DEEP INELASTIC SCATTERING

Selected Experimental Results from DIS 2005:
XIIIth Workshop on Deep Inelastic Scattering
in Madison, Wisconsin, April 27 – May 1

Wesley H. Smith
University of Wisconsin – Madison

Seminar at Northwestern University

May 23, 2005

Thanks to Working Group Organizers

Structure Functions & Low x
- Jianwei Qiu
- Un-Ki Yang
- Jo Cole

Diffraction & Vector Mesons:
- Valery Khoze
- Xavier Janssen
- Marta Ruspa

Electroweak & Beyond the Standard Model:
- C.-P. Yuan
- Beate Heinemann
- Alex Tapper

Hadronic Final States:
- Pavel Nadolsky
- Steve Maxfield
- Claudia Glasman

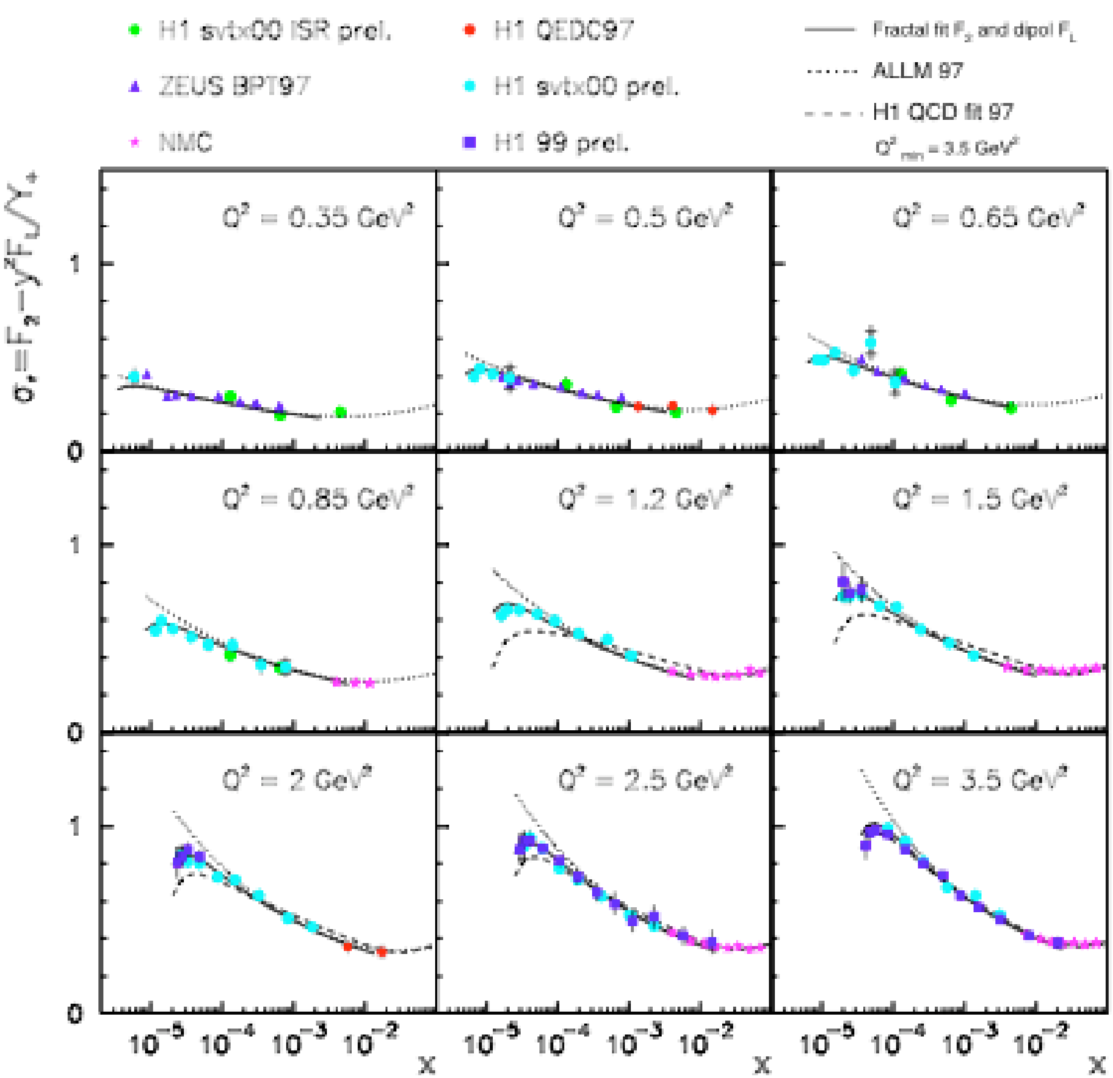
Heavy Flavors:
- Gennaro Corcella
- Andy Mehta
- Massimo Corradi

Spin Physics:
- Krishna Kumar
- Pasquale Di Nezza
- Marco Stratmann

Future of DIS:
- Uta Stoesslein
- Dave Soper

and especially to conference summary from Allen Caldwell and the 271 participants who gave 240 talks

F_2 & F_L measurements at Low Q^2



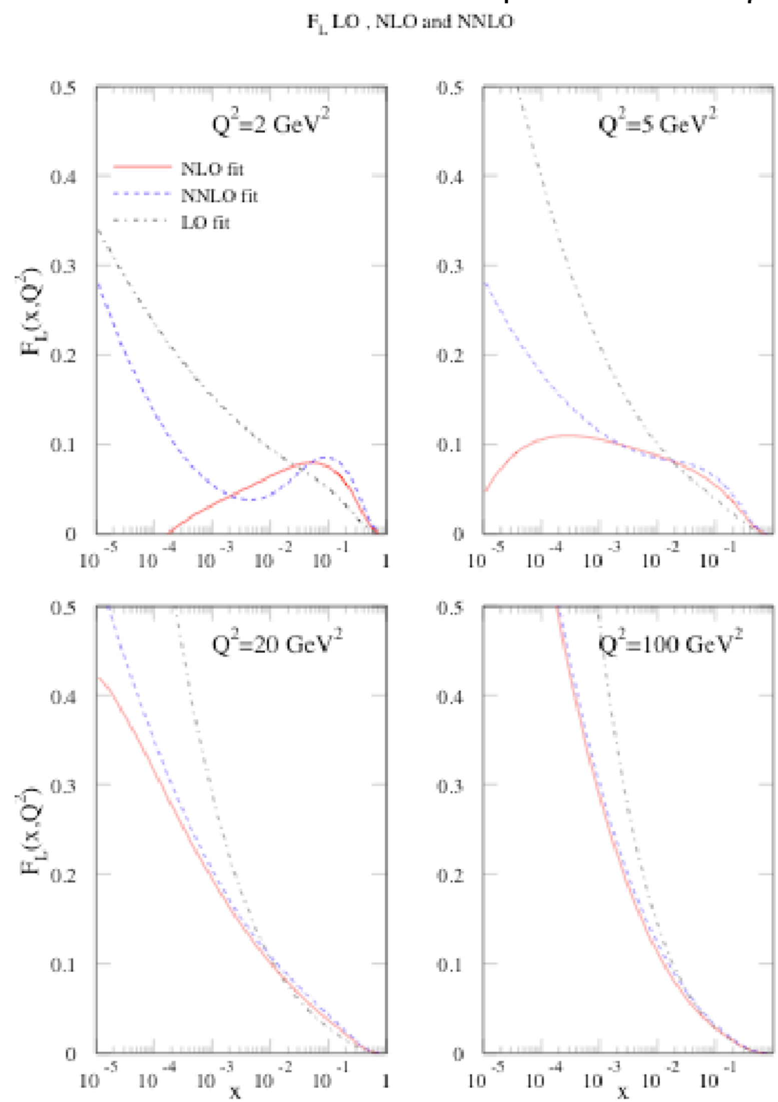
(E. Lobodzinska/A. Petrukhin) (H1)

- Precision low Q^2 F_2 measurements
- Number of different methods
- Extension into the higher x region - overlap with fixed target data
- Close to completing HERA-I structure function programme

Recent Progress on PDFs – MRST

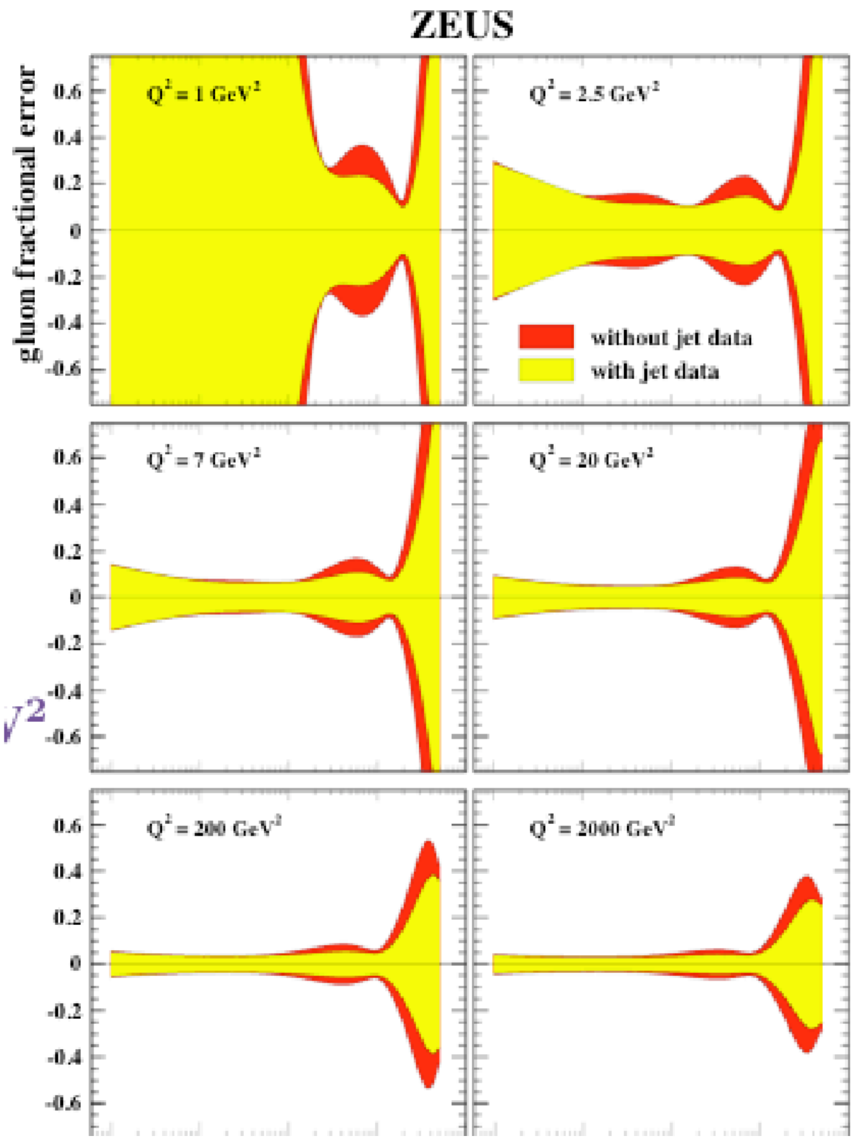
(R. Thorne)

- Discussion of impact on LHC physics: W & Z cross sections; also jet cross sections
- General move towards NNLO PDFs - expect this to become the standard
  - But note the impact on certain distributions:



PDFs from ZEUS data

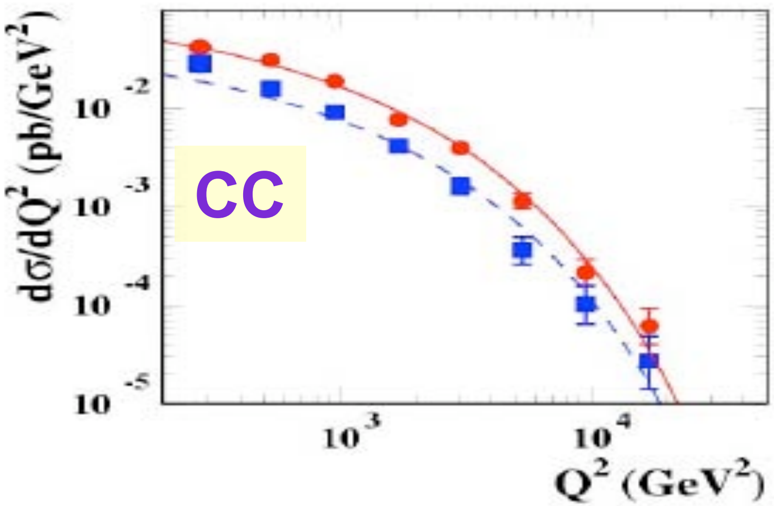
(J. Terron)

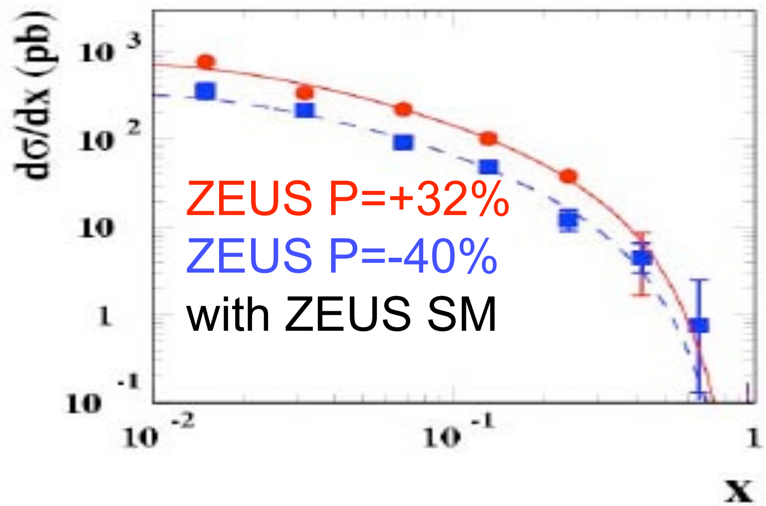


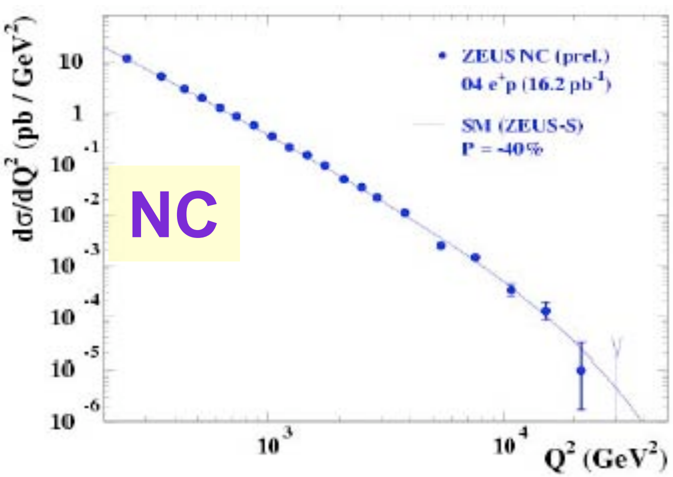
- Addition of NC DIS jet data and direct-enriched dijet photoproduction data to ZEUS PDF fit
- Improves gluon density uncertainties at moderate x
- Also allows precise α_S determination from ZEUS data alone:
  $\alpha_S = 0.1183 \pm 0.0058$
- Comparison to Bethke 2004:
  $\alpha_S = 0.1182 \pm 0.0027$

Polarized NC/CC Cross Sections at HERA

- ZEUS(NC/CC) by A. Tapper, H1(CC) by A. Nikiforov







Well described by the SM

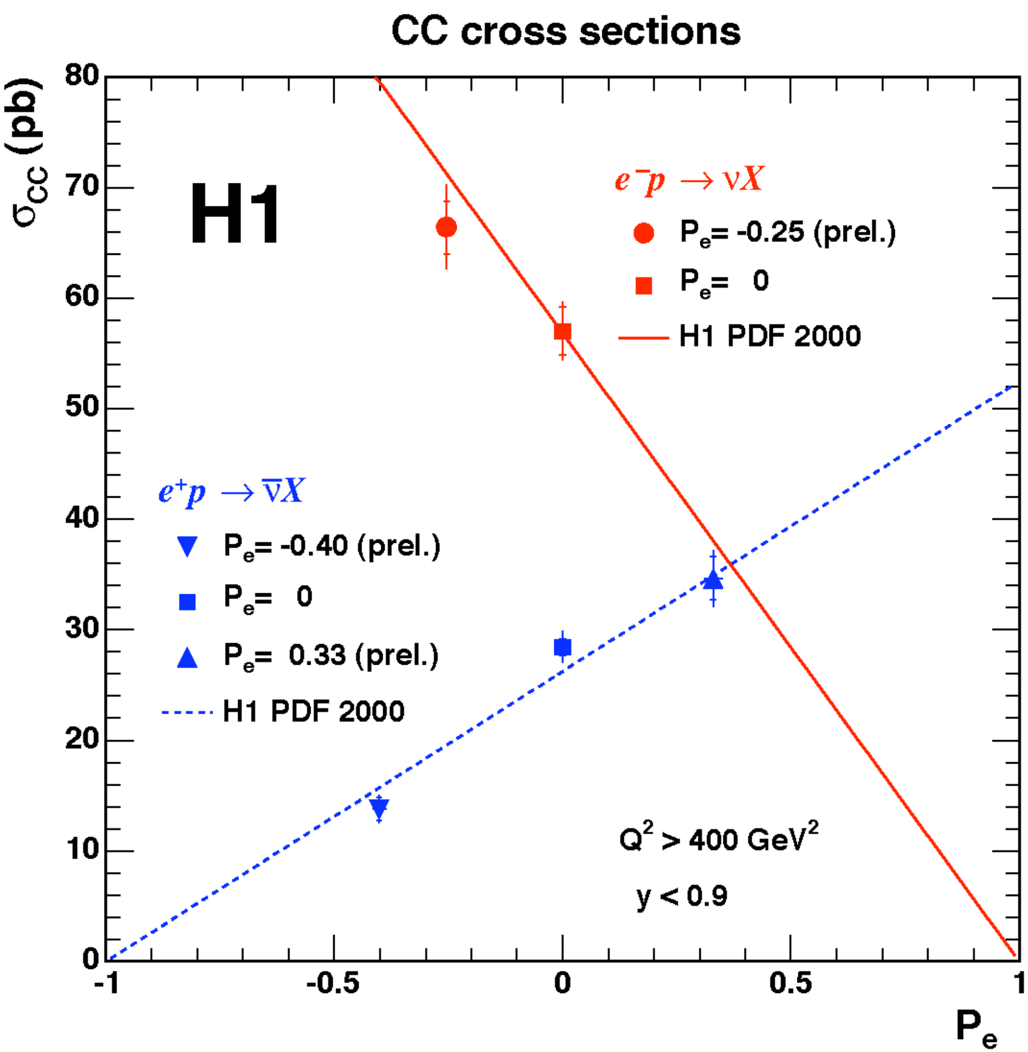
Test with more data

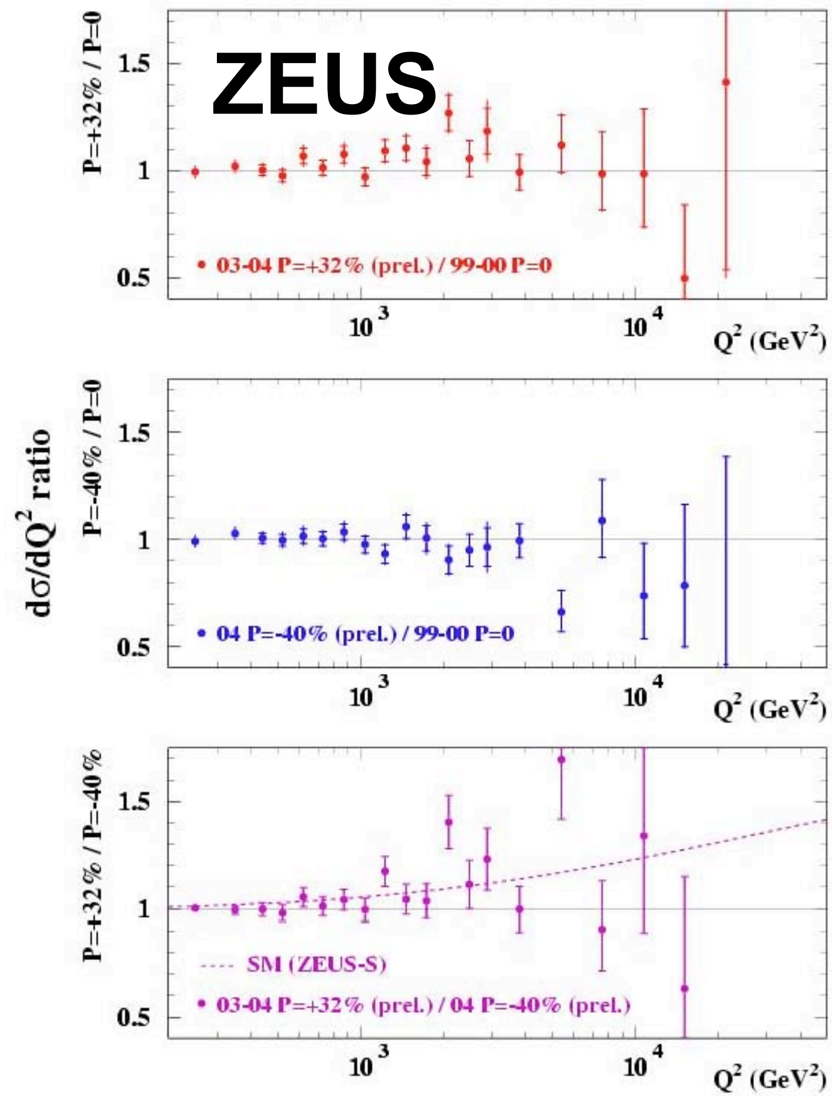
at very high Q^2

➔ precise PDFs at high x

High Q^2 CC & NC DIS w/polarized leptons

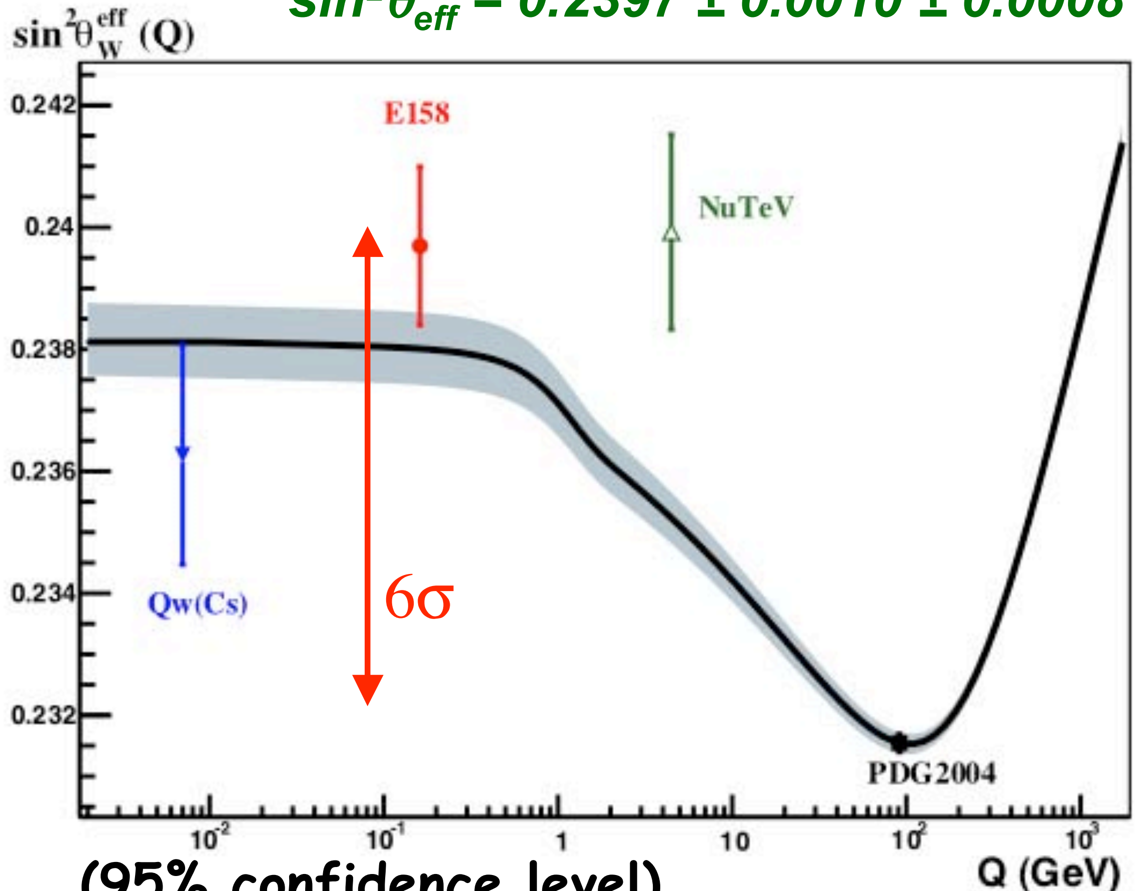
Consistent with standard model





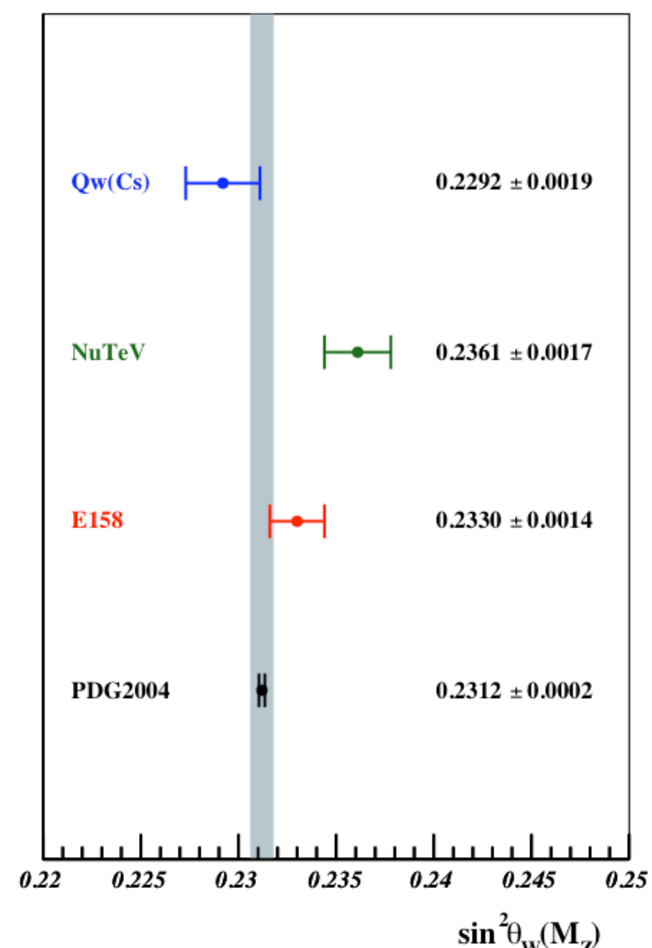
Mixing angle from parity violating Moller scattering (SLAC 158)

$\sin^2\theta_{eff} = 0.2397 \pm 0.0010 \pm 0.0008$



(95% confidence level)

$\sin^2\theta_W^{MS}(M_Z)$

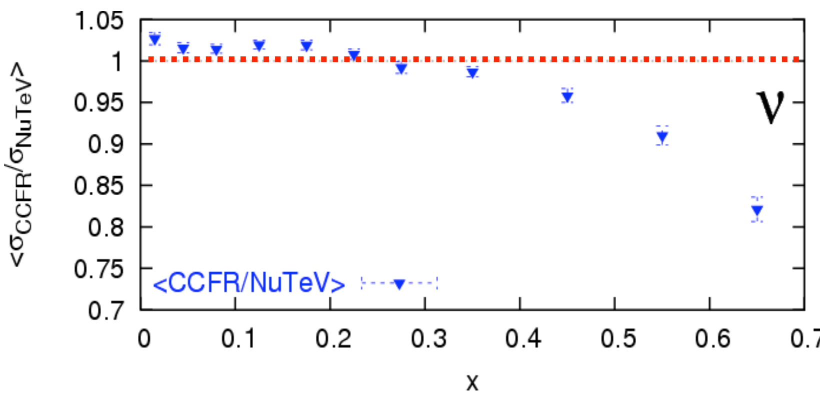


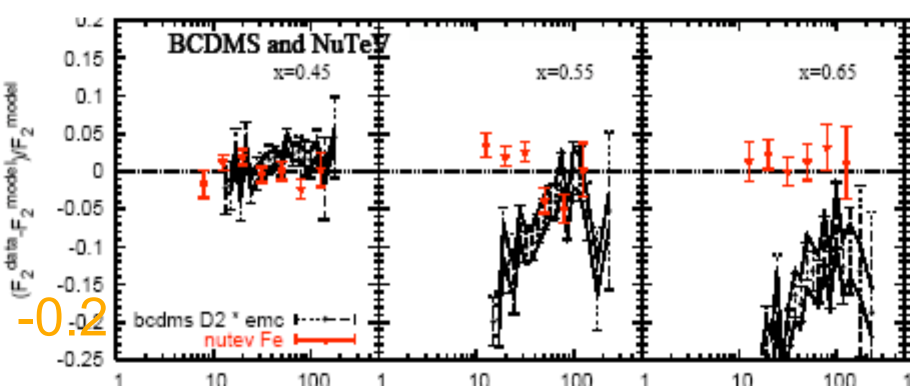
* Limit on Λ_{LL} ~ 7 or 16 TeV
* Limit on SO(10) Z' ~ 1.0 TeV
* Limit on lepton flavor violating coupling ~ $0.01G_F$

hep-ex/0504049

NuTeV SFs

- Final NuTeV diff. cross sections (Eν = 20-360 GeV, x = 0.01 - 0.7)
- F_2, xF_3 are finalized too.





-0.2

nucl. corr at x=0.65:0.85

NuTeV F_2, xF_3 at x = 0.65 are 20% higher than CCFR, 10–15% higher than charged lepton data

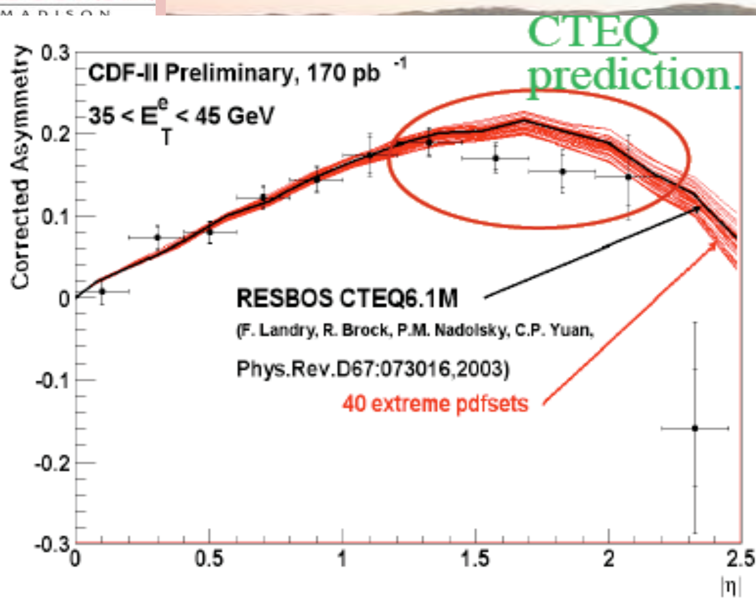
Improved calibration of B-field, calorimeter, MC model: explain 11%

Higher F_2: < 5% nuclear effect at x = 0.65? need to be understood before NuTeV high-x data can be used in the global PDFs analysis

CHORUS(lead) data can resolve, and future MINOS/Minerva

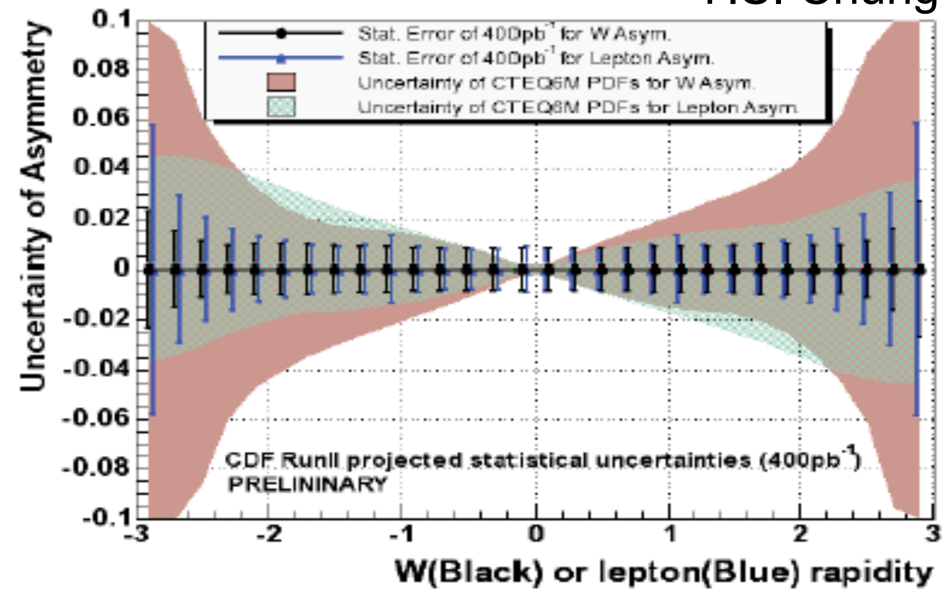
M. Tzanov

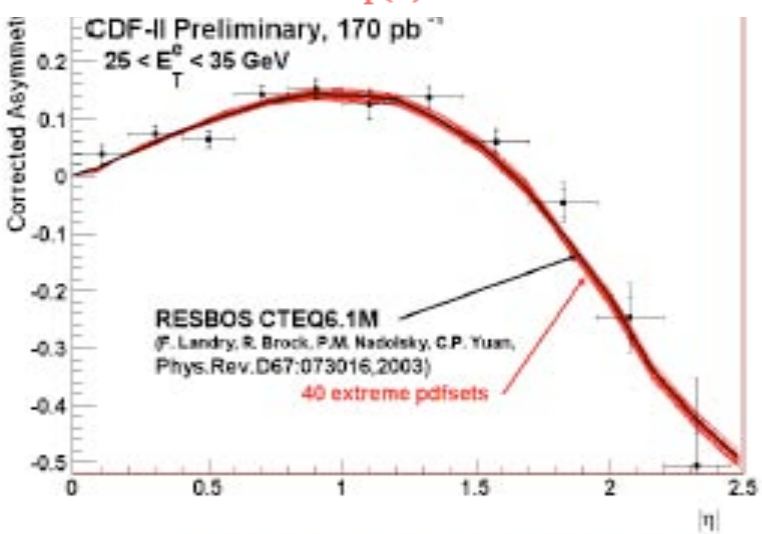
W charge asymmetry at Tevatron



35 GeV < $E_T(e)$ < 45 GeV

Y.S. Chung





25 GeV < $E_T(e)$ < 35 GeV

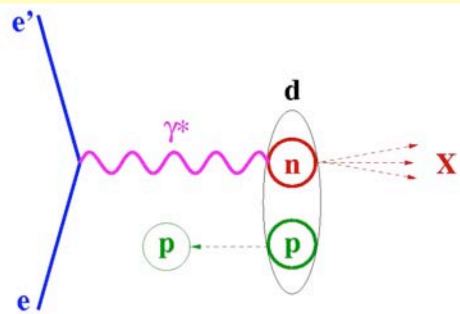
Run II CDF measurements with higher Et cut to prove d/u at higher x

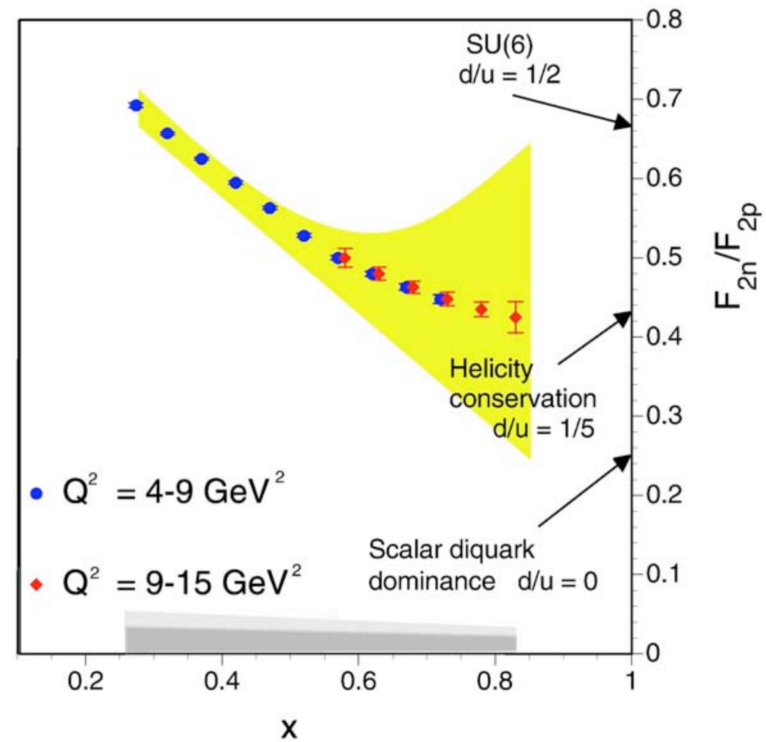
Would be interesting how the PDF with nucl. Corr (d/u->0.2) compare with the CDF data

Big improvement with direct W asymmetry measurement is expected.

Dedicated efforts to measure d/u at high x from JLab

Measure SF of nearly on-shell neutron by detecting slow spectator proton in semi-inclusive ed -> ep X reaction : JLab CLAS++, BONUS exp. (almost scattering off free nucleon) —S. Kuhn

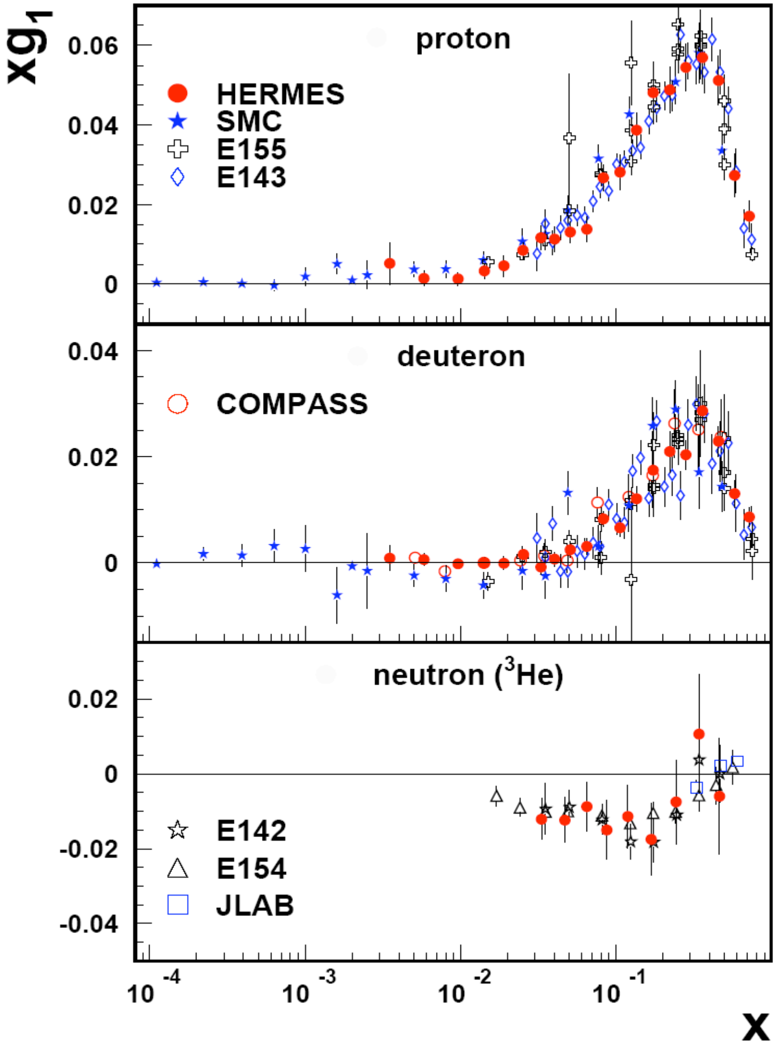


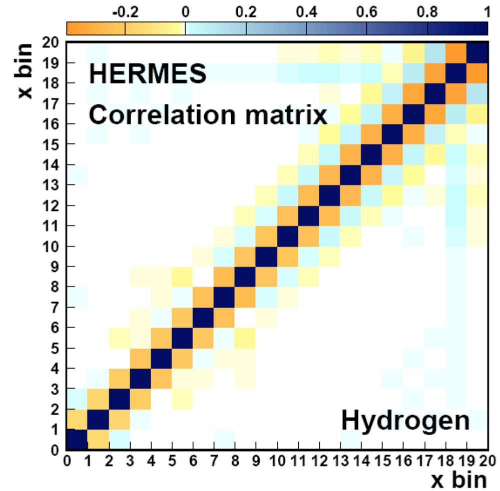


Parity violation in DIS on ^{1}H: very sensitive to d/u — P.A. Souder

$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[a(x) + f(y)b(x)\right] \qquad a(x) = \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)}$$

Polarized Structure Functions: g_1





D.Reggiani

New treatment of smearing. Correlation matrix:

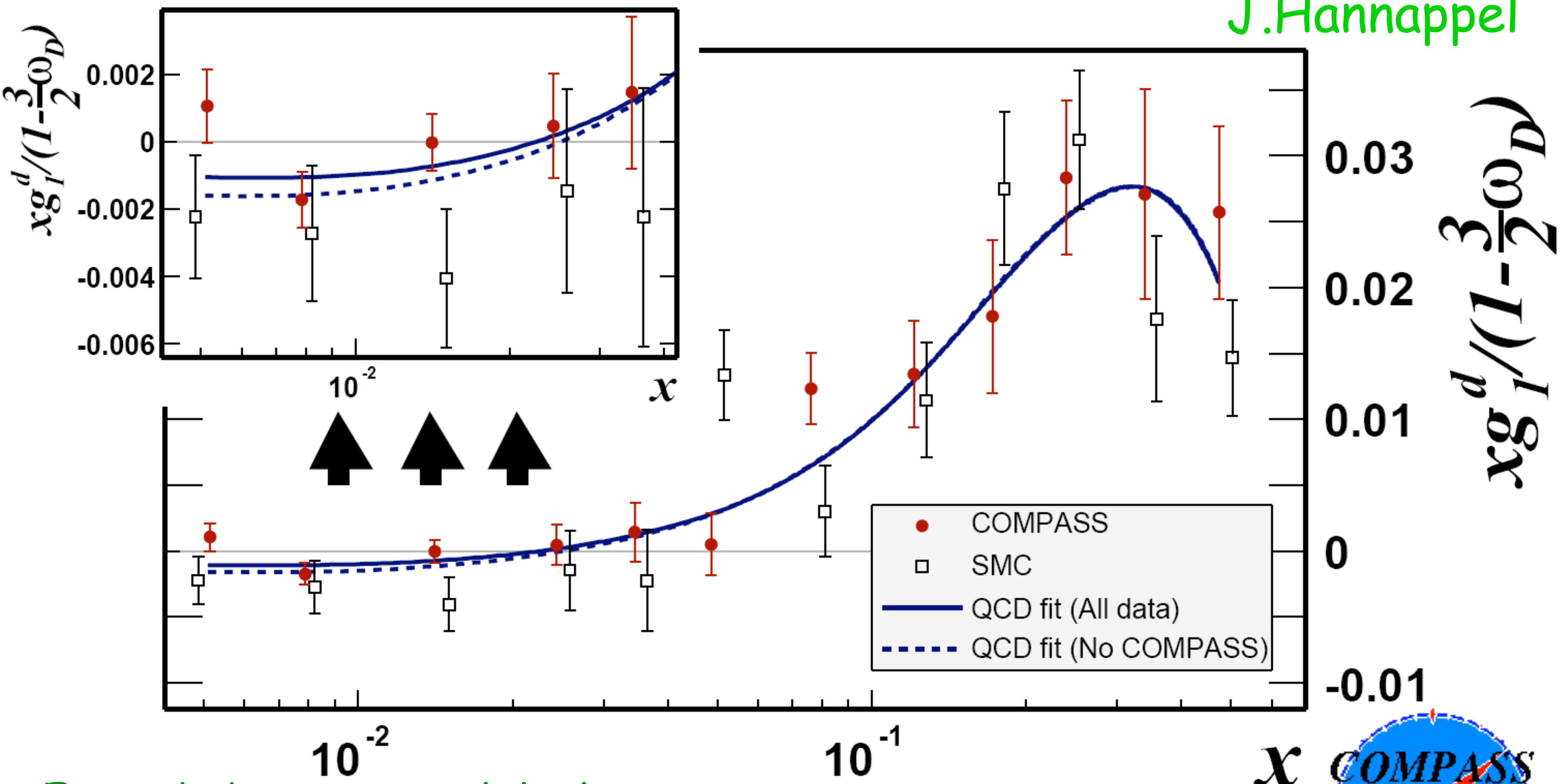
- removes systematical correlations
- introduces statistical correlations

First Moments Calculation

Exp.	$Q^2 (GeV^2)$	x range	Target	Moment	HERMES Moment
SMC E143	5 5	0.03-0.7 0.03-0.8	p p	0.128±0.006 0.117±0.003	**0.1141±0.0026** **0.1174±0.0027**
SMC E143	5 5	0.03-0.7 0.03-0.8	d d	0.043±0.007 0.043±0.003	**0.0416±0.0013** **0.0433±0.0013**

Polarized Structure Functions: g_1

J.Hannappel



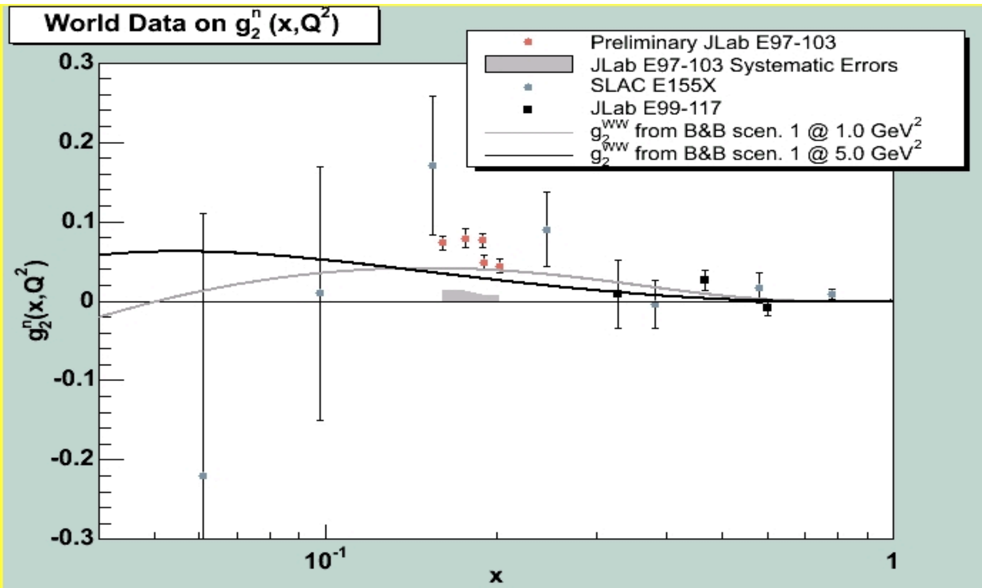
Extended x-range with higher accuracy.

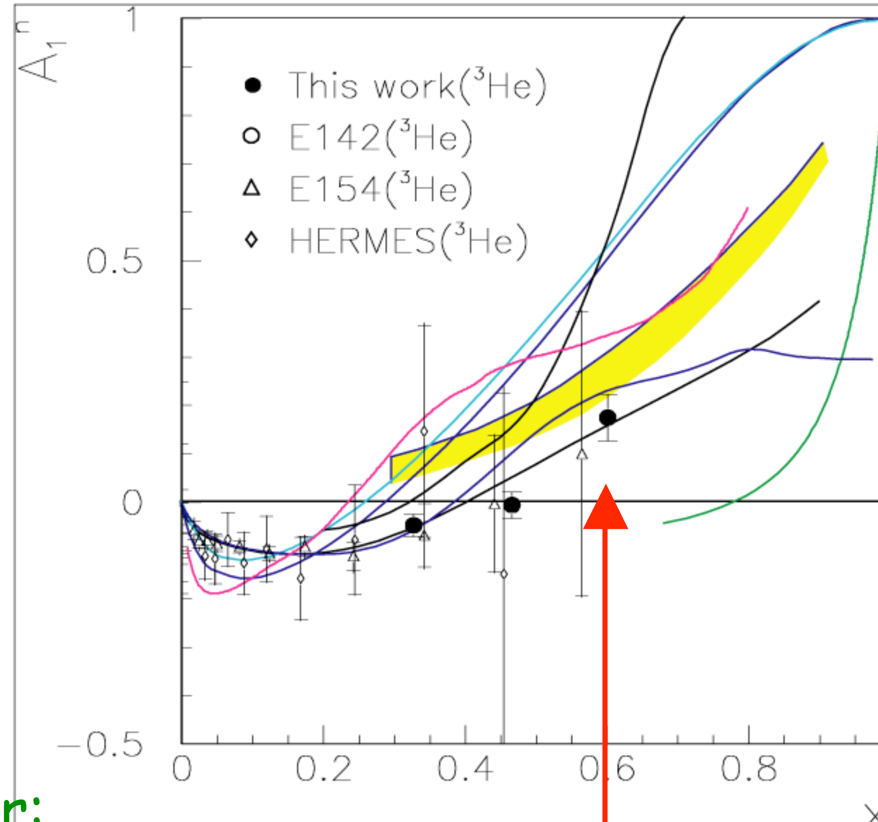
COMPASS systematically > SMC at low-x.

Spin Structure at high x

Jefferson Lab

J.P.Chen





Precision measurements at high x for:

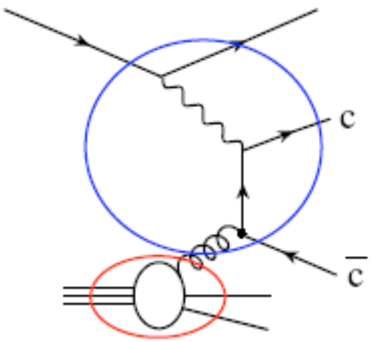
A_1^n, $\Delta u/u$, $\Delta d/d$, A_2^n, g_1^n, g_2^n, A_1^p, A_1^d, g_2^n, …

Sometimes statistical errors improved by 1 order of magnitude

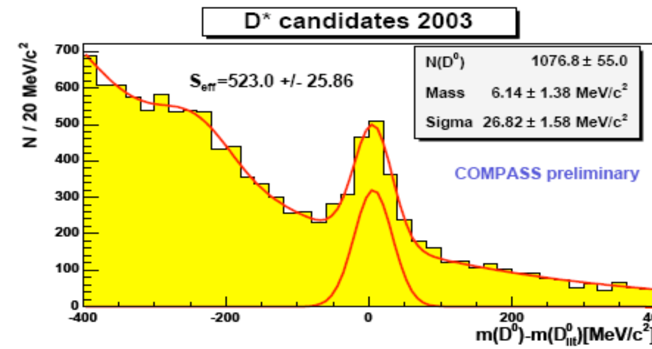
> 0

Gluon Polarization

C.Bernet



Direct measurement of ΔG/G via open charm production has still too few events.



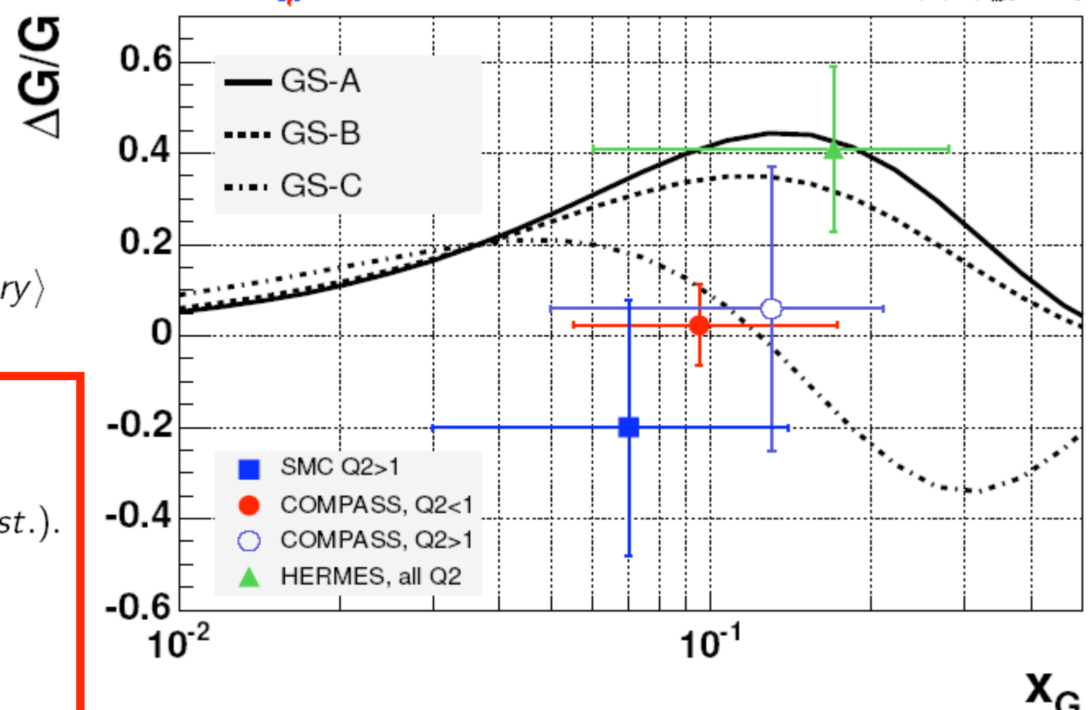
Measurement of ΔG/G via high Pt hadrons more powerful but model dependent

$$A_{||} = R_{pgf} \langle \hat{a}_{pgf} \rangle \frac{\Delta G}{G} + \langle background\ asymmetry \rangle$$

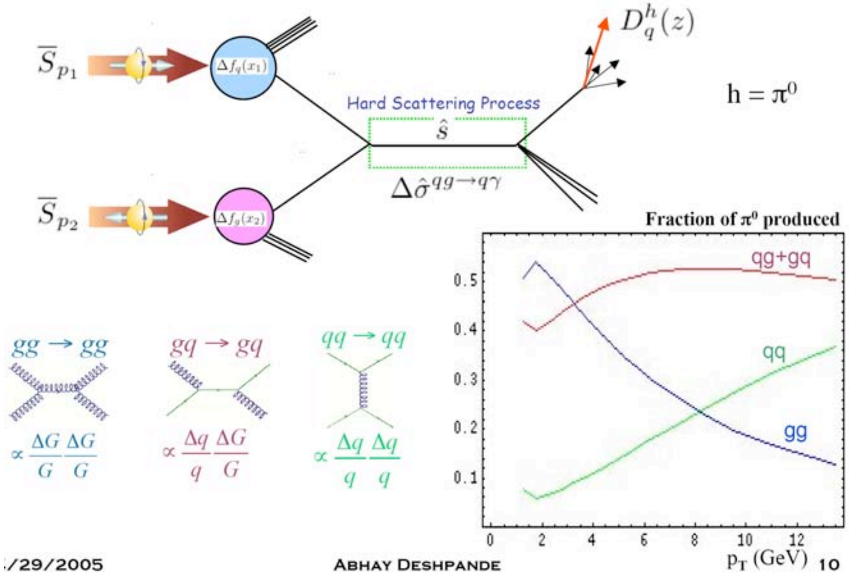
2002+2003 data, $Q^2 < 1$ GeV^2

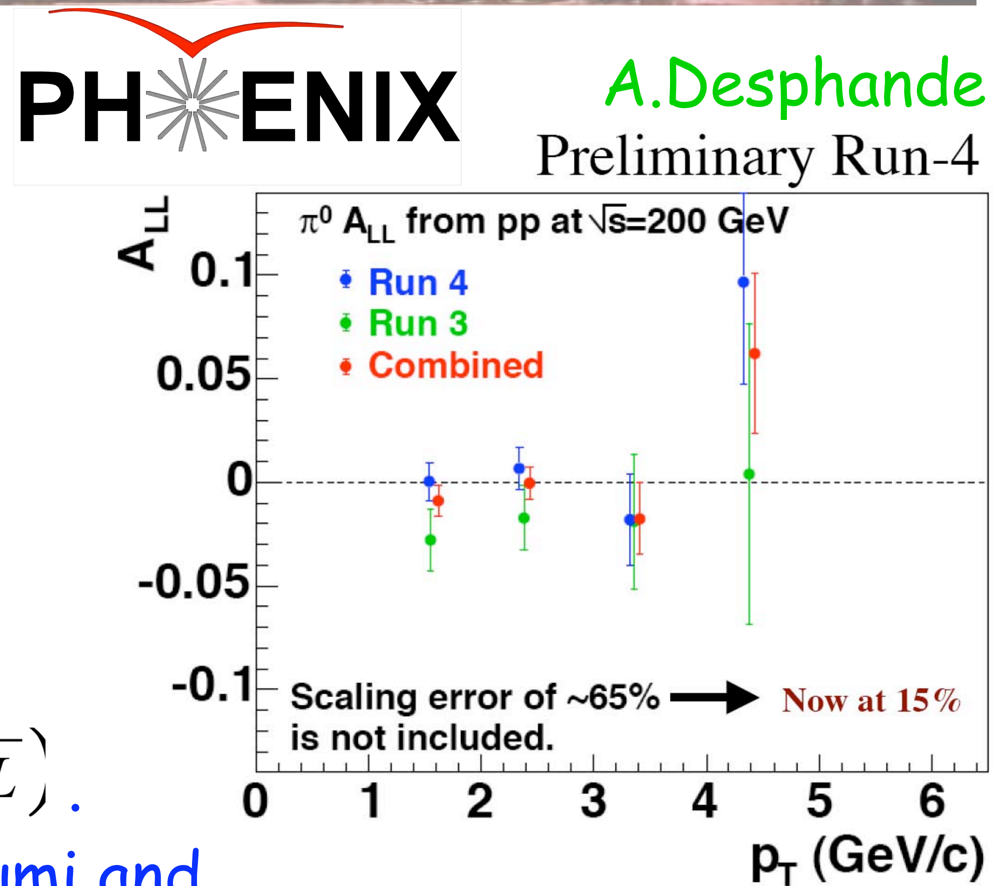
$$\frac{\Delta G}{G} = 0.024 \pm 0.089(stat.) \pm 0.057(syst.).$$

- either ΔG is small,
- either $\Delta G/G$ has to cross 0 around $x_G = 0.1$.



Gluon Polarization





- Uncertainty still large $\left(P^2\sqrt{L}\right)$.
- Dramatic improvement by lumi and beam polarization (~70%)

New silicon VTX will increase the x range coverage for ΔG

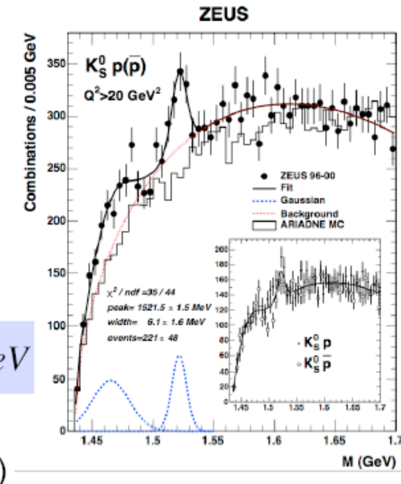
Strange Pentaquark H1 and ZEUS

Observation of Θ^+

ZEUS Collaboration: S. Chekanov et al.
Physics Letters B 591 (2004) 7-22

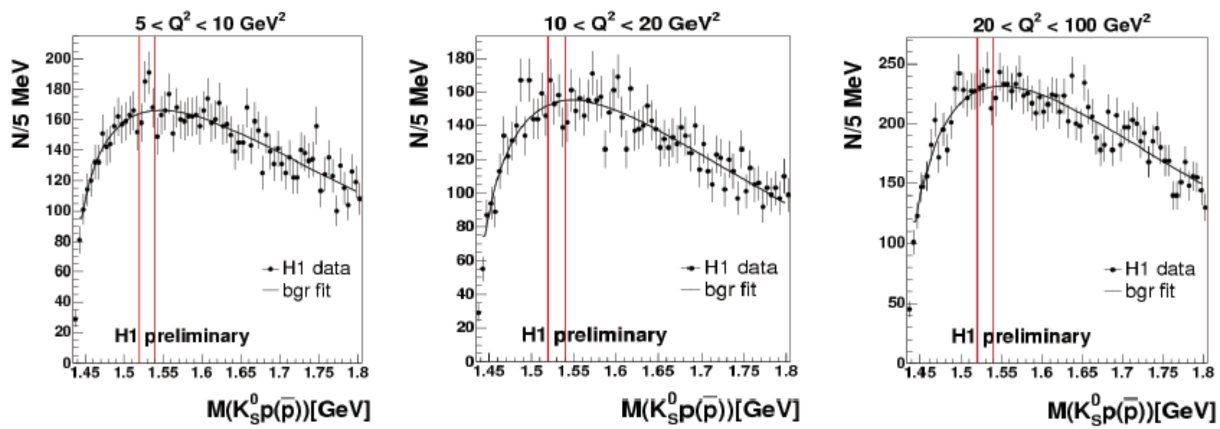
- Kinematics range
  $Q^2 > 20 GeV^2$
  $P_T(\Theta^+) > 0.5 GeV, |\eta(\Theta^+)| < 1.5$
- A signal with ~4.6 σ statistical significance was observed at
  $M = 1521.5 \pm 1.5(stat)^{+2.8}_{-1.7}(syst) MeV$
- Gaussian width 6.1±1.5 MeV (experimental resolution ~2 MeV)

ZEUS ➽



…but is there really a contradiction?

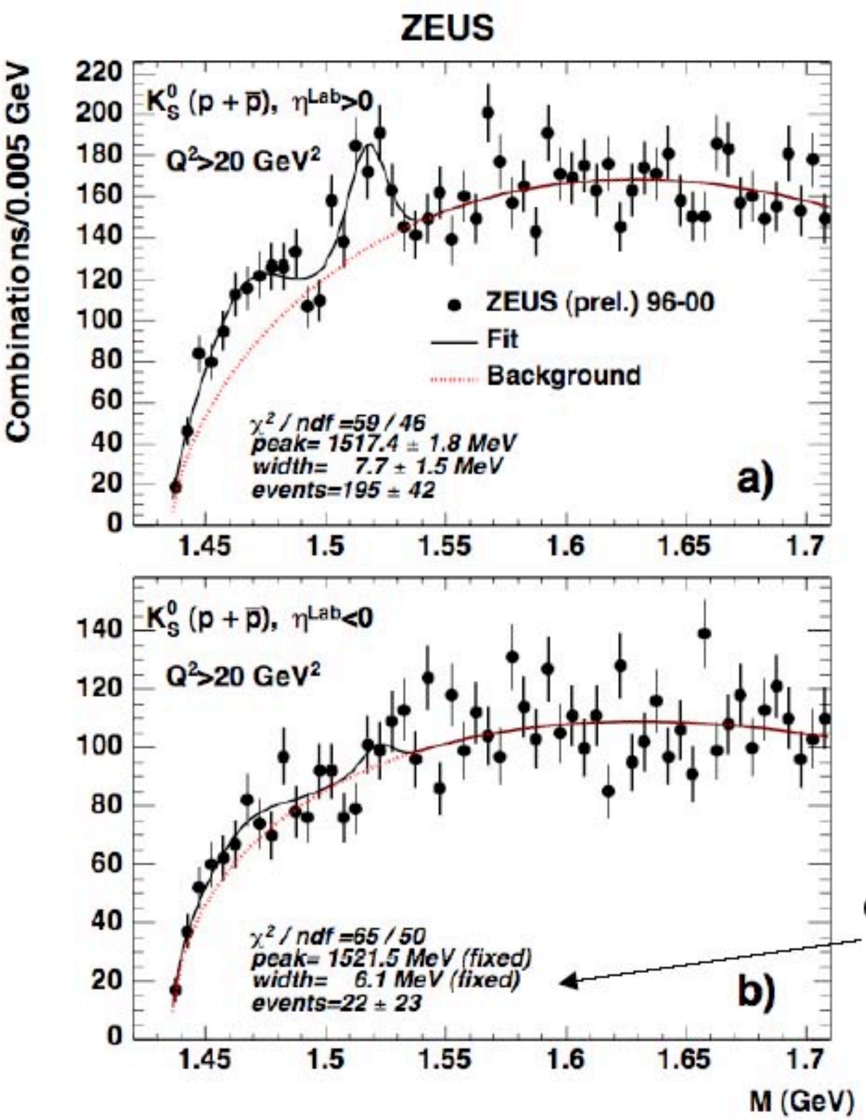
H1 ➽



no significant signal in the interesing mass range 1.52 to 1.54 GeV

Both ZEUS & H1 have taken a closer look...

ZEUS *Zhenhai Ren*



- Published already
  - Non-observation of Ξ^{--} in $\Xi^- \pi^-$
  - Observation of $\Theta^+ \to K^0_s P$
  - $\sigma(ep \to e\Theta + X) : 125 \pm 27(stat)^{+36}_{-28}(syst)\,pb$

Goal of new ZEUS studies

- Look at various kinematics regions
  - Understand the production mechanism?
- check statistical sensitivity to established states

Θ^+ May favor proton-remnant fragmentation origin

- Production rate is higher at forward region than rear region
- Production rate is higher for particle than for anti-particle
  - however the statistics is too small to make strong conclusion

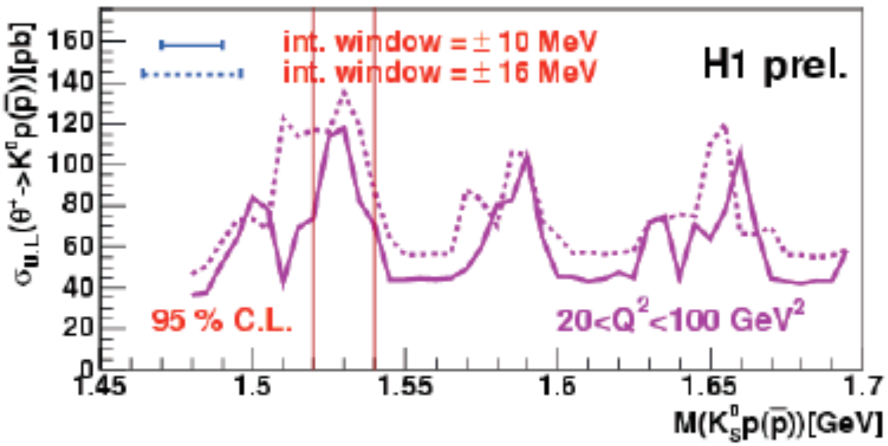
H1: extraction of upper limit for θ^+ cross section

Comparison with ZEUS:

Christiane Risler

low-momentum dE/dx selection
$20<Q^2<100$ GeV^2
$0.1 < y < 0.6$

M=1.52 GeV $\sigma_{U.L.}$~ 100 pb *



ZEUS observation:
Q2>20 GeV2, 0.04 < y <0.95, p_T>0.5, |η|<1.5
σ(ep->e +X->eK^{0}pX)=125 ± 27(stat) +36 -28 (syst.) pb (prel.)

$\sigma_{U.L.}$ ~ 100 pb not in contradiction with ZEUS measured cross section

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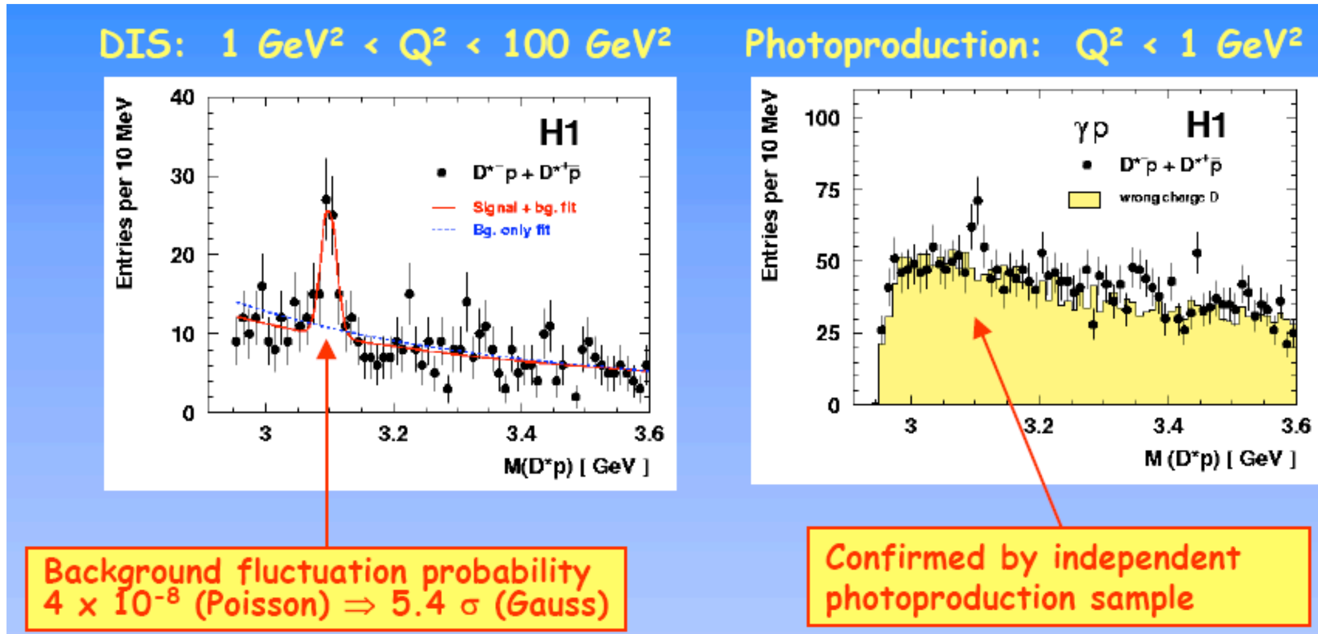
* at M=1.522 GeV assuming a resolution of 5 (8) MeV
$\sigma_{U.L.}$ = 89.6 (116.3) pb

Charm Pentaquark at HERA

Karin Daum /Yehuda Eisenburg

Seen by H1…



H1 Preliminary:

$$R_{cor}(D^*p(3100)/D^*) = 1.59 \pm 0.33\%^{+0.33}_{-0.45}\%$$

…but negative results (in different processes) from ALEPH, FOCUS, CDF, BELLE

…and ZEUS same process

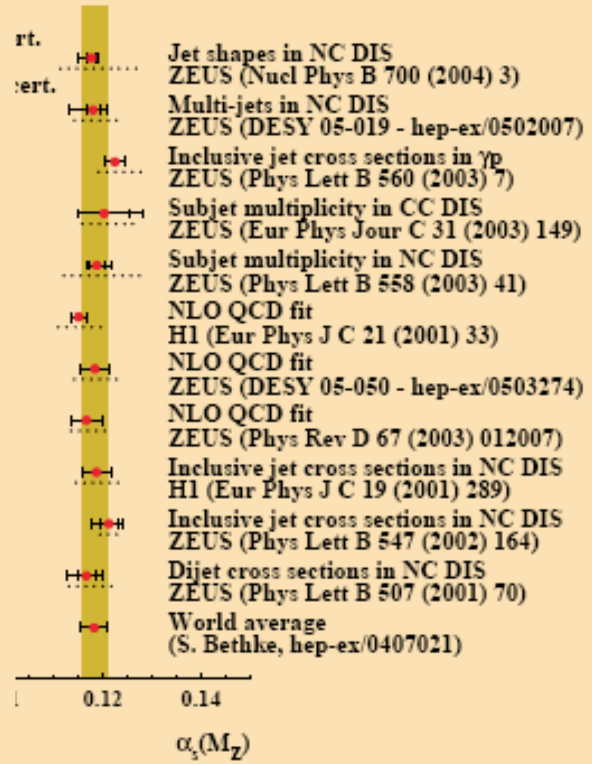
Precision Measurements of α_s

Claudia Glasman

- Review of α_S determinations from H1 and ZEUS experiments.
- Evaluation of HERA averages of $\alpha_S(M_Z)$ and scale dependence of α_S.

Process	Coll.	Value	Stat.	Experim.	Theory	Total
Dijet NC DIS	ZEUS	0.1166	0.0019	$^{+0.0024}_{-0.0033}$	$^{+0.0057}_{-0.0044}$	$^{+0.0065}_{-0.0058}$
Inc. Jet NC DIS	ZEUS	0.1212	0.0017	$^{+0.0023}_{-0.0031}$	$^{+0.0028}_{-0.0027}$	$^{+0.0040}_{-0.0044}$
Inc. Jet NC DIS	H1	0.1186	$\rightarrow$	$^{+0.0030}_{-0.0030}$	$^{+0.0051}_{-0.0051}$	$^{+0.0059}_{-0.0059}$
3/2 Jet NC DIS	ZEUS	0.1179	0.0013	$^{+0.0028}_{-0.0046}$	$^{+0.0064}_{-0.0046}$	$^{+0.0071}_{-0.0066}$
3/2 Jet NC DIS	H1	0.1175	0.0017	$^{+0.0050}_{-0.0050}$	$^{+0.0054}_{-0.0068}$	$^{+0.0076}_{-0.0086}$
Subjet NC DIS	ZEUS	0.1187	0.0017	$^{+0.0024}_{-0.0009}$	$^{+0.0093}_{-0.0076}$	$^{+0.0097}_{-0.0078}$
Jet Shape NC DIS	ZEUS	0.1176	0.0009	$^{+0.0009}_{-0.0026}$	$^{+0.0091}_{-0.0072}$	$^{+0.0092}_{-0.0077}$
Subjet CC DIS	ZEUS	0.1202	0.0052	$^{+0.0060}_{-0.0019}$	$^{+0.0065}_{-0.0053}$	$^{+0.0103}_{-0.0077}$
NLO QCD Fit	ZEUS	0.1183	$\rightarrow$	$^{+0.0028}_{-0.0028}$	$^{+0.0051}_{-0.0051}$	$^{+0.0058}_{-0.0058}$
NLO QCD Fit	H1	0.1150	$\rightarrow$	$^{+0.0017}_{-0.0017}$	$^{+0.0051}_{-0.0050}$	$^{+0.0054}_{-0.0053}$
Inc. Jet γp	ZEUS	0.1224	0.0001	$^{+0.0022}_{-0.0019}$	$^{+0.0054}_{-0.0042}$	$^{+0.0058}_{-0.0046}$

- experimental uncertainties: $\sim 3\%$
- theoretical uncertainties: $\sim 4\%$ (jet cross sections and NLO QCD fits)
  $\sim 8\%$ (internal structure of jets)



Most precise determinations used in averages

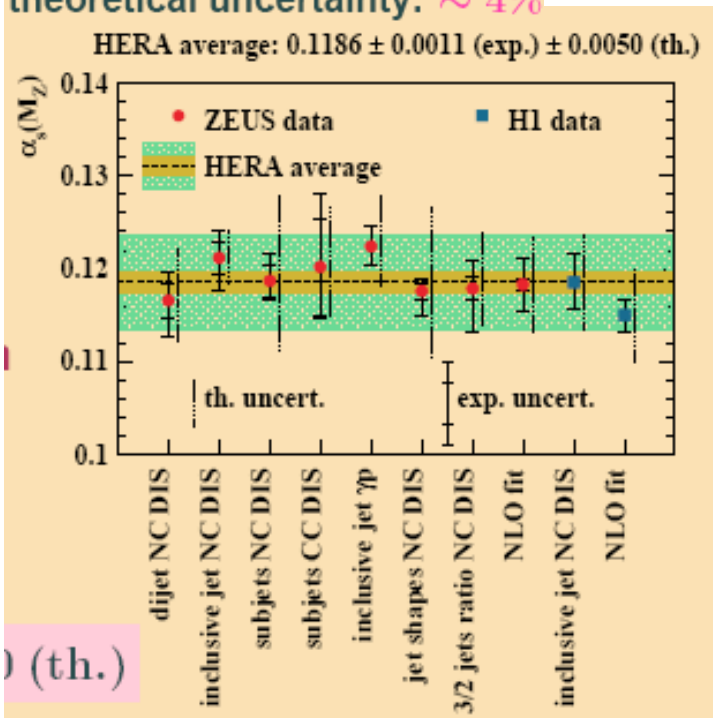
More on α_s

- Averaging must take proper account of *correlations* in e.g
  - Energy-scale uncertainties, PDFs, hadronisation corrections, terms beyond NLO

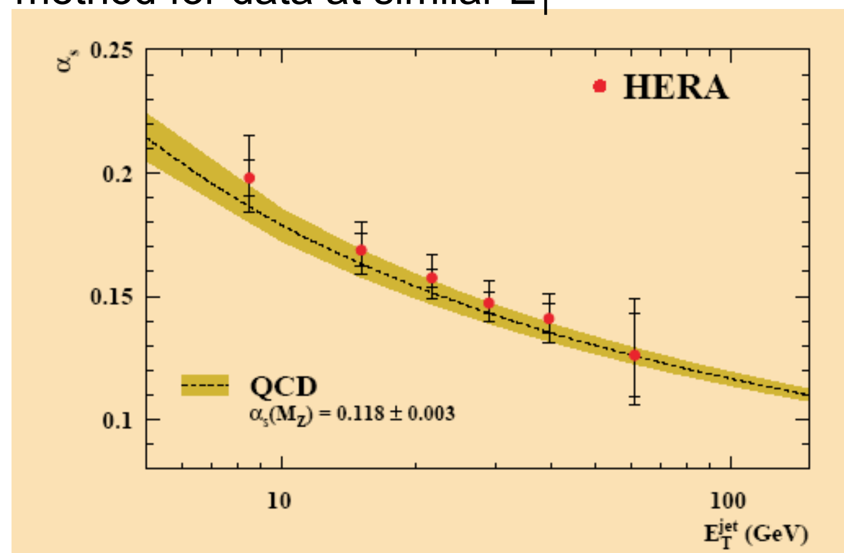
$$\rightarrow \overline{\alpha_s(M_Z)} = 0.1186 \pm 0.0011\ (\text{exp.}) \pm 0.0050\ (\text{th.})$$

experimental uncertainty: $\sim 0.9\%$

theoretical uncertainty: $\sim 4\%$



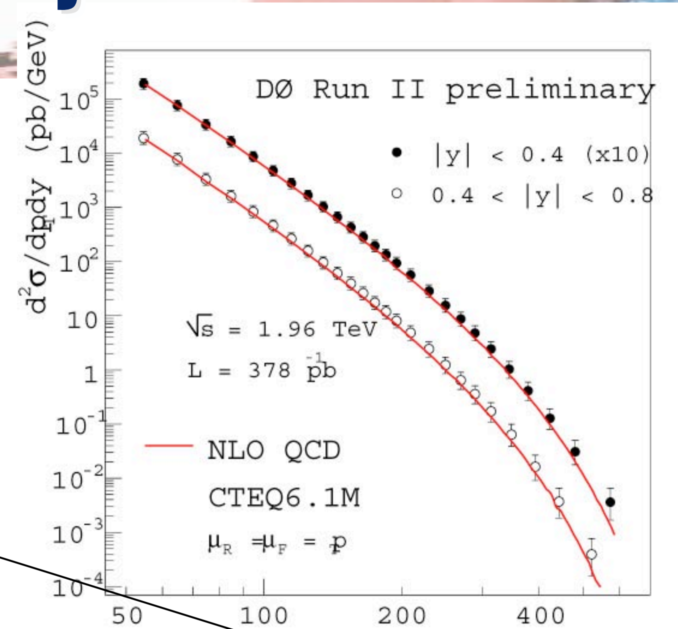
Combined running of α_s using correlation method for data at similar E_T



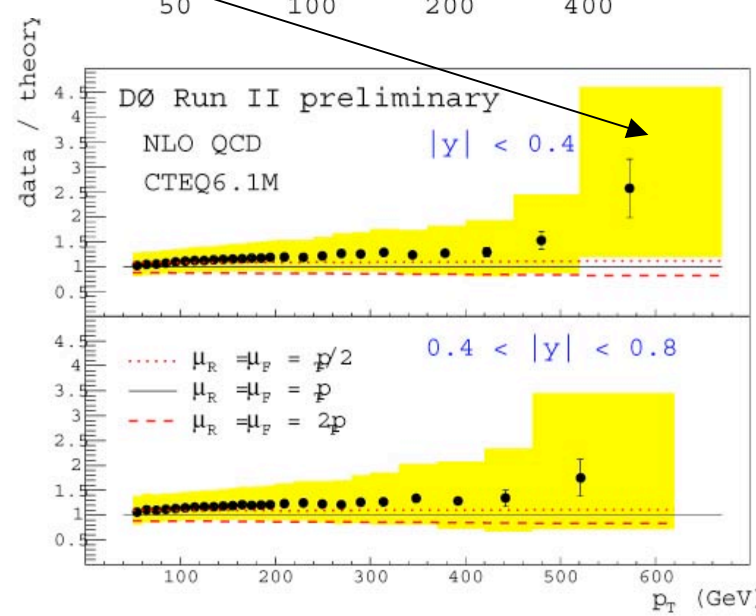
…Next steps will need NNLO

Inclusive jet and dijets from D0

Brian Davies



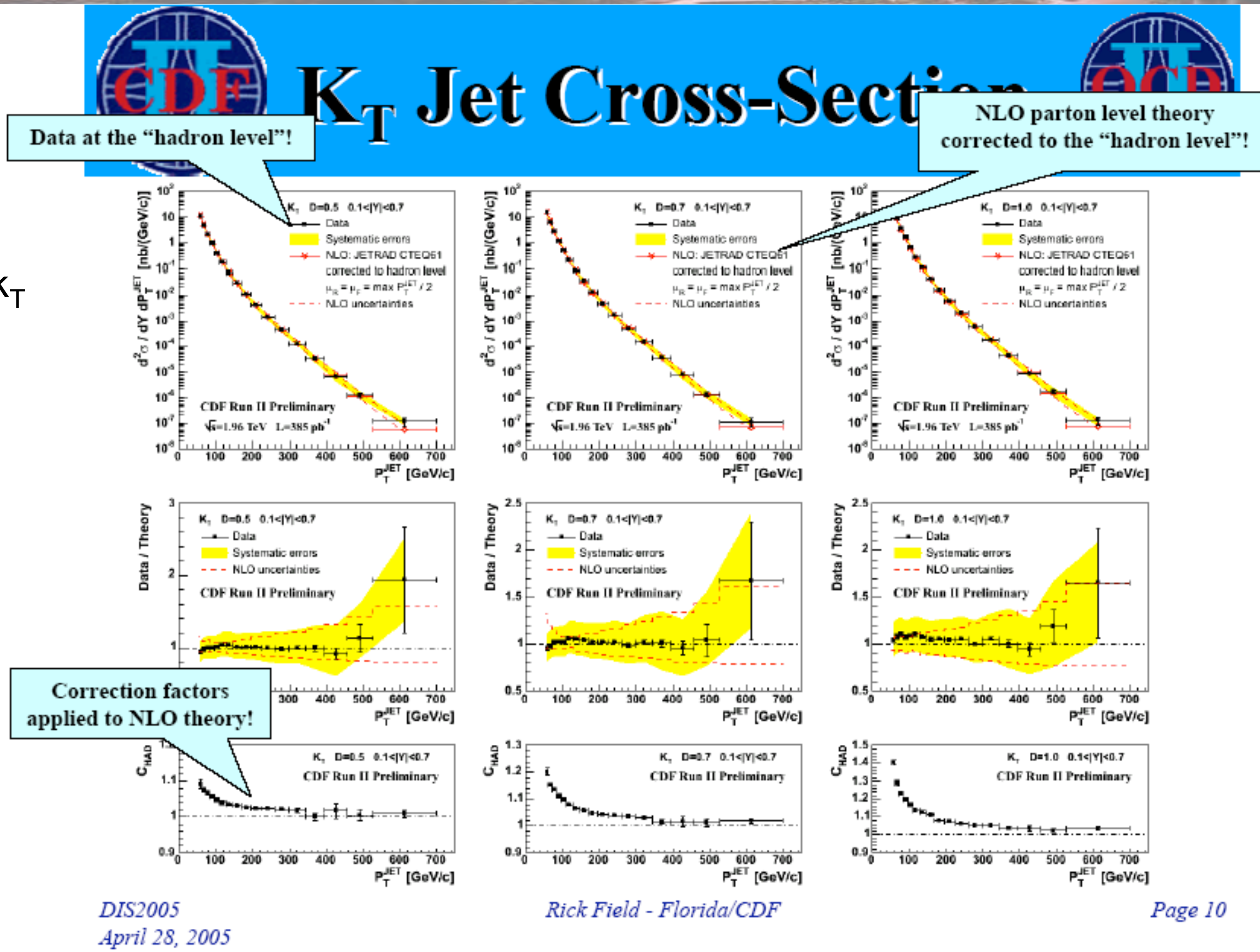
- Run II has ~0.7 fb^{-1} (~half being analysed here)
- Increased beam energy $\Rightarrow$ extended p_T reach promising sensitivity to gluon at high x
- New cone algorithm IR safe
- Dominant experimental systematic from jet energy scale (~5%) – still understanding new detector components
- Also looking at flavour tagging of jets with μs (vertex tagging to come) and φ decorrelations



Jet measurements at CDF

Rick Field

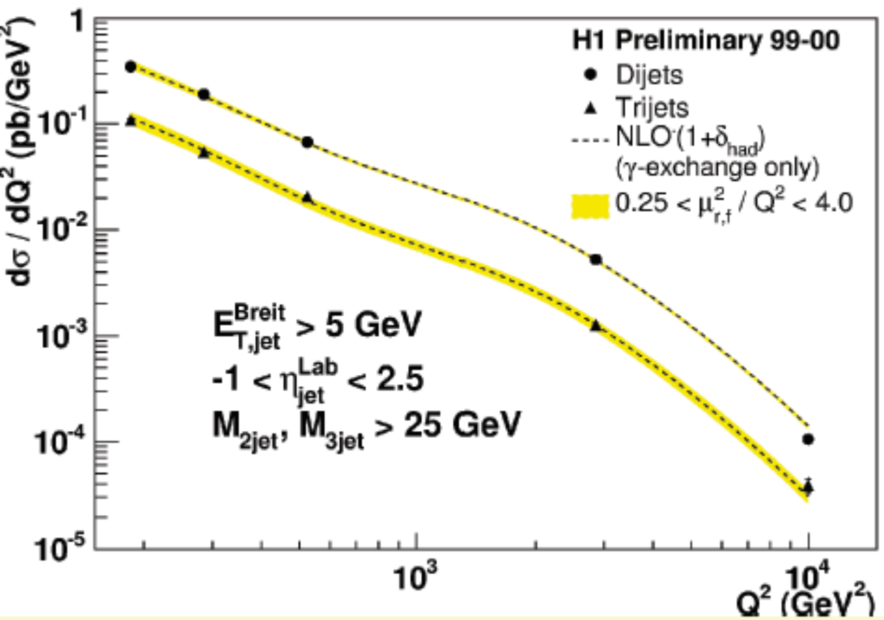
•Now using k_T algorithm



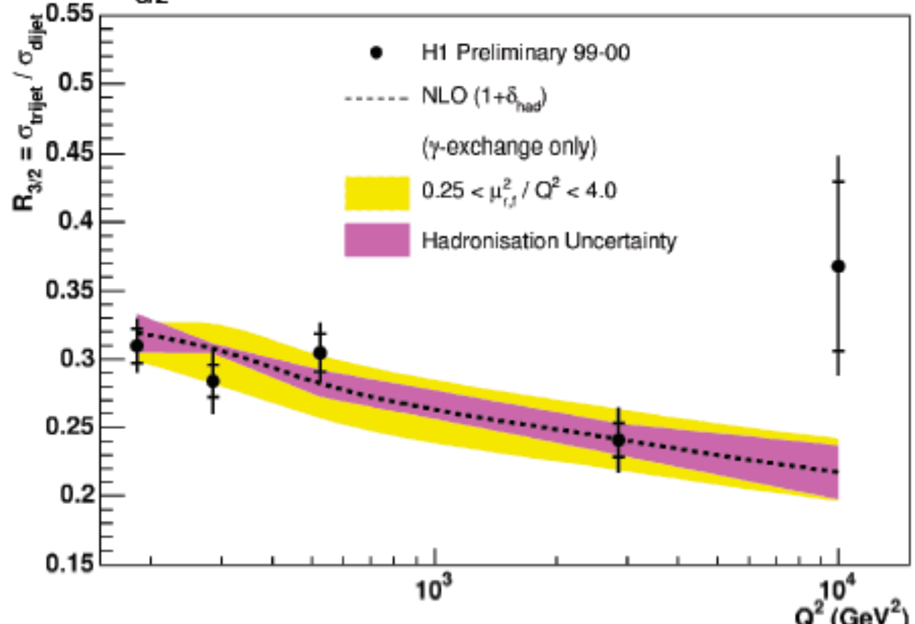
Jet Production at High Q^2 (H1)

Thomas Kluge

- Measure 2- and 3-jet cross sections at high Q^2 - $150 < Q^2 < 15000$ GeV^2
- Use to make α_S determination

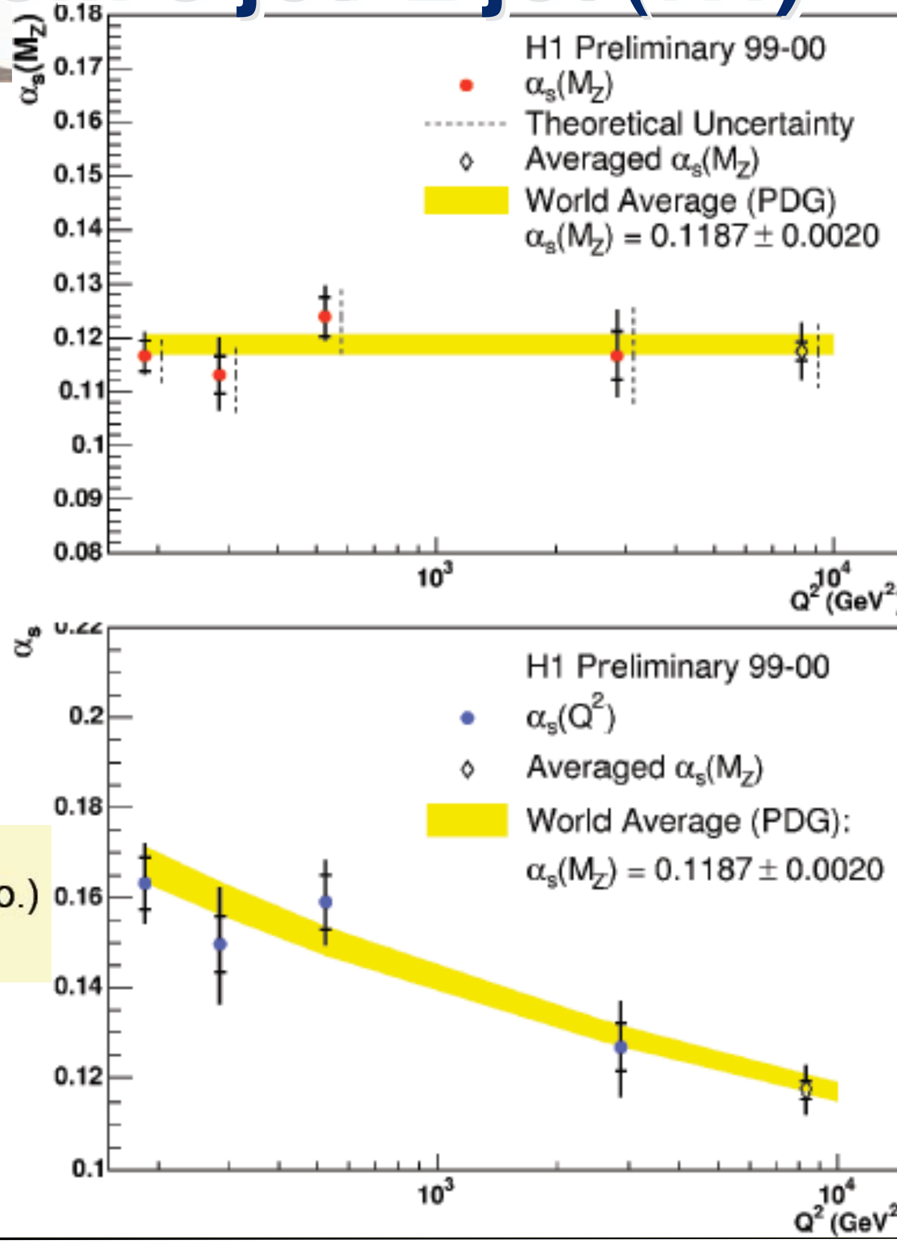


R3/2 Ratio of Tri- to Dijet Cross Section



Highest bin needs electroweak corrections from Z exchange. Not used

Extract α_s from 3 jet/ 2 jet (H1)



- Measure cross section ratio $R_{3/2}$
- Reduced experimental and theory uncertainties (e.g. μ_R dependence reduced to ~5%)

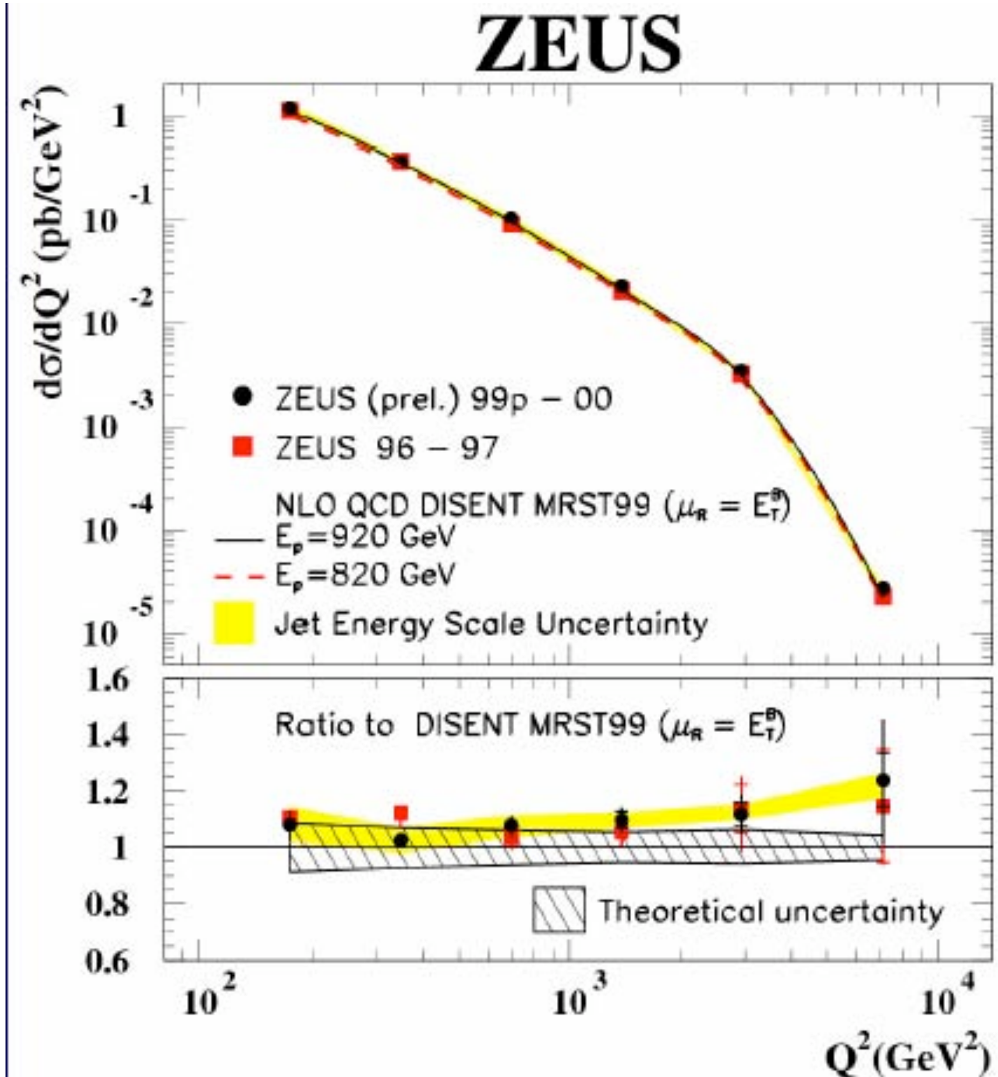
$$\alpha_s(m_Z) = 0.1175 \pm 0.0017 \pm 0.005 \,{}^{+0.0054}_{-0.0068} \text{ (stat.+syst.+theo.)}$$

Inclusive Jet Cross-Sections in Neutral Current DIS Events Using the Breit Frame

Jeff Standage

New measurement with 1999/2000 ZEUS data

- Data points consistent with NLO prediction within the uncertainties.
- This measurement is directly sensitive to value of $\alpha_s(M_Z)$ and the scale dependence of α_s.
- Consistent with NLO predicted ~10% increase in cross-section

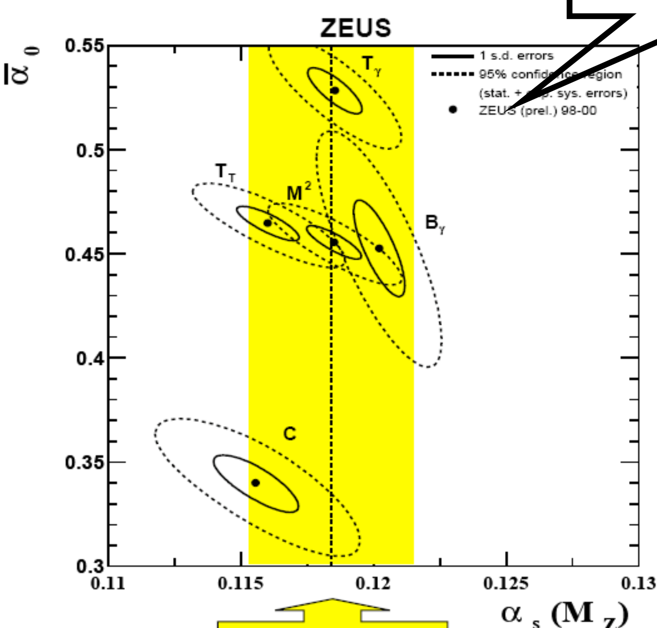


Event shapes from ZEUS

- Choose IR- and collinear-safe event shape variables.
- Compare with NLO + power corrections (Dokshitzer, Webber)
  (+ resummation for differential distributions)

Adam Everett

1/n dn/dF



World Average

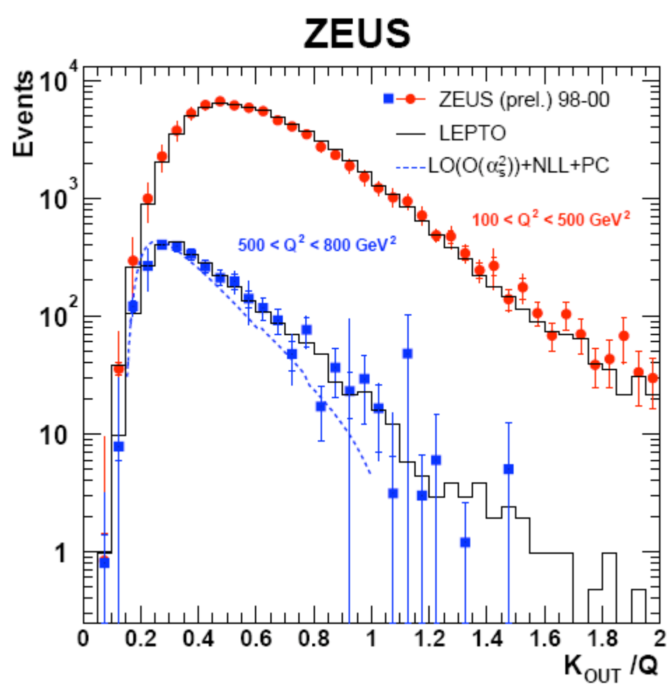
- $\alpha_0 \approx 0.45 - 0.5$

Momentum out of plane

$$K_{out} = \sum_i |\vec{p}_i|$$

Higher order process

Calculations LO for this



No fits performed up to now

First comparison with LO+NLL+PC is shown

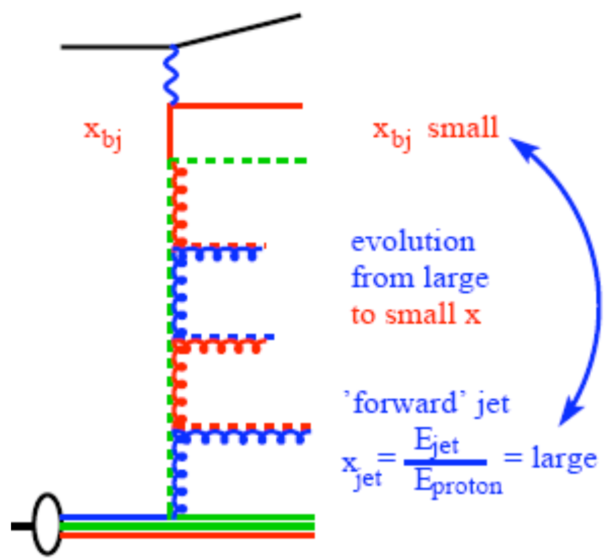
- $\alpha_s(M_Z) = 0.118$
- $\alpha_0 = 0.52$

Waiting on generalized resummation program

ZEUS 98-00 (82.2 pb^{-1})
$Q^2 > 100$ GeV^2

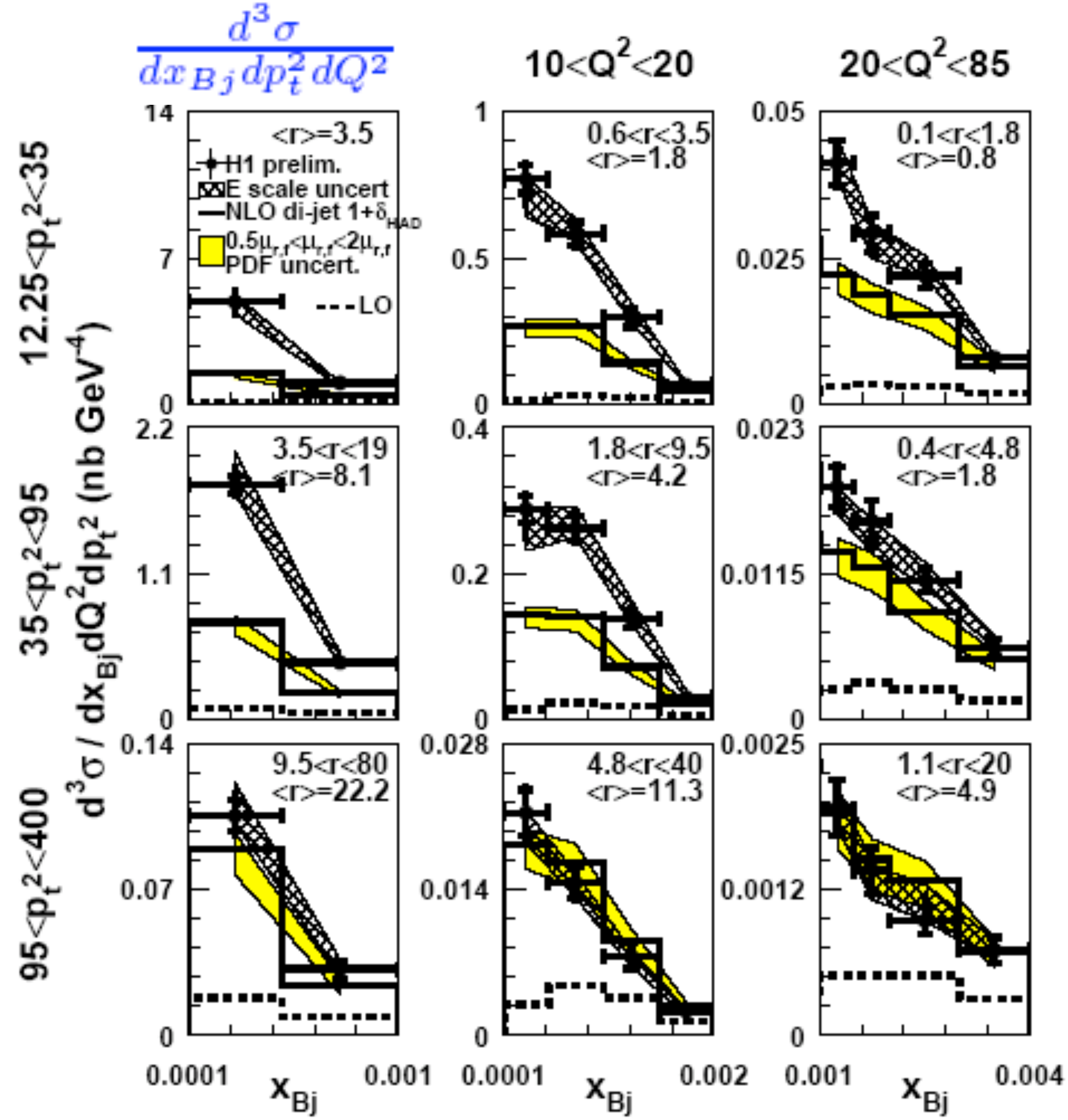
Measurement of Forward Jet Production at low x in DIS (H1)

Albert Knutsson

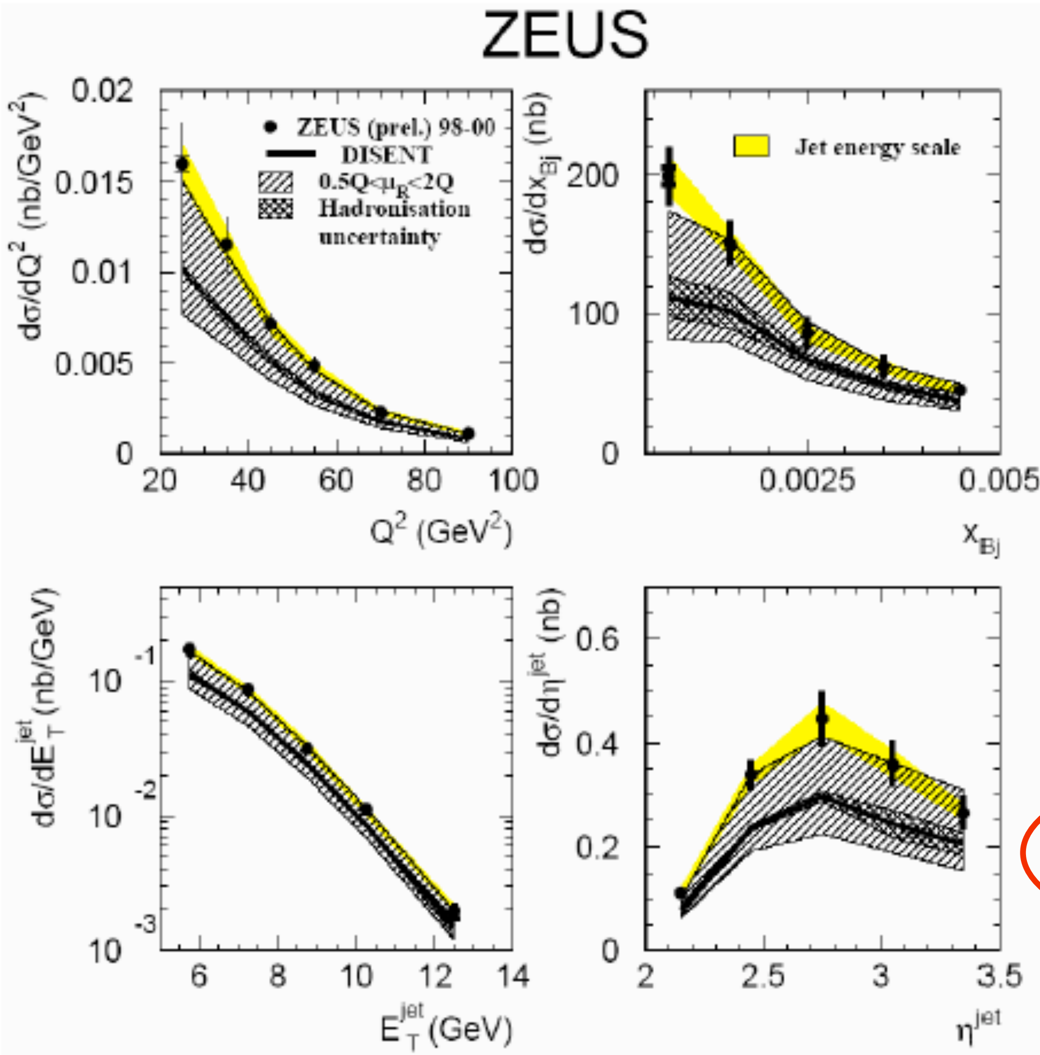


Large x_{Bj}, Q^2 and $p_t^2 \Rightarrow$
NLO describes data

Smaller x_{Bj}, Q^2 and $p_t^2 \Rightarrow$
NLO insufficient



Inclusive Forward Jet production in DIS (ZEUS)



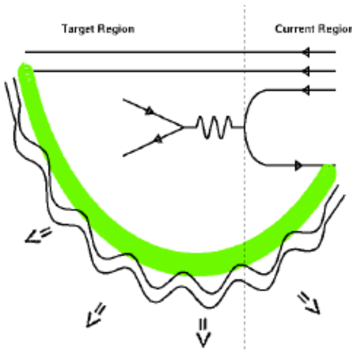
- Average hadronisation correction obtained with LEPTO and ARIADNE
- Proton PDF CTEQ5D
- NLO predictions lower than data but within theoretical uncertainties (except very low x_{Bj})
- Theory has too large uncertainty
- No disagreement with NLO DGLAP has been observed for forward jets

Different way of estimating scale uncertainty?

Charged multiplicity distributions (ZEUS)

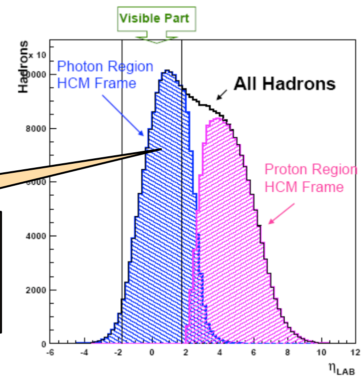
Breit Frame analysis of multiplicities *Michele Rosin*

Careful look at: current region in B.F. ≡ one e^+e^- hemisphere

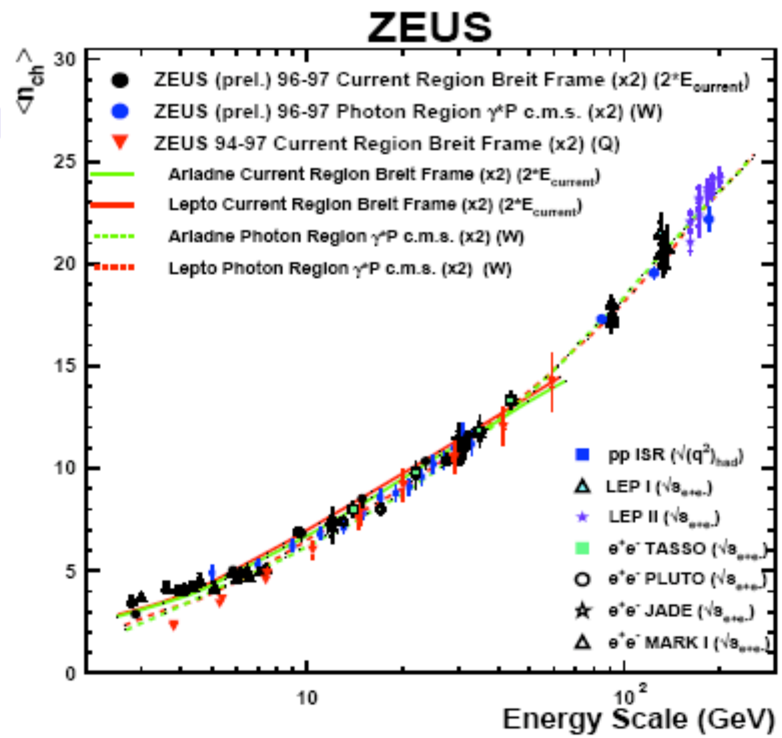


No migrations: $E_{Breit} = \frac{\sqrt{Q^2}}{2}$

With migrations: $\begin{cases} N < N_{expected} \\ E_{Breit} < \frac{\sqrt{Q^2}}{2} \end{cases}$



Photon region in HCM mostly target region in BF



- Measurement in current region of the Breit frame shows similar dependence to e^+e^- if $2{*}E_{current}$ is used as the scale
- The same dependence is observed for the photon region of the HCM frame vs. W.

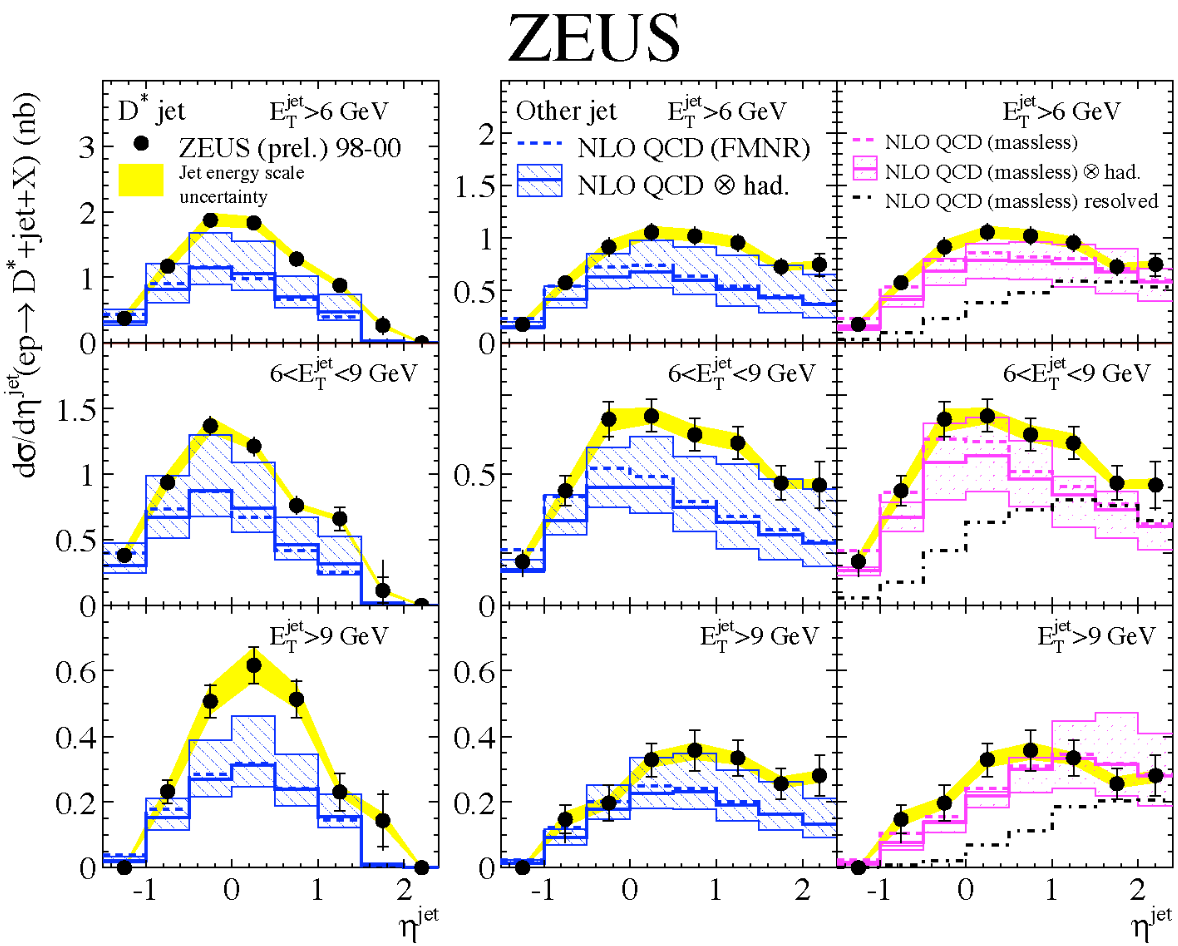
ZEUS D* Jet photoproduction

Events with a D^* and ≥ 1 jet ($E_T > 6$GeV)

D^*-jet and "other"-jet distribution

Consistent with NLO massive (FMNR) and Massless calculations

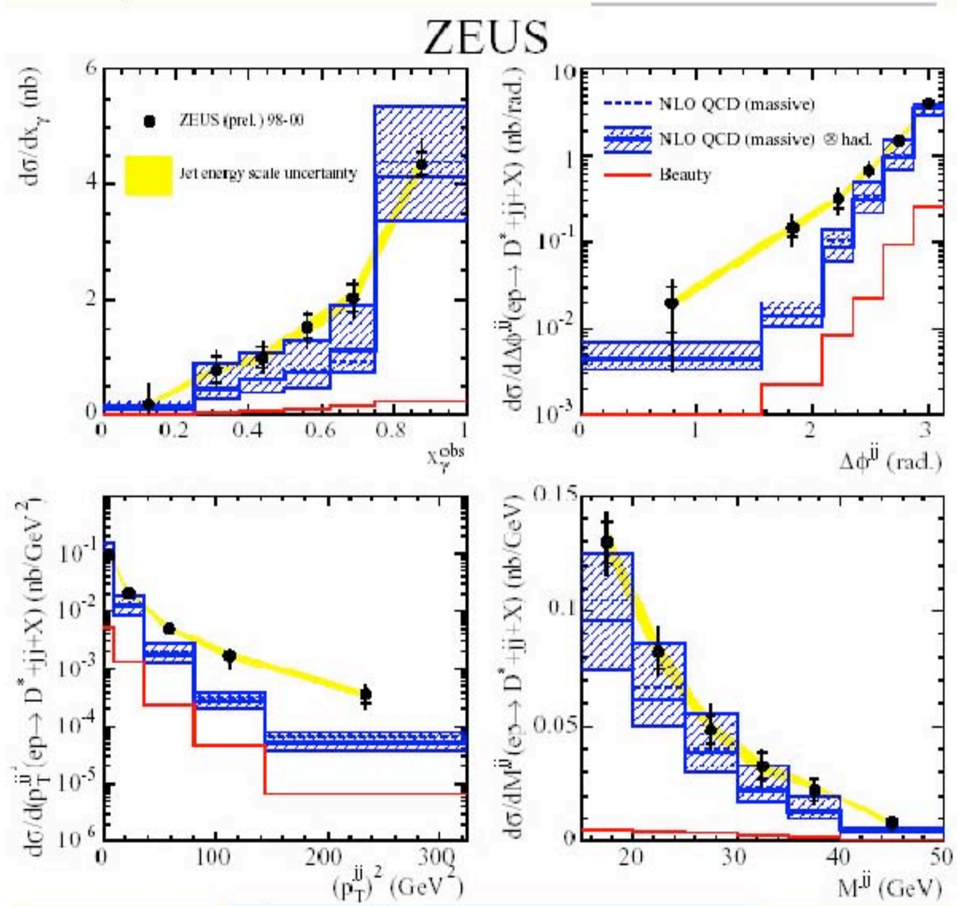
T. Kohno



ZEUS D* dijets

Dijet correlations, directly sensitive to NLO corrections

T. Kohno



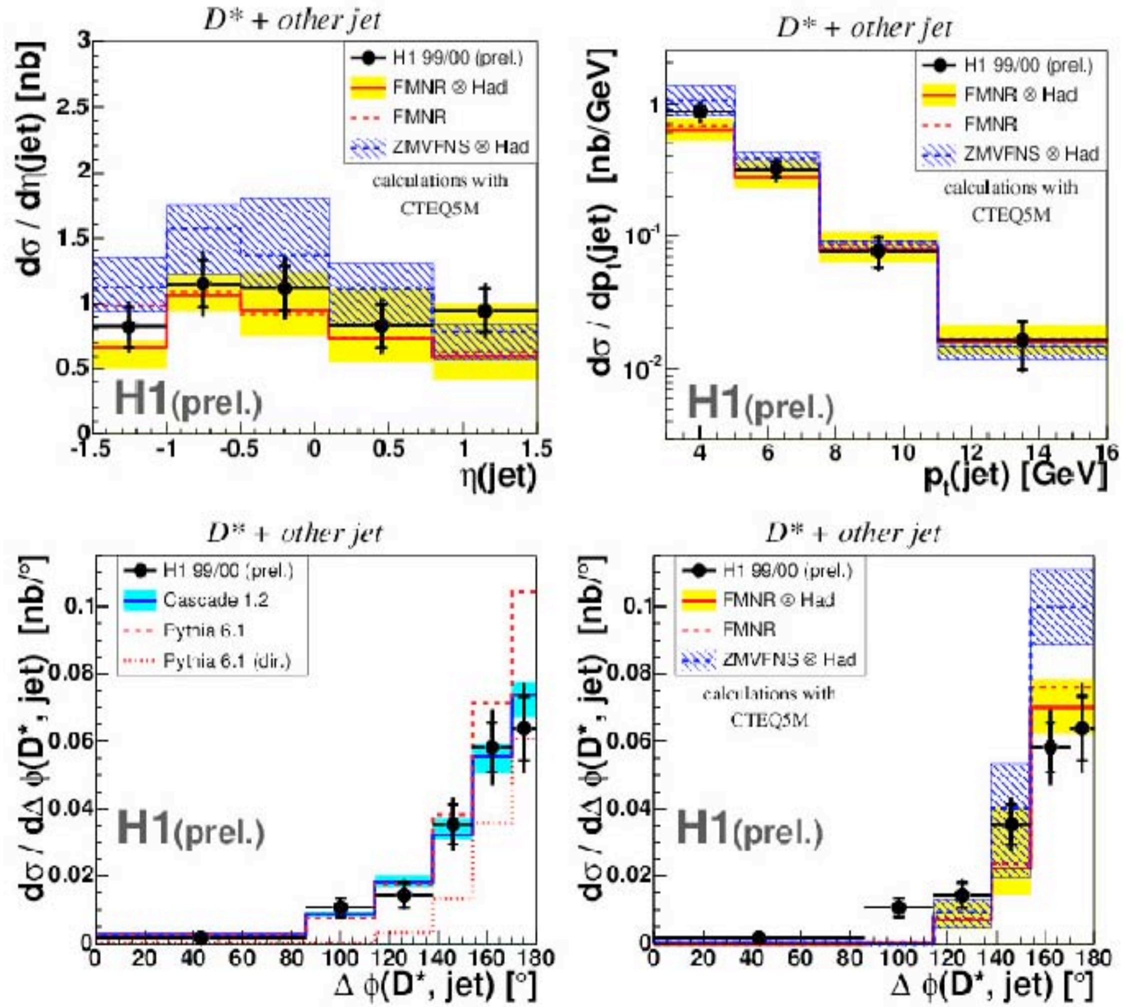
FMNR too low at large p_T^{jj} and low $\Delta\phi$

Need higher orders or matching with PS

H1 Charm + jet photoproduction

D^* and "other"-jet $P_T > 3$GeV (tagged PhP)

G. Fluke

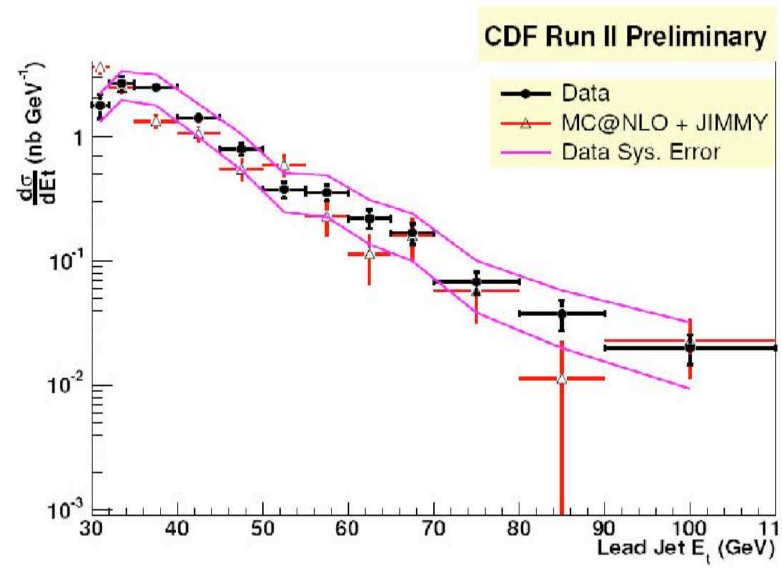


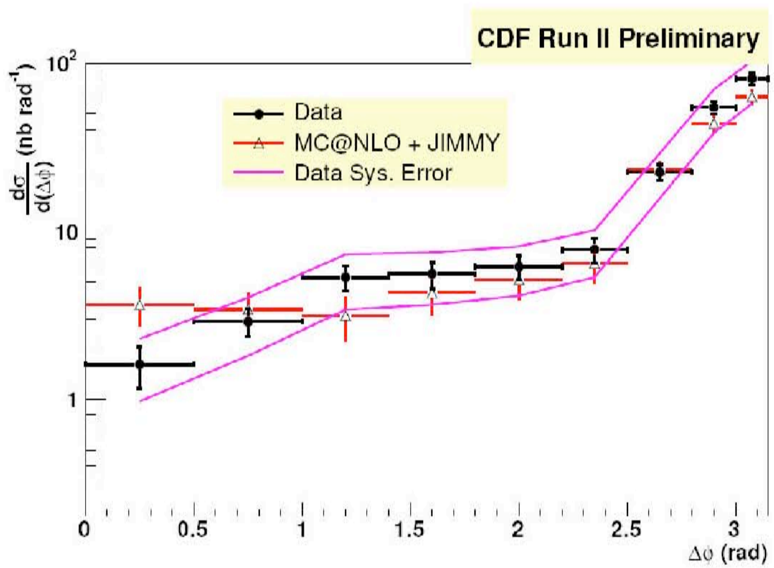
Δ_ϕ not well reproduce by massive and massless NLO

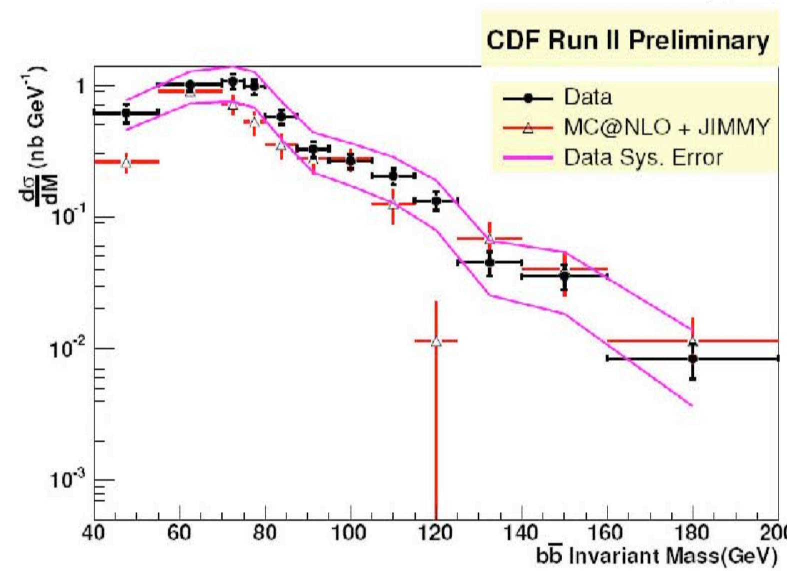
CDF b-jets

R. Lefevre

- Jet algorithm: JetClu with $R_{cone} = 0.7$
- Kinematical range
  - 2 b-jets within $|\eta| < 1.2$
  - $E_T^{1st\ b\text{-}jet} > 30$ GeV, $E_T^{2nd\ b\text{-}jet} > 20$ GeV
- Data sample: 65 pb^{-1}
  - Jet 20 only (prescaled trigger)
- Comparison to MC@NLO ⊕ JIMMY
  - Default JIMMY – Small MC sample



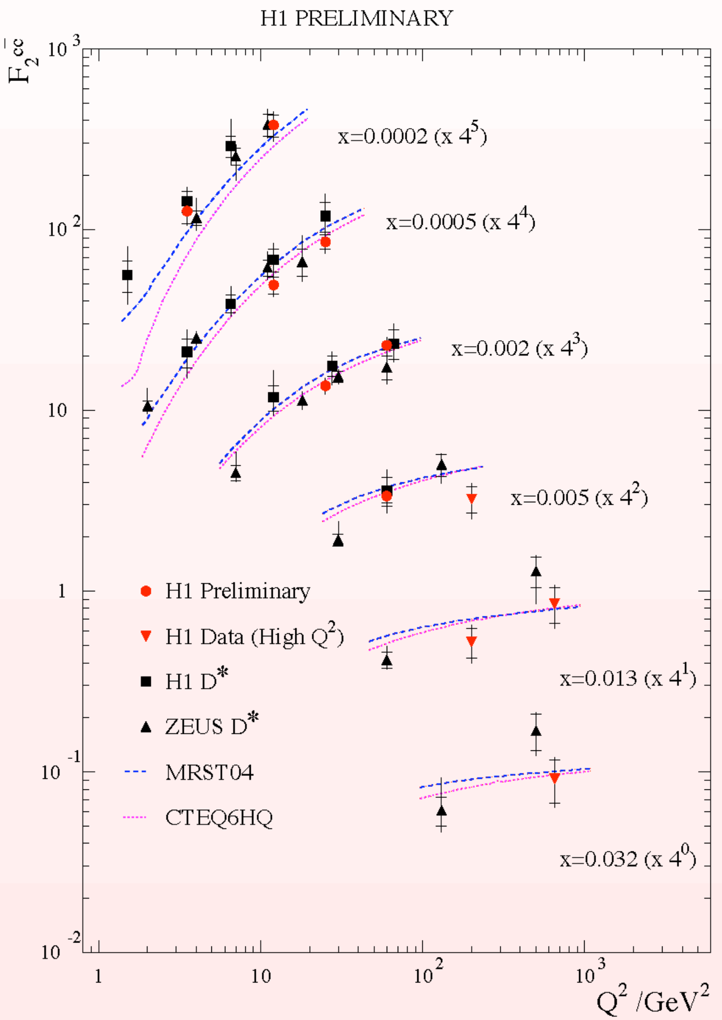




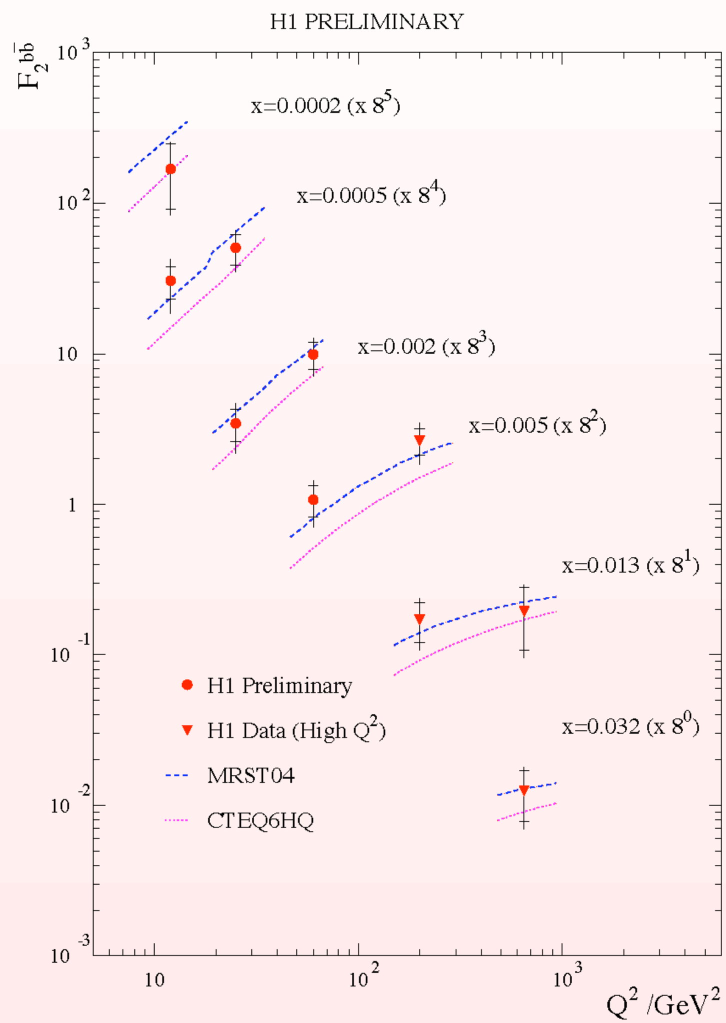
$F_2^{q\bar{q}}$ from H1, ZEUS vs. NLO

T. Klimkovich

$F_2^{c\bar{c}}$ vs Q^2



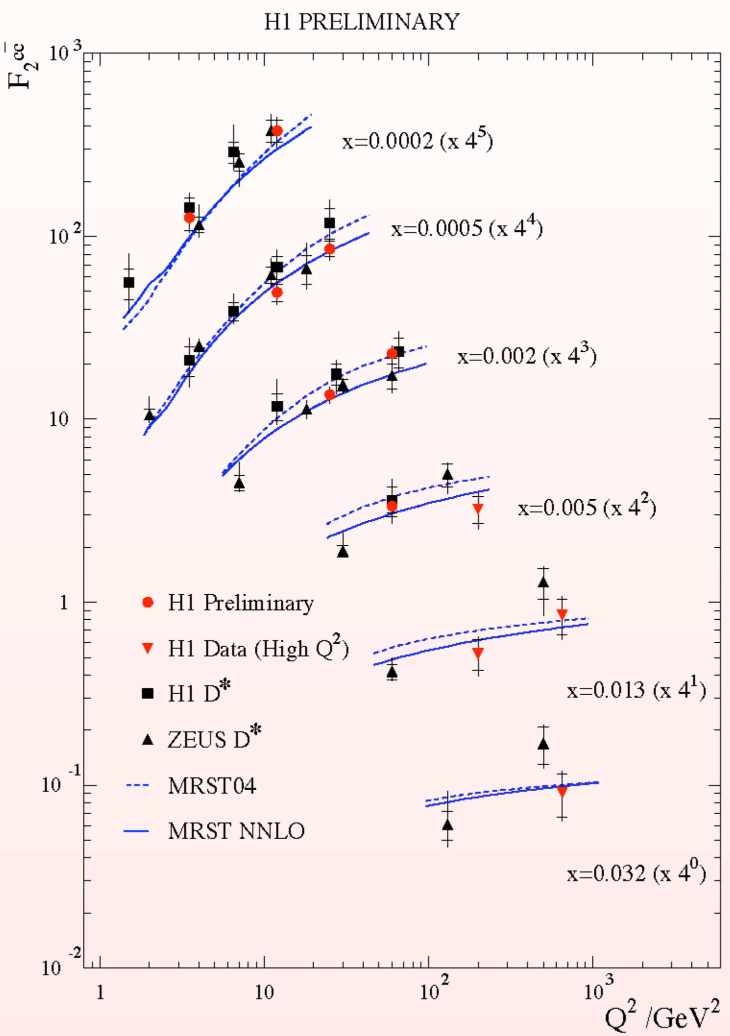
$F_2^{b\bar{b}}$ vs Q^2



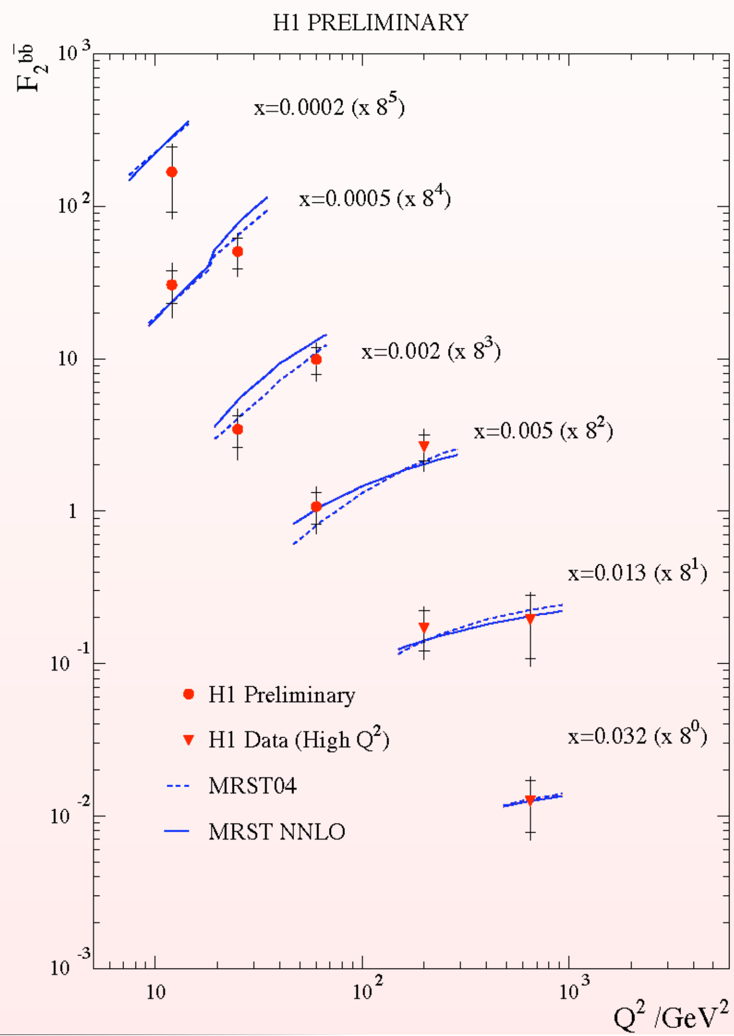
H1, ZEUS $F_2^{q\bar{q}}$ vs. NNLO (MRST)

T. Klimkovich

$F_2^{c\bar{c}}$ vs Q^2

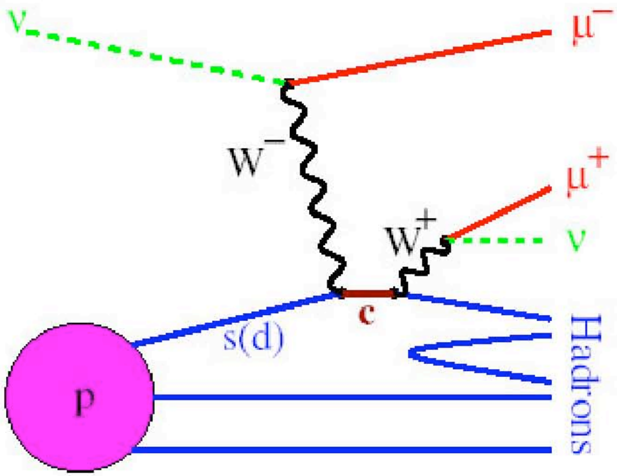


$F_2^{b\bar{b}}$ vs Q^2



NuTeV $s/\bar{s}$ sea

D. Mason

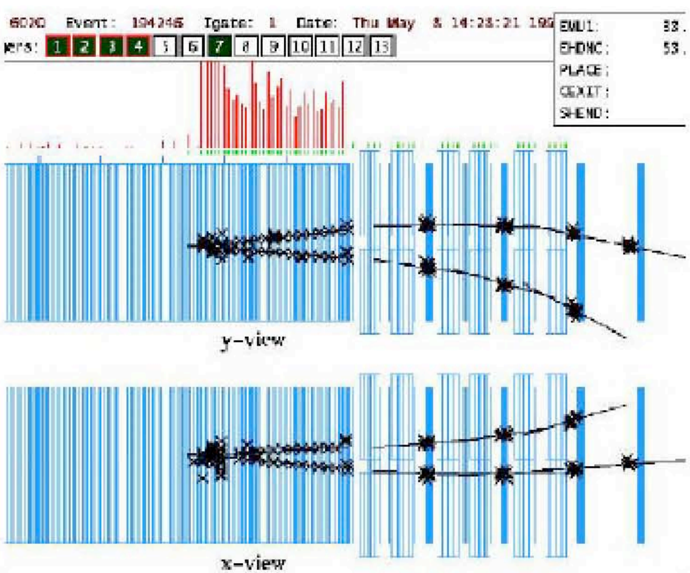


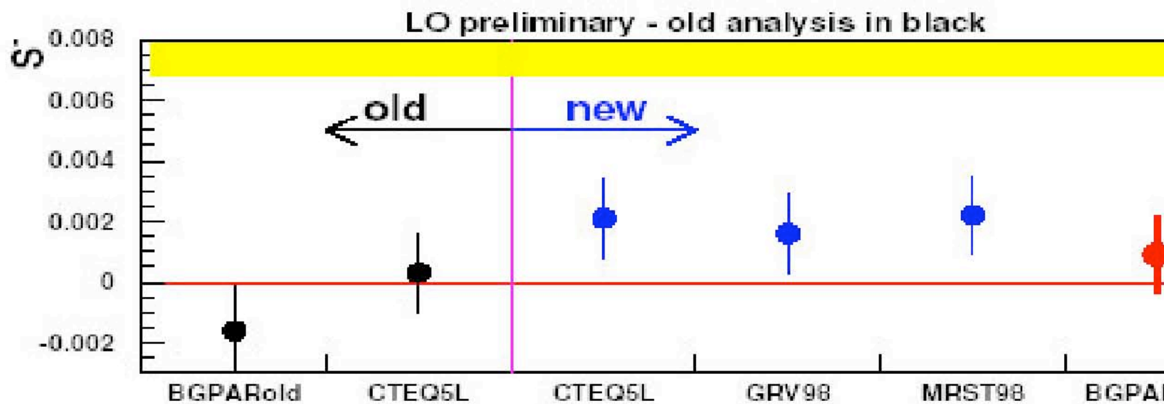
$\nu N \to \mu^- c(\to \mu^+)X$

Signed selected beam, look at $s(x)$ and $\bar{s}(x)$ independen

Complete data sample (20 times previous results)

LO analysis, extract $S^- = \int dx\ x(s(x) - \bar{s}(x))$



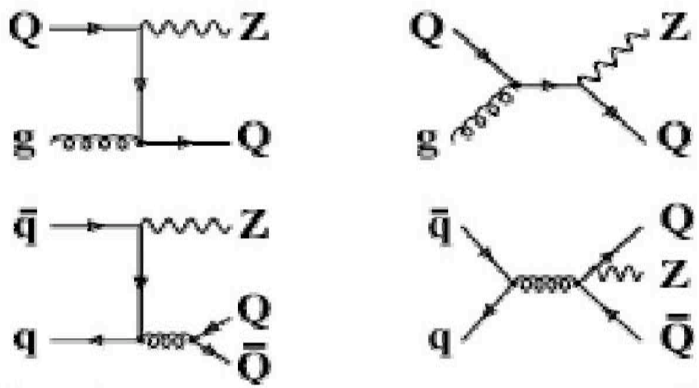


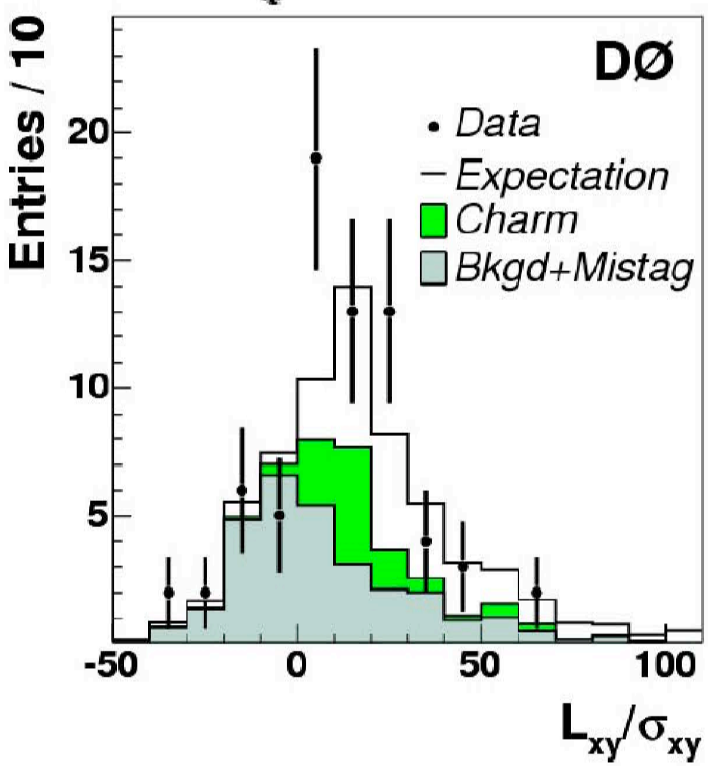
Strange asymmetry compatible with zero

$S^- = 0.0068$ required to explain $\sin^2\theta_W$ anomaly

Z + (b-jet) from DØ

N. Parua





$p\bar{p} \rightarrow Z + b$ **production sensitive to b-pdf**

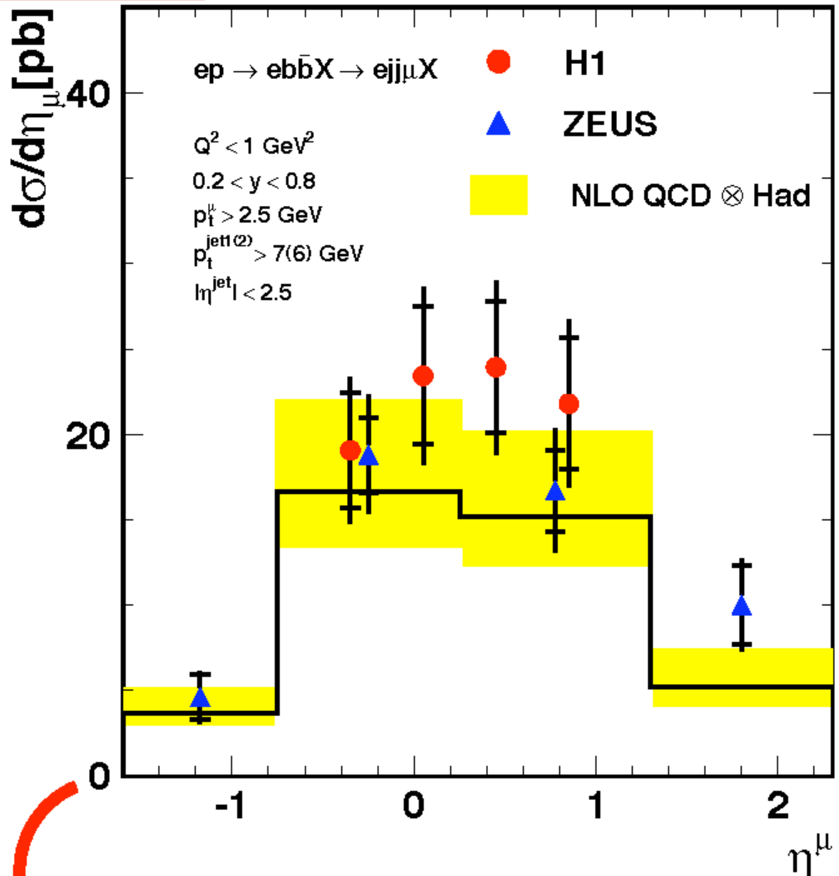
180 pb^{-1} of Run-II data $\sim 5000\ Z(\rightarrow l^+l^-)$**+jet**

require a secondary vertex significance > 7

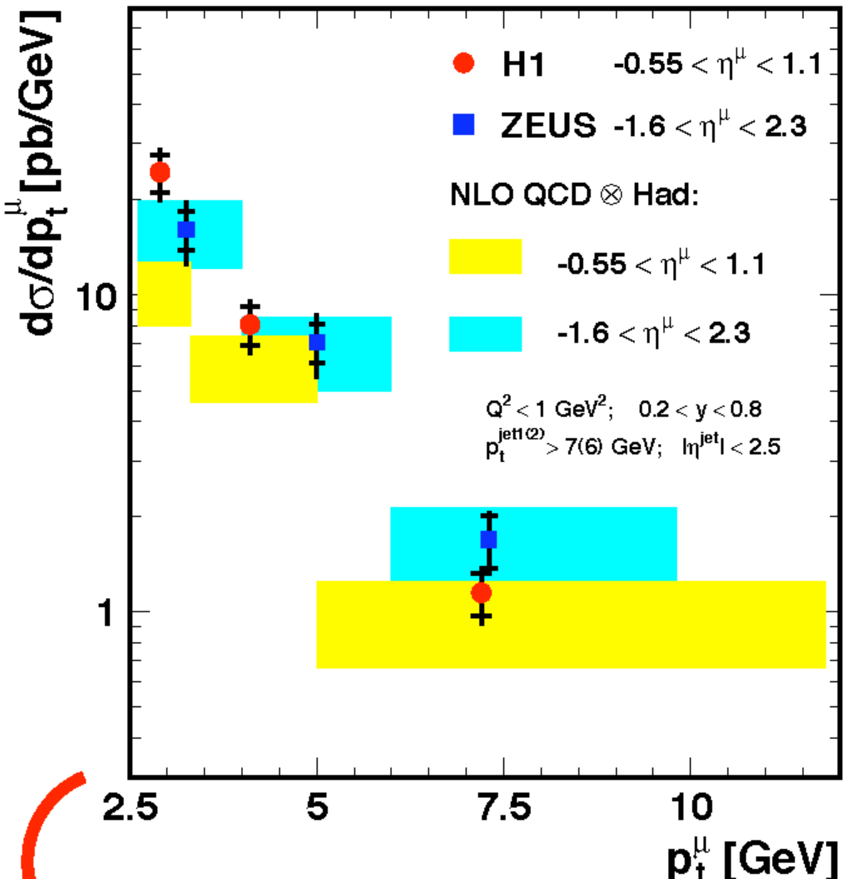
$$\frac{\sigma(Z+bjets)}{\sigma(Z+jets)} = 0.021 \pm 0.004(\text{stat.})^{+0.002}_{-0.003}(\text{syst.})$$

Theory: 0.018 ± 0.004 **(NLO+CTEQ6)**

H1 vs ZEUS b: μ + dijet photoprod.

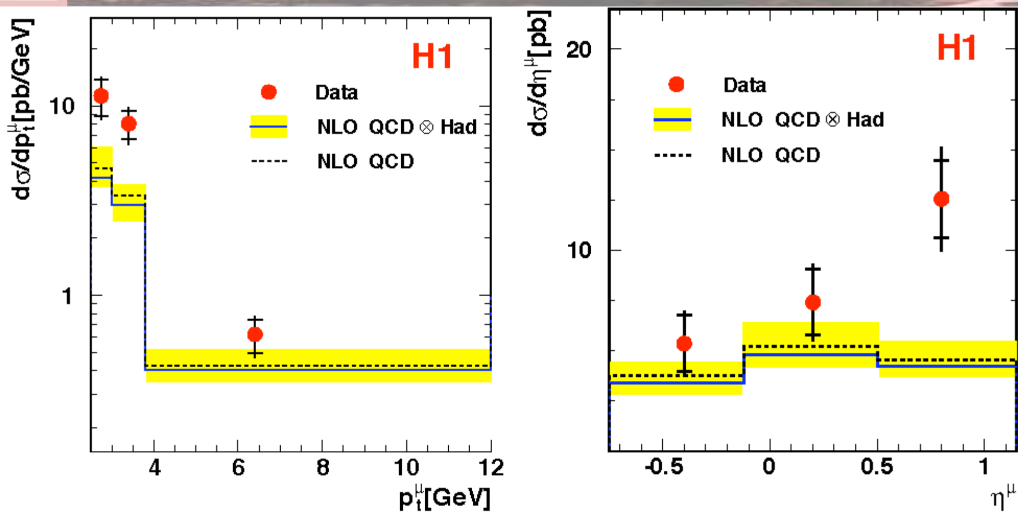


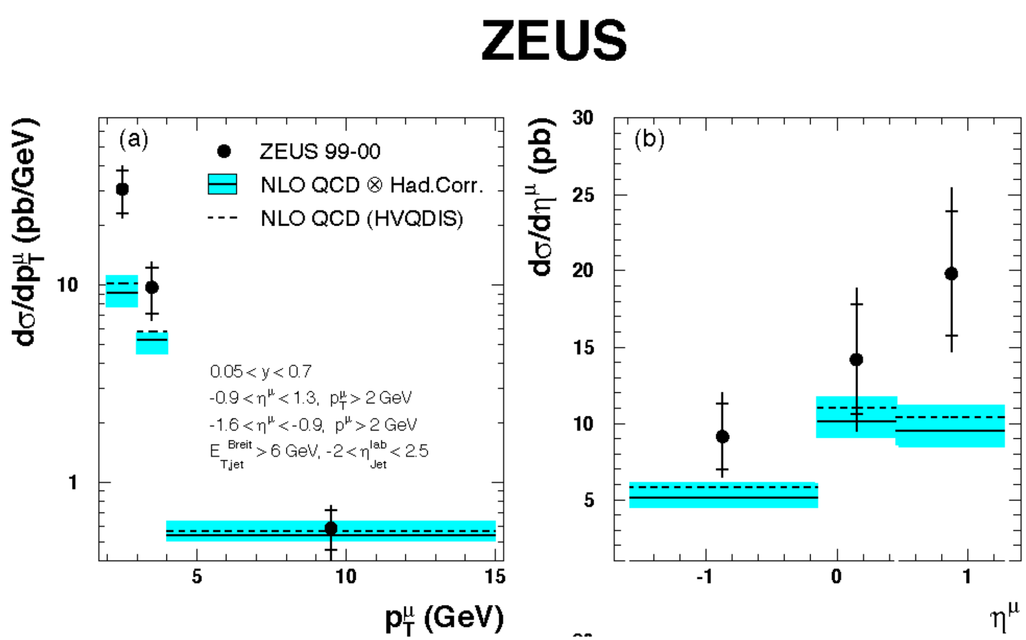
Good agreement H1 vs ZEUS



ZEUS: No excess at low p_t^μ

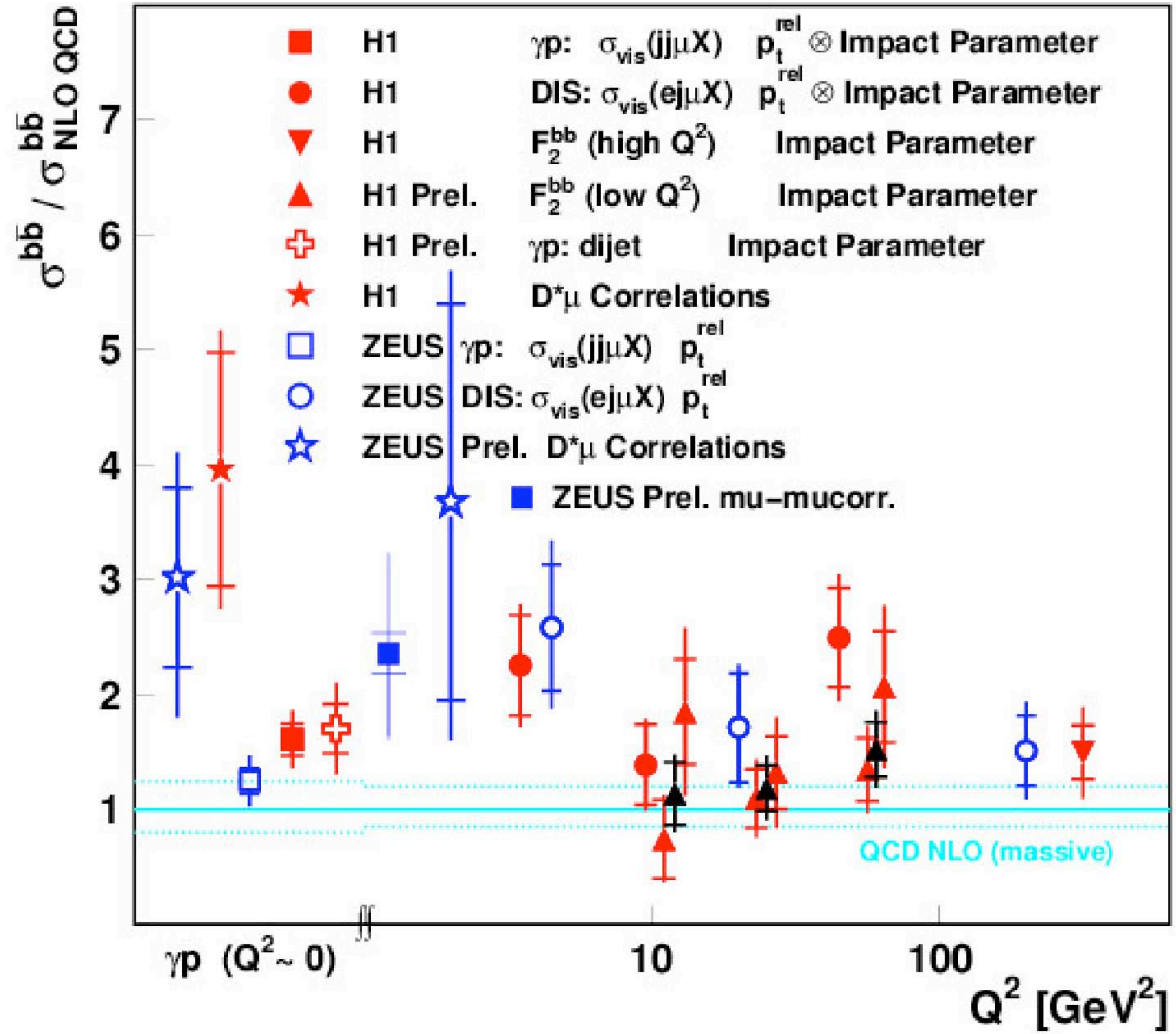
H1 vs ZEUS b: μ + jet in DIS





⇒ Good agreement

Summary of HERA b-physics



Diffractive DIS at HERA

HERA: 10% of low-x DIS events are diffractive

Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2

W = invariant mass of γ-p system

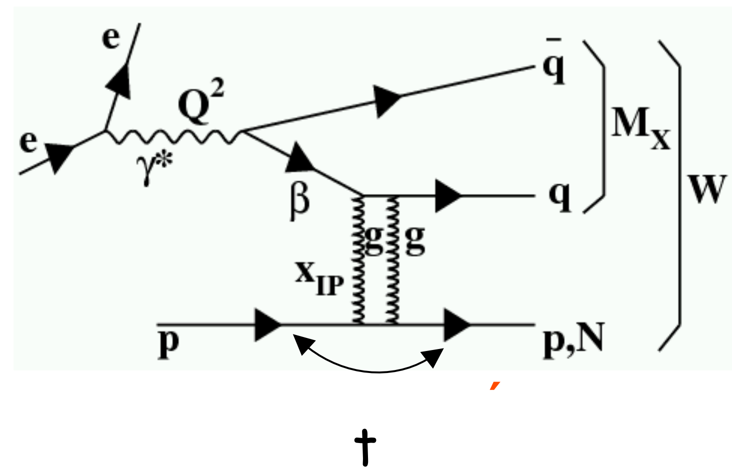
M_X = invariant mass of γ-IP system

P

x_{IP} = fraction of proton's momentum taken by IP

ß = Bjorken's variable for the IP
= fraction of IP momentum carried by struck quark
= x/x_{IP}

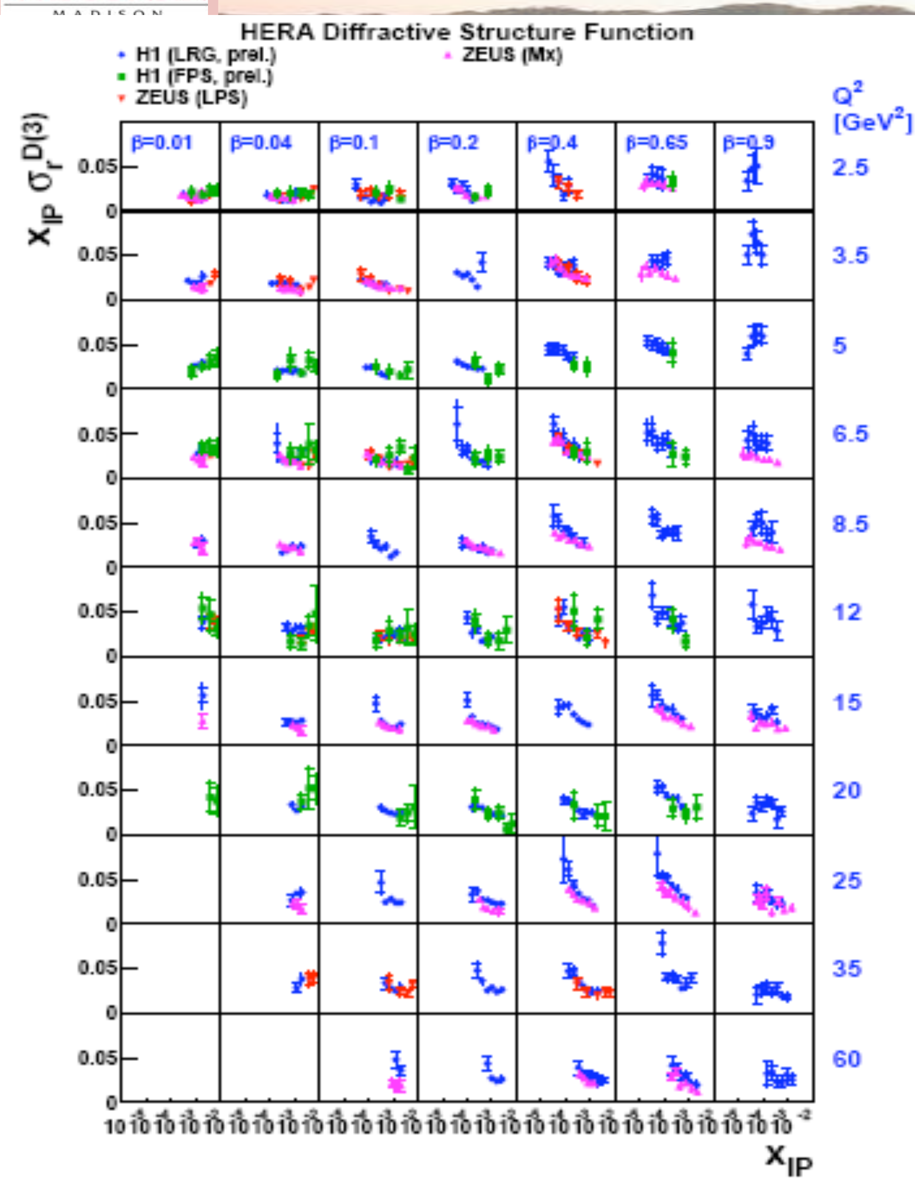
Diffractive DIS



Probe structure of color singlet exchange → F_2^D

M.Kapishin, Inclusive diffraction at HERA

Diffractive structure function

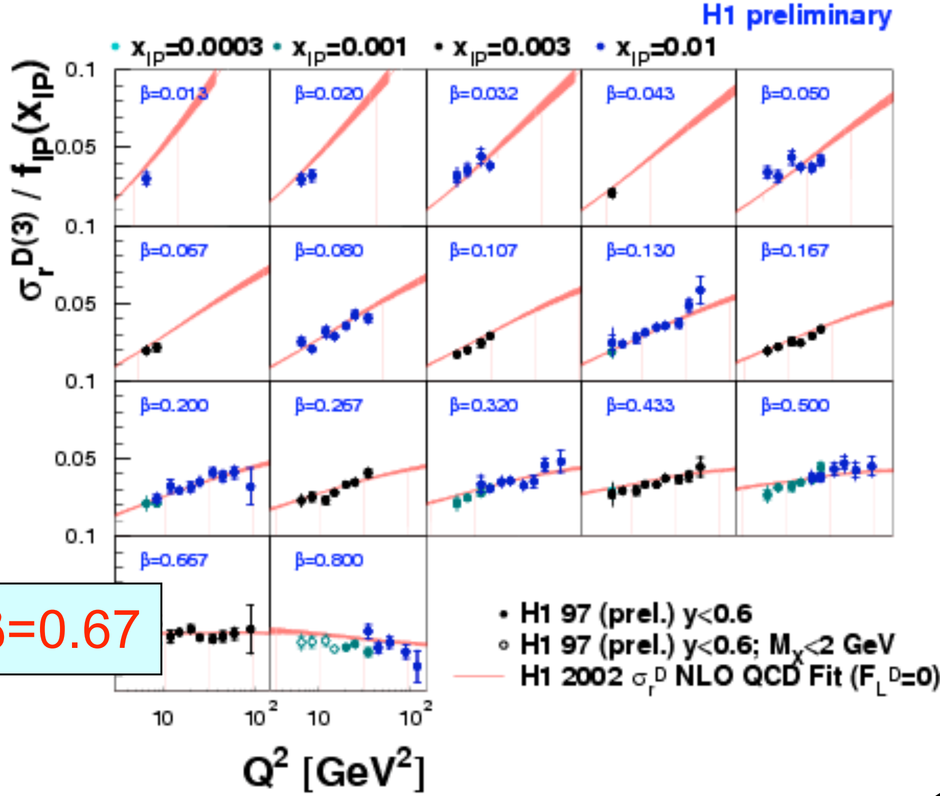


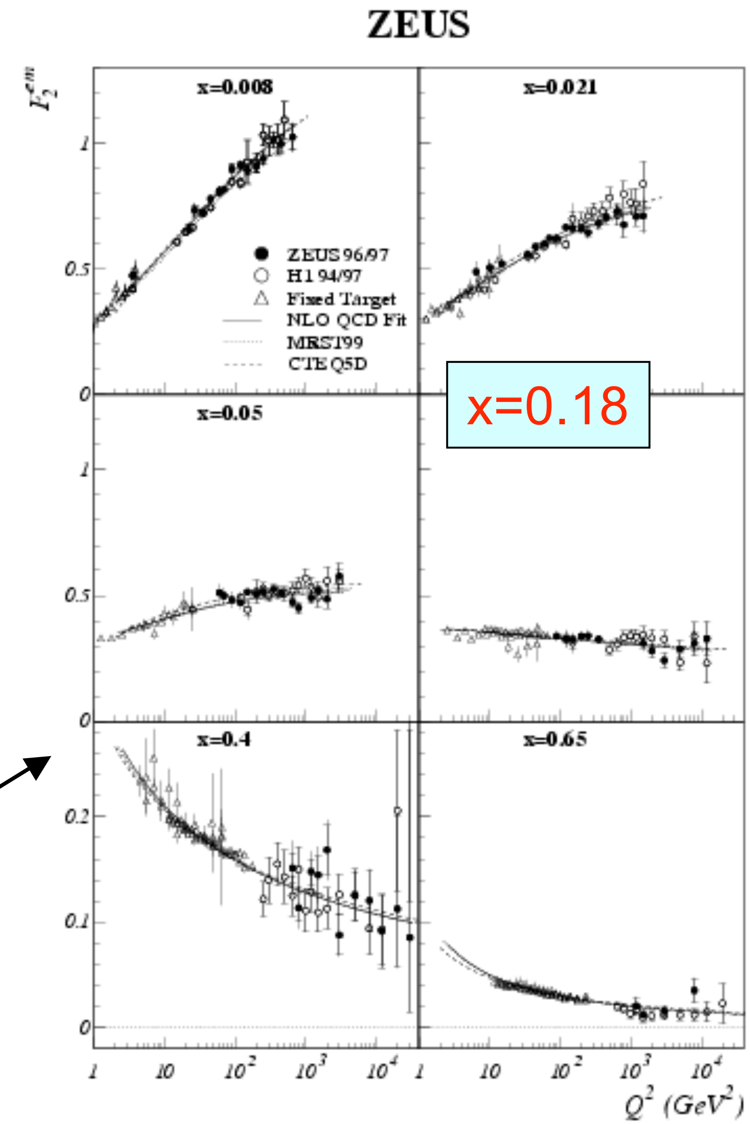
Precise data

Wide kinematic coverage

- M_x: higher β region
- LPS: higher x_{IP} region

Scaling violation of $F_2^{D(3)}$



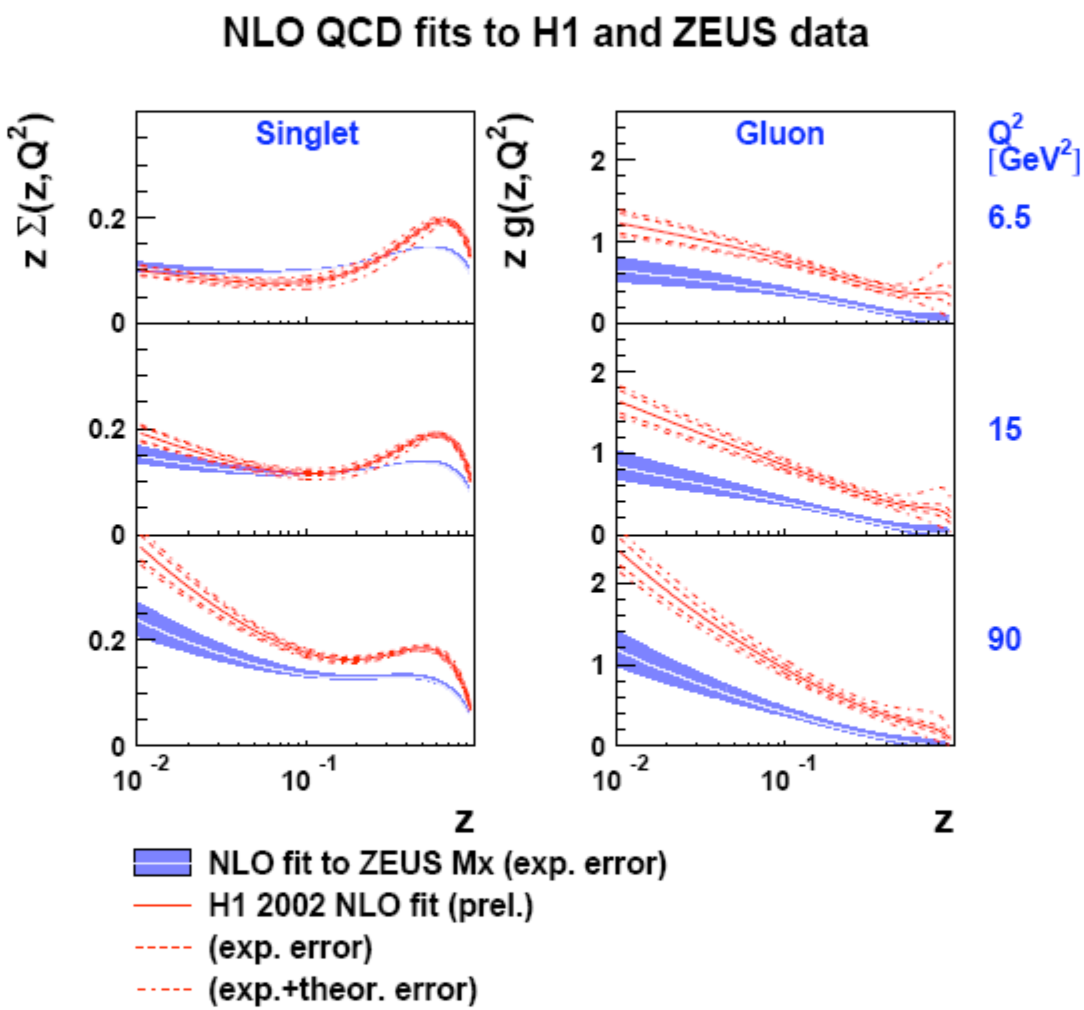


Inclusive data

- Positive scaling violations to highest β

$\rightarrow$ lot of gluons

NLO DGLAP fits



Observations:

- Singlet similar at low Q^2, evolving diffrenly to higher Q^2
- Gluon factor $\sim$ 2 smaller than H1 gluon

Reminder that data comparisons revealed differences

- at low M_X (high β)
  Most of those points are not included in the fit
- in the Q^2 dependences
  Different Q^2 evolution means different gluon

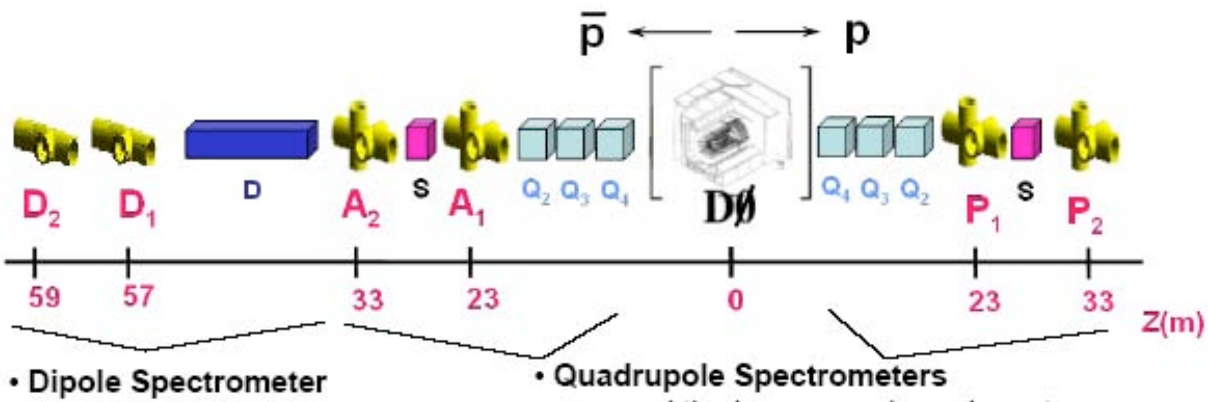
$\rightarrow$ Observed differences in the data explain the differences in the extracted pdfs

Regge factorization assumed

by P. Newmann, F.-P. Schilling, P Laycock

Diffraction at the TEVATRON

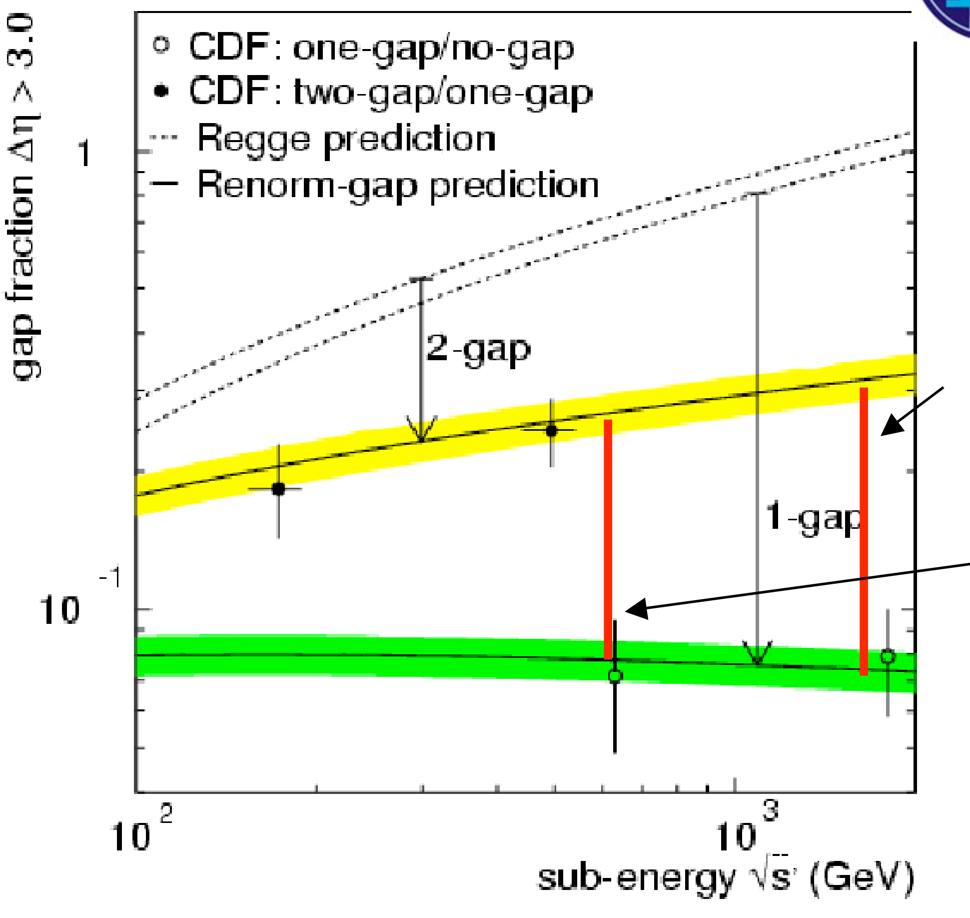
Now both CDF and D0 have roman pots and are actively pursuing broad diffractive physics program

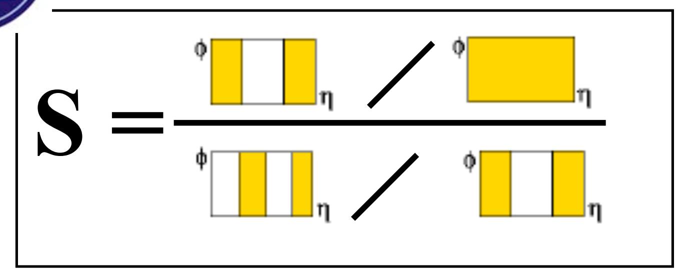


- FPD being calibrated and working as planned.
- Level 1 FPD triggers being commissioned (new data samples).
- Comparing measurements with FPD tag vs. Gap tag yields new insight into processes

Gap survival probability

K. Goulianos





$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \mathrm{GeV}) \approx 0.23$$

$$S^{1-gap/0-gap}_{2-gap/1-gap}(630\ \mathrm{GeV}) \approx 0.29$$

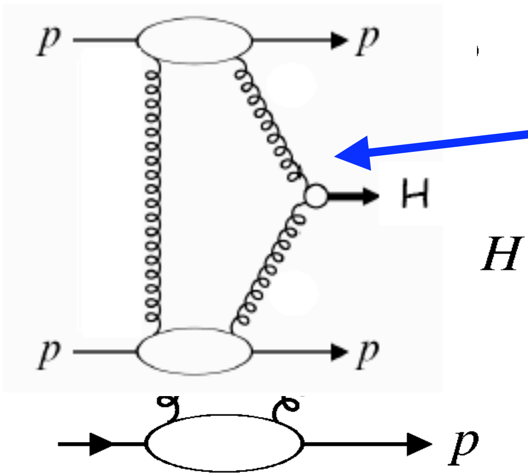
Results similar to predictions by:

Gotsman-Levin-Maor

Kaidalov-Khoze-Martin-Ryskin

Soft color interactions

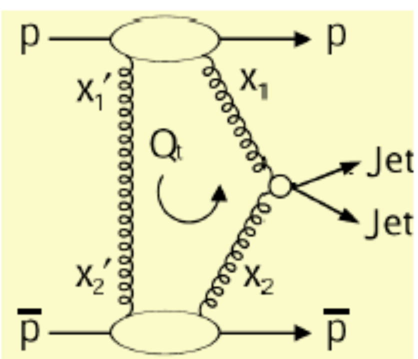
TEVATRON to LHC



Vacuum quantum numbers !

Attractive Higgs studies at LHC

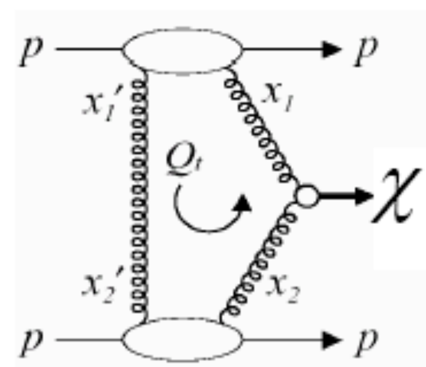
Exclusive DPE dijet production



$R_{jj}=M_{jj}/M_x$

Much larger cross section

Exclusive low-mass states



$p\bar{p} \rightarrow p\chi\bar{p}$

$\quad \rightarrow J/\psi\,\gamma \rightarrow \mu\mu\gamma$

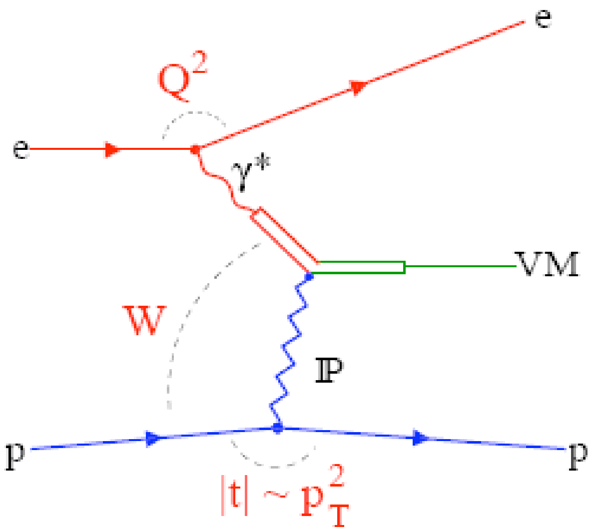
(γ is soft)

(same quantum numbers as Higgs boson)

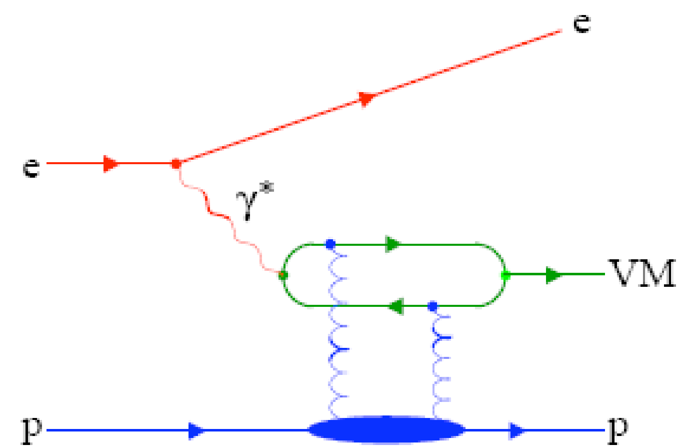
Vector Meson Production

$$e + p \rightarrow e + VM\ (= \rho, \omega, \phi, J/\psi, ...)\ (\text{or } \gamma) + p$$

Regge Theory



pQCD Models

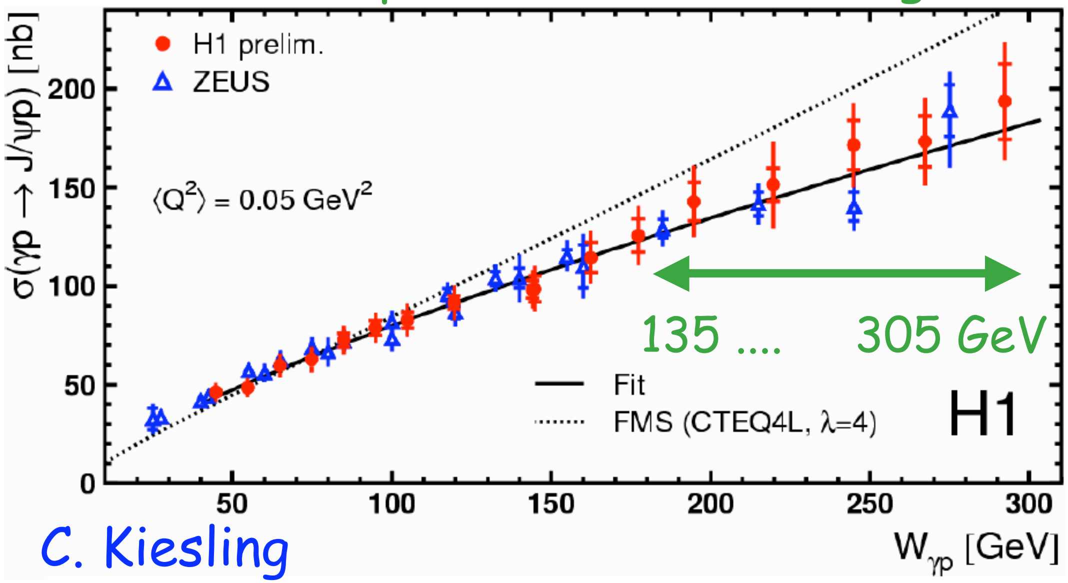


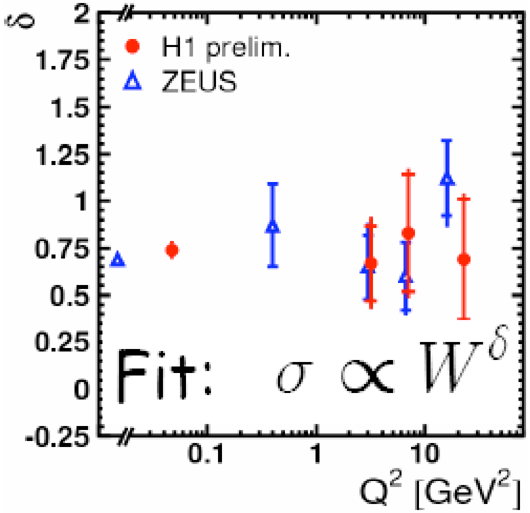
- Soft $I\!P$omeron exchange
- $\sigma \propto (\frac{W}{W_0})^{4(\alpha_{I\!P}(t)-1)}$
- $\alpha_{I\!P}(t) = 1.08 - 0.25|t|$
- Works for light VM

- Exchange of $\geq$ 2 gluons
- $\sigma \propto (xG(x, K^2))^2$
- Steep rise of $xG(x, K^2)$
- Requires hard scale: Q^2, m_q, t

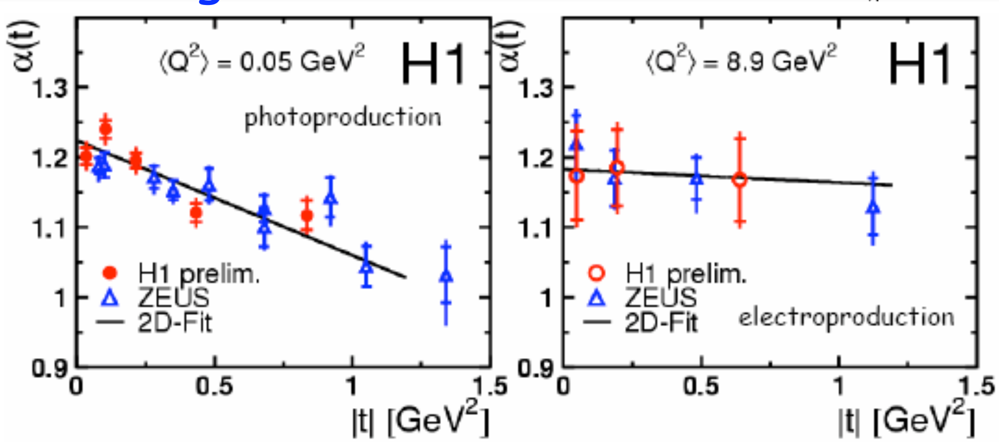
Elastic J/Ψ Production

New Photoproduction data at high W





- Steep rise with W
- δ constant with Q2



$$\alpha(t) = \alpha_0 + \alpha' t$$

Photoproduction:

$\alpha' = (0.164 \pm 0.028 \pm 0.030)$ GeV^{-2}

Electroproduction:

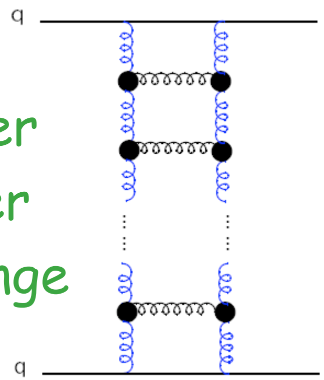
$\alpha' = (0.019 \pm 0.139 \pm 0.076)$ GeV^{-2}

→ Similar trajectories

ρ^0 and J/ψ at high |t|

C. Gwilliam D. Szuba

Higher Order exchange

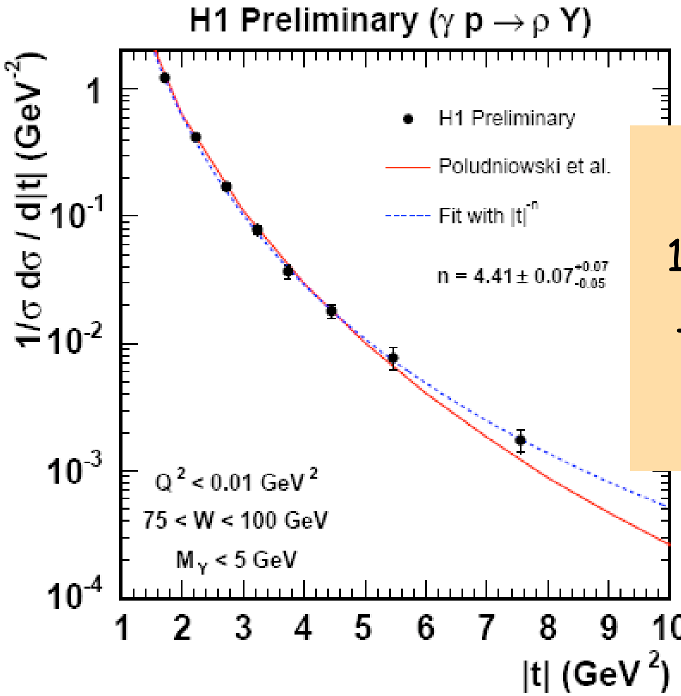


Sums perturbative series in α_s

$\Rightarrow$ Effective gluon ladder ("QCD Pomeron")

Can be described by BFKL evolution at low x

Poludinowski *et al.*
[hep-ph/0306232]
[hep-ph/0311017]

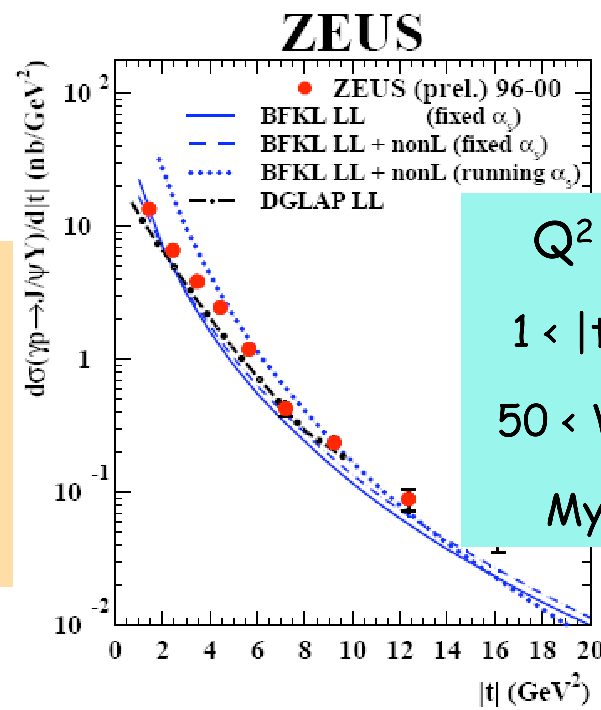


$Q^2 < 0.01$ GeV^2

$1.5 < |t| < 10$ GeV^2

$75 < W < 95$ GeV

My < 5 GeV



$Q^2 \sim 0$ GeV^2

$1 < |t| < 20$ GeV^2

$50 < W < 150$ GeV

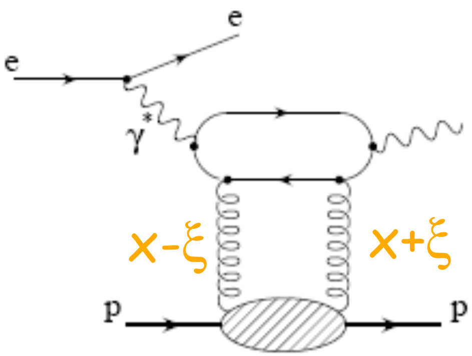
My < 30 GeV

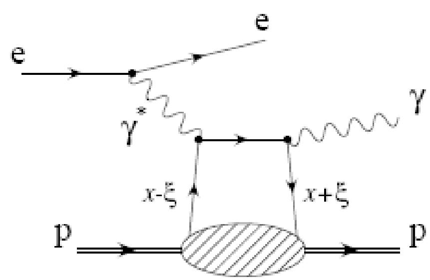
BFKL based model describes t dependence

DVCS cross section at HERA

$$e + p \to e + p + \gamma$$

S. Glazov





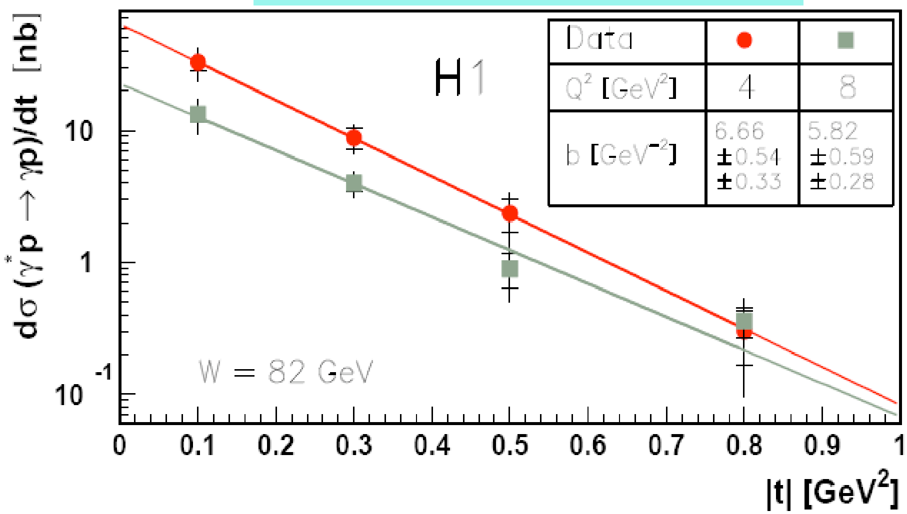
Generalised PDF:

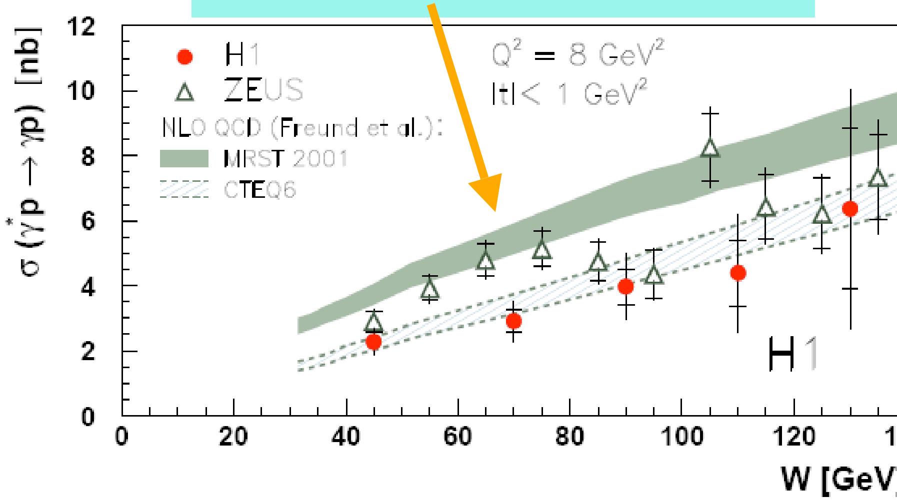
Hq,g (x,ξ,t) → (ξ=0, t=0) → q(x),g(x)

H̃q,g (x,ξ,t) → Δq(x),Δg(x)

+ E and Ẽ: no PDF equivalent

First t measurement → Fix model normalisation





Sensitivity to GPD parametrisation ?

Future of DIS

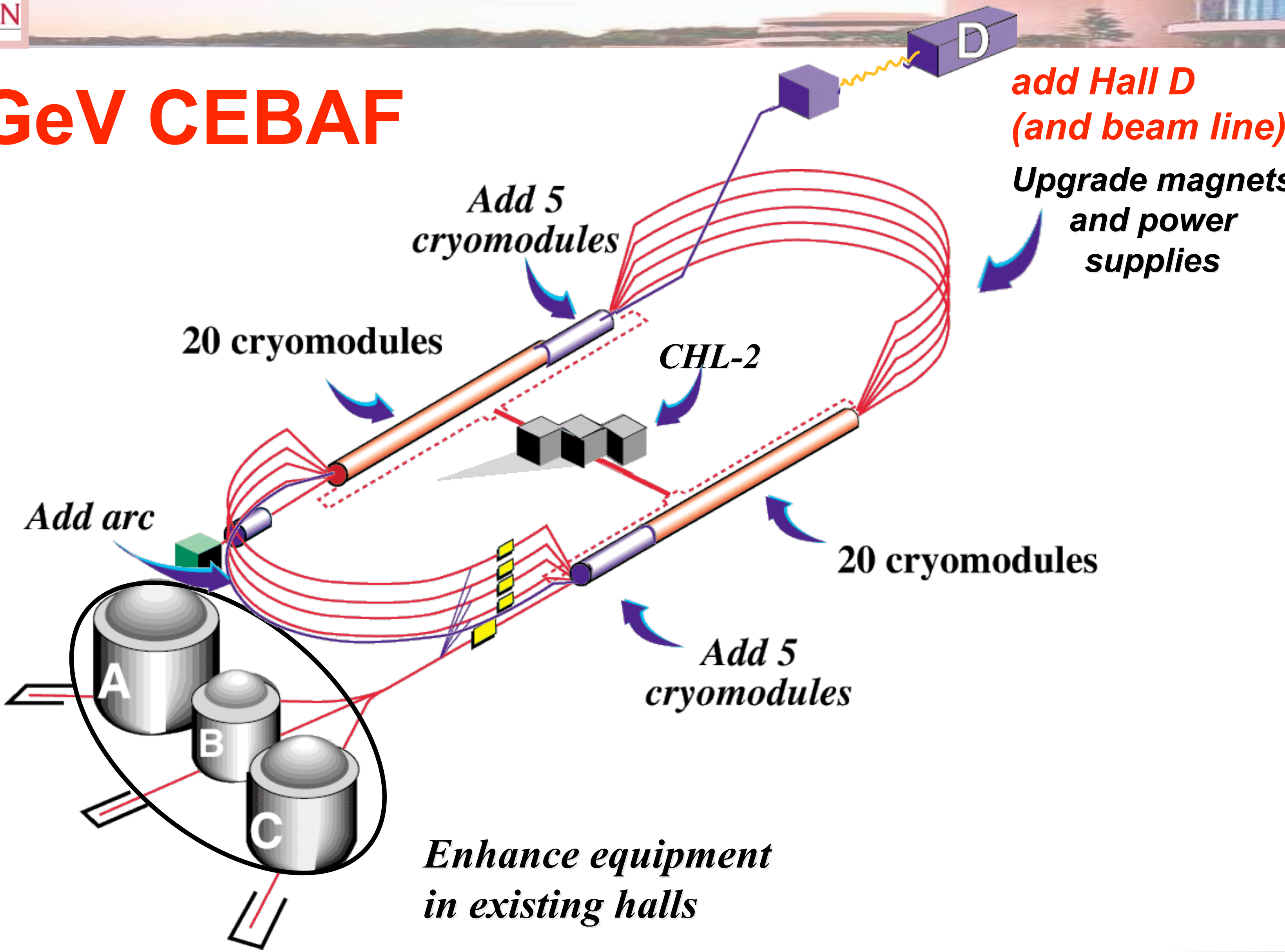
Key measurements:

- Hadron structure – JLAB, MINERνA, COMPASS+ fixed target at CERN. Require large statistics – need subtle correlations, differences of cross sections, multiply differential cross sections → wavefunctions !

- Small-x physics – LHC, eRHIC (eLIC), ILC, eLHC. Luminosity requirement modest. However, need optimized (forward) detectors, high energies.

- Spin – eRHIC (eLIC). Requires large luminosity, high energy to reach small-x glue.

12 GeV CEBAF


D
add Hall D
(and beam line)
Upgrade magnets
and power
supplies
Add 5
cryomodules
20 cryomodules
CHL-2
Add arc
20 cryomodules
Add 5
cryomodules
A
B
C
Enhance equipment
in existing halls

CEBAF Status & Plans

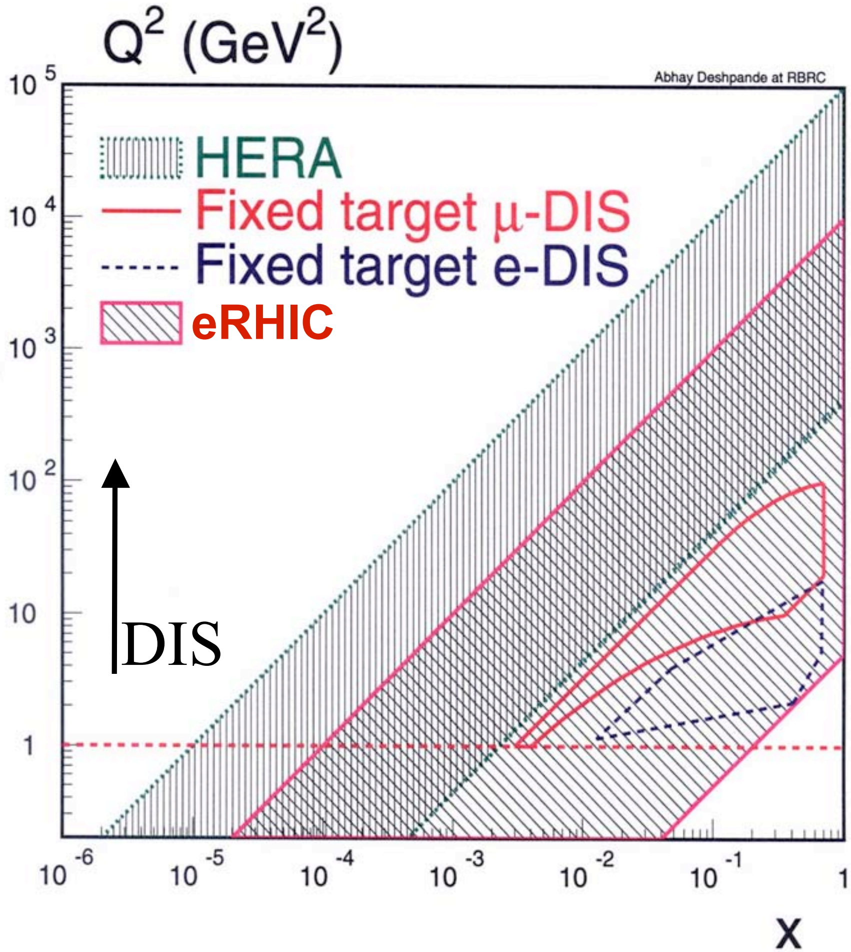
CEBAF operation @ 6 GeV has provided results with unprecedented precision on structure functions and form factors (including strangeness)

Upcoming years will highlight precision hypernuclear studies, standard model tests and . . .

The Upgrade to 12 GeV is essential to provide access to new kinematic regions and will:

- determine with extreme precision the spin and flavour structure of the nucleon in the valence region
- provide a totally new and complete view of the nucleon structure → access to quark angular momentum
- finally (after > 30 years) determine the origin of the EMC effect
- test our understanding of quark confinement
- and much much more . . .

eRHIC vs. Other DIS Facilities



New kinematic region for polarized DIS

E_e = 10 GeV (~5–12 GeV variable)

E_p = 250 GeV (~50–250 GeV variable)

E_A= 100 GeV/nucleon

Sqrt[S_{ep}] = 30–100 GeV

Kinematic reach of eRHIC:

- **X = 10^{-4} —> 0.7 (Q^2 > 1 GeV^2)**
- **Q^2 = 0 —> 10^4 GeV^2**

Polarization of e,p and He beams at least ~ 70% or better

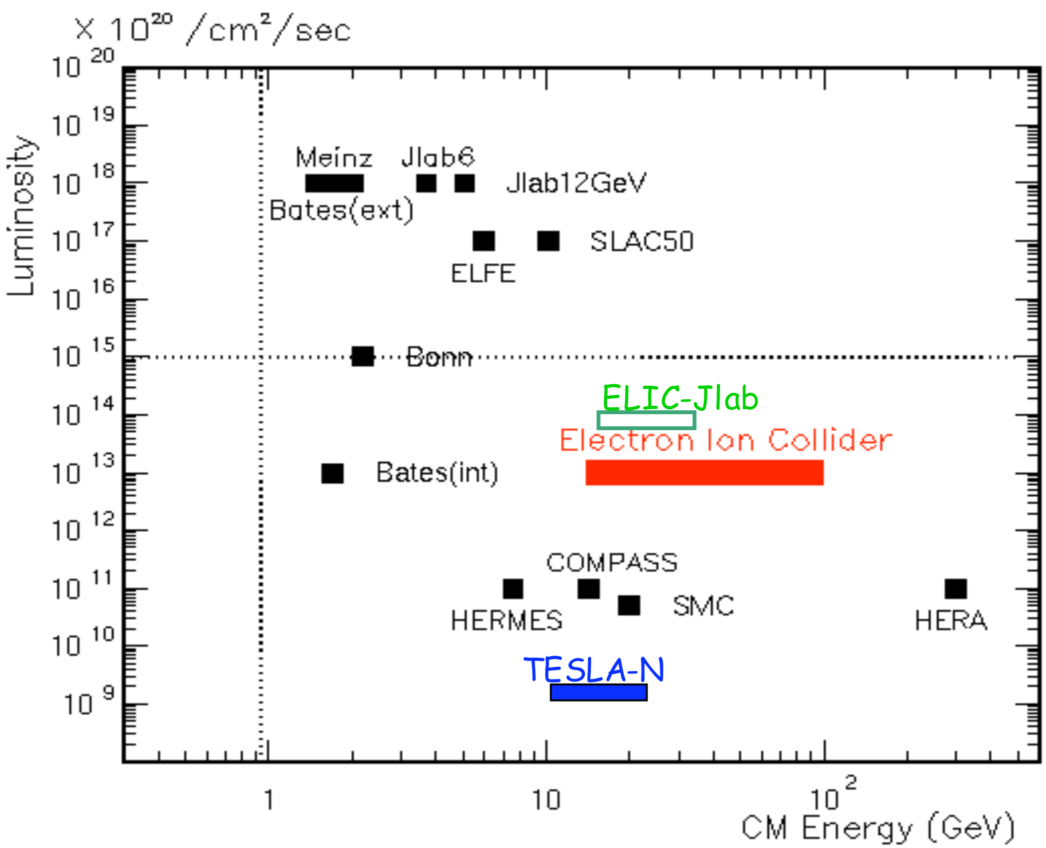
Heavy ions of ALL species at RHIC

Luminosity Goal:

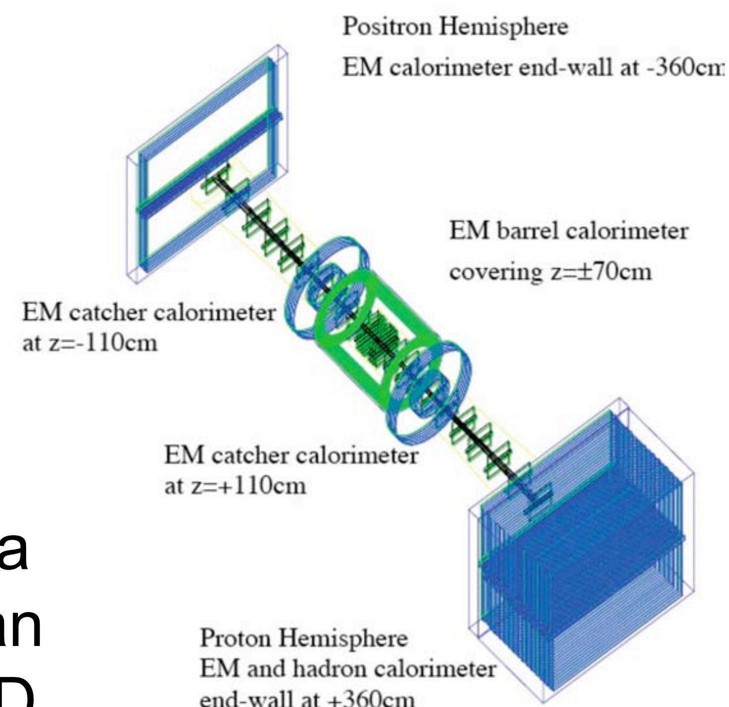
- L(ep) ~$10^{33\text{–}34}$ cm^{-2} sec^{-1}

Key step: NSAC review 2005/2006.

eRHIC



- Variable beam energy
- P-U ion beams
- Light ion polarization
- Huge luminosity



Optimized detector design will make a big difference in the physics which can be accessed. Towards Bjorken's FAD.

ILC & eLHC

ILC: high energy, so in principle e^+e^- gives access to small-x. However, low rates, need forward detectors. Better is e γ, but likely staged.

eLHC:
extends HERA physics by 1 order of magnitude in x. Time scale and cost acceptable ?

CERN AB 2004 079
CLIC Note 608

QCD EXPLORER BASED ON LHC AND CLIC-1

D. Schulte, F. Zimmermann
CERN, Geneva, Switzerland

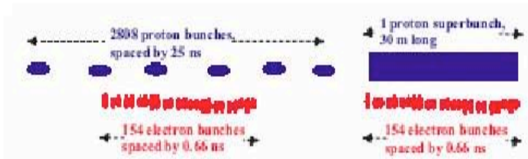
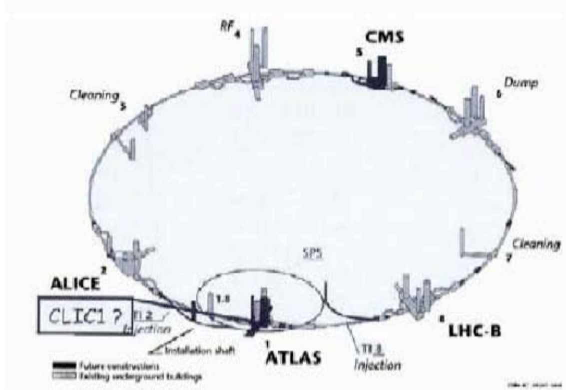


Figure 1: Bunch filling patterns in LHC and CLIC for the nominal LHC (left) and with an LHC superbunch (right).

Upgraded LHC and CLIC



$1.1\ 10^{31}\ cm^{-2}\ s^{-1}$

Table 1: Beam Parameters

parameter	symbol	electrons	protons
beam energy	E_b	75 GeV	7 TeV
bunch population	N_b	4×10^9	6.5×10^{13}
rms bunch length	σ_z	35 μm (Gaussian)	12.4 m (uniform)
bunch spacing	L_{sep}	0.66 ns	N/A
number of bunches	n_b	154	1
effective line density	λ	2.0×10^{10} m^{-1}	2.1×10^{12} m^{-1}
IP beta function	$\beta^*_{x,y}$	0.25 m	0.25 m
spot size at IP	$\sigma_{x,y}$	11 μm	11 μm
full interaction length	l_{IR}	2 m	
norm. rms emittances	$\gamma\epsilon_{x,y}$	73 μm	3.75 μm
collision frequency	f_{coll}	100 Hz	
luminosity	L	1.1×10^{31} cm^{-2}s^{-1}	
beam-beam tune shift	$\xi_{x,y}$	N/A	0.004

L perhaps higher with TESLA cavities (L. Gladilin et al., hep-ph/0504008)

M.Klein, 30. 04. 2005 DIS05 Madison

Conclusions

Structure Functions:

- HERA-I program ⇨ new precision PDFs, HERA-II data & NNLO will improve
- Additional data from NuTeV, SLAC 158, TeVatron

Spin Physics

- Polarized SF now from JLab, RHIC, COMPASS (Gluon Polarization)
- Many fascinating other results not covered here

Hadronic Final States:

- Pentaquarks seen by some and not by others…
- Jet measurements precisely determine α_S & check NLO

Heavy Flavors

- Improved understanding of jets and heavy quarks
- NLO (NNLO) explains F_2 for c (b) quarks

Diffraction:

- Moving towards consistent picture of inclusive diffractive DIS
- VM & DVCS constrain the generalized parton distributions

Future of DIS:

- Many opportunities: 12 GeV CEBAF, eRHIC, LHC, ILC, eLHC….