @ HERA
- μN @ SPS
- ?N @ FNAL



- ee @ LEP
- B-factories

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

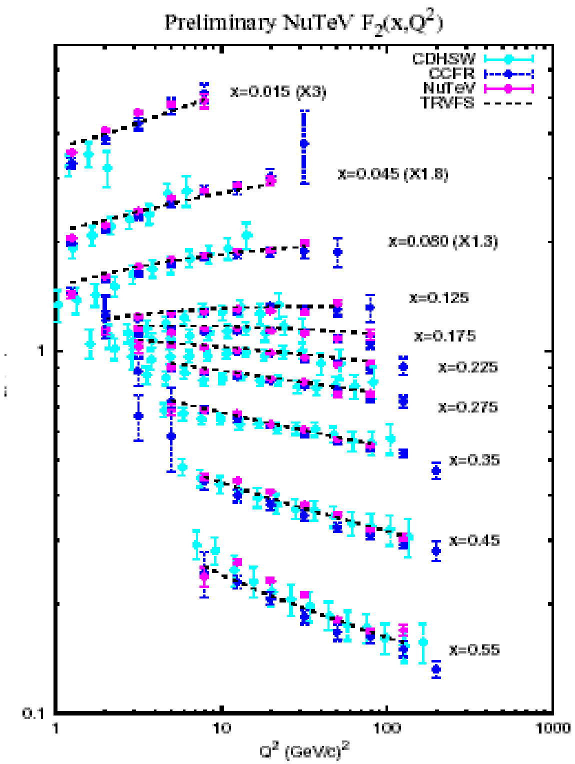
→ **selected topics from ~50 talks**

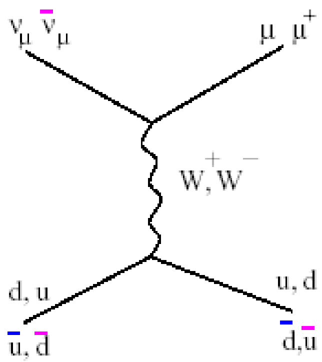
$F_2^{\nu N}$ new high stat data from improved ? and ? beams $xF_3^{\nu N}$

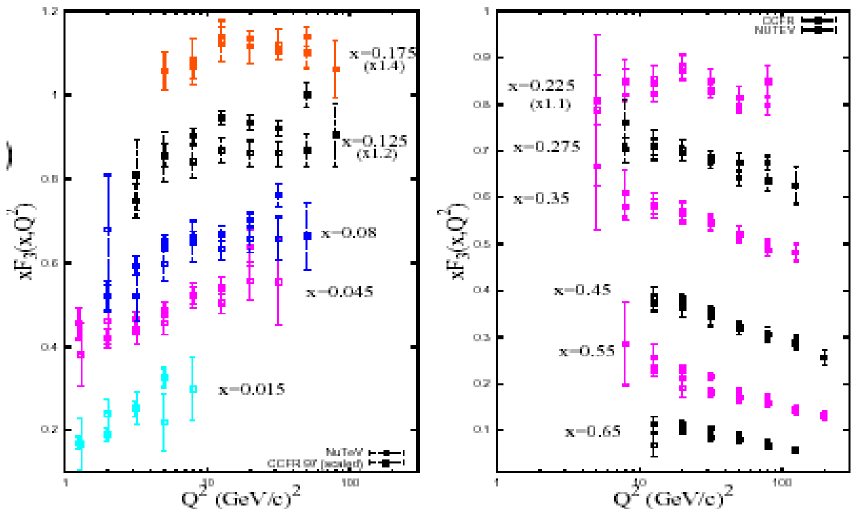
better control of largest systematics: E_μ and E_{Had}

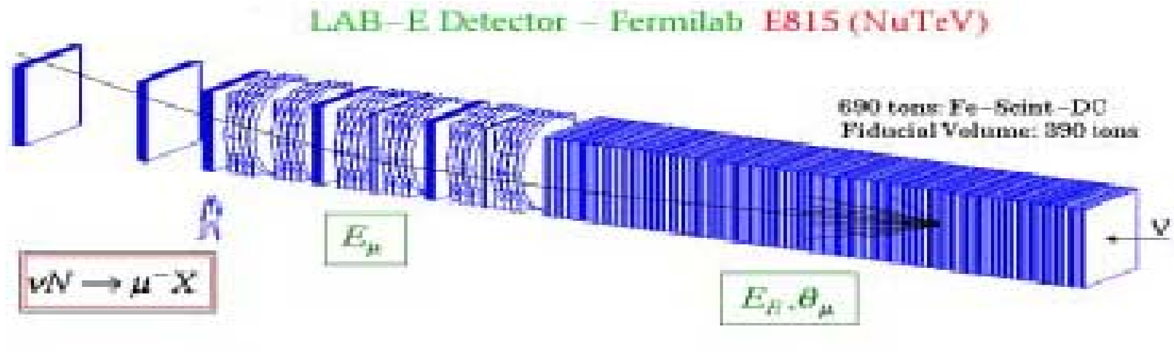
$$F_2^{\nu(\overline{\nu})} = \Sigma x(q + \overline{q} + 2k)$$

$$xF_3^{\nu(\overline{\nu})} = \Sigma x(q - \overline{q}) \pm 2x(s - c)$$





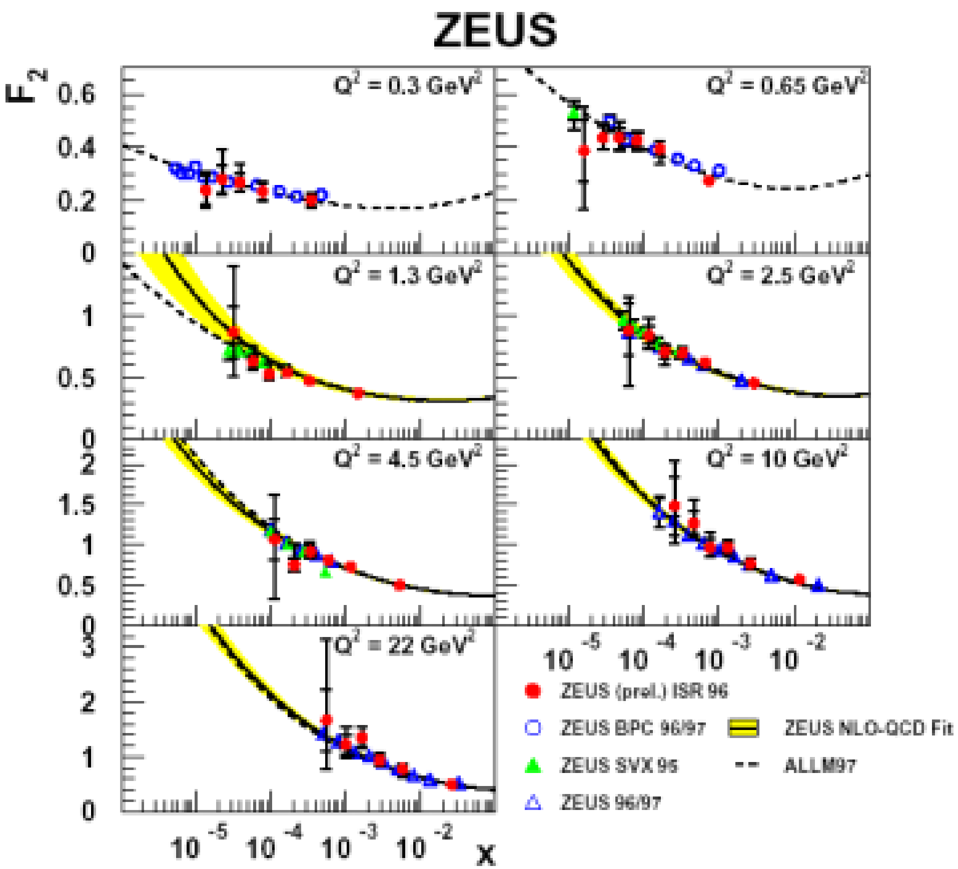


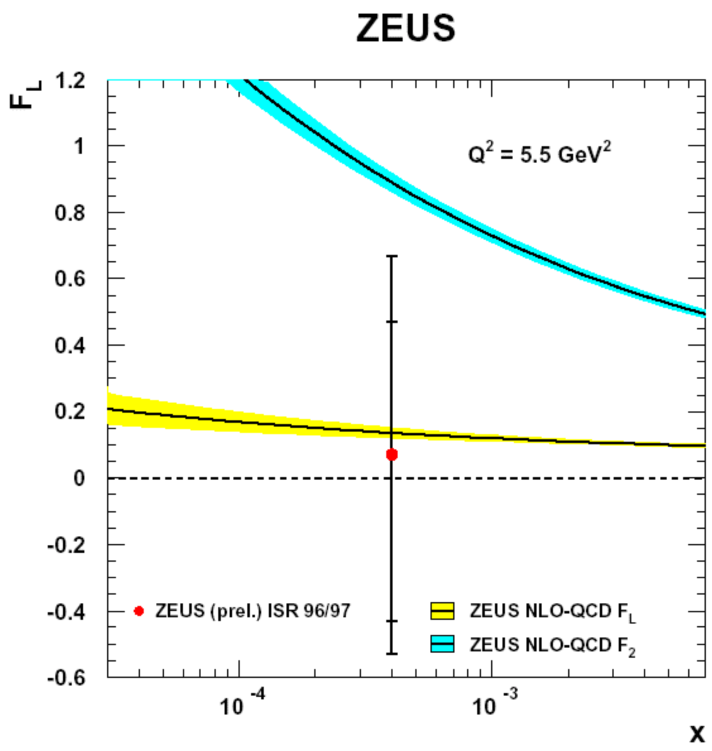


Data taken in 1996-97

F_2^p first measurements using ISR events ~36pb^{-1} F_L^p

ISR reduces E_e → access of lower Q^2 values





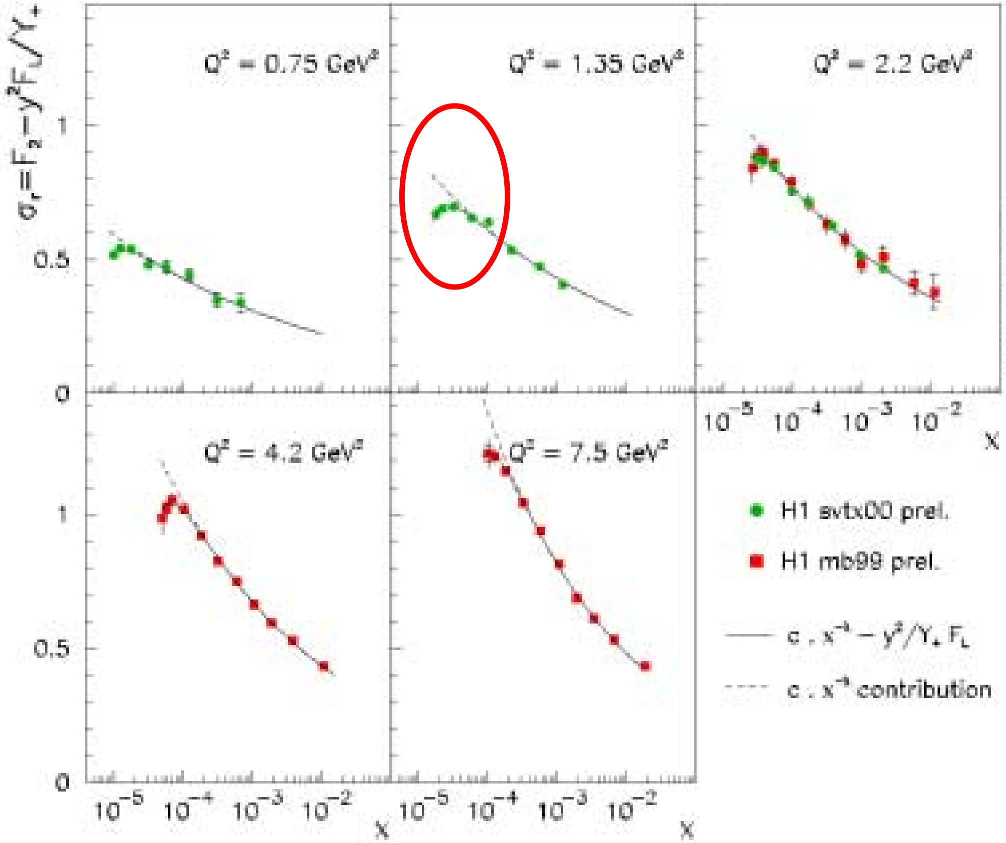
J. Cole, ZEUS

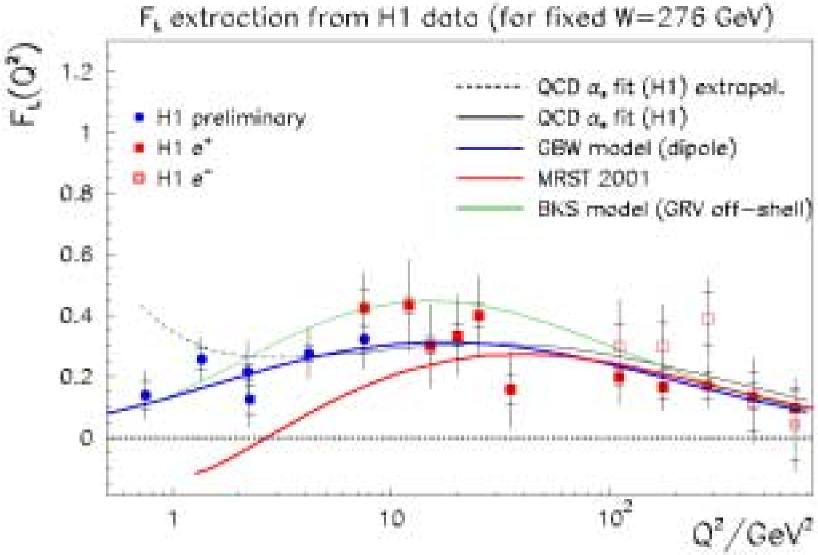
[see also V. Lendermann, H1, for new F_2 measurement at low W, low Q^2]

F_L^p new data from ep cross sections

at high y: $\sigma_{FIT} = c \cdot x^{-\lambda} - \frac{y^2}{1+(1-y)^2} F_L$

F_2^p





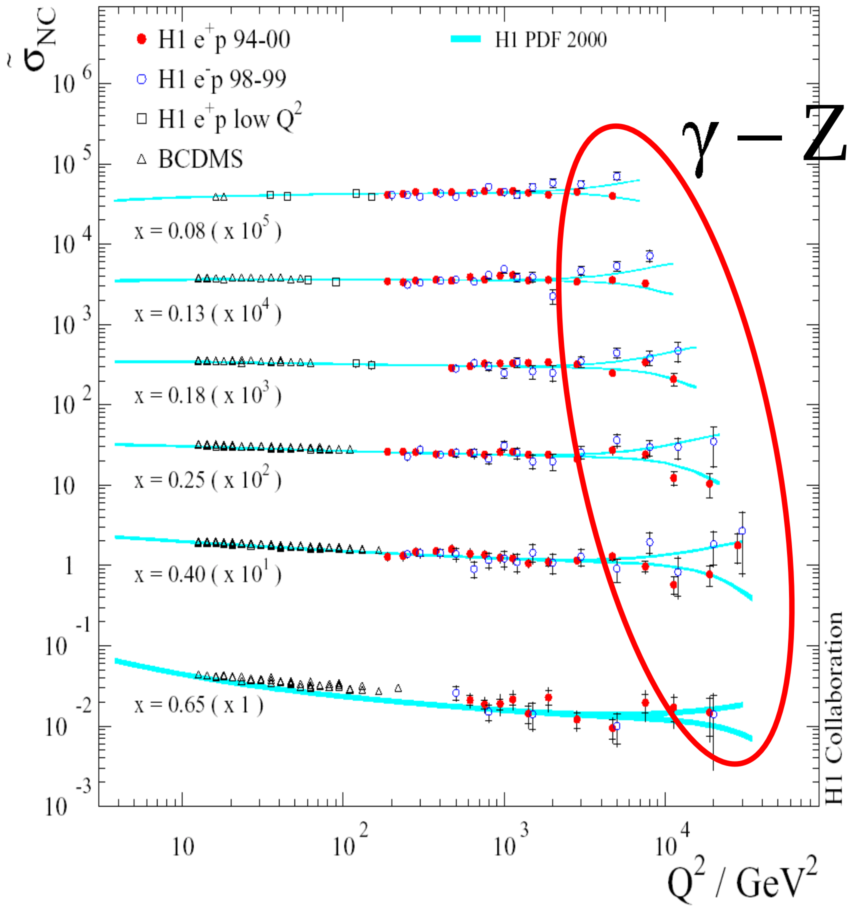
- for the first time F_L extracted at low Q^2 (~ $1 GeV^2$) low x region
- precision of extraction improved

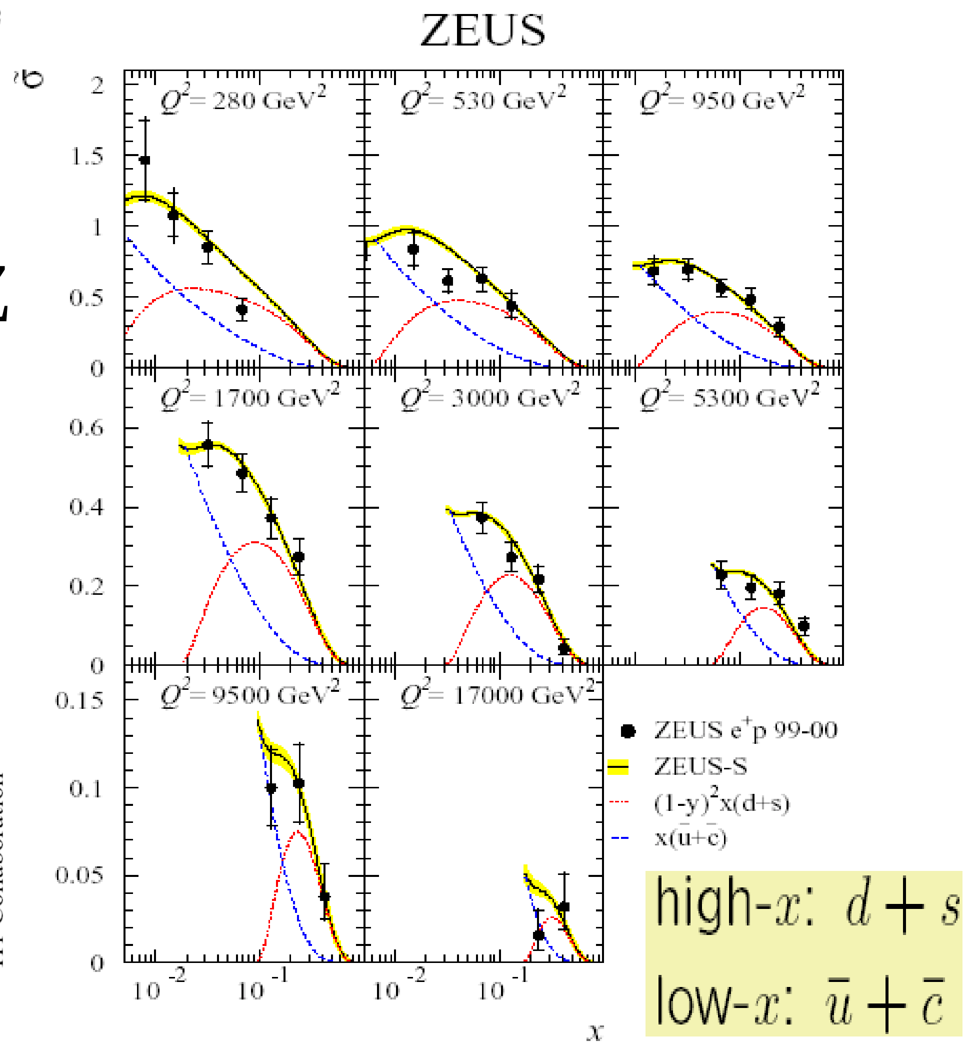
E. Lobodzinska, H1

→ low E_p running needed for accurate $F_L(x)$ measurement

final HERA I s_{NC} and σ_{CC} data: e^+p (99-00) and e^-p (98-99)

$$\tilde{\sigma}^{\pm}_{NC} = \tilde{F}_2 \mp \frac{Y_-}{Y_+} x\tilde{F}_3, \qquad Y_\pm = 1 \pm (1-y)^2$$

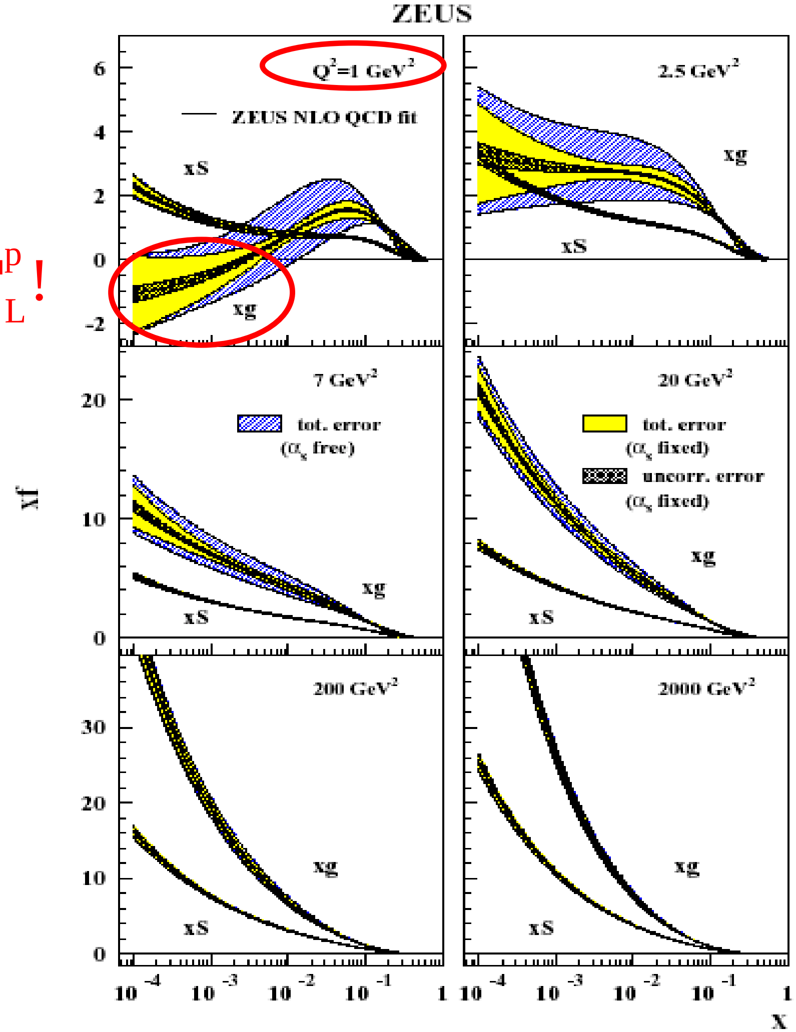




A. Dubak, H1

J. Rautenberg, ZEUS

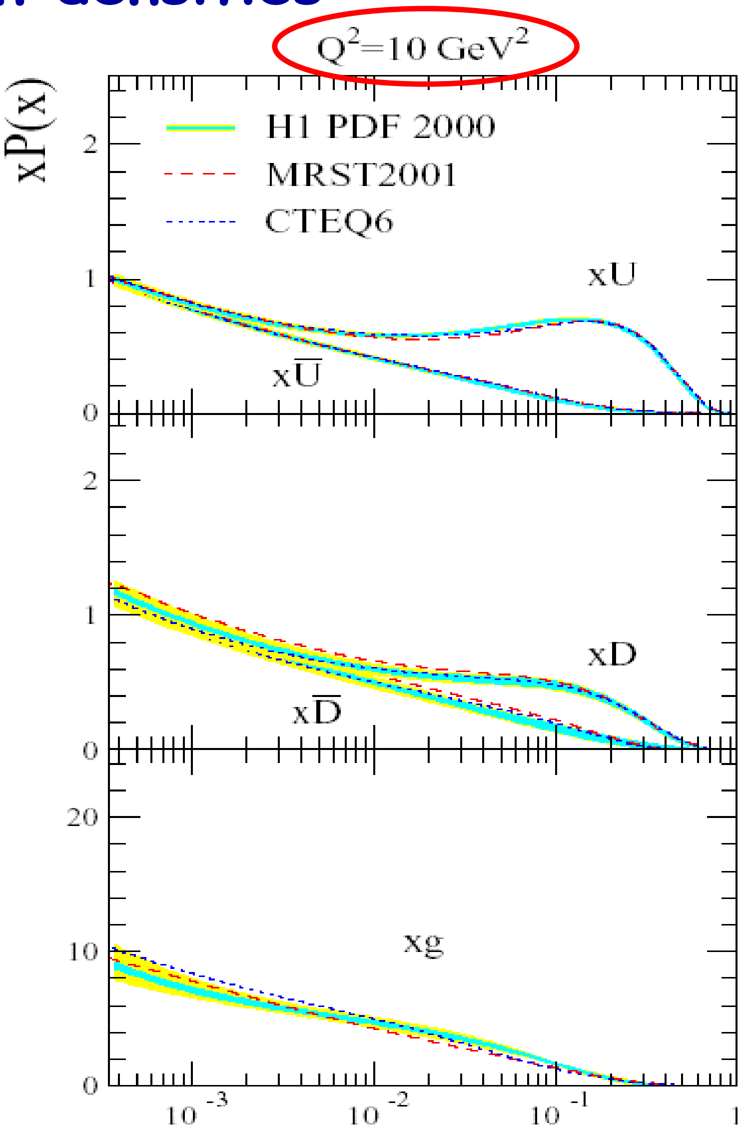
updates of QCD fits and parton densities



F_L^p!

NC & CC, e^+p & e^-p until 1999

J. Rautenberg, ZEUS

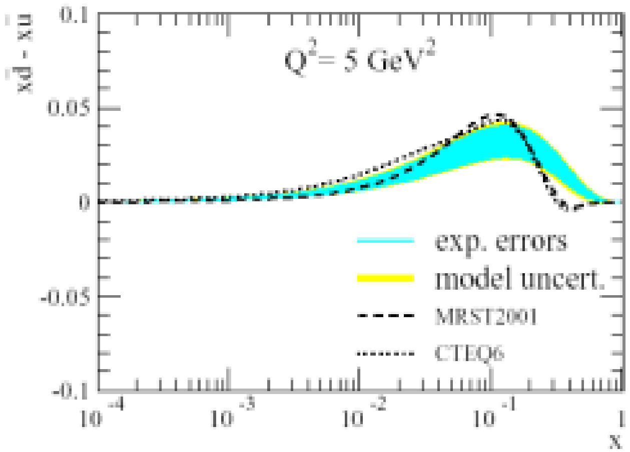


in remarkable agreement with global Fits MRST and CTEQ

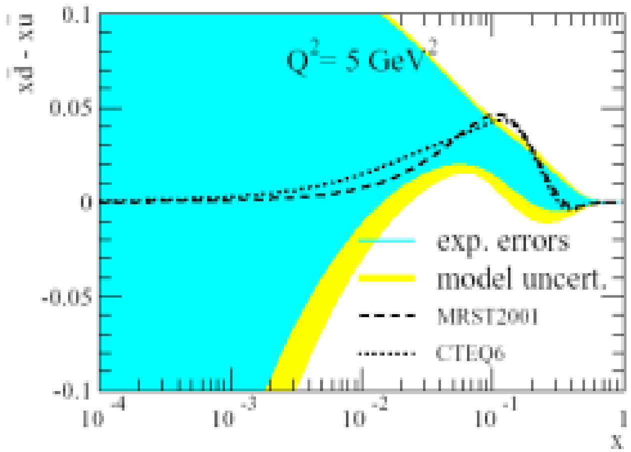
B. Reisert, H1

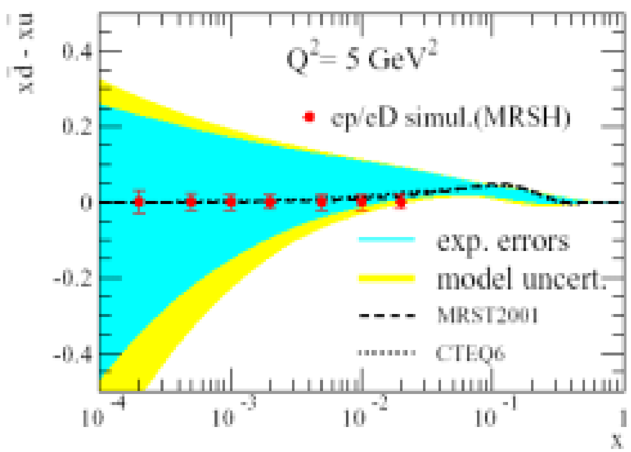
Impact of Low x Constraint: $\bar{d} - \bar{u}$

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)

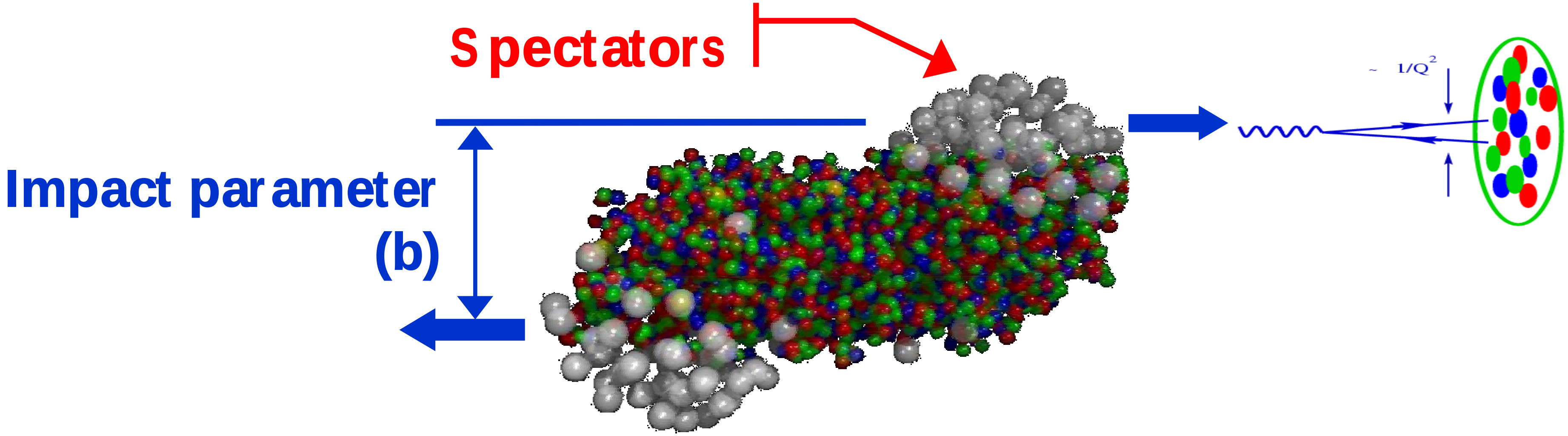
B. Reisert, H1

Relativistic Heavy Ion Collider

- Run 1 (2000) : Au-Au @ $\sqrt{S_{NN}}$ = 130 GeV
- Run 2 (2001-2): Au-Au, p-p @ $\sqrt{S_{NN}}$ = 200 GeV
  - (1-day run): Au+Au @ $\sqrt{S_{NN}}$ = 20 GeV
- Run 3 (2003): d-Au, p-p @ $\sqrt{S_{NN}}$ = 200 GeV

B. Cole

RHIC A-A collisions and low x



- N_{part} gives # of nucleons that "participate" in collision

  A = 197 for Au ⇒ maximum N_{part} in Au-Au is 394

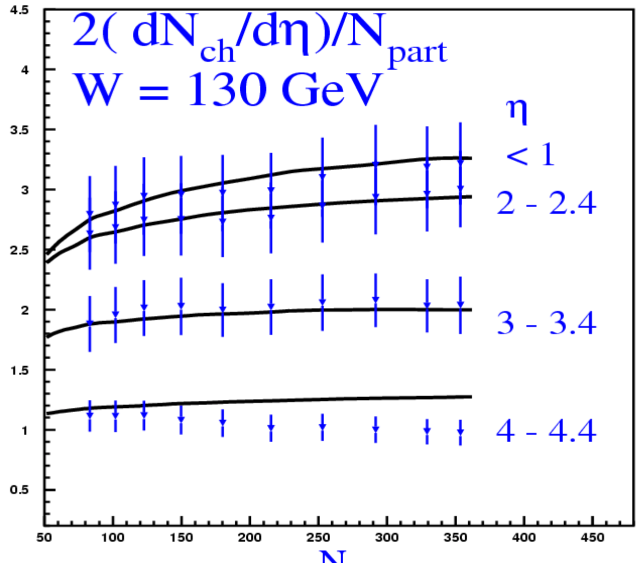
- b determines centrality ("violence") of collision

  central collisions (small b) → larger N_{part} , high density gluons of roughly $dN_G/dA \sim 4\ fm^{-2}$ assuming k_t~1 GeV/c

- produced particle properties E_T and N_{chg} determined by "low x" gluon dynamics (input from HERA) ? → test it!

dN/dη saturation model comparisons

PHOBOS data vs **Kharzeev and Levin PLB523(2001)79**



→large gluon flux in highly boosted nucleus related to new scale Q_S^2 :

$$\rho \propto Q_s^2 / \alpha_s(Q_s^2)$$

→take $Q_s(s)$ s-dependence from Golec-Biernat & Wüsthoff (from HERA)

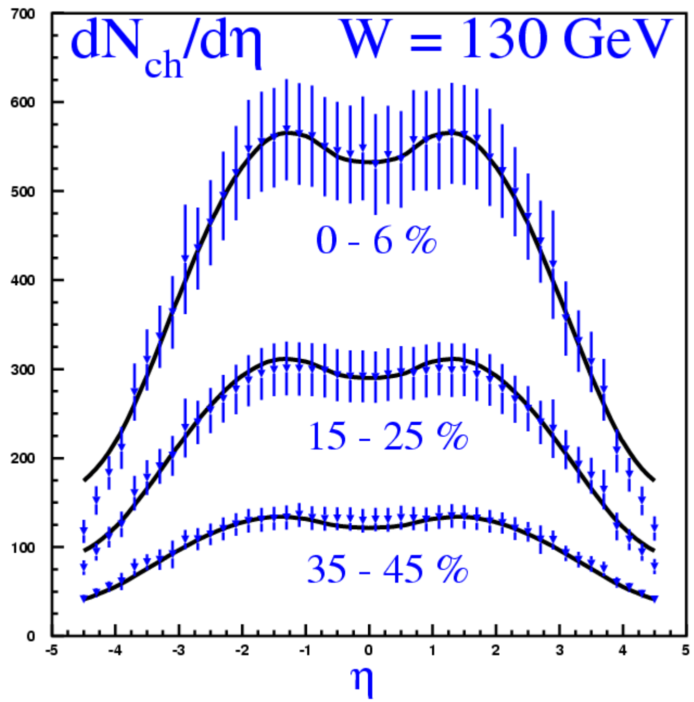
$$Q_s(s) / Q_s(s_0) = (s/s_0)^{\lambda/2}, \lambda \sim 0.3$$

→explicit dependence on $\rho_{nucleon}$

$$Q_s^2 = c\alpha_s(Q_s^2)\, xG(x, Q_s^2)\, \rho_{nucleon}$$

+ "additional model input"

→ remarkable agreement with data @ 130 GeV…

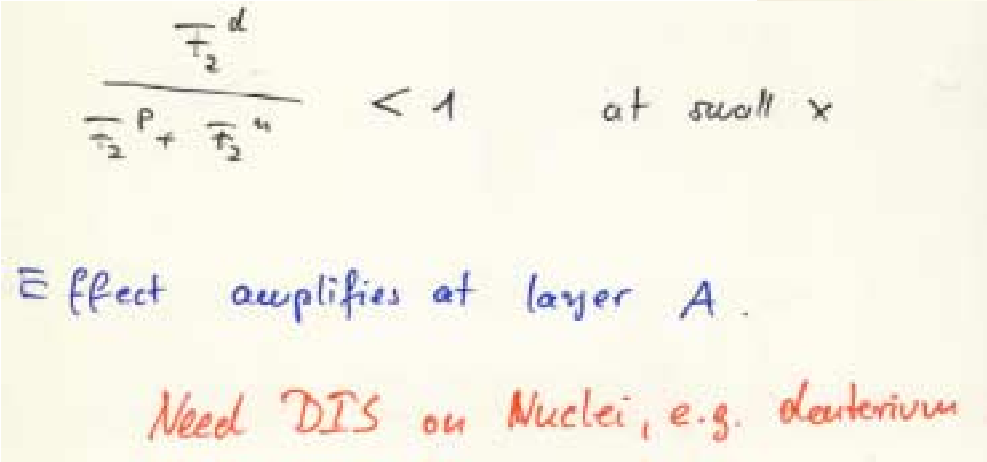


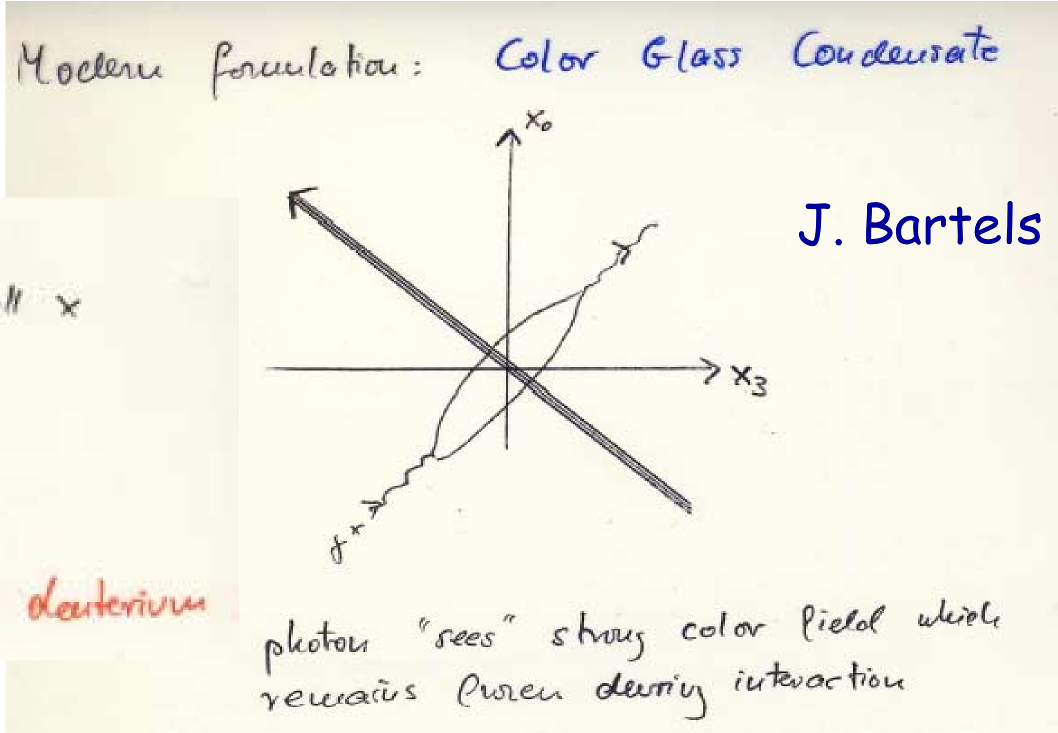
summary: RHIC A-A collisions and low x   B. Cole

- closest thing we have to *ab initio* calculation
- they provide falsifiable predictions !
- connect RHIC physics to DIS observables, e.g.
  $\sqrt{s}$ dependence of $dN/d\eta \Leftrightarrow$ saturation in DIS

- but, there are still many issues (e.g.):
  - What is the value for Q_s ?   Is it large enough ?
  - Is Q_s really proportional to ρ_{part} ($A^{1/3}$)?
  - How is $dN/d\eta$ related to number of emitted gluons ?
- How do we conclusively decide that saturation applies (or not) to initial state at RHIC ?

saturation in DIS





J. Bartels

→ exciting prospect of precision eA measurements at small x:

scattering is coherent over nucleus → diquark sees much larger # of partons: $xg(x_{eff},Q^2) = A^{1/3}\, xg(x,Q^2)$, $xg \propto x^{-\lambda}$

$x_{eff}^{-\lambda} = A^{1/3} x^{-\lambda}$ so $x_{eff} \approx x A^{-1/3\lambda} = x/A^3$ ($Q^2 < 1$ GeV^2)

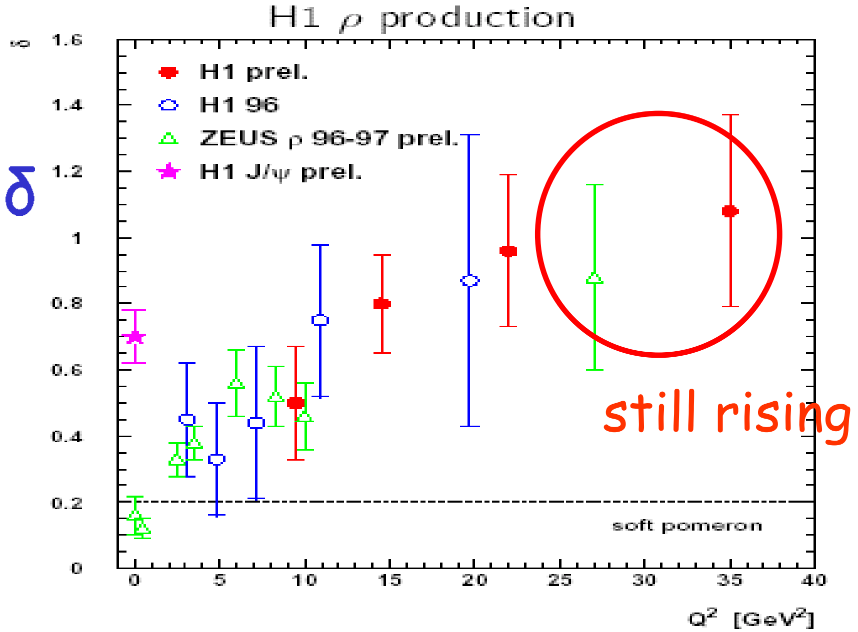
$= x/A$ ($Q^2 \approx 100$ GeV^2)

A. Caldwell

electro- and photoproduction of vector mesons

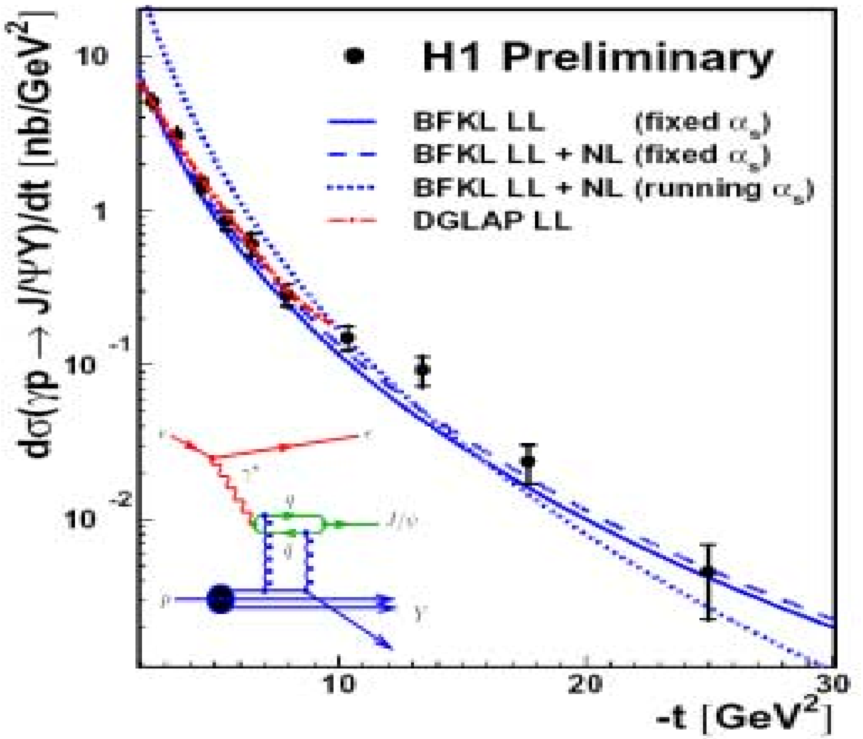
- s(J/?) rises fast with W^d
  d = 0.69 ± 0.02 (ZEUS)
  and d is flat in Q^2
- described by pQCD, hard scale $M_{J/?}$
- sensitive to gluon $s_L \propto |xG(x,Q^2)|^2$

$\sigma \propto W^\delta$ fit in bins of t



- for ?: high Q^2 possible hard scale

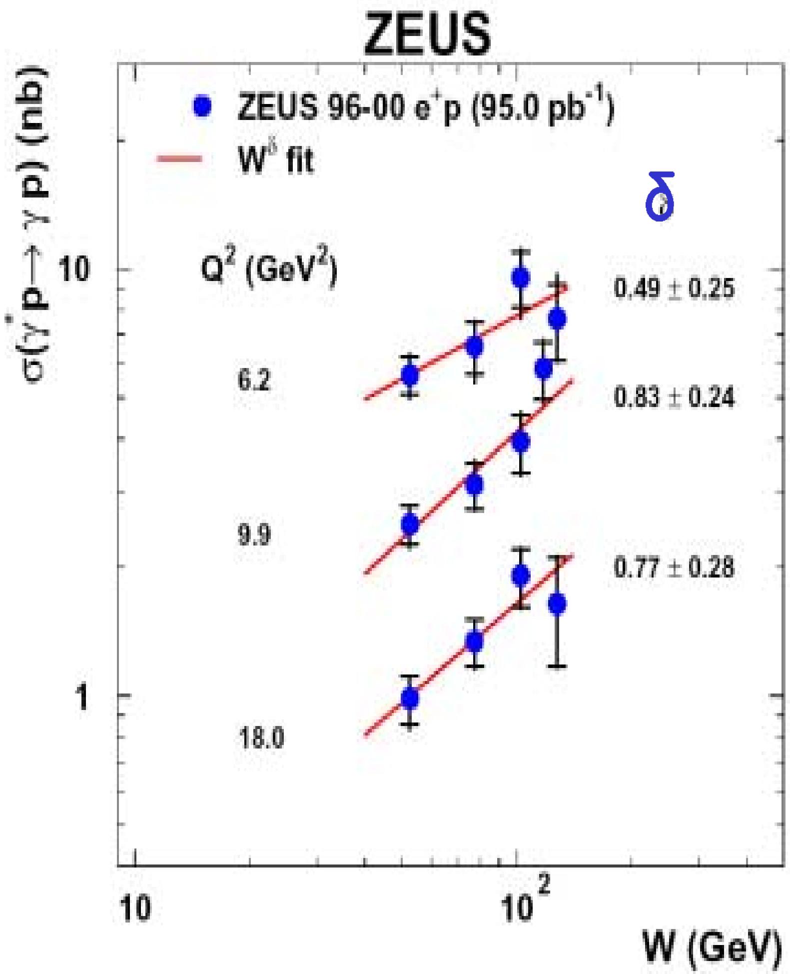
inelastic J/? at high |t|

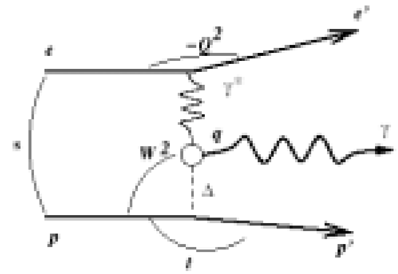


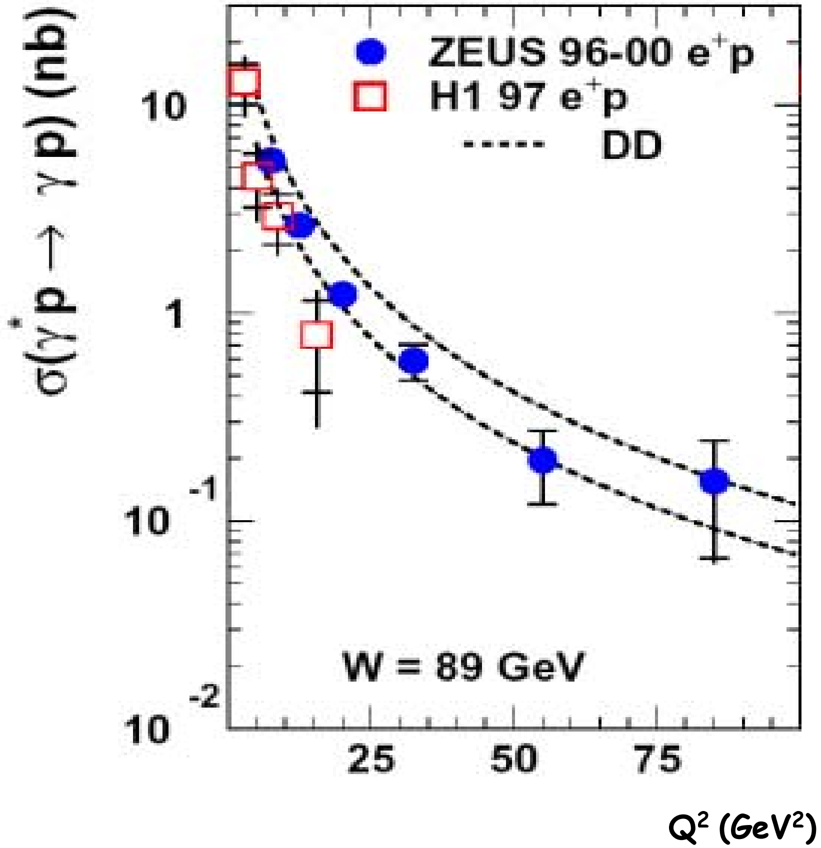
- Dependence at large $|t|$: $\propto (-t)^{-n}$
  $\Rightarrow n = 3.00 \pm 0.08(stat.) \pm 0.05(syst.)$
  for $|t| > 3.5\,\mathrm{GeV}^2$
- Increase $|t| \Rightarrow$ sys. increase in n
- $n \simeq 3$ similar to ρ, ϕ (ZEUS)

 J. Tandler, ZEUS; P.Fleischmann, M. Beckingham, H1

new results on DVCS cross section





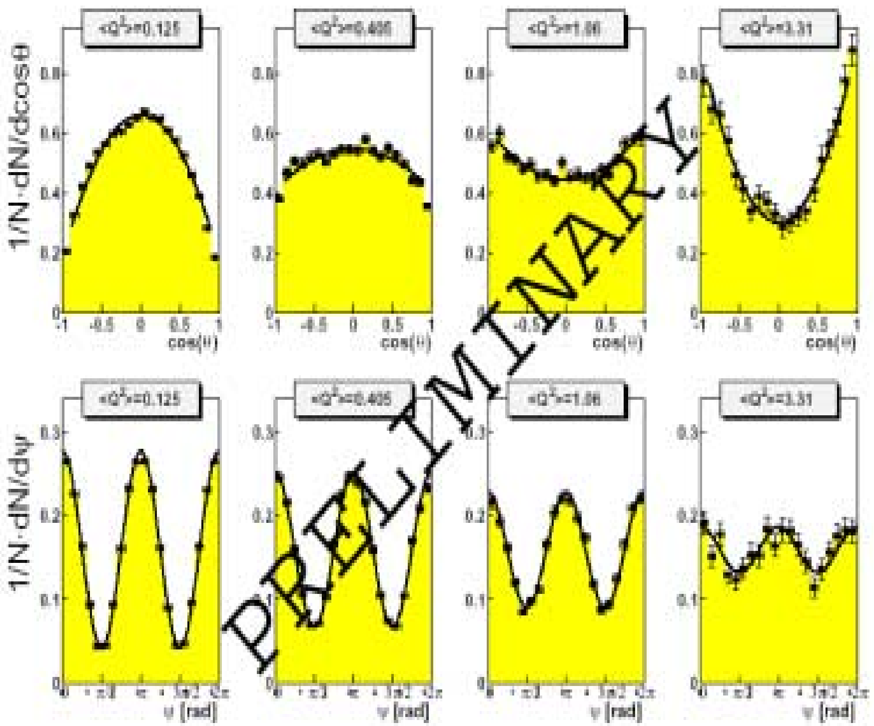


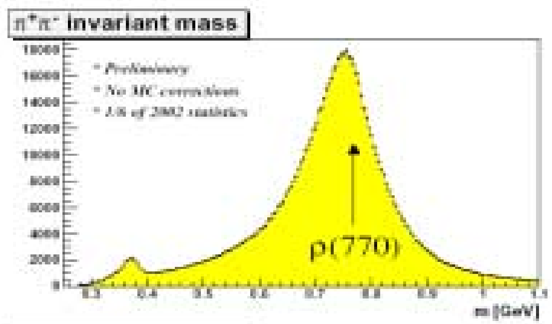
Q^2 dependence well described by GPD or colour dipole based models (integrated over experimental t range)

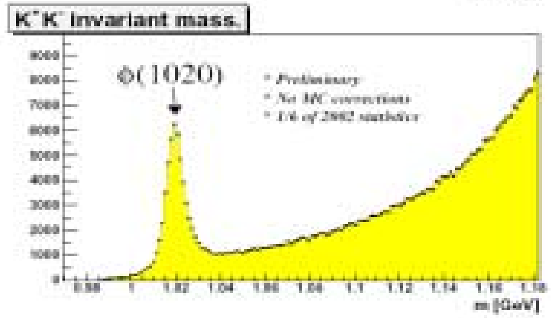
vector mesons with COMPASS

- 160 GeV μ^+ beam, Pol. ~76%
- ^{6}LiD target, Pol. ~57%
- prel. results with 1/6 of 2002 stat.

angular distributions





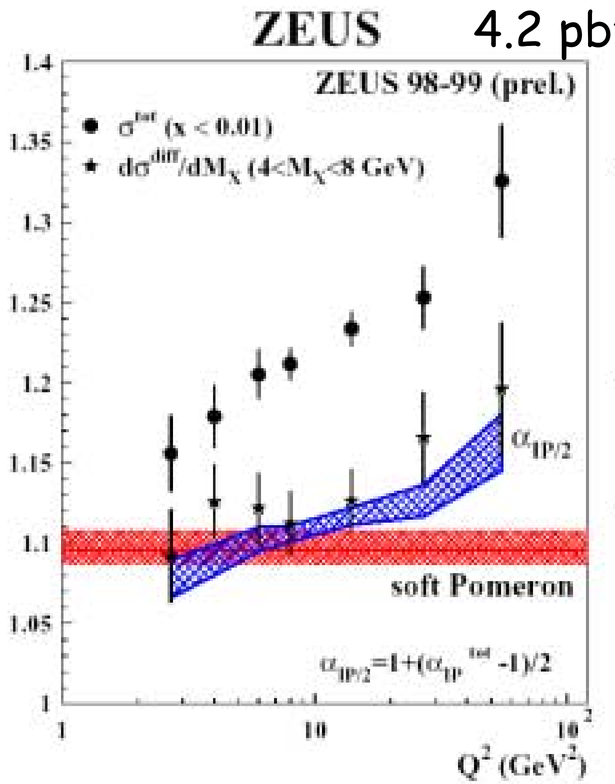


Outlook

- High luminosity allows to collect large statistics sample.
- Trigger conditions allow the measurement in transition region from soft diffraction to pQCD.
- Possibility to measure double spin asymmetries with high accuracy.
- Spin transfer mechanism can be studied (violation of SCHC).
- Study of GPD at large Q^2.

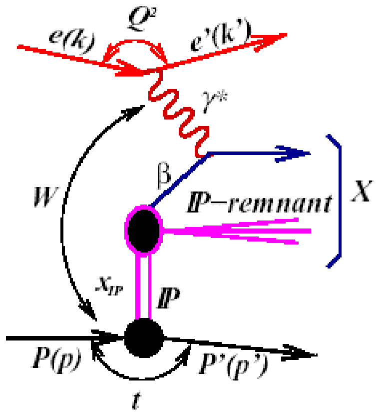
energy dependence of hard diffraction

M_X method using FPC

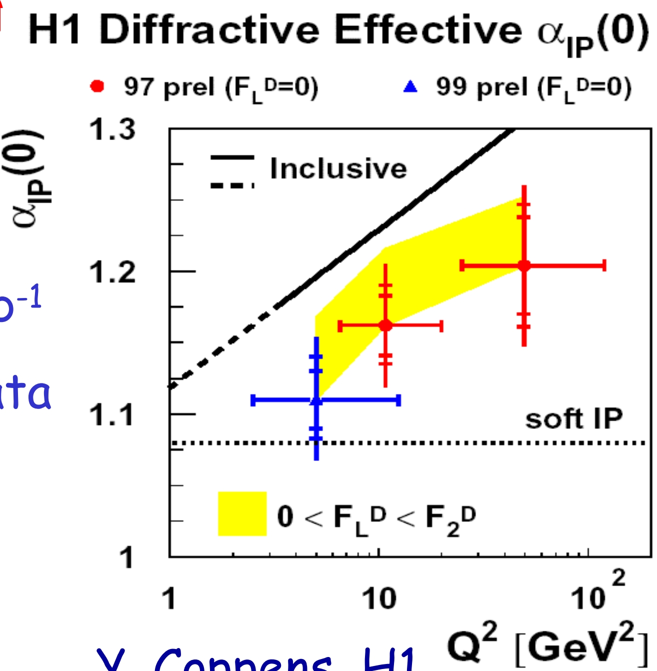


4.2 pb^{-1}

H. Lim, ZEUS



- $\sigma^{tot}_{\gamma^* p} = \frac{4\pi^2\alpha}{Q^2} \cdot F_2(x, Q^2)$
  $\sim \frac{1}{W^2} Im T_{\gamma^* p \to \gamma^* p}(W^2, t=0) \sim (W^2)^{\alpha^{tot}_{IP}(0)-1}$
  (Optical theorem)
- $\frac{d^2\sigma^{diff}}{dM_X dt} \sim \quad |T_{\gamma^* p \to \gamma^* p}|^2 \quad \sim (W^2)^{2(\alpha^{diff}_{IP}(0)-1)}$
  at $t = 0$
- Data ($4 < M_X < 8$ GeV) show
  $\Longrightarrow \alpha^{diff}_{IP} \approx 1 + (\alpha^{tot}_{IP} - 1)/2$



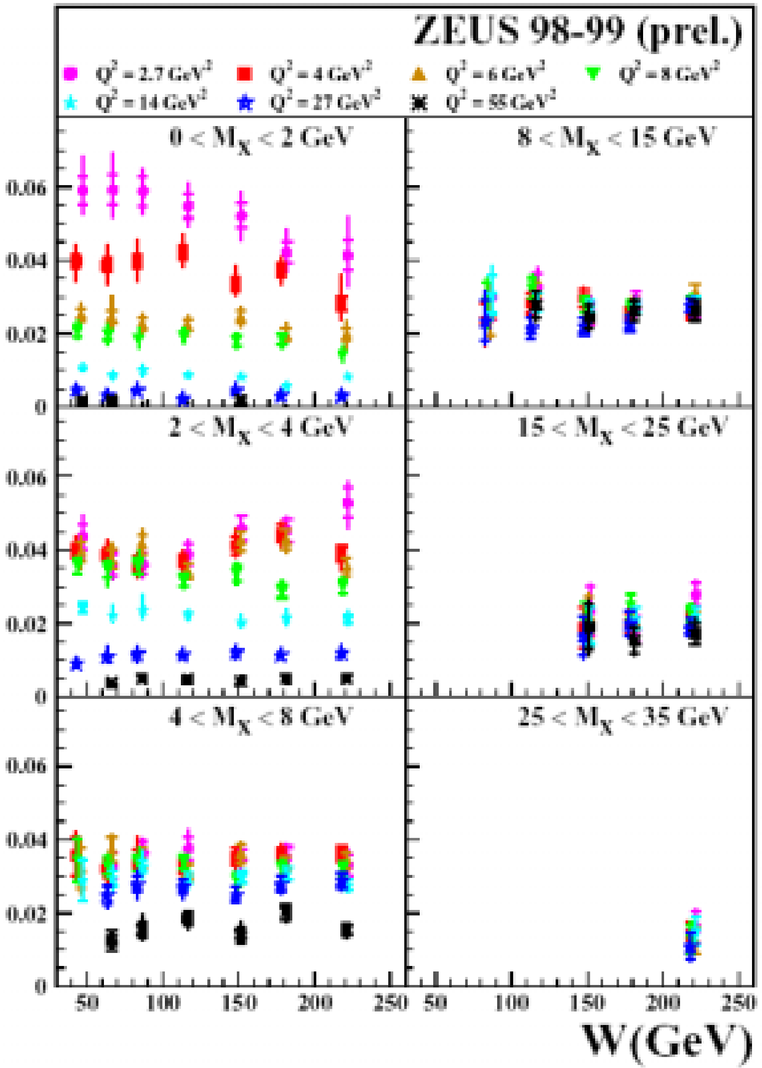
new: 3.4 pb^{-1}

from 99 data

Y. Coppens, H1

→ strong indication for pQCD

diffractive contribution to σ_{tot} (?*p)



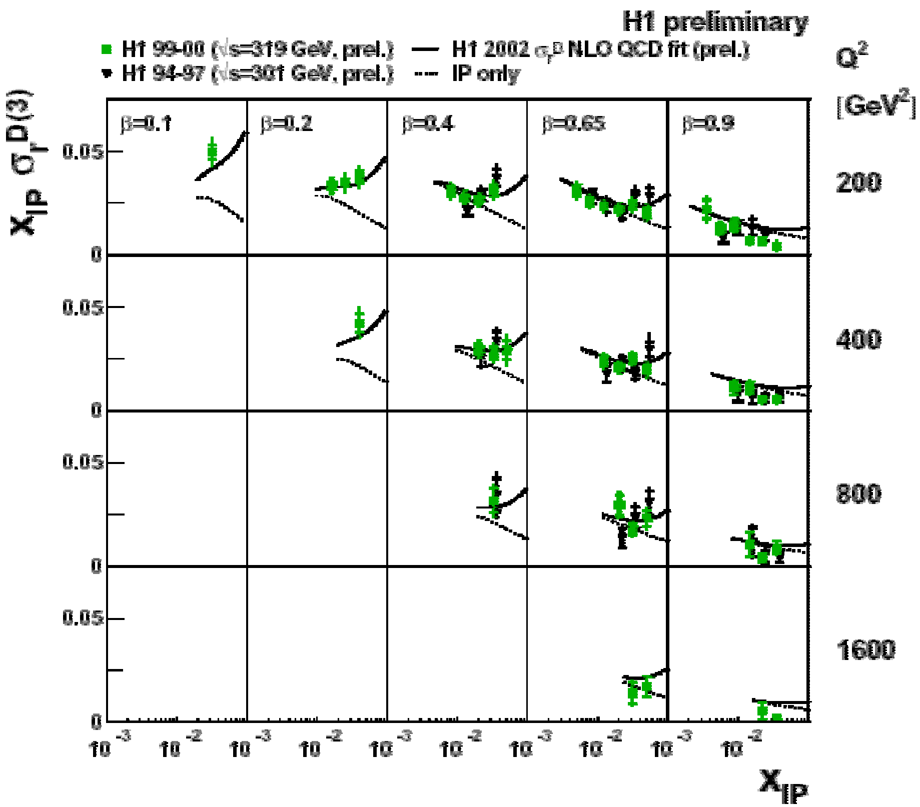
$$r_{tot}^{diff} = \frac{\int_{M_a}^{M_b} dM_X d\sigma^{diff}_{\gamma^* p \to XN, M_N < 2.3 GeV}/dM_X}{\sigma^{tot}_{\gamma^* p}}$$

- For $M_X < 2$ GeV, r_{tot}^{diff} is falling with W .
- For $M_X > 2$ GeV, r_{tot}^{diff} is constant with W .
  $\Longrightarrow$ The diffractive cross section has about the same W -dependence as σ^{tot} .
- The low M_X bins exhibit a strong decrease of r_{tot}^{diff} with increasing Q^2 .
- For $M_X > 8$ GeV, no Q^2 dependence is observed.
- At $W = 220$ GeV,
  $\sigma^{diff}_{(M_X < 35 \text{ GeV})}/\sigma^{tot}$ $\sim 20\%$ at $Q^2 = 2.7$ GeV²
  $\sim 10\%$ at $Q^2 = 27$ GeV²
  $\Longrightarrow$ Slowly decreasing with Q^2

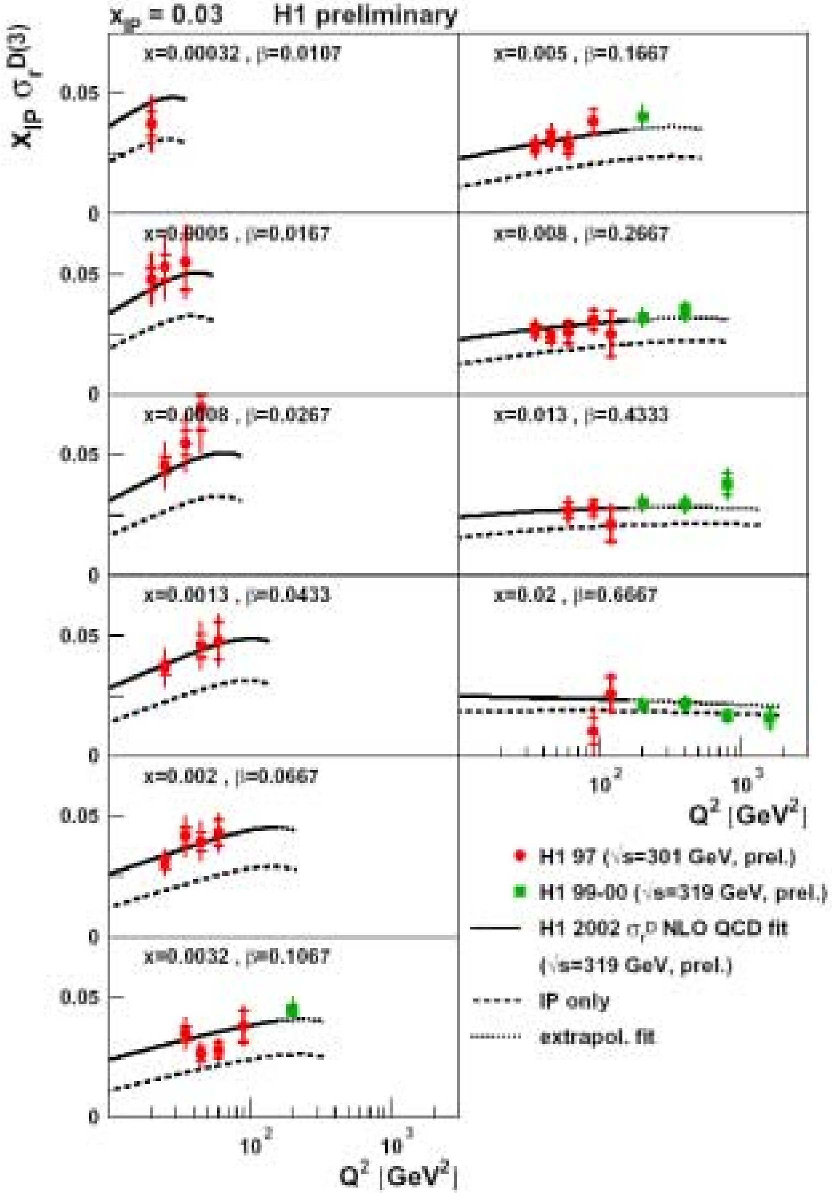
H. Lim, ZEUS

reduced inclusive diffractive cross section at high Q^2

new H1 data 99/00: 65 pb^{-1}

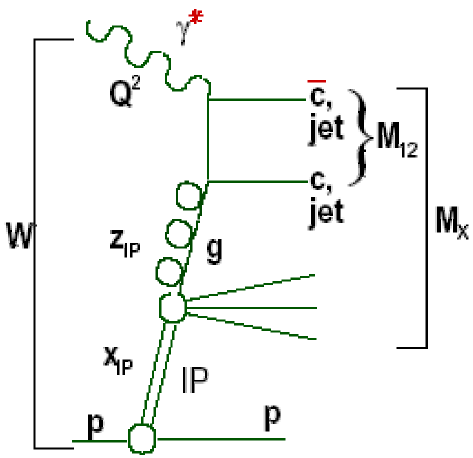


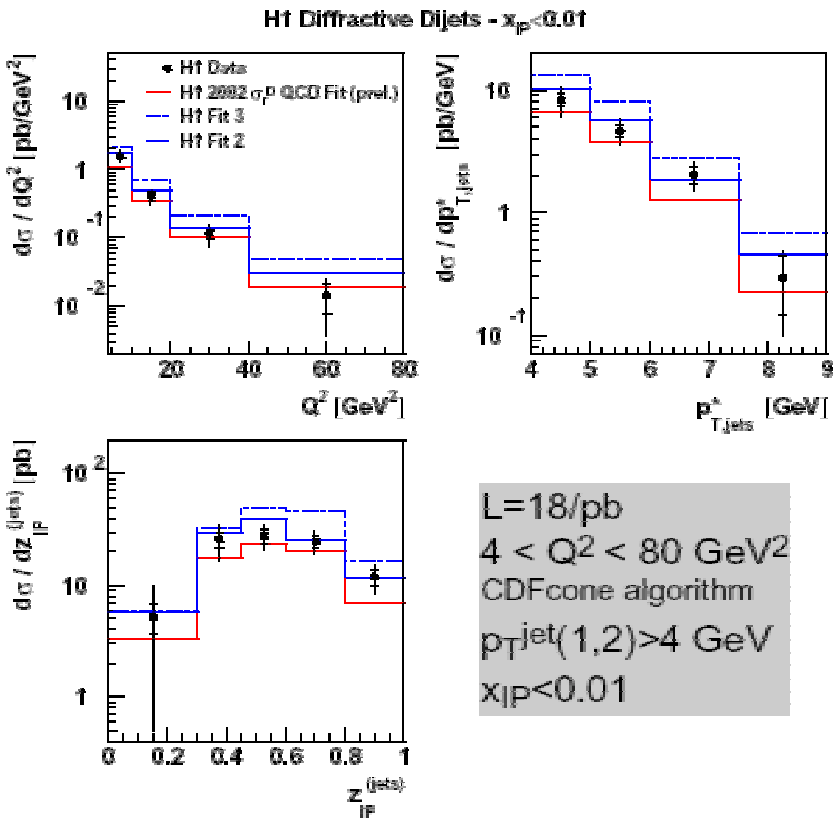
subleading trajectories important at low ß



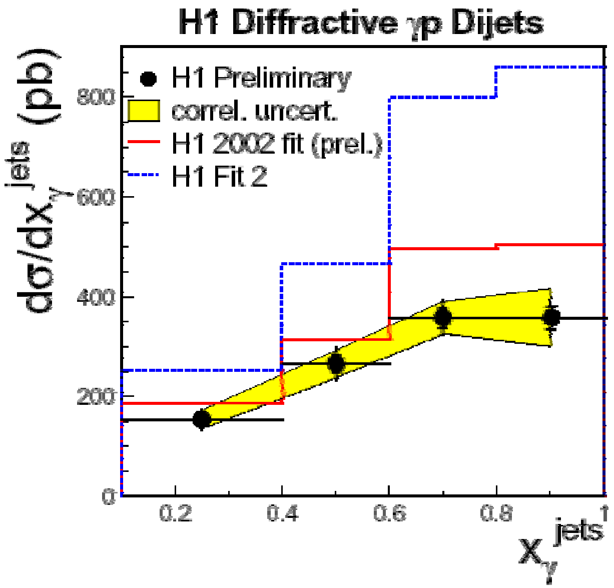
→ data well described by pQCD

test of QCD factorization in diffractive production





L=18/pb
$4 < Q^2 < 80$ GeV^2
CDFcone algorithm
$p_T^{jet}(1,2)>4$ GeV
$x_{IP}<0.01$

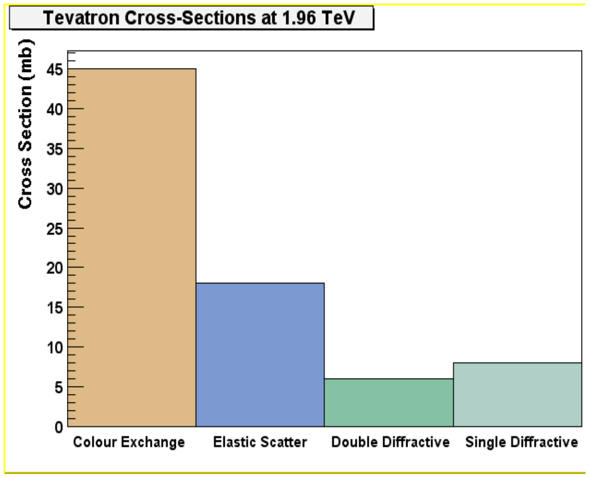


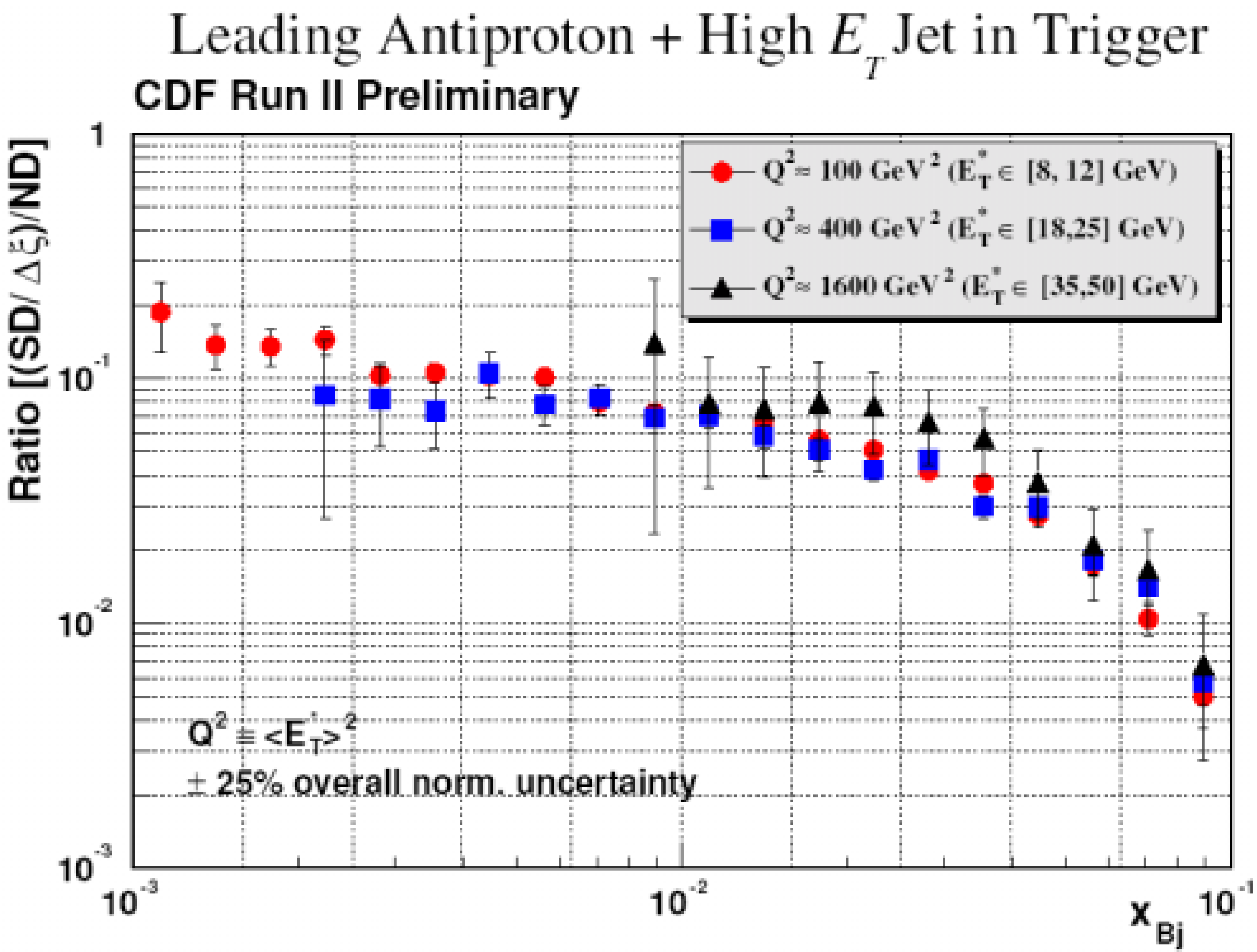
Factorisation in Diffraction:

- Factorisation holds in DIS
- ep vs. $p\bar{p}$ factorisation breaking
- Factorisation seemingly broken in Photoproduction

	E_{cm} (GeV)	Suppression
DIS	90..260	1
γp	165..240	≈1.8±0.45 (exp.)
$p\bar{p}$	1800	≈10

Q^2 dependence of SD/ND ratio @ 1.96 TeV





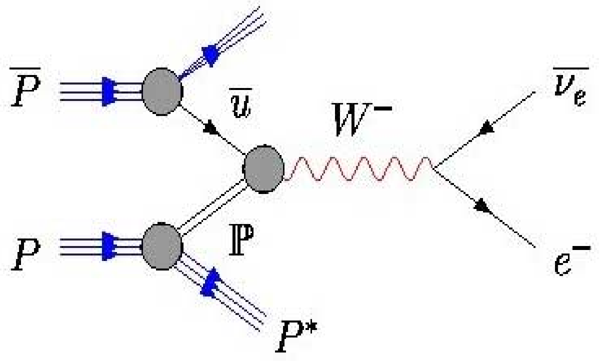
x-Bjorken of Parton:

$$x_{Bj} = \frac{\sum_i E_T^{jet} e^{-\eta_{jet}}}{\sqrt{s}}$$

(i=1,2,3 if Jet3 E_T>5 GeV)

→ Q^2 evolution of Pomeron similar to that of proton (?)

W and Z Boson Production at D0 by the Diffractive Process



Sample	Gap Fraction (%) Diffractive/All (*)	Probability that Background would fluctuate to the Data in the (0,0) bin for W and Z Data	
W cent	1.08 + 0.19 - 0.17	1×10^{-14}	**7.7σ**
W fwd	0.64 + 0.18 - 0.16	6×10^{-8}	**5.3σ**
W All	**0.89 + 0.20 – 0.19**	3×10^{-14}	**7.5σ**
Z	**1.44 + 0.62 - 0.54**	5×10^{-6}	**4.4σ**

First observation of Z Diffractive

DØ Preliminary

(*) Includes correction for multiple interaction contamination.
Sys error dominated by background fitting.

$$\frac{d\sigma}{d\eta} = \frac{1}{2s} \sum_{ij} \int d(\cos\theta) \int \frac{dx_{\mathbb{P}}}{x_{\mathbb{P}}} \int d\hat{s}\, F_{\mathbb{P}/p}(x_{\mathbb{P}}) f_{i,\mathbb{P}}(\beta, \mu^2) f_{j,\bar{p}}(x, \mu^2) \hat{s} \frac{d\hat{\sigma}_{ij}}{d\hat{t}}$$

$$F_{\mathbb{P}/p}(x_{\mathbb{P}}) = N \int dt \;\; \exp(4.6t) \left(\frac{1}{x_{\mathbb{P}}}\right)^{1.90+0.52t}$$

Pomeron Structure

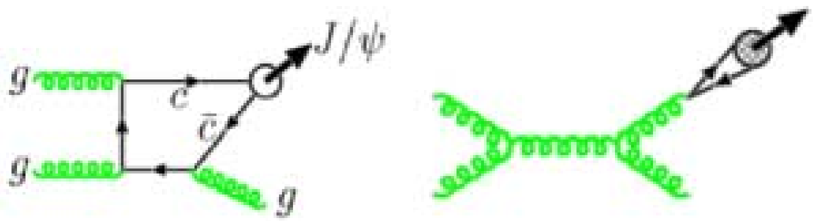
(Anti)Proton Structure

Run I data

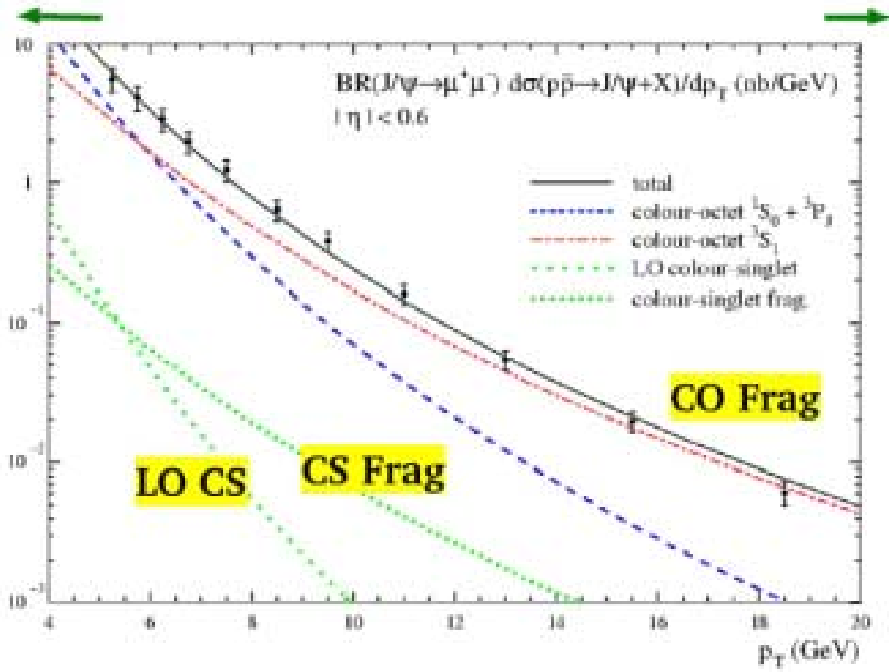
charmonium production – simplest laboratory to study the binding of quarks to hadrons

B. Naroska

- Pre-Tevatron: Colour singlet fusion
  - Low by orders of magnitude



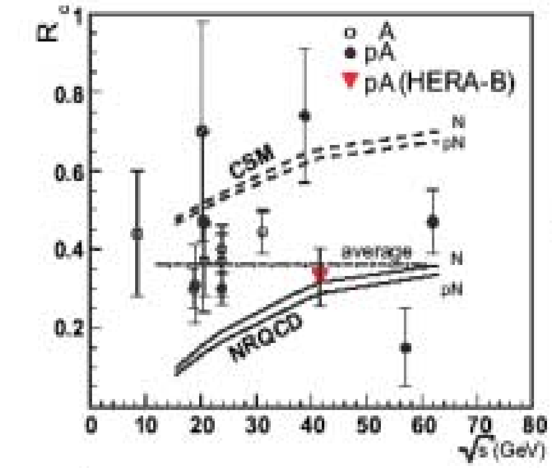
- Two new ingredients:
  - Gluon fragmentation important (e.g. CS fragmentation)
  - Colour octet states important- e.g. NRQCD expansion:
    - $d\sigma(H) = \sum_n d\sigma|c\bar{c}(n)| \langle O^H(n)\rangle$
    - n includes colour singlet and octet states
    - Expansion in α_s and v (relative velocity of quark and anti-quark)

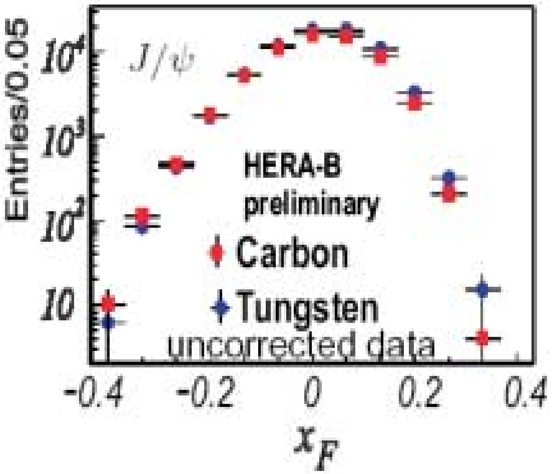


Beneke, Krämer, PRD 55(1997) 5269
CDF Data: PRL 79(1997) 572
(Run 1A data, 18 pb^{-1})

Colour octet fragmentation dominates at high p_T

Charmonium Production at HERA-B





Dirk Krücker - HERA-B Collaboration

- First results based on 2000 data published:
  $\langle R_{\chi_c} \rangle = 0.32 \pm 0.06_{stat} \pm 0.04_{sys}$

CS

$$R_{\chi_c} = \frac{\sum_{i=1}^{2} \sigma(\chi_{ci}) Br(\chi_{ci}) \to J/\psi\gamma}{\sigma(J/\psi)}$$

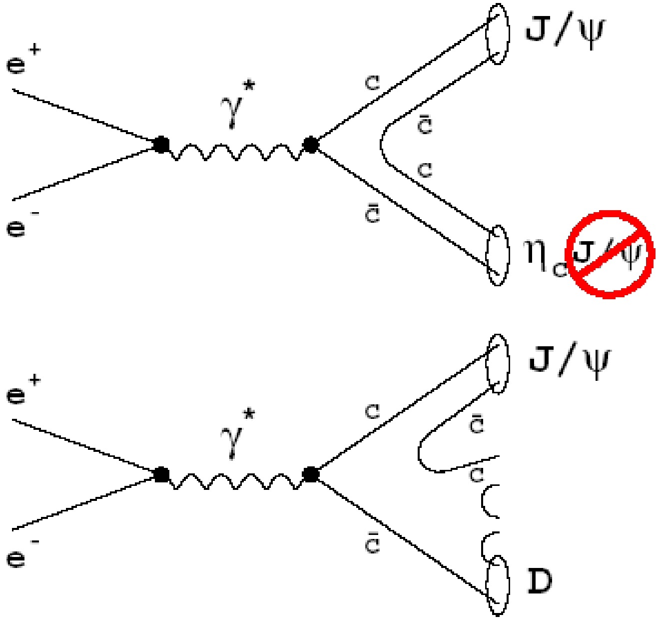
CO

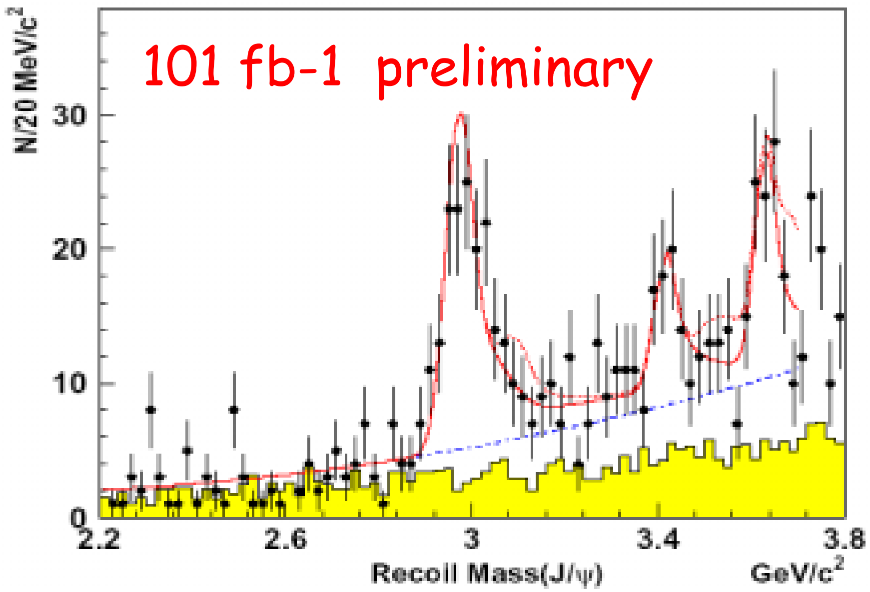
- About 300000 J/ψ's and 20000 χ_c's in 2002/2003 data, many ongoing analyses

New results coming soon

Study of $e^+e^- \to J/\psi + charmonium$

Study in detail J/ψ recoil mass spectrum around $\sim 3\,\mathrm{GeV}/c^2$



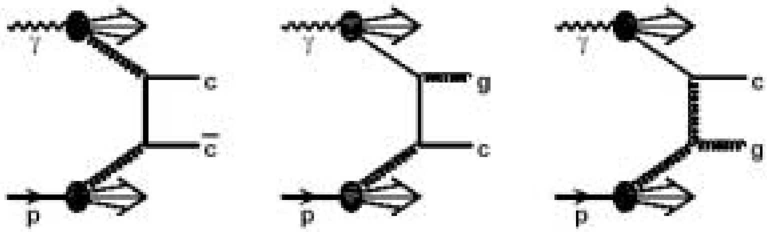


	N	$M\,[\mathrm{GeV}/c^2]$	σ	N	$M\,[\mathrm{GeV}/c^2]$	σ
η_c	175 ± 23	2.972 ± 0.007	9.9	179 ± 22	2.971 ± 0.006	10.6
J/ψ	-9 ± 17	fixed	--	0.0	fixed	--
χ_{c0}	61 ± 21	3.409 ± 0.010	2.9	72 ± 21	3.408 ± 0.009	3.8
$\chi_{c1} + \chi_{c2}$	-15 ± 19	fixed	--	0.0	fixed	--
$\eta_c(2S)$	108 ± 24	3.630 ± 0.008	4.4	97 ± 22	3.628 ± 0.007	4.9
$\psi(2S)$	-38 ± 21	fixed	--	0.0	fixed	--

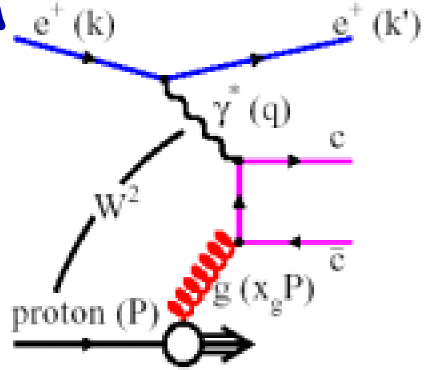
…and many more new results, J/psi cc / J/psi X = 82 +- 15 +- 14 %

P.Pakhlov DIS'03, April 23-27, 2003

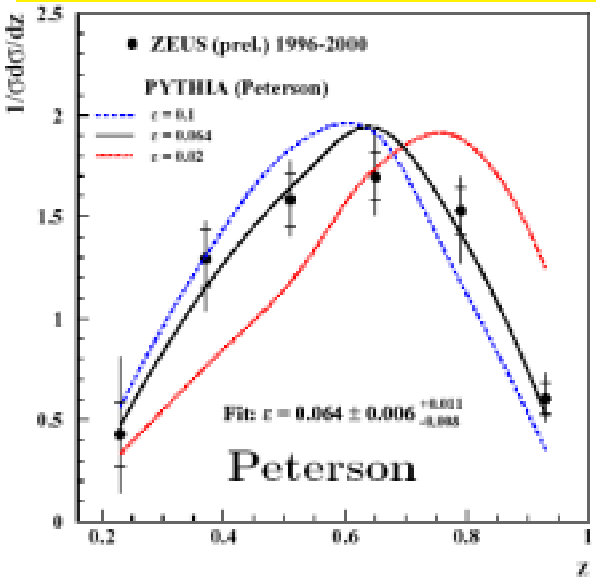
news on open charm production from HERA



At parton level
pQCD is expected
to work !
$c \Longrightarrow D$?



Charm fragmentation function



$$f(z) \propto \frac{1}{z(1-1/z-\epsilon/(1-z))^2}$$

$\epsilon = 0.064 \pm 0.006^{+0.011}_{-0.008}$ (ZEUS prel.)

$\epsilon = 0.05$ (PYTHIA default)

$e^+e^- \Rightarrow$ $\epsilon = 0.053$ (LL fit to ARGUS data)

→ **universal !**

Charm fragmentation fractions

ZEUS prel. (γp) $P_T(D,\Lambda_c) > 3.8\,\mathrm{GeV}$, $\lvert\eta(D,\Lambda_c)\rvert < 1.6$		Combined e^+e^- data	H1 prel. (DIS)
$f(c \to D^+) = 0.249 \pm 0.014^{+0.004}_{-0.008}$	new	0.232 ± 0.010	$0.202 \pm 0.020^{+0.045}_{-0.033}{}^{+0.029}_{-0.021}$
$f(c \to D^0) = 0.557 \pm 0.019^{+0.005}_{-0.013}$		0.549 ± 0.023	$0.658 \pm 0.054^{+0.117}_{-0.142}{}^{+0.080}_{-0.048}$
$f(c \to D_s^+) = 0.107 \pm 0.009 \pm 0.005$		0.101 ± 0.009	$0.156 \pm 0.043^{+0.036}_{-0.035}{}^{+0.050}_{-0.046}$
$f(c \to \Lambda_c^+) = 0.076 \pm 0.020^{+0.017}_{-0.001}$	new	0.076 ± 0.007	
$f(c \to D^{*+}) = 0.223 \pm 0.009^{+0.003}_{-0.005}$		0.235 ± 0.007	$0.263 \pm 0.019^{+0.056}_{-0.042}{}^{+0.031}_{-0.022}$

charm fragmentation fractions are universal

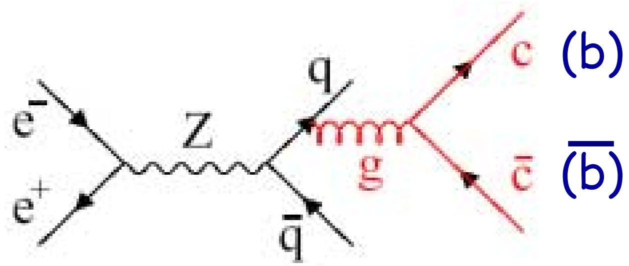
it is valid to use charm fragmentation parameters measured in e^+e^- annihilations to describe $D-$production in $e^{\pm}p$ collisions

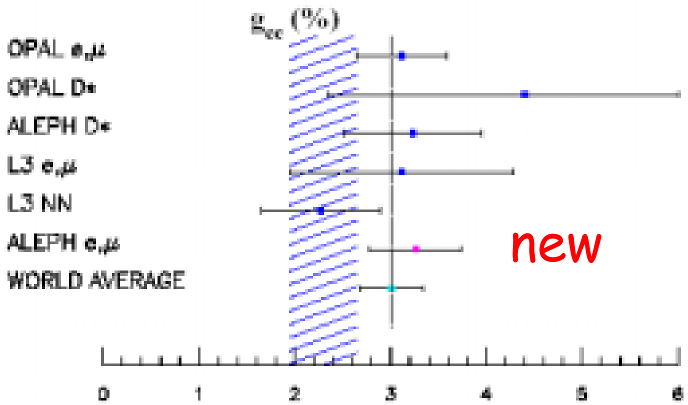
HERA provides own charm hadronisation measurements with competitive precision

QCD tests sensitive to α_s and heavy quark masses

Andrea Giammanco - ALEPH

Gluon splitting to $c\bar{c}$ at the Z^0 resonance





Hatched area: theoretical prediction ±15%.

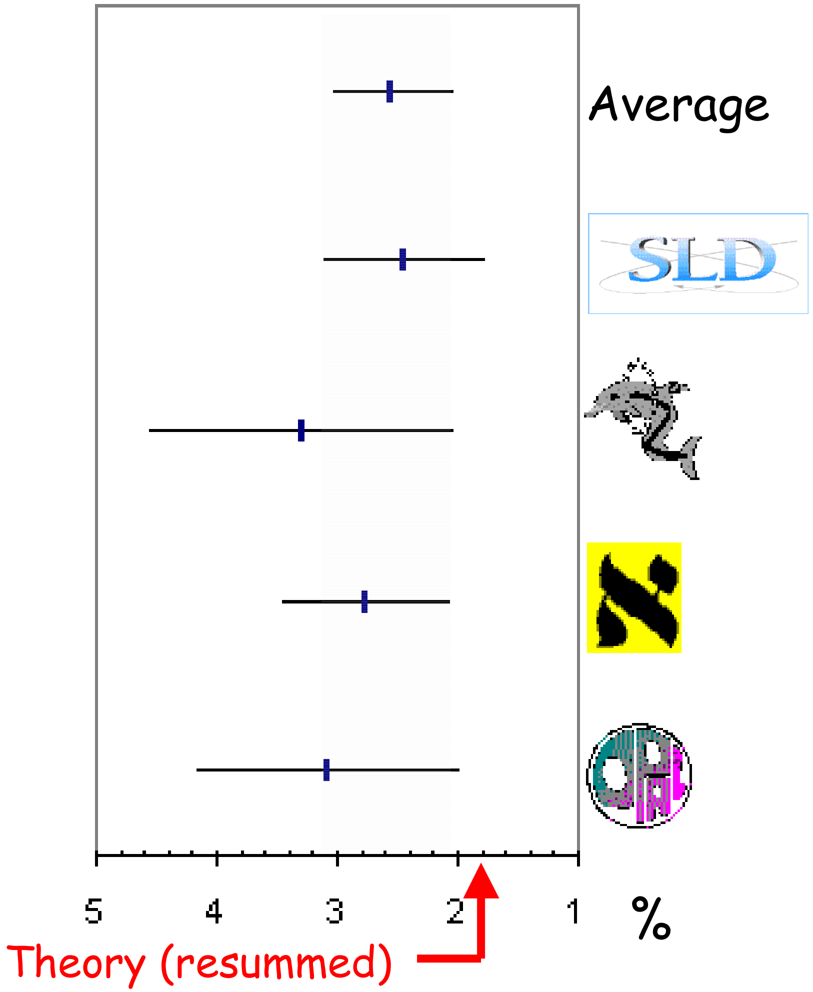
Uncertainties due to m_c and α_s are not shown.

New World Average:

$g_{c\bar{c}} = (3.01 \pm 0.33)\%$

Hagar Landsman (OPAL)

Gluon splitting to bbbar and b fragmentation

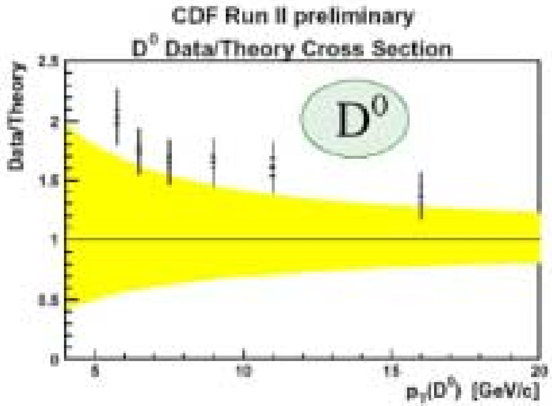


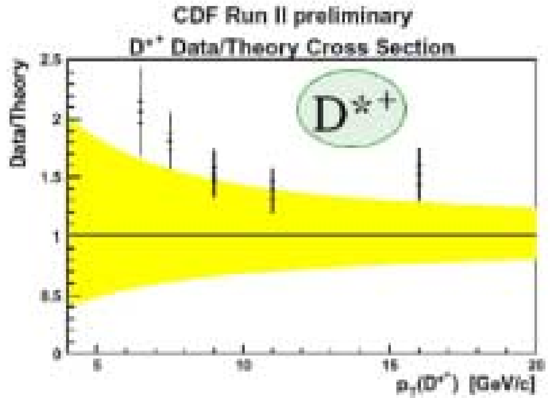
Charm Cross Section cont.

Calculation from M.Cacciari and P.Nason: Resummed pQCD (FONLL)

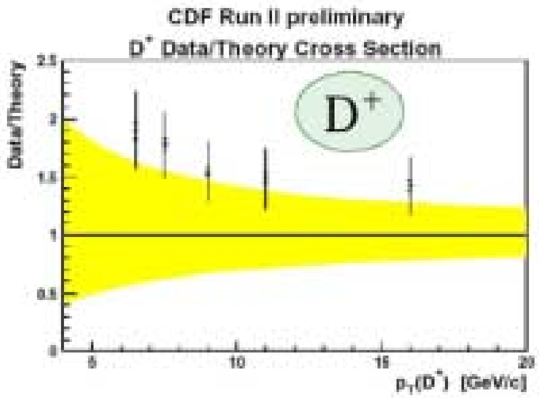
Ratio of measured to predicted cross section:

~70 pb^{-1}





CTEQ6M PDF
m_c = 1.5GeV
Fragm.function:
from Aleph meas.
Renorm.and fact.scale:
$m_T=(m_c^2+p_T^2)^{1/2}$
Uncertainty:
vary scale from .5 to 2

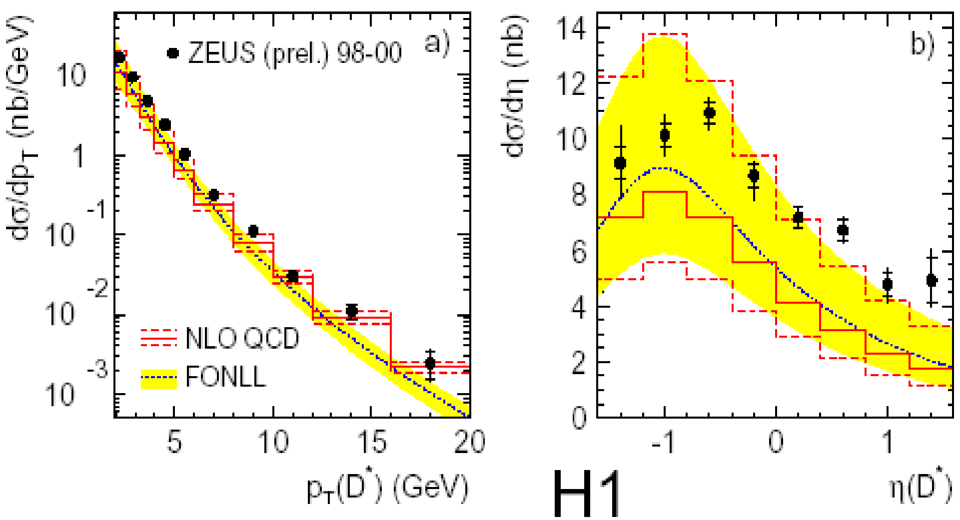


- Measured cross section higher
- Not incompatible with uncertainties
- p_T shape consistent for D mesons

- $O(10^7)\ D^0 \rightarrow K\pi$ expected in 2 fb^{-1} (in ~2005)

 a challenge for theory

ZEUS



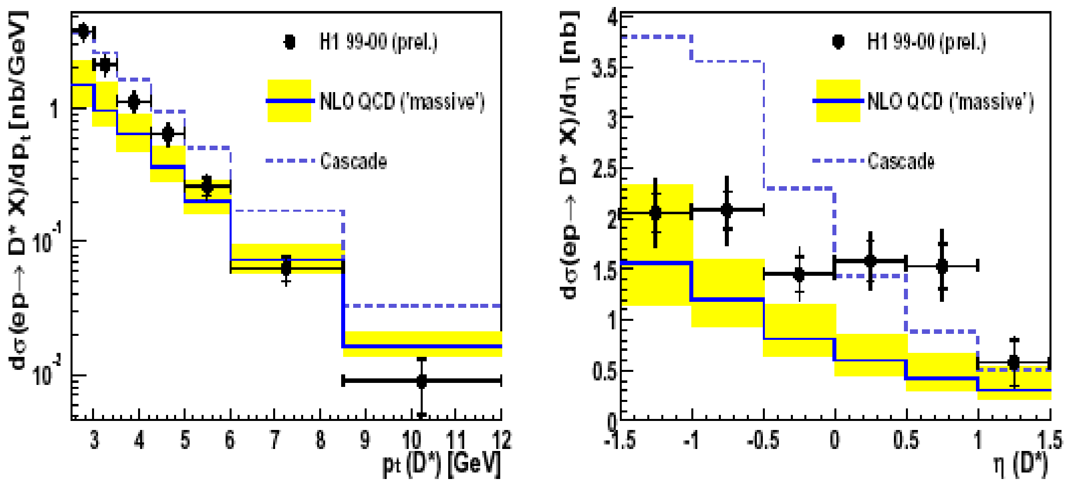
$Q^2 < 1\ \mathrm{GeV}^2$; $130 < W_{\gamma p} < 280$ GeV 79 pb^{-1}

$p_T^{D^*} > 1.9$ GeV; $|\eta^{D^*}| < 1.6$

No electron tag

R. Hall-Wilton, ZEUS

H1



Electron tag: 49 pb^{-1}

$Q^2 < 0.01\ \mathrm{GeV}^2$; $171 < W_{\gamma p} < 256$ GeV

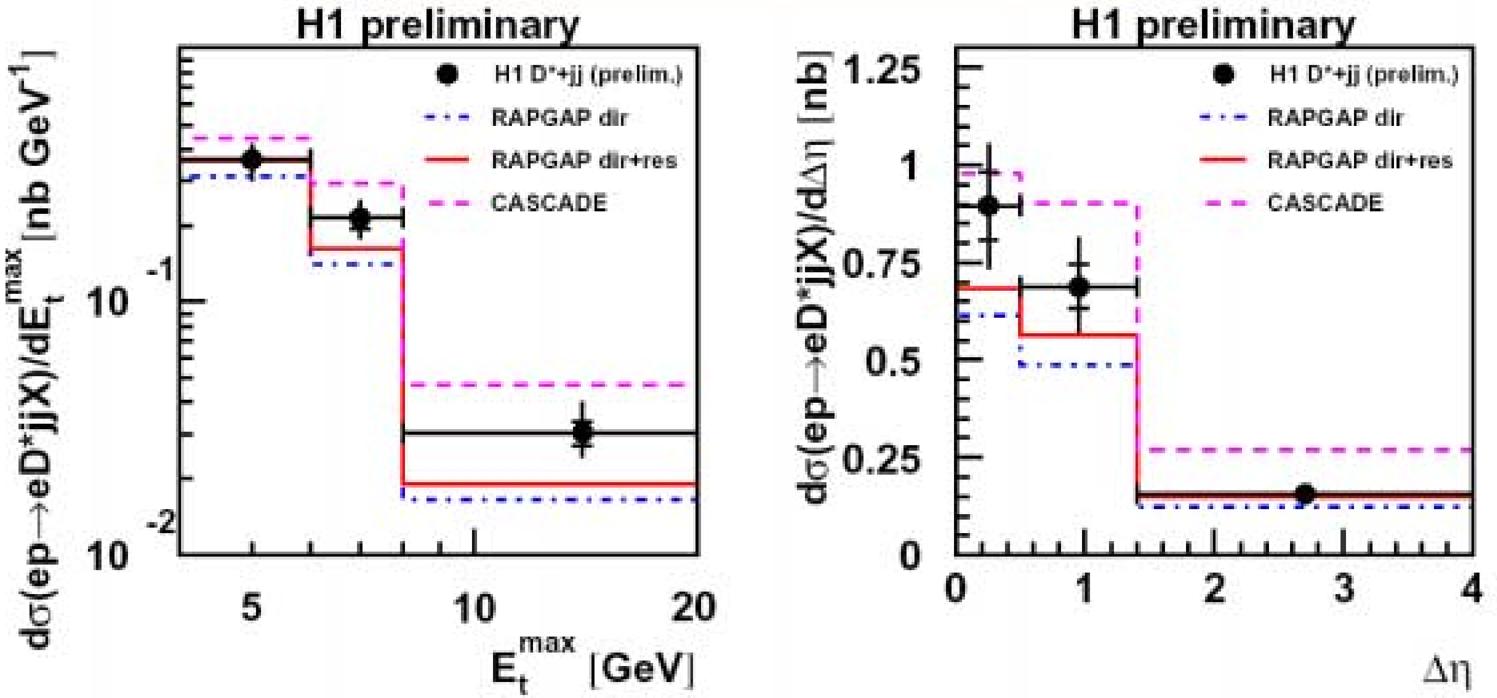
$p_T^{D^*} > 2.5$ GeV; $|\eta^{D^*}| < 1.5$

- NLO below data
  (low p_T, $\eta > 0$)
- FONLL not better
  even below NLO at high p_T
- CASCADE too hard

G. Flucke, H1

ep -> ccX

first **Differential Jet Cross Sections** in DIS



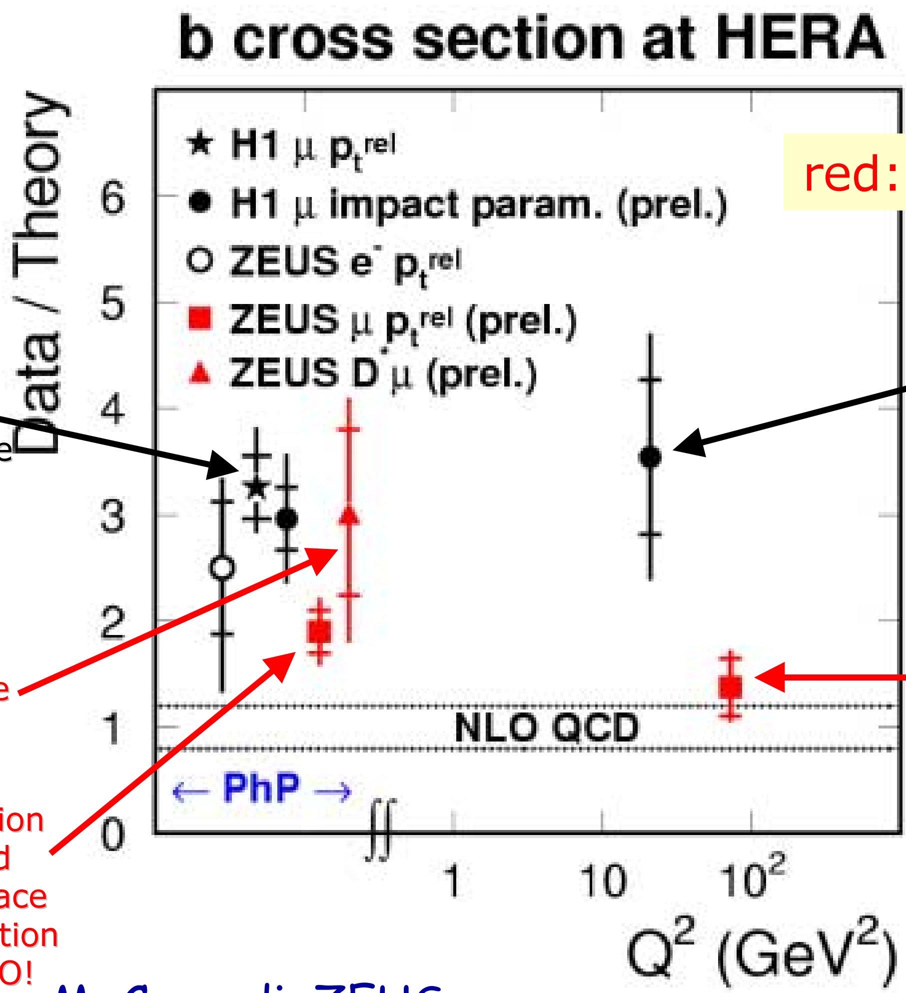
→ RAPGAP direct and direct+resolved below the data for large E_t^{max} and small $\Delta\eta$

→ CASCADE above the data

→ new level of testing QCD

303, 23-27/04/2003 Sebastian Schmidt, MPI Munich

A tricky business...



red: ICHEP02 results

H1 Photoproduction:
jets extrapolated
to the full phase space

H1 DIS:
jets extrapolated
to the full phase space

C. Gerlich, H1

ZEUS D*-muon:
extrapolated to the
parton level

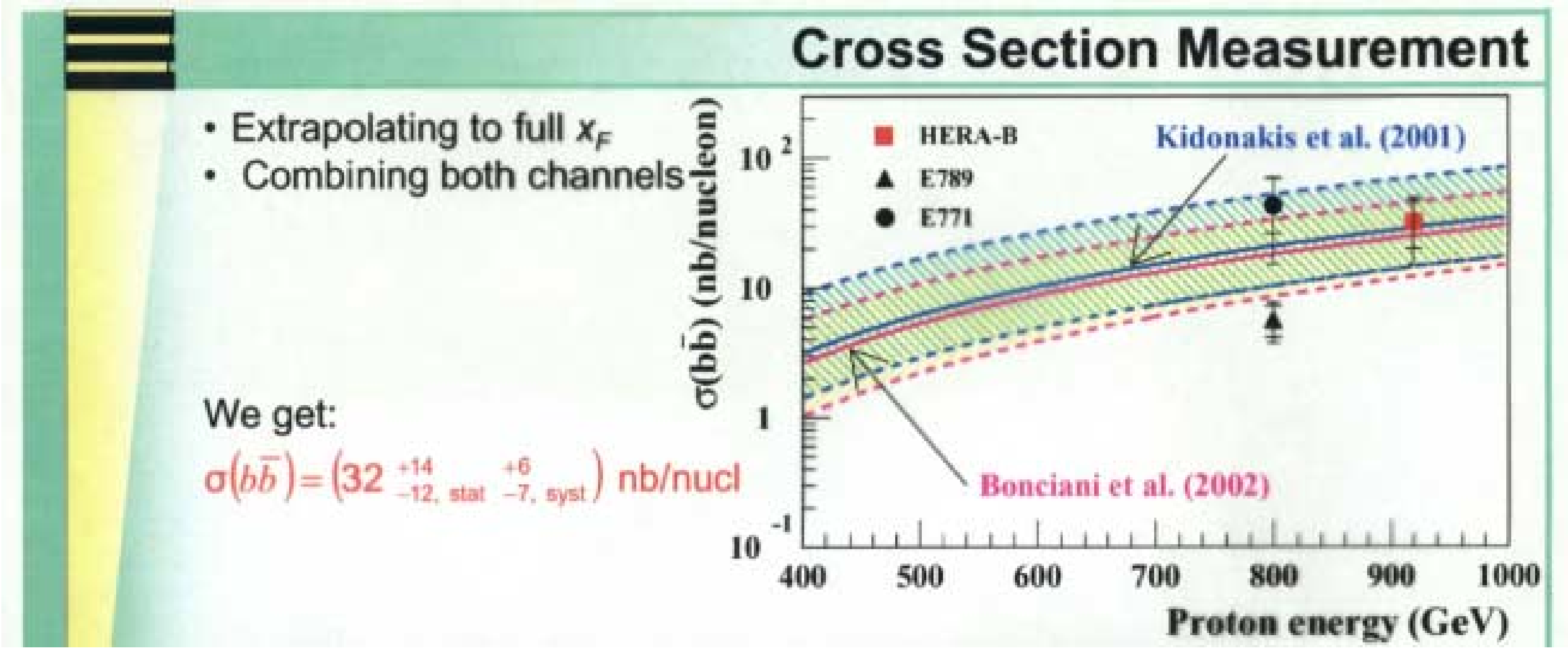
This analysis
visible cross section
jets in the Breit frame

ZEUS Photoproduction
muon extrapolated
to the full phase space
The visible cross section
agrees with the NLO!

M. Corradi, ZEUS

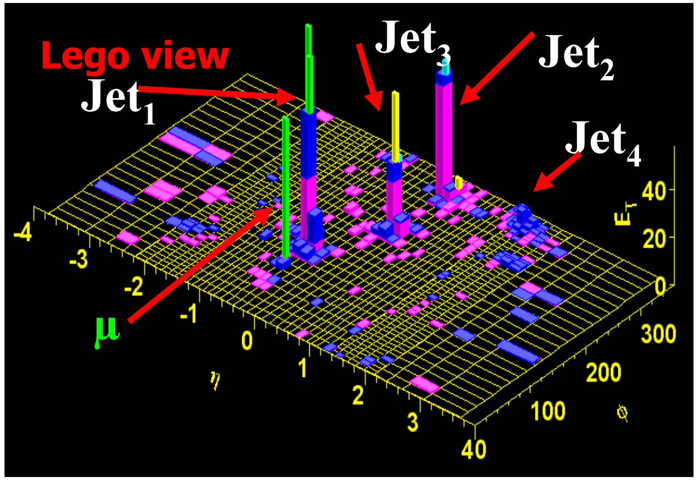
V. Chiochia, ZEUS

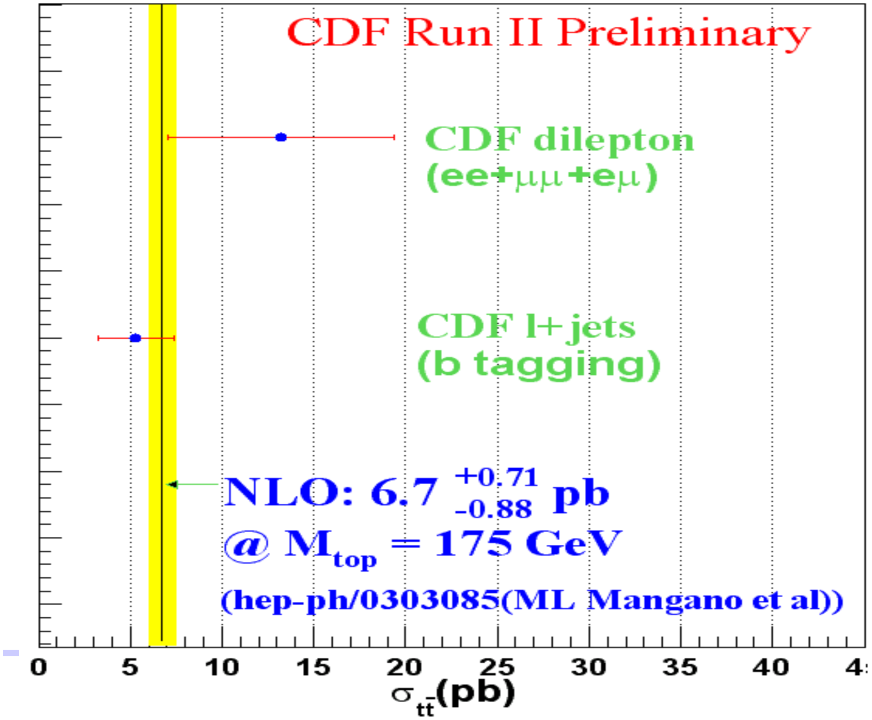
HERA-B: pN -> bb

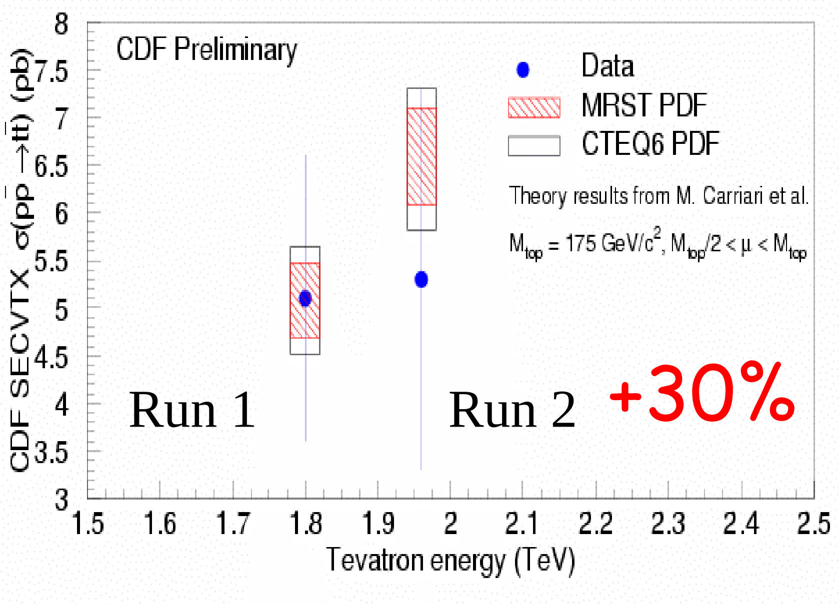


30x more statistics on tape
-> will be systematics limited (J/psi BR and total Xsect)
-> can measure p_T and x_F dependence

σ_{tt}: lepton + jets cross section







$$\sigma_{tt} = 5.3 \pm 1.9_{stat} \pm 0.8_{sys} \pm 0.3_{lum}\ \text{pb}$$

It was a lively and fruitful workshop

in

Санкт-Петербург