Linear Collider @ DESY on Polarized HERA

presented by E. Rondio

A. Deshpande

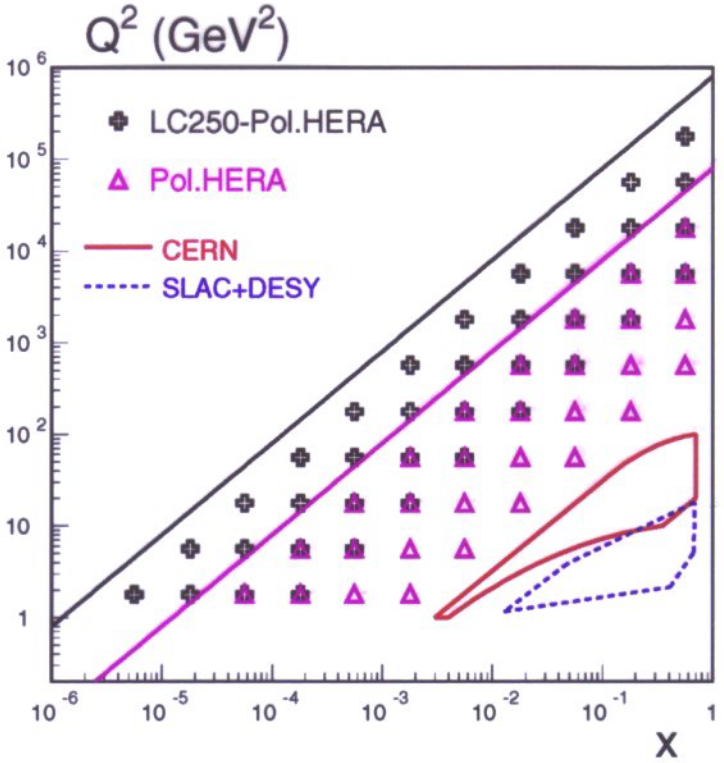
15.09.2000

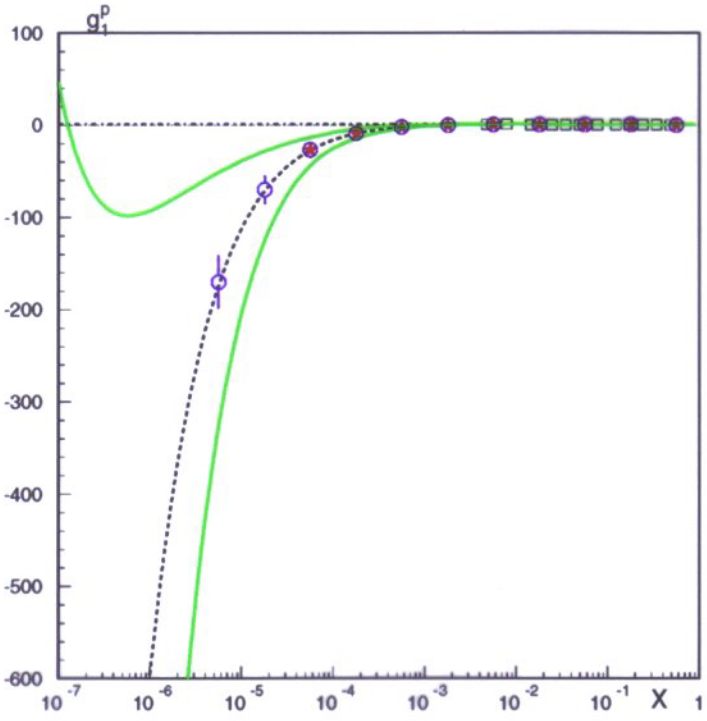
Next Linear Collider Project @ DESY:

- $e^+ \cdot e^-$ **Collisions** $\sqrt{s} \sim 500 - 1500$ **GeV**
- **Geographical Location:**
  Starting from DESY (Hamburg) oriented approx. North West with one end of the collider close to the WEST Hall of HERA $\Longrightarrow$ **Almost Tangential**
- **If 250-750 GeV** $e^{\pm}$ **beam from LC and** $\sim$ **820 GeV** $\vec{p}$ **can collide in the WEST Hall**
  $\Longrightarrow$ **Polarized DIS will explore an entirely new region of** $x - Q^2$
- **Crucial: High** Q^2 **investigations: Contact Interactions, Leptoquark studies, in the next few years at HERA and other facilities**
- **High luminosity (?)**
- **Will need to reverse the direction of the proton beam circulation!**
- **New Detector (?)**
  Modified ZEUS/H1 (?) $\Longrightarrow$ **Change Orientation (!) & move it to the WEST area.**

Linear Collider on Polarized HERA

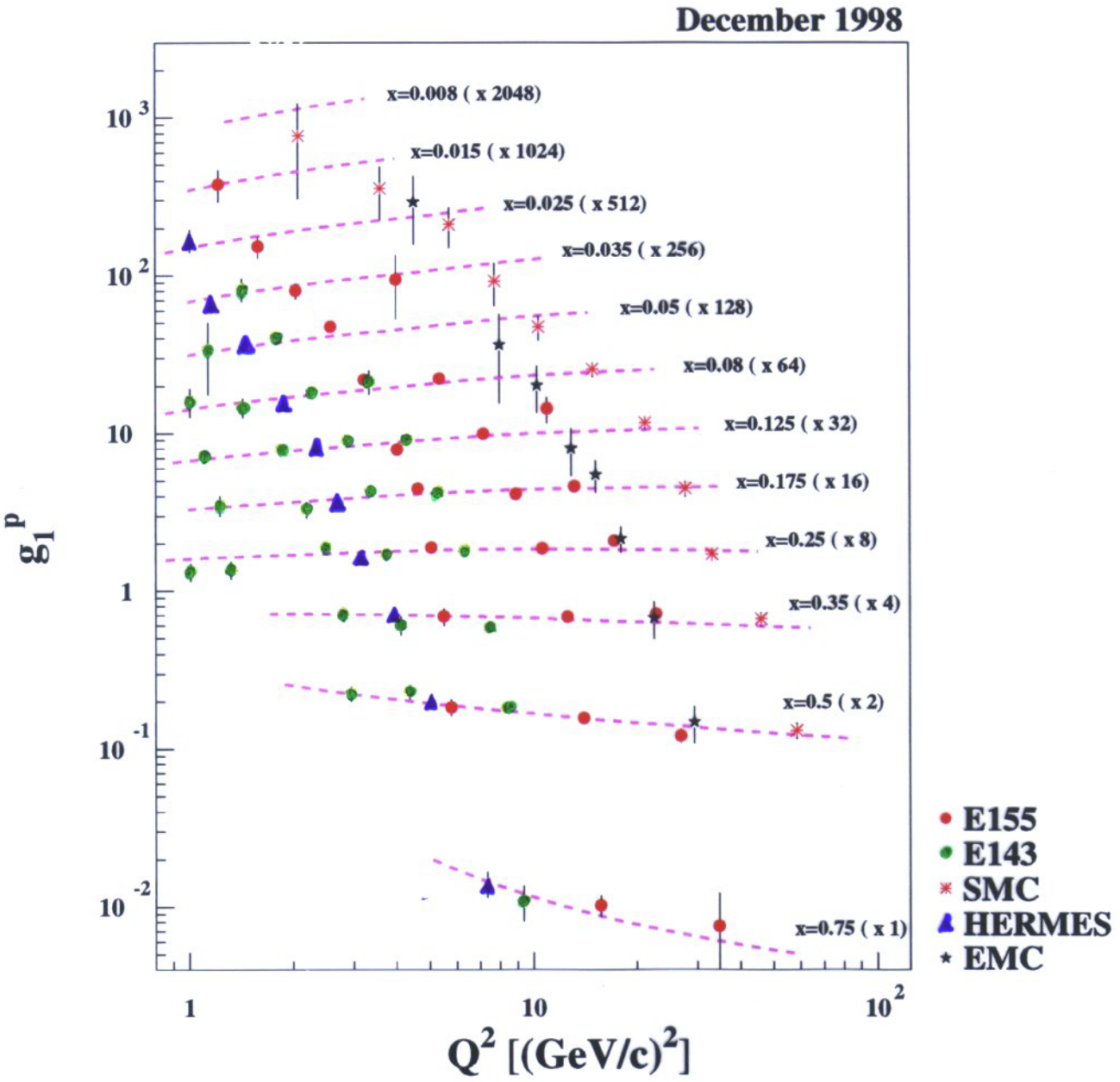
A. Deshpande





PROTON $g_1(x, Q^2)$

E155, G. S. Mitchell, DPF'99



phenomenological fit

Workshop on Polarized Protons at High Energy - Accelerator Challenges and Physics Opportunities

DESY, Hamburg, Germany

17-20, May 1999

HERA $\vec{e}\vec{p}$ 1997 Workshop Participants + New from RHIC Spin

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- **Updates** on previous studies:
  - LO $\rightarrow$ NLO
  - Detector Effects and measurability
  - Updates with new data gathered in the past year
- **New investigations with polarized protons** on:
  - Semi-inclusive production of charged hadrons
  - Diffraction
  - $g_1(x, Q^2)$ at very low x and low Q^2
  - Deeply virtual Compton scattering
  - Spin transfer in Λ polarization
  - R-Parity Violation, Leptoquarks ....
- **Technical Aspects of Polarized $\vec{e} \cdot \vec{p}$ Collider:**
  - Polarized sources (Polarization and Intensity)
  - Acceleration of polarized beams
  - Polarimetry
- **Recent studies for RHIC Spin Experiments @ BNL,** Compass @ CERN, and HERMES @ DESY

Physics Topics: 1997/99 Workshops

- Polarized Structure Functions g_1, g_5, g_2 $\surd\surd$
- Polarized Gluon Distribution ΔG: $\surd\surd$
  - NLO-pQCD fits of g_1
  - Di-Jet events in DIS
  - 2-Track events in DIS
  - Combined fits: g_1 + Di-Jets
  - Photoproduction
- Polarized semi-inclusive measurements $\surd$
- Polarized parton distribution in photon Δq^γ $\surd\surd$
- Diffraction/Vector Meson
- DHG Sum rule: $(\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow})$ at $Q^2 = 0$ $\surd\surd$
- $(W^\pm, Z^0)$ Production
- High Q^2 anomaly $\rightarrow$ polarized HERA $\surd\surd$
- Target fragmentation $\surd\surd$
- Λ Polarization $\surd$
- Deeply virtual polarized Compton scattering $\surd$
- $\vec{p}\vec{p}$ scattering with HERA-$\vec{N}$ $\surd\surd$

Green: Not good; $\surd$: Good; $\surd\surd$: Very Good

1997 Workshop on Physics With Polarized Protons at HERA

http://www.desy.de/~gehrt/heraspin

Conveners: A. De Roeck & T. Gehrmann

DESY-Proceedings-1998-01, February 1998

1999 Polarized Protons at High Energies - Accelerator Challenges and Physics Opportunities

http://www.desy.de/heraspin

Organizers: D. Barbar, A. De Roeck, V. W. Hughes, & F. Willike

Extremely active participation from BNL's machine physics groups and RHIC Spin: Phenix and Star Collaborations

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PARTICIPANTS

G. Altarelli	(CERN)	T. Gehrmann	(DESY)	M. Maul	(Regensburg)
B. Badelek	(Uppsala/Warsaw)	R. Gerhards	(DESY)	E. Mirkes	(Karlsruhe)
S.P. Baranov	(Moscow)	S.V. Goloskokov	(Dubna)	K. Müller	(DESY)
D. Barber	(DESY)	N. Goodman	(UC London)	Y. Naryshkin	(St. Petersburg)
J. Bartels	(Hamburg)	O. Grebeniouk	(St. Petersburg)	W.D. Nowak	(DESY-Zeuthen)
S.D. Bass	(Bonn)	P. Guichon	(Saclay)	S. Nurushev	(Serpukhov)
L. Bauerdick	(DESY)	G. Hoffstätter	(GSI)	G. Rädel	(CERN)
S. Belostotski	(St. Petersburg)	V.W. Hughes	(Yale)	K. Rith	(Erlangen)
G. Bernardi	(Paris)	H. Ihssen	(NIKHEF)	E. Rondio	(Warsaw)
J. Blümlein	(DESY-Zeuthen)	E.M. Kabuß	(Mainz)	M.G. Ryskin	(St. Petersburg)
A. Bravar	(Mainz)	J. Kalinowski	(DESY/Warsaw)	A. Saalfeld	(Munich)
M.M. Brisudová	(LANL)	N. Kochelev	(DESY-Zeuthen/Dubna)	A. Schäfer	(Regensburg)
A. Bruell	(DESY)	V. Korotkov	(DESY-Zeuthen/Serpukhov)	J. Scheins	(Aachen)
J. Butterworth	(UC London)	F. Kunne	(Saclay)	P. Schüler	(DESY)
J. Collins	(Penn State)	J. Kwieciński	(Krakow)	G.M. Shore	(Swansea)
J. Contreras	(Dortmund)	B. Lampe	(Munich)	J. Smith	(DESY/Stony Brook)
N. d'Hose	(Saclay)	E. Leader	(London)	M. Stratmann	(Durham)
J. Dainton	(Liverpool)	J. Lichtenstadt	(Tel Aviv)	A. Tkabladze	(DESY-Zeuthen)
D. de Florian	(CERN)	G. Lobo	(LAL Paris)	G. Venezziano	(CERN)
A. De Roeck	(DESY)	A. Magnon	(Saclay)	J.M. Virey	(Marseille)
A. Deshpande	(Yale)	Y. Makdisi	(Brookhaven)	M. Vogt	(DESY)
M. Düren	(Erlangen)	G. Mallot	(Mainz)	W. Vogelsang	(CERN)
J. Ellis	(CERN)	S. Manayenkov	(St. Petersburg)	S. Willfahrt	(Karlsruhe)
J. Feltesse	(Saclay)	L. Mankiewicz	(Munich)	R. Windmolders	(Mons)
S. Forte	(INFN-Torino)	O. Martin	(Regensburg)	M. Wobisch	(Aachen)

General Aim: Improve up on the 1996 Workshop Studies $\Longrightarrow$ Detector level physics studies; Explore new topics; Development of Tools: MC Generators, Detector Simulations; Address technical issues: Polarized Sources, Accelerator Issues, Proton Beam Polarimetry

Polarized $\vec{e}\vec{p}$ scattering @ HERA

Spin measurements in the kinematic region

- Q^2 : $0 \longrightarrow \sim 5 \times 10^4$ GeV^2
  Photoproduction $\longrightarrow$ high Q^2
  Present $Q^2_{\mathrm{MAX}} \sim 100$ GeV^2
- $10^{-5} \leq x \leq 0.6$
  Low $x \Longrightarrow 0.002 \leq x_g \leq 0.2$
  Present $x_{\mathrm{MIN}} \sim 10^{-3}$

Polarized HERA Machine Parameters (assumed for workshop studies)

- $E_{\mathrm{p}} \sim 820$ GeV; Polarization $\sim 70\%$
- $E_{\mathrm{e}} \sim 27.5$ GeV; Polarization $\sim 70\%$
- Polarization Measurement Uncertainties
  $\Delta P_e/P_e \sim 5\%$; $\Delta P_p/P_p \sim 5\%$
- High Luminosity Lumi-Upgrade: ~ 170 pb^{-1}/year
- ZEUS and H1 Detectors

(Have Already!) (Not Yet!)

2nd Generation of Spin Experiments End!

Open Questions and Conclusions

Low x behavior of the spin structure functions $g_1(x, Q^2)$

- **Spin Muon Collaboration at CERN**
  Final Observation: $\Delta\Sigma = 0.23 \pm 0.06$
  Ellis-Jaffe sum rule violated
  Bjorken verified with $\sim$10% accuracy
  Strongly recommends measurements at lower x

- **E143, E154, E155 Collaborations at SLAC**
  Similar conclusions on Spin Sum Rules
  Neutron low x spin structure function divergent (??)
  Strongly recommend measurements at lower x

- **HERMES at DESY**
  Consistent results with CERN and SLAC
  Running experiment, but will **NOT** extend the presently explored $x - Q^2$ range

- **Numerous** theoretical predictions for g_1 in the low x region $\Longrightarrow$ **Disagree with each other**
  No Clue in region $x < 3.0 \times 10^{-3}$!

Approved future Spin Experiments: COMPASS @ CERN and PHENIX and STAR with RHIC-Spin @ BNL
will NOT measure g_1 at low x

2nd Generation of Spin Experiments End!

Open Questions and Conclusions

Polarized Gluon Distribution $\Delta G(x, Q^2)$

- **Spin Muon Collaboration**
  Used pQCD analysis at NLO to determine $\Delta G(x, Q^2)$ and its first moment $\Longrightarrow$ large uncertainties
  The spin puzzle??$\Longrightarrow$ Unsolved!

- **E143, E154, E155 at SLAC**
  Use NLO-pQCD analysis
  Determined $\Delta G(x, Q^2)$ and its first moment with large uncertainty
  Can't say if this solves the spin puzzle

- **HERMES at DESY**
  "Direct" Method: ΔG in LO $\rightarrow$ First glympse?
  $\Longrightarrow$ High-p_{T} hadrons
  $\Longrightarrow$ Open charm production process
  $\Longrightarrow$ Detector upgrade...
  Conclusive determination of ΔG : seems unlikely

- **COMPASS @ CERN and RHIC Spin Experiments** will try to access $\Delta G(x, Q^2)$ using the "direct" methods

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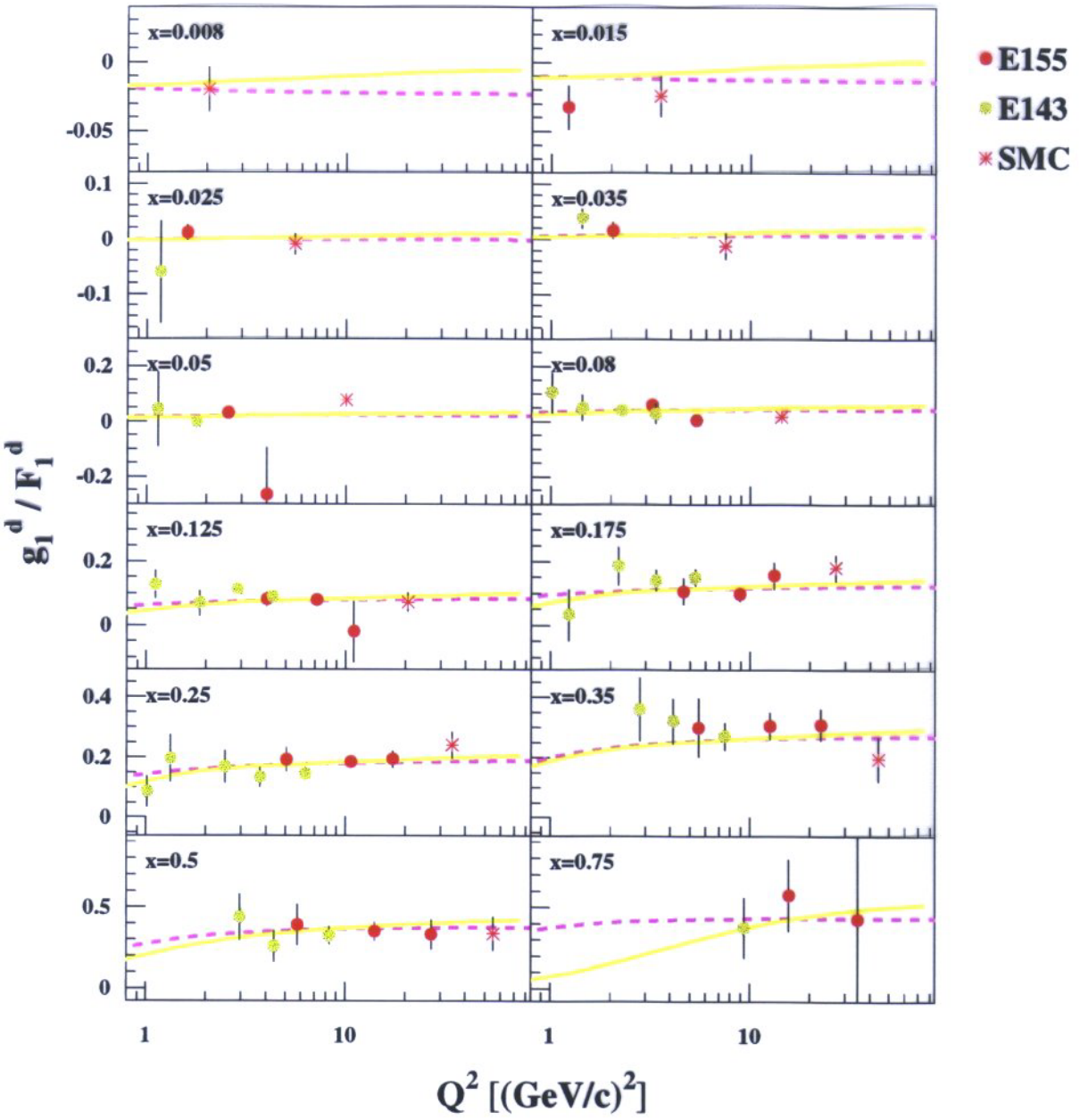
Polarized HERA can do all that and extend the $x - Q^2$ range of measurements

DEUTERON ASYMMETRY

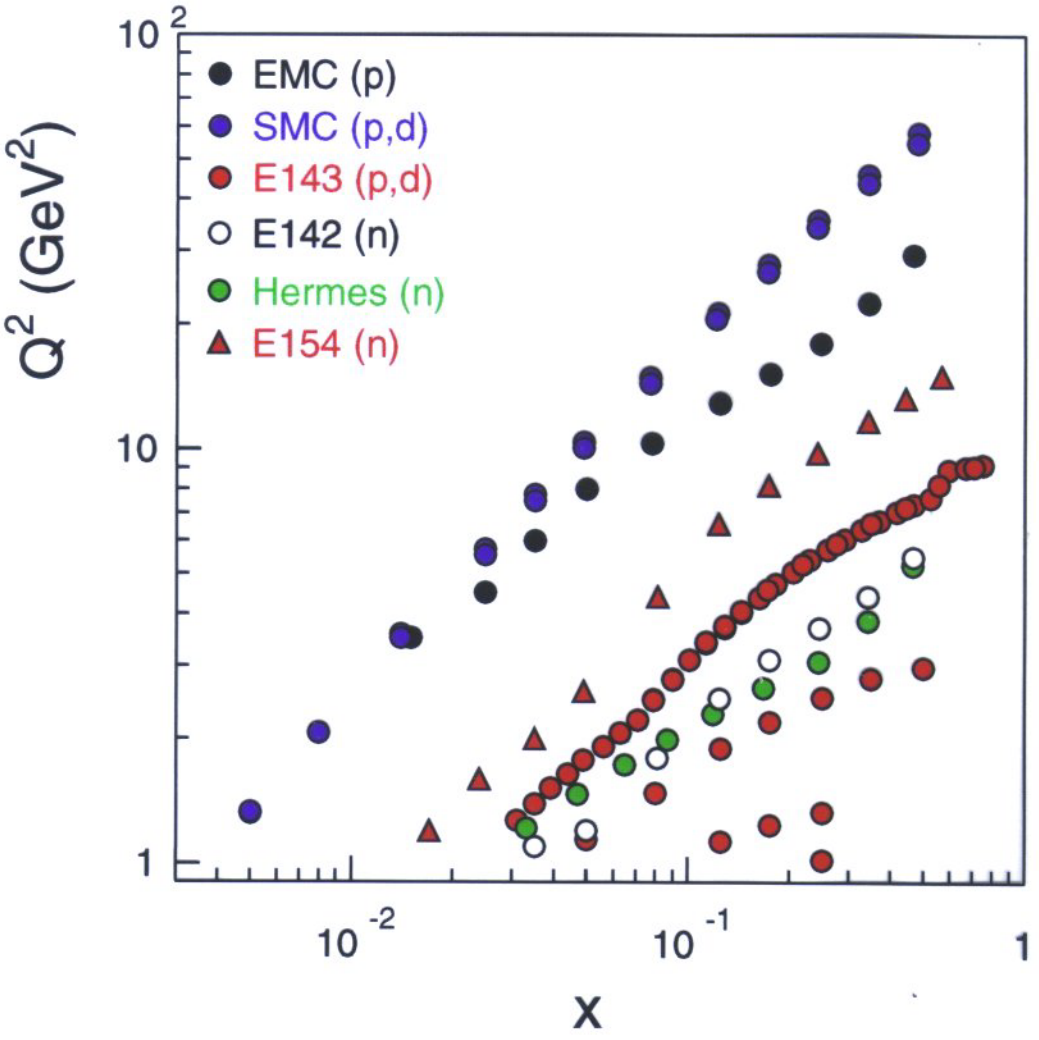


phenomenological fit

E154 NLO fit

hep-ex/9904002

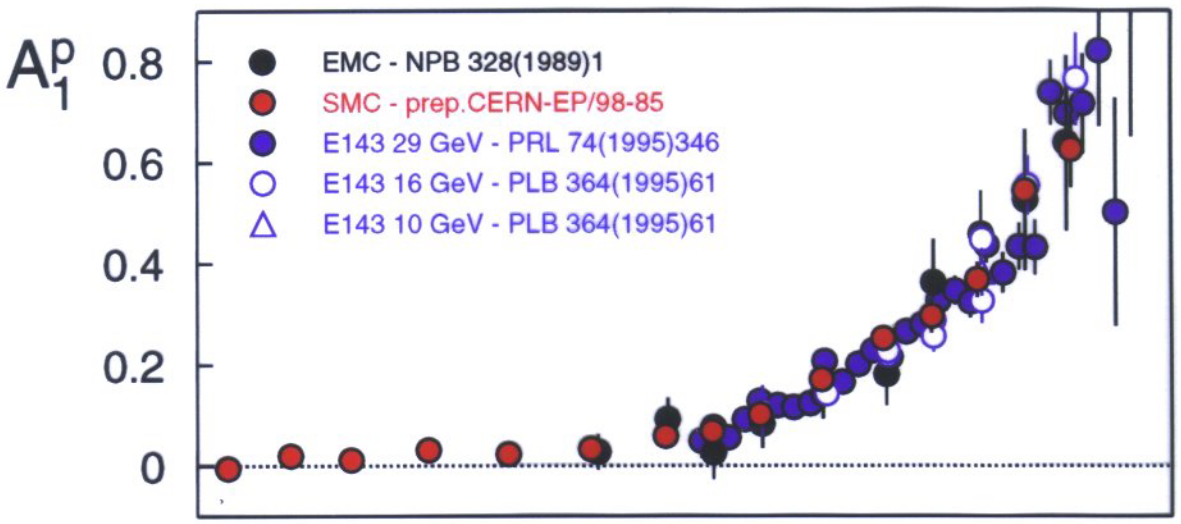
Kinematic coverage

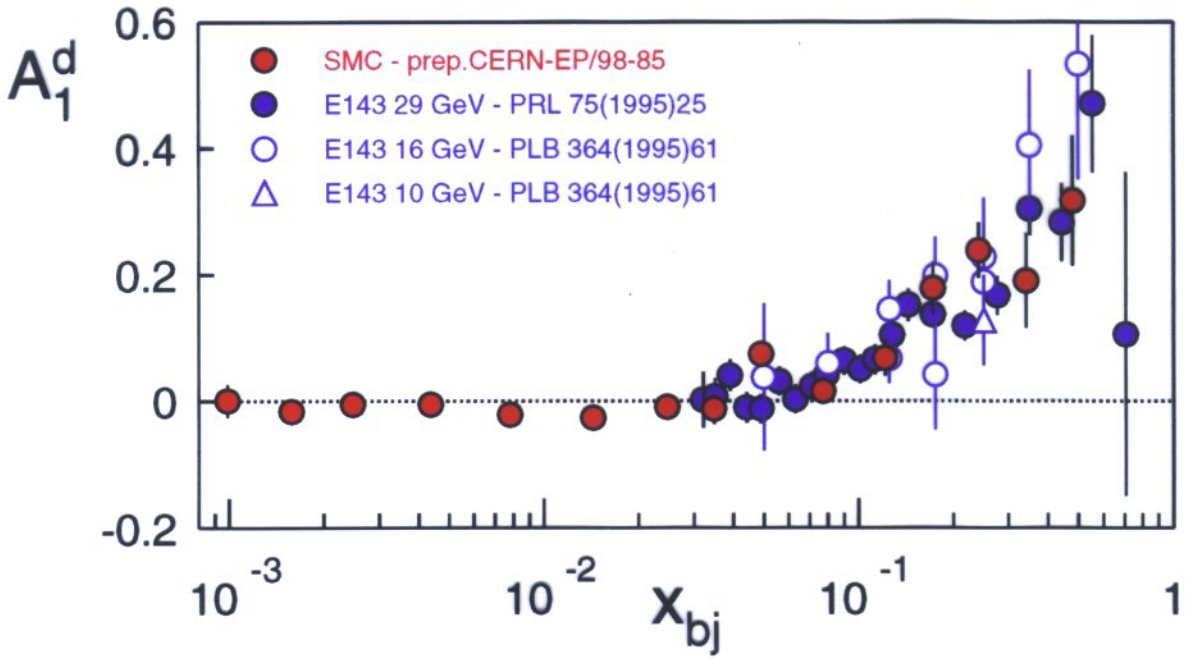


$$3 \cdot 10^{-3} < x < 0.8 \;,\; 1\,\mathrm{GeV}^2 < Q^2 < 60\,\mathrm{GeV}^2$$

A_1^p and A_1^d

Consistent set of all published data.

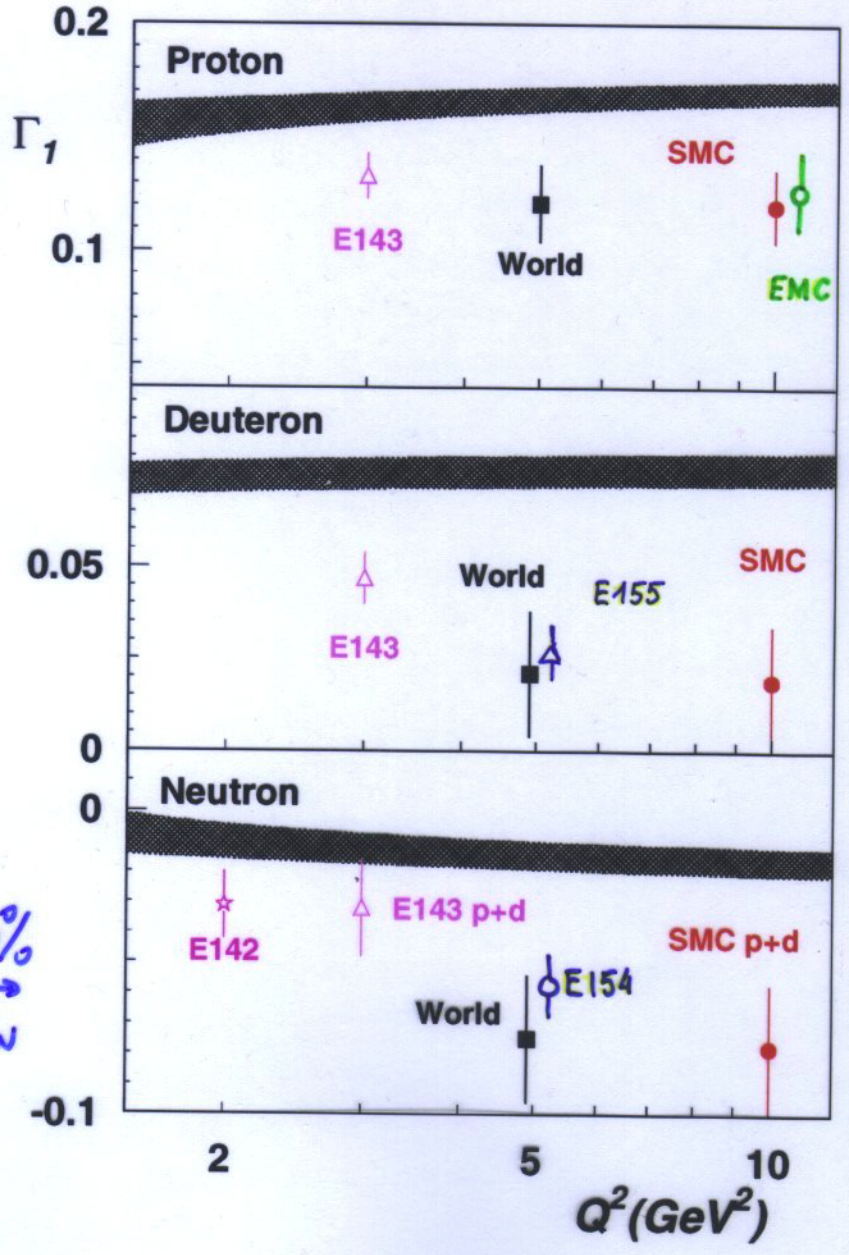




more data expected soon (E155, Hermes)

FIRST MOMENT Γ_1 OF g_1

- SMC World data (EMC, SMC, E142, E143, E154, Hermes)
- QCD extrapolations: SMC, E154, World
  Regge extrapolations: E142, E143, Hermes



$\int (q^\uparrow - q^\downarrow) \approx 30\%$ $\vec{S}_N$

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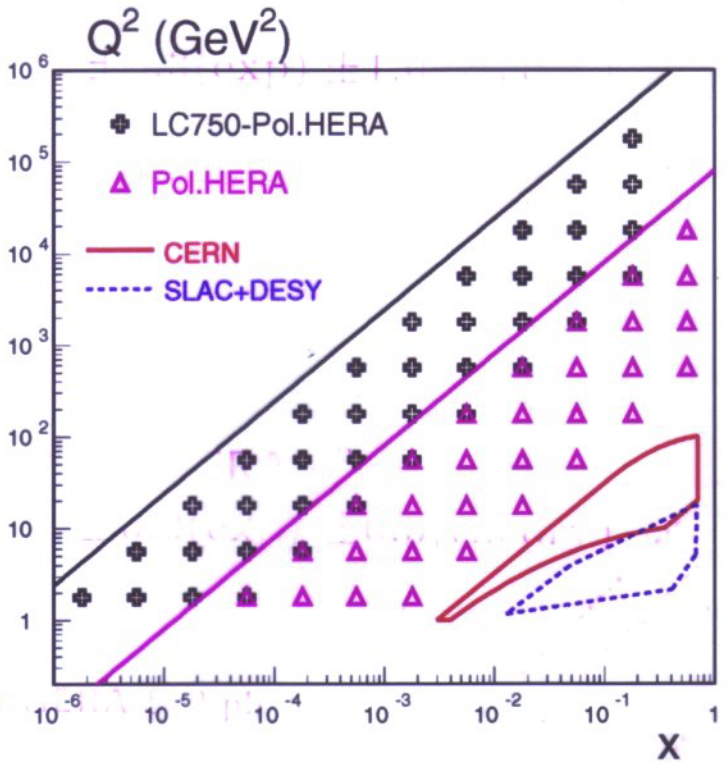
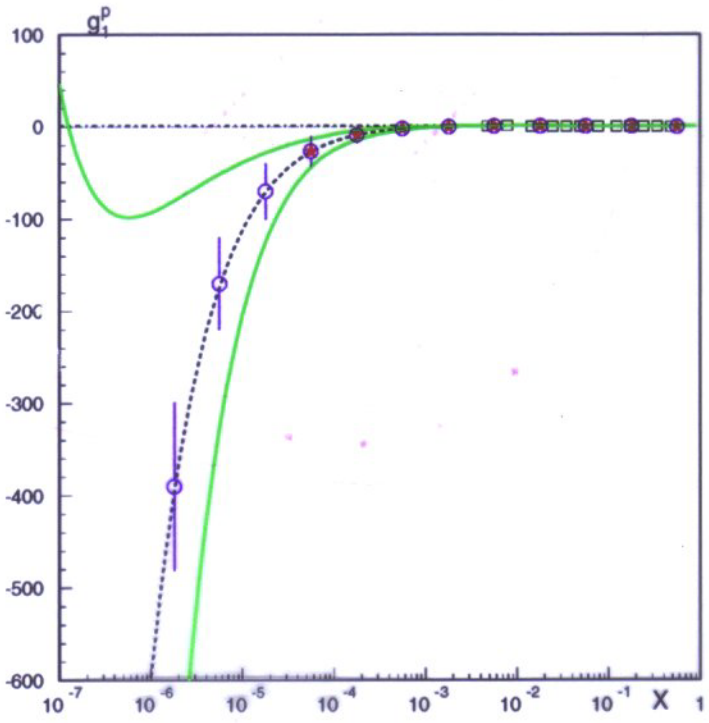
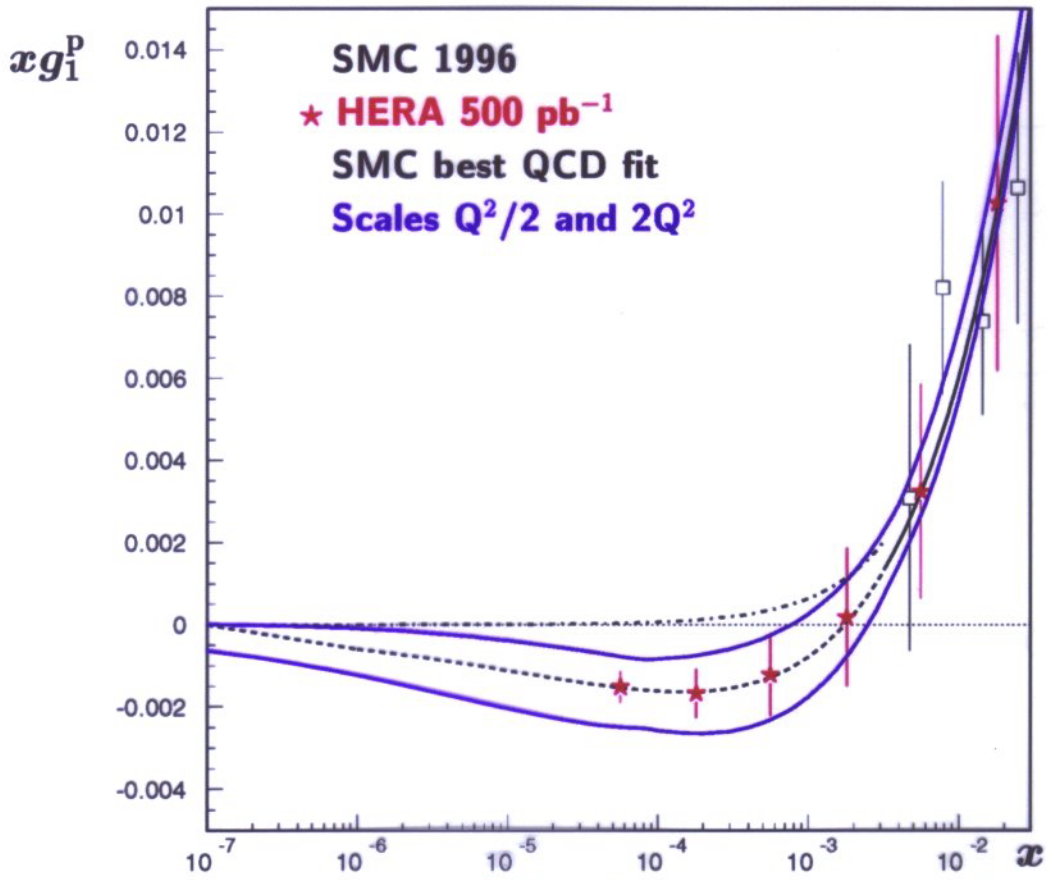




Reduction in $\delta(\Delta G)$

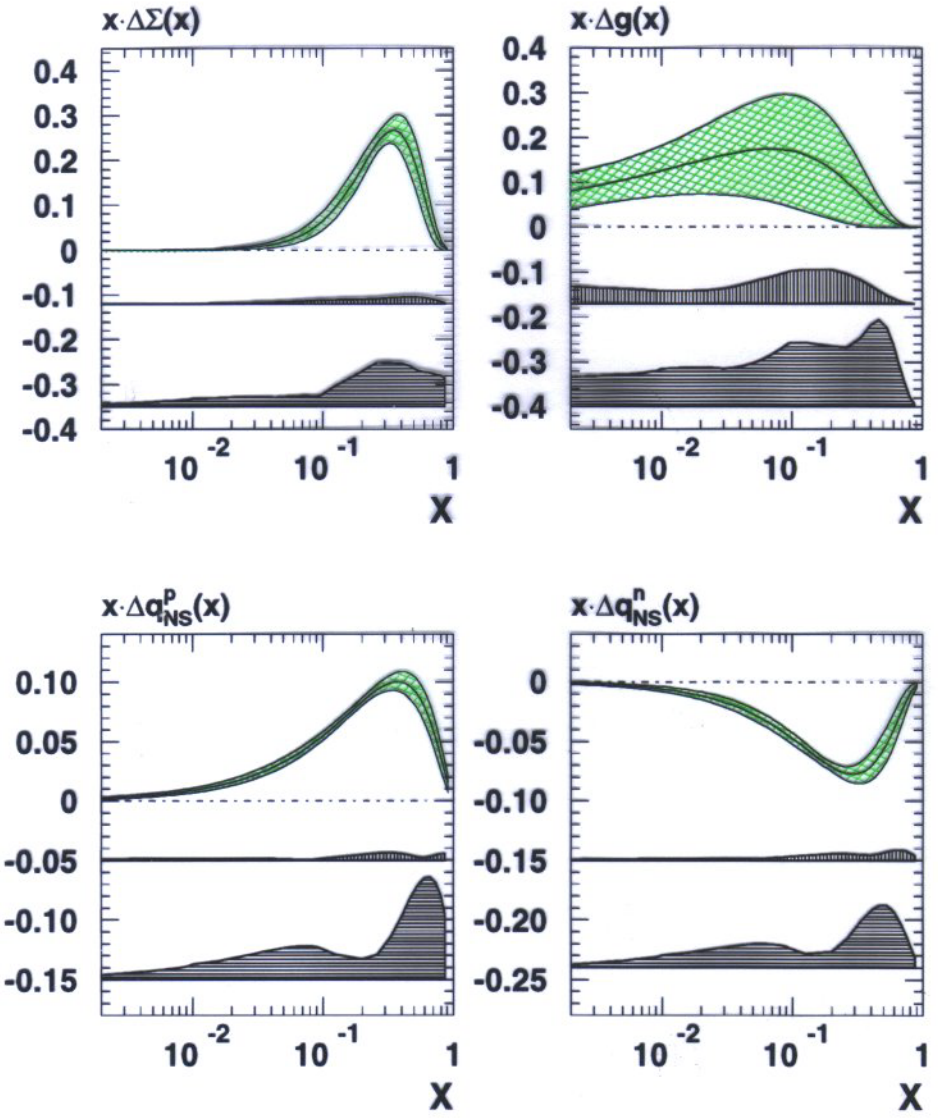
- Access $\Delta G(x, Q^2)$ through **pQCD analysis at NLO**
- **1997 Workshop:** SMC, PLB 412 (1997) 414
  $\delta(\int \Delta G) = \pm 0.3(\text{exp}) \pm 1.0(\text{theory})$ @ $Q^2 = 1$ GeV^2
- Main sources of theoretical uncertainty:
  1. Factorization and renormalization Scales,
  2. Function form of the pdfs at the starting scale,
  3. $\delta(\alpha_S(M_Z^2))$

  $\Longrightarrow$ **Large correlation to low x region!**
- **Above Data + HERA g_1^p** EPJ C6 (1999) 121-131
  $\delta(\int \Delta G) = \pm 0.2(\text{exp}) \pm 0.3(\text{theory})$



Overall: a factor of 3 reduction in uncertainty expected

PDF at $Q_i^2 = 1\,\mathrm{GeV}^2$ in the AB scheme



The uncertainties are statistical (cross hatched band), experimental systematic (vertically hatched band), and theoretical (horizontally hatched band).

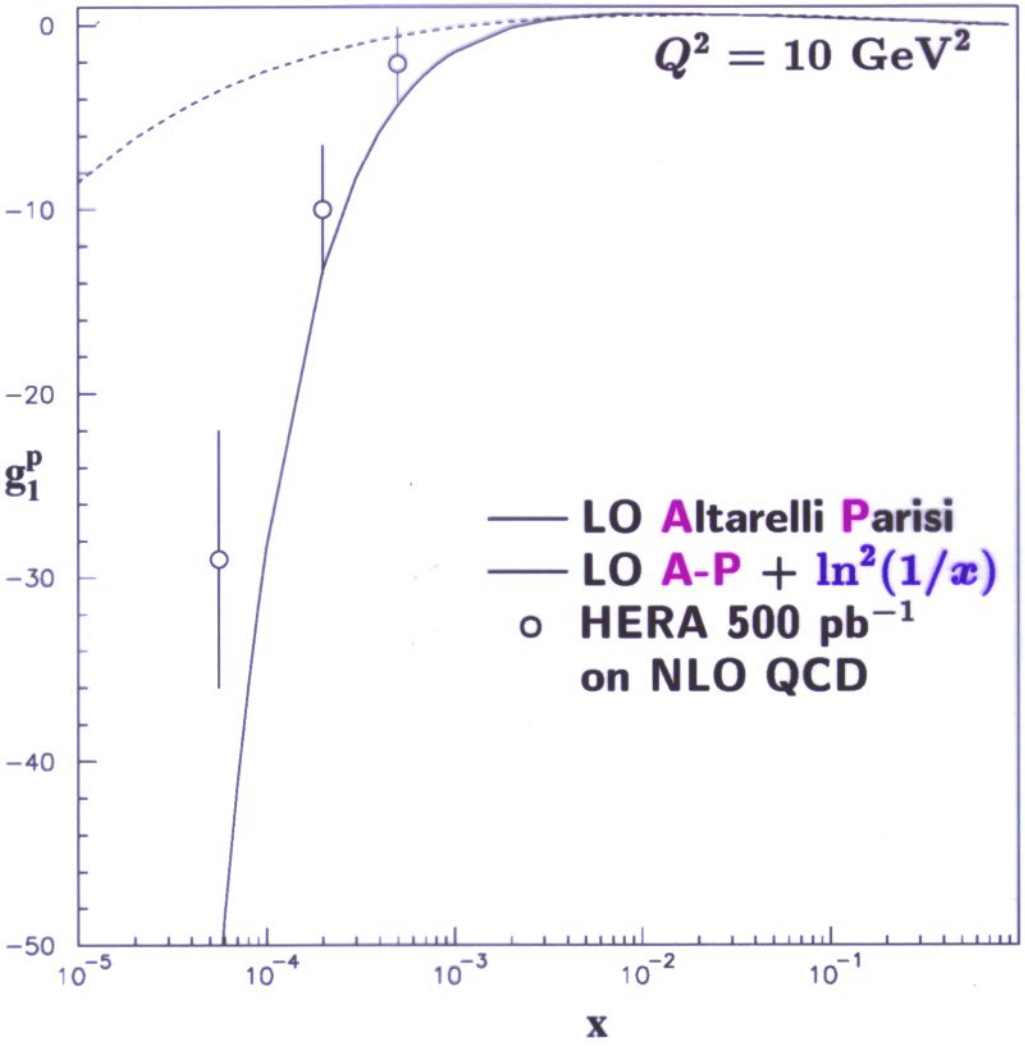
Low x Resummation

J. Kwiecinski & B. Ziaja

- g_1^p at low x dominated by double logarithmic terms $\Longrightarrow \ln^2(1/x)$. Unpolarized case: $\ln(1/x)$

  (J. Bartels et al., Z.Phys. C70 (1996) 236; C72 (1996) 627)

- Prediction of g_1^p using $\Longrightarrow$ LO Altarelli-Parisi Equation + Resummed $\ln^2(1/x)$ terms in splitting and coefficient functions



Data at HERA can differenciate between various scenarios. Particularly Interesting Possibility: Linear Collider + Polarized Protons@HERA

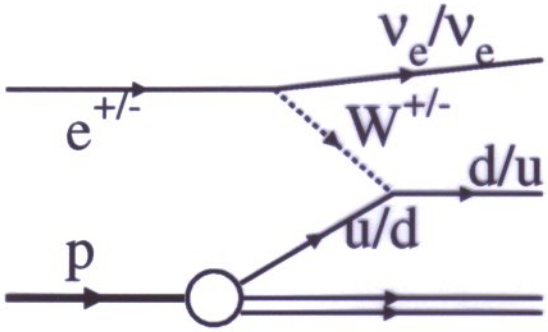
High Q^2 region and Polarization

- J. Virey: Contact Interactions $\Longrightarrow$ Next Slide
- N. Kochelev: Instantons in Protons: hep-ph/9711274
  - Instanton Liquid Model
  - Large contribution of instantons at high x and high Q^2
    * $A_{\rm Instanton} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \longrightarrow -1$
    * $A_{\rm pQCD} \longrightarrow +1$
- J. Ellis et al.: Strange Stop Production - R Parity violating interactions: Phys. Lett. B408 (1997) 252
  - $e\ d \rightarrow \tilde{\rm t}$
    * $\sigma(e^+_R\ p_R) \ll \sigma(e^+_R\ p_L)$
  - $e\ s \rightarrow \tilde{\rm t}$
    * $\sigma(e^+_R\ p_R) < \sigma(e^+_R\ p_L)$
    * $\sigma(e^-_R\ p_L) < \sigma(e^+_L\ p_R)$
- Experimental Aspects that will need attention!
  - $e^\pm$ beam divergences in going from $e^\pm_L \Longleftrightarrow e^\pm_R$
  - Frequency of above change
  - False asymmetries
  - May learn to do this: Electroweak physics program after luminosity upgrade

Parity Violating Spin Structure Functions

G. Contreras et al./ M. Anselmino et al.

Charged Current Events in $\vec{e}\vec{p}$ Scattering



- **Unique measurement at HERA**
- **Identify ν via missing momentum**

$$\frac{d^2\sigma}{dx dQ^2} \sim \{a\,[F_1 - \lambda b F_3] + \delta\,[a g_5 - \lambda^2 b g_1]\}\frac{1}{(Q^2 + M_W^2)^2}$$

where

$a = 2(y^2 - 2y + 2)$; $\quad b = y(2 - y)$; $\quad \lambda = \pm 1$ for $e^{\pm}$

$\delta = \pm 1$ for $\uparrow\downarrow$ and $\uparrow\uparrow$ spin orientations

$$A_{cc}^{W^+} = \frac{-2bg_1 + ag_5}{aF_1 - bF_3} \qquad A_{cc}^{W^-} = \frac{+2bg_1 + ag_5}{aF_1 + bF_3}$$

Hera kinematically region: $a \gg b$

$\Longrightarrow$ g_5 dominates $\rightarrow$ Extract g_5

$$g_5^{W^-} = \Delta u + \Delta c - \Delta \bar{d} - \Delta \bar{s}$$
$$g_5^{W^+} = \Delta d + \Delta s - \Delta \bar{u} - \Delta \bar{c}$$

Extract information on valence quark distributions at very high Q^2

Extracting g_5

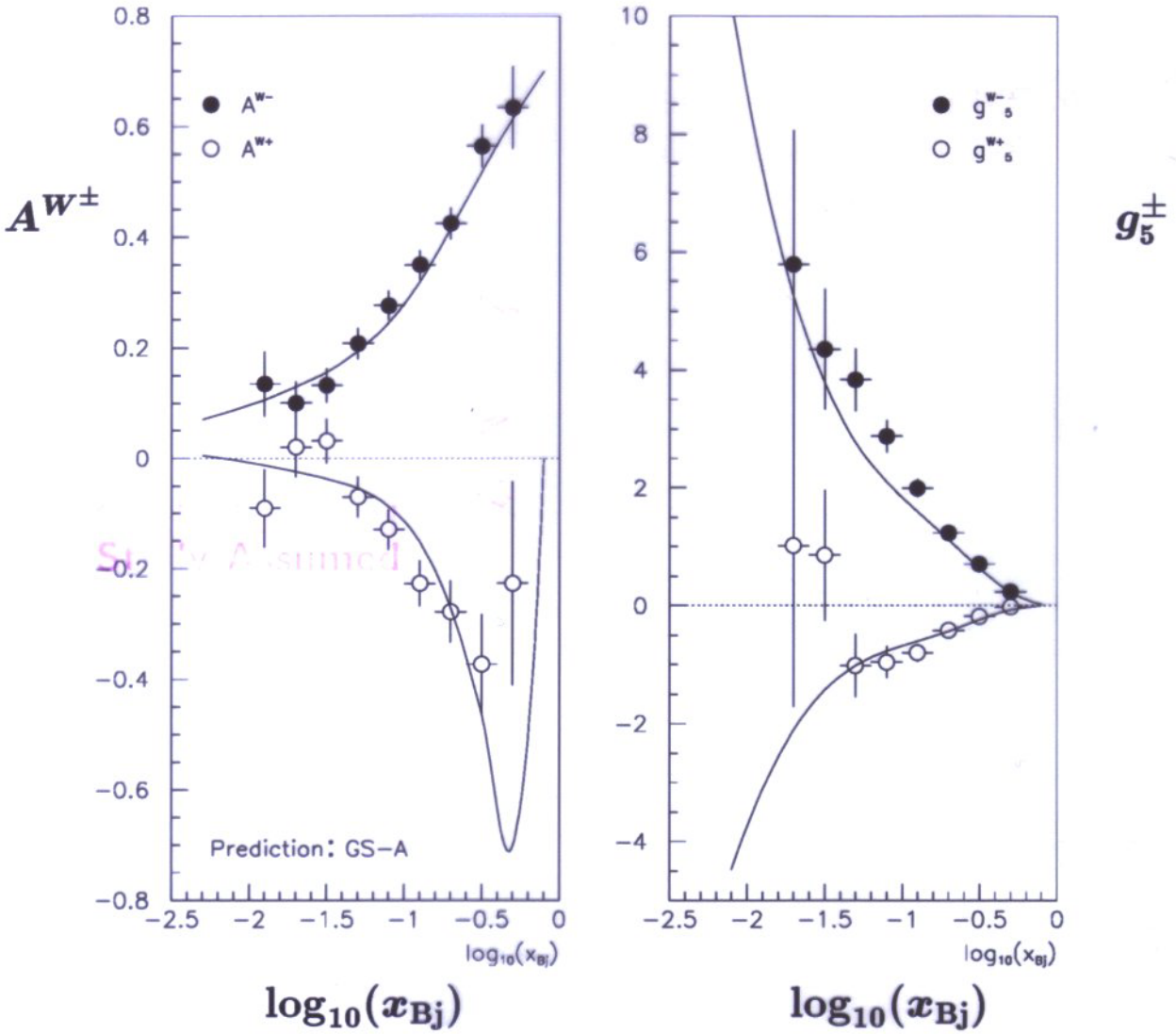
Asymmetries : $A^{W^\pm} \approx \dfrac{g_5^{W^\pm}}{F_1^{W^\pm}}$

Selection

- $p_T^{\text{miss}} \geq 15$ GeV
- $Q^2 \geq 225$ GeV^2
- Detector simulation

Assumption

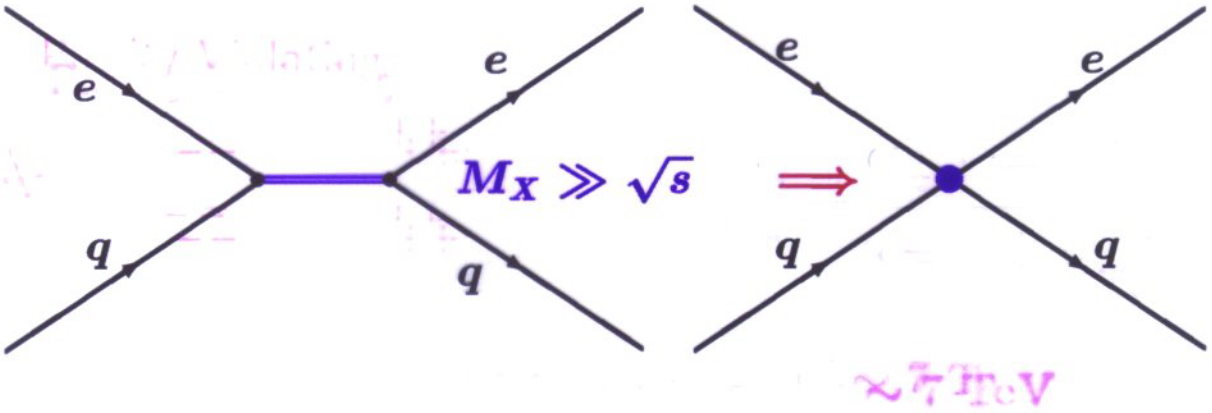
- $e^- p$: $\mathcal{L} = 250$ pb^{-1}
- $e^+ p$: $\mathcal{L} = 250$ pb^{-1}



$\log_{10}(x_{\text{Bj}})$ $\log_{10}(x_{\text{Bj}})$

Contact Interactions

J.M.Virey



Effective Lagrangian for Contact Interactions

$$\mathcal{L}_{\rm CT} = \sum_{q=u,d} \eta_{i,j} (\bar{e}_i \gamma^\mu e_i)(\bar{e}_j \gamma_\mu e_j)$$

where

$\eta_{i,j} = (4\pi\epsilon)/\Lambda_{i,j}^2$, $\epsilon = \pm 1$; $(i,j) = (L,R)$

$\Longrightarrow$ 8 Cross-sections: $LL^\pm, RR^\pm, LR^\pm, RL^\pm$

$\Longrightarrow$ $\sigma_{e_e}^{h_e h_p}$; e_e = Charge of $e^\pm$; h = helicities of e,p

Study Assumed

- $\mathcal{L} = 250 \mathrm{pb}^{-1}$/spin configuration/e-charge
- Q^2 resolution of ZEUS detector
- $200 < Q^2 < 5 \times 10^4$ GeV^2
- Beam Polarization: $P_e = P_p = 0.70$
- Systematic Uncertainty on Asymmetry measurement: $\delta A_{\rm syst}/A \sim 10\%$

Construct ~60 spin or/and charge asymmetries

Contact Interactions (continued)....

J. M Virey

Most Sensitive Asymmetries

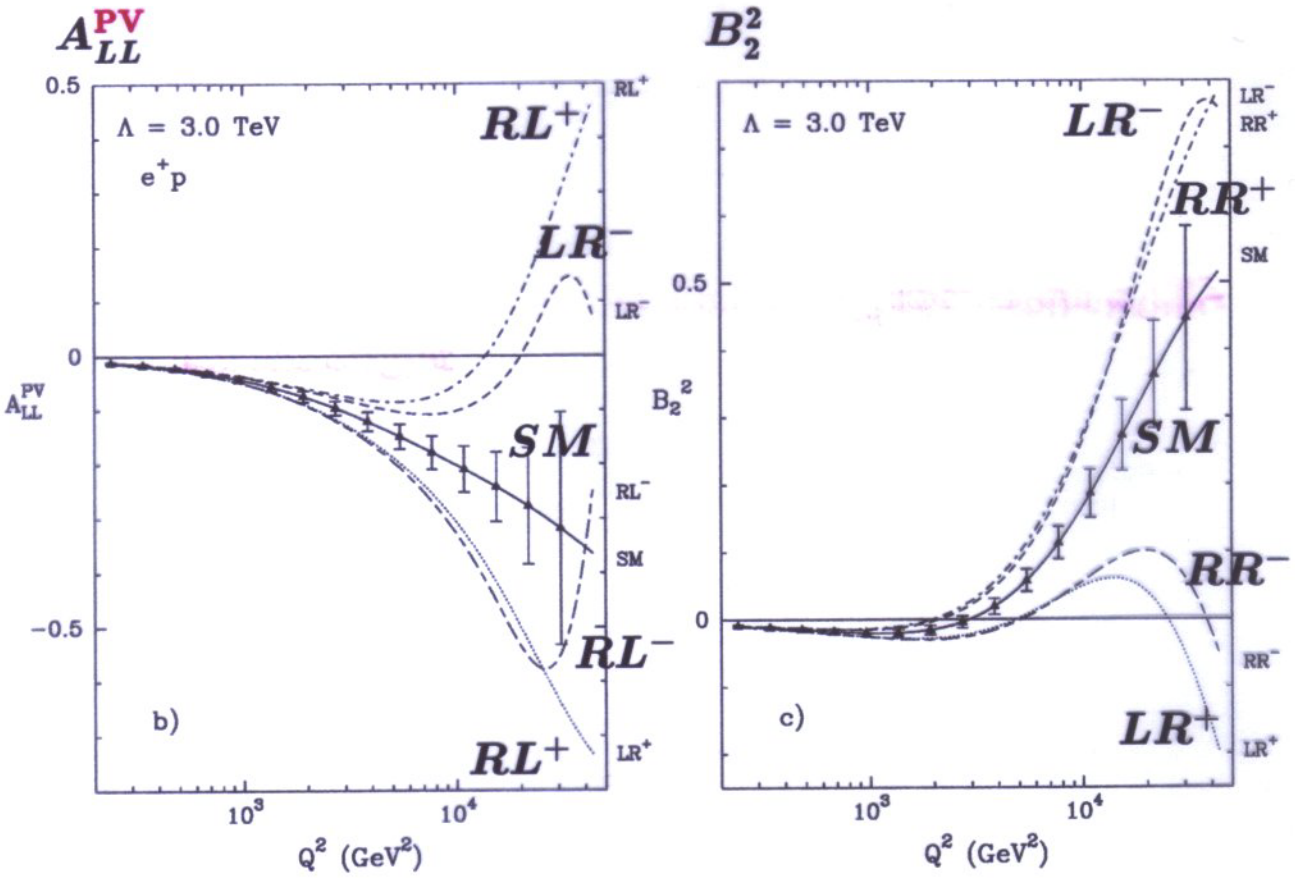
Partity Violating

$$A_{LL}^{PV} = \frac{\sigma^{--}{}_{+} - \sigma^{++}{}_{+}}{\sigma^{--}{}_{+} + \sigma^{++}{}_{+}}$$

"Mixed"

$$B_2^2 = \frac{\sigma^{++}_{-} - \sigma^{++}_{+}}{\sigma^{++}_{-} + \sigma^{++}_{+}}$$

Helicity structure sensitivity up to scales $\sim$ 7 TeV



Helicity structure of the new interaction could be probed/resolved