Physics With A Polarized $\vec{e}\vec{p}$ Collider

Abhay Deshpande[1]
abhay.deshpande@yale.edu

IUCF, Bloomington, Indiana
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Outline of the talk:

- Motivation: Why Polarize HERA?
  - Some surprises with spin
  - History polarized and unpolarized DIS
  - Recent results
  - Open questions
- Physics With Polarized HERA
- Concluding remarks
  A Case for Polarized HERA

- Comments:
  - Very Long Term Future: LC-HERA$e \cdot p/\vec{e} \cdot \vec{p}$
  - An electron storage ring in the RHIC tunnel ???
    RHIC-$\vec{e} \cdot A$ and RHIC-$\vec{e} \cdot \vec{p}$
    Comments!

[1]Yale University, Physics Department, New Haven, CT 06520-8121

Some Spin Surprises

1. **Stern & Gerlach (1921):**
   Space quantization associated with quantized spin directions
2. **Goudsmidt & Ulhenbeck (1926):**
   Atomic fine structure and electron spin magnetic moment
3. **Stern (1933):**
   Proton anomalous magnetic moment $\mu_p/\mu_N = 2.79$
4. **Kusch (1947):**
   Electron spin anomalous magnetic moment (QED) $\mu_e = 1.00119\mu_0$
5. **Prescott & SLAC-Yale Collaboration (1978):**
   Electroweak interference from $\vec{e} \cdot d$ DIS parity non-conservation
6. **EMC Collaboration (1989)**
   Proton sprin structure/puzzle/crisis

Spin measurements have high discovery potential!

Crossing the $x - Q^2$ Barrier in DIS

Unpolarized Scattering:

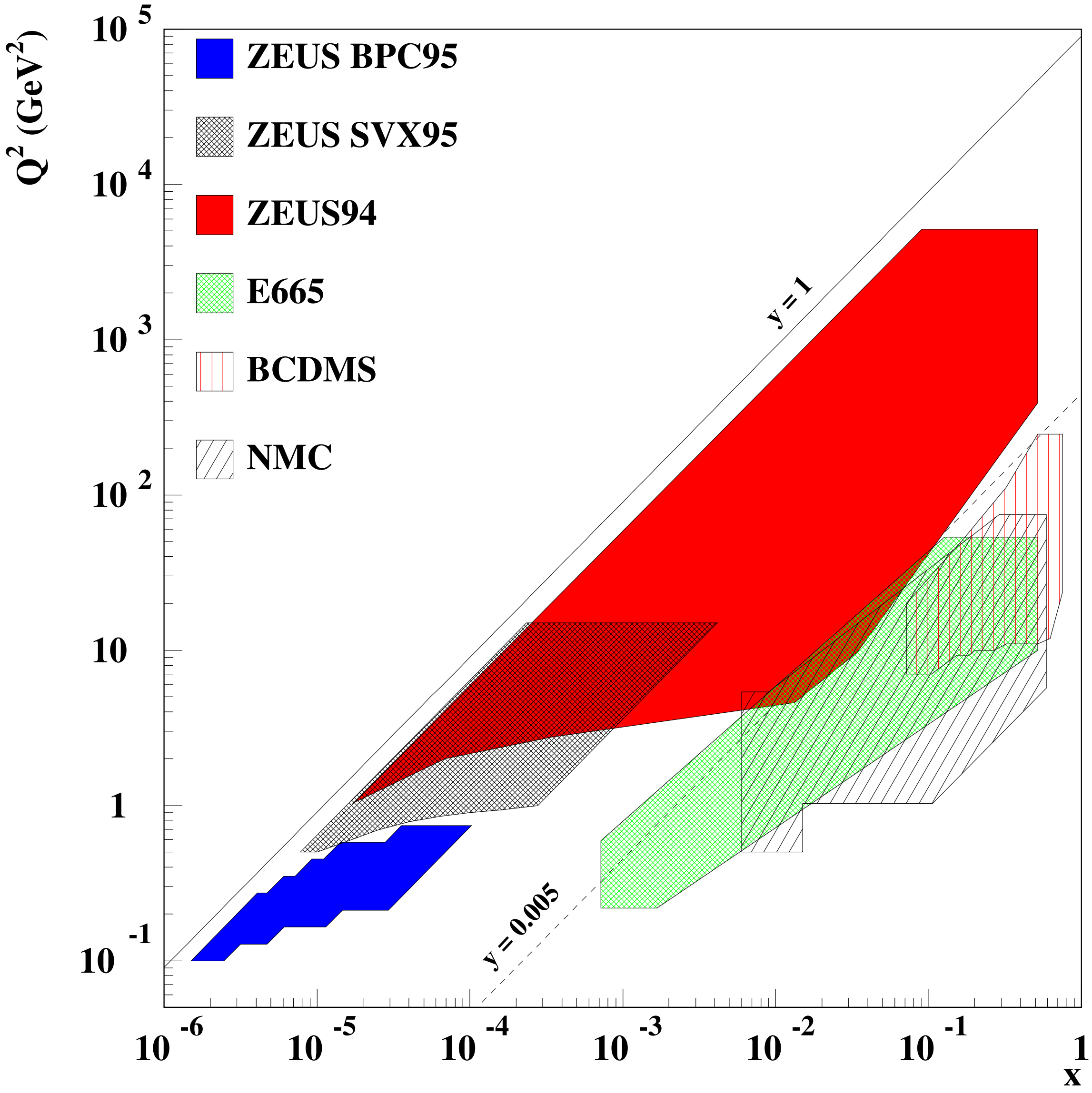
1. Elastic $e \cdot p$ scattering (SLAC, 1950s):
   $Q^2 \sim 1\ \mathrm{GeV}^2 \Longrightarrow$ Finite size of the proton
2. Inelastic $e \cdot p$ scattering (SLAC, 1960s):
   $Q^2 > 1\ \mathrm{GeV}^2 \Longrightarrow$ Parton structure of the proton
3. Inelastic $\mu \cdot p/d$ scattering (CERN, 1980s):
   $Q^2 > 1\ \mathrm{GeV}^2 \Longrightarrow$ Unpolarized EMC Effect
4. Inelastic $e \cdot p$ scattering (DESY/HERA, 1990s):
   $Q^2 > 1\ \mathrm{GeV}^2$ and Low x
   $\Longrightarrow$ Unexpected rise in F_2
   Study of pQCD thourgh numerous physics processes!

Polarized Scattering:

1. Inelastic $\vec{e} \cdot \vec{p}$ scattering (SLAC-Yale, 1970s):
   $Q^2 > 1\ \mathrm{GeV}^2; \quad x_{\mathrm{min}} \sim 0.1$
   $\Longrightarrow$ Confirm Quark Parton Model picture
2. Inelastic $\vec{\mu} \cdot \vec{p}$ scattering (EMC CERN, 1980s):
   $Q^2 > 1\ \mathrm{GeV}^2; \quad x_{\mathrm{min}} \sim 0.01$
   $\Longrightarrow$ Ellis Jaffe Sum rule violation!
   $\Longrightarrow$ The Spin Crisis/Puzzle
3. Inelastic $\vec{\mu} \cdot \vec{p}$ SMC, $\vec{e} \cdot \vec{p}$ SLAC, and lately, $\vec{e} \cdot \vec{p}$ HERMES (1990s): $Q^2 > 1\ \mathrm{GeV}^2; \quad x_{\mathrm{min}} \sim 0.003$
   Confirmed E-J violation, Confirmed Bj-Sum 10%, Semi-inclusive...
4. What Next? $\Longrightarrow$ Polarize the proton beam at HERA

The Extended $x - Q^2$ Range

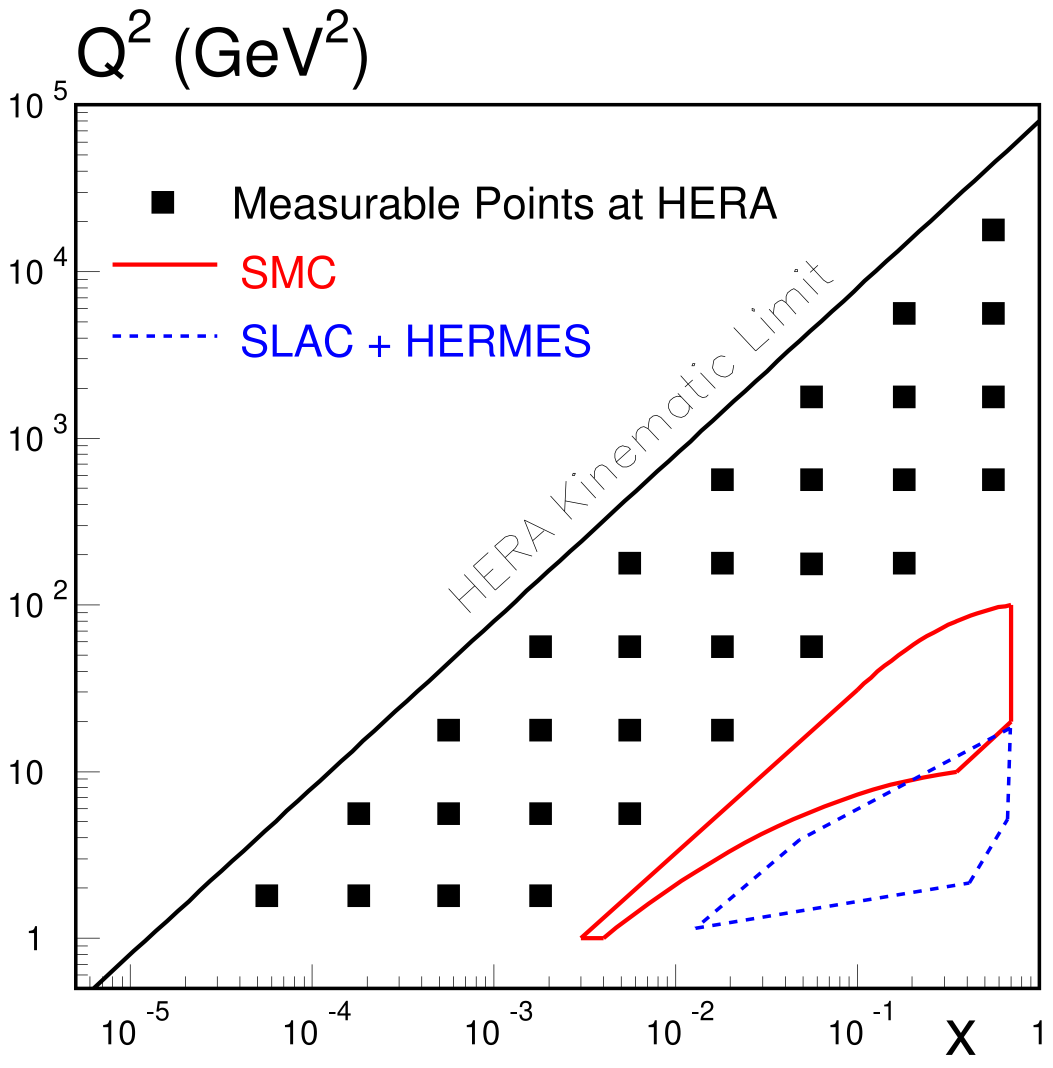
Presently For Unpolarized DIS



Unique for HERA!

The Extended $x - Q^2$ Range

Future: For Polarized DIS



Unique for HERA!

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

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

1997 Workshop on Physics With Polarized Protons at HERA

http://www.desy.de/$\sim$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	(Moscov)	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. Veneziano	(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 $Q^2_{\mathrm{MAX}} \sim 100 \ \mathrm{GeV}^2$
- $10^{-5} \leq x \leq 0.6$
  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)

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

(Have Already!) (Not Yet!)

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-$\vec{N}$ $\surd\surd$

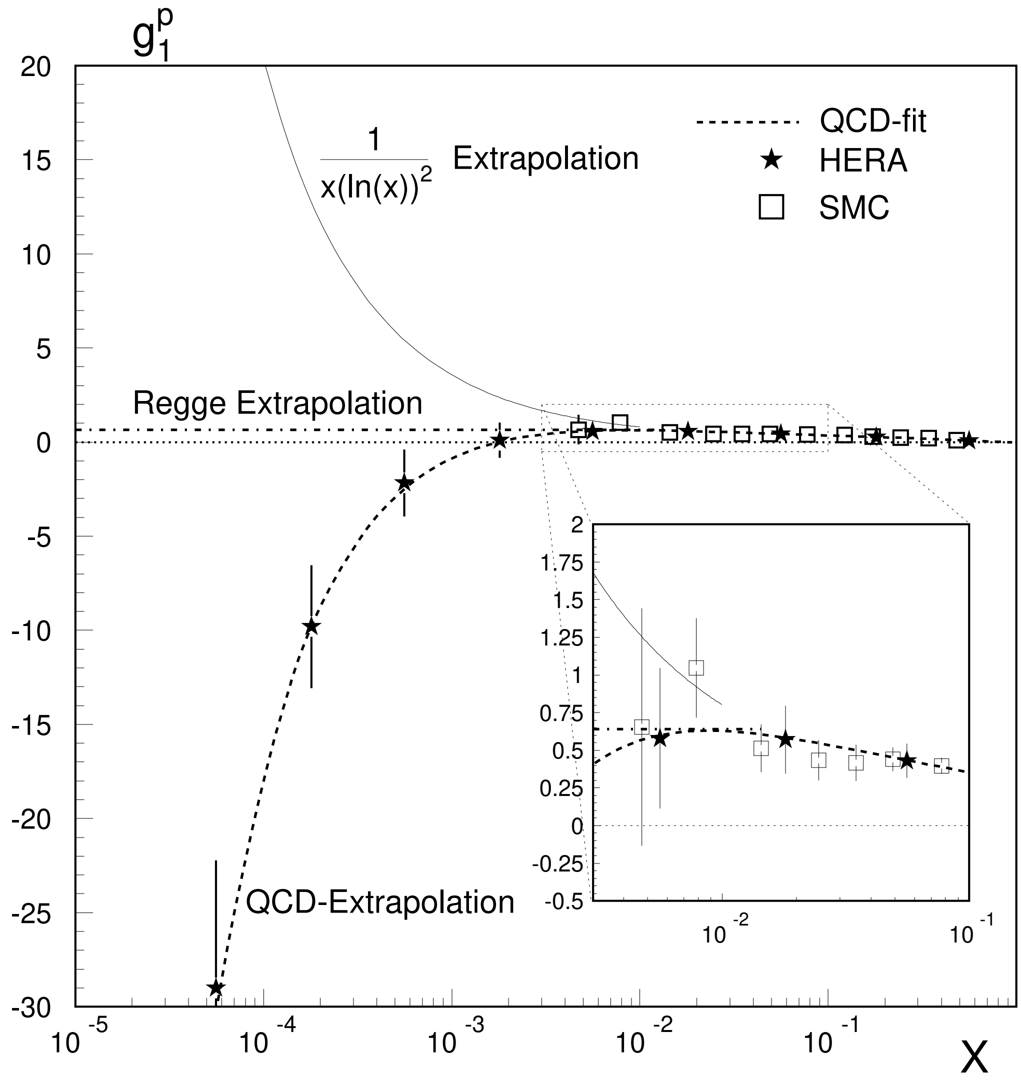
Green: Not good; $\surd$: Good; $\surd\surd$: Very Good

Spin Structure Function $g_1(x, Q^2)$

A. Deshpande, V. W. Hughes, J. Lichtenstadt

Statistical accuracy of g_1^p estimates using

- HERA detector acceptance & Det. Sim. (1999)
  - $\theta_e < 177^o$
  - $E'_e > 5$ GeV
  - $0.01 < y < 0.9$
  - $Q^2 > 1$ GeV^2
- $\mathcal{L} = 500$ pb^{-1} data collected in ~3 years



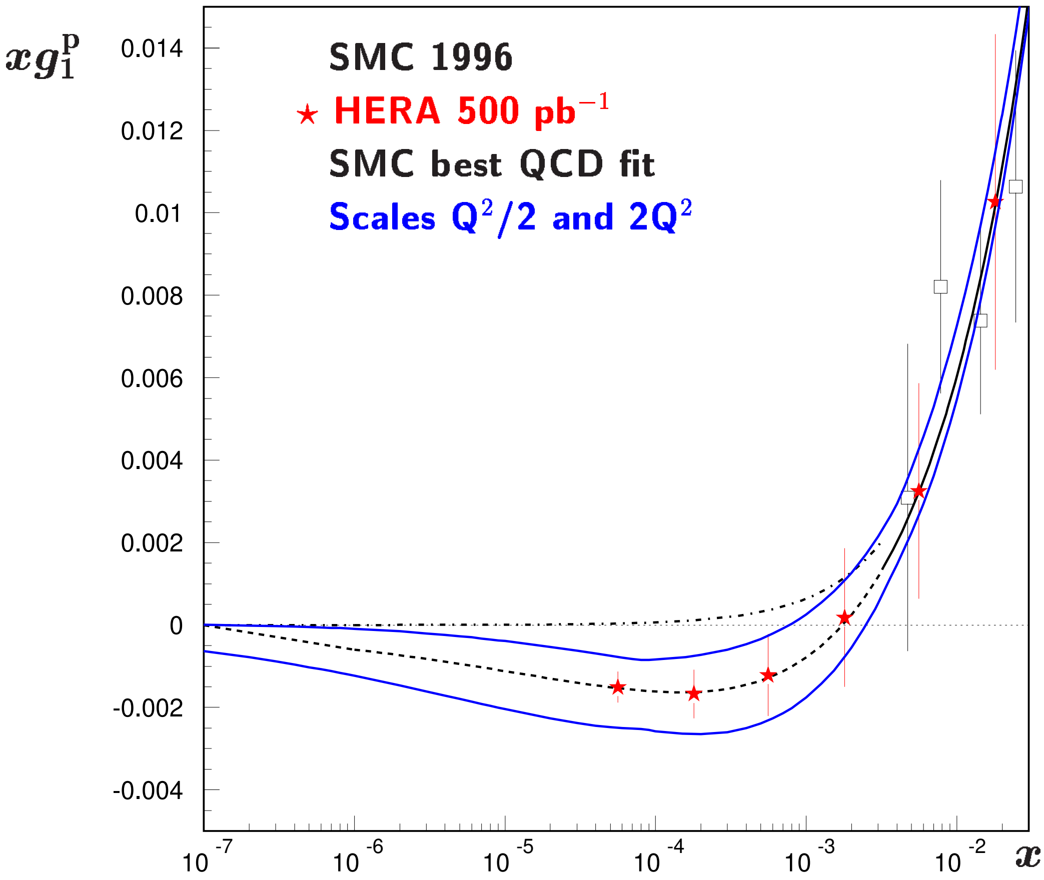
Will reduce the largest source of uncertainty

The measurement will be unique!

Reduction in $\delta(\Delta G)$

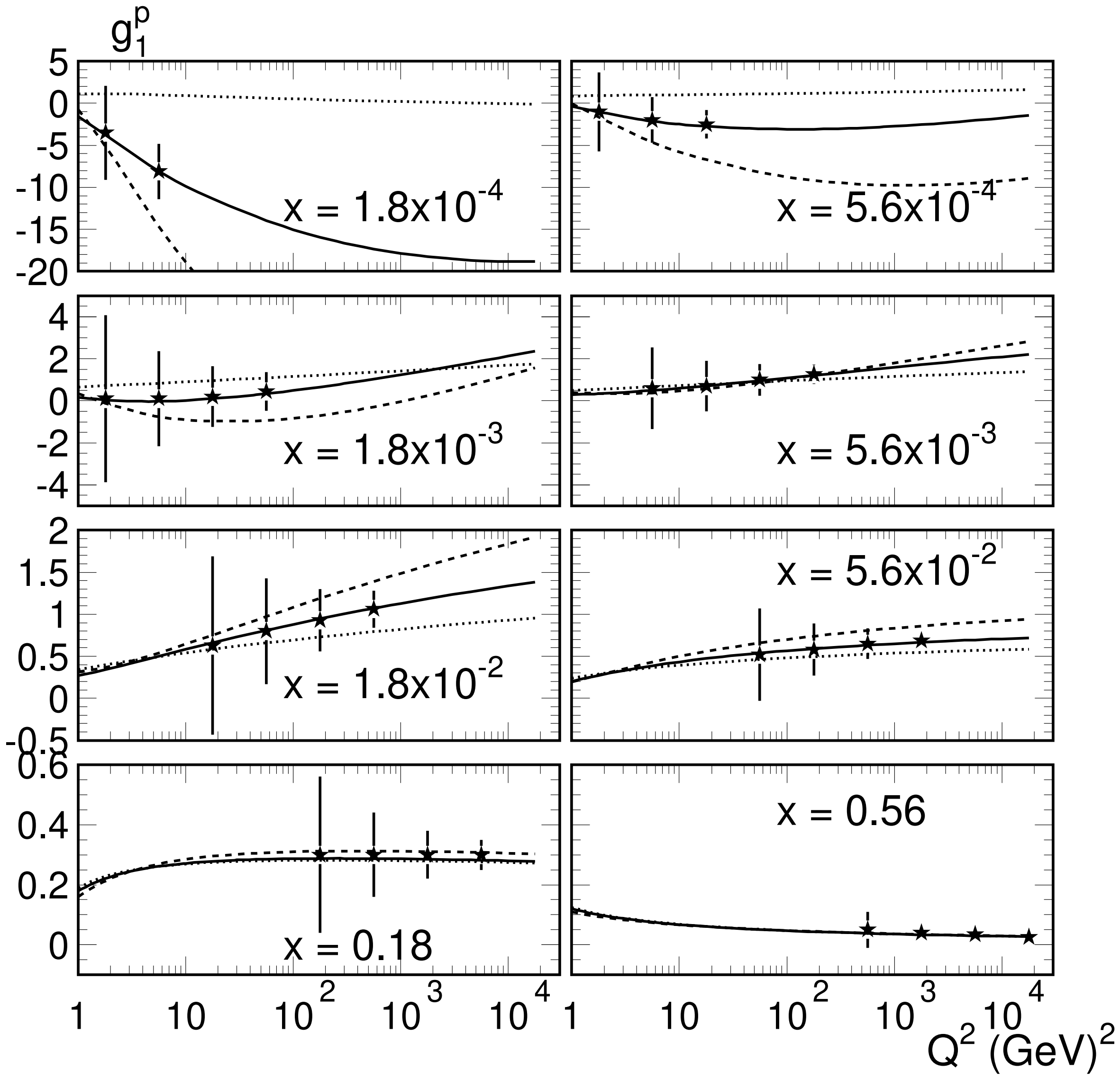
- Access $\Delta G(x, Q^2)$ through pQCD analysis at NLO
- 1997 Workshop: SMC, PLB 412 (1997) 414
  $\delta(\int \Delta G) = \pm 0.3(\mathrm{exp}) \pm 1.0(\mathrm{theory})$ @ $Q^2 = 1$ GeV^2
- Main sources of theoretical uncertainty:
  1. Factorization and renormalization Scales,
  2. Function form of 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
  $\delta(\int \Delta G) = \pm 0.2(\mathrm{exp}) \pm 0.3(\mathrm{theory})$



Overall: a factor of 3 reduction in uncertainty expected

$g_1^{\rm p}$ at HERA vs. Q^2



Standard Fit

Minimal Gluon Fit, $\Delta G(Q^2 = 1\ \mathrm{GeV}^2) = 0$

Maximal Gluon Fit, $\Delta G(Q^2 = 1\ \mathrm{GeV}^2) = a_8$

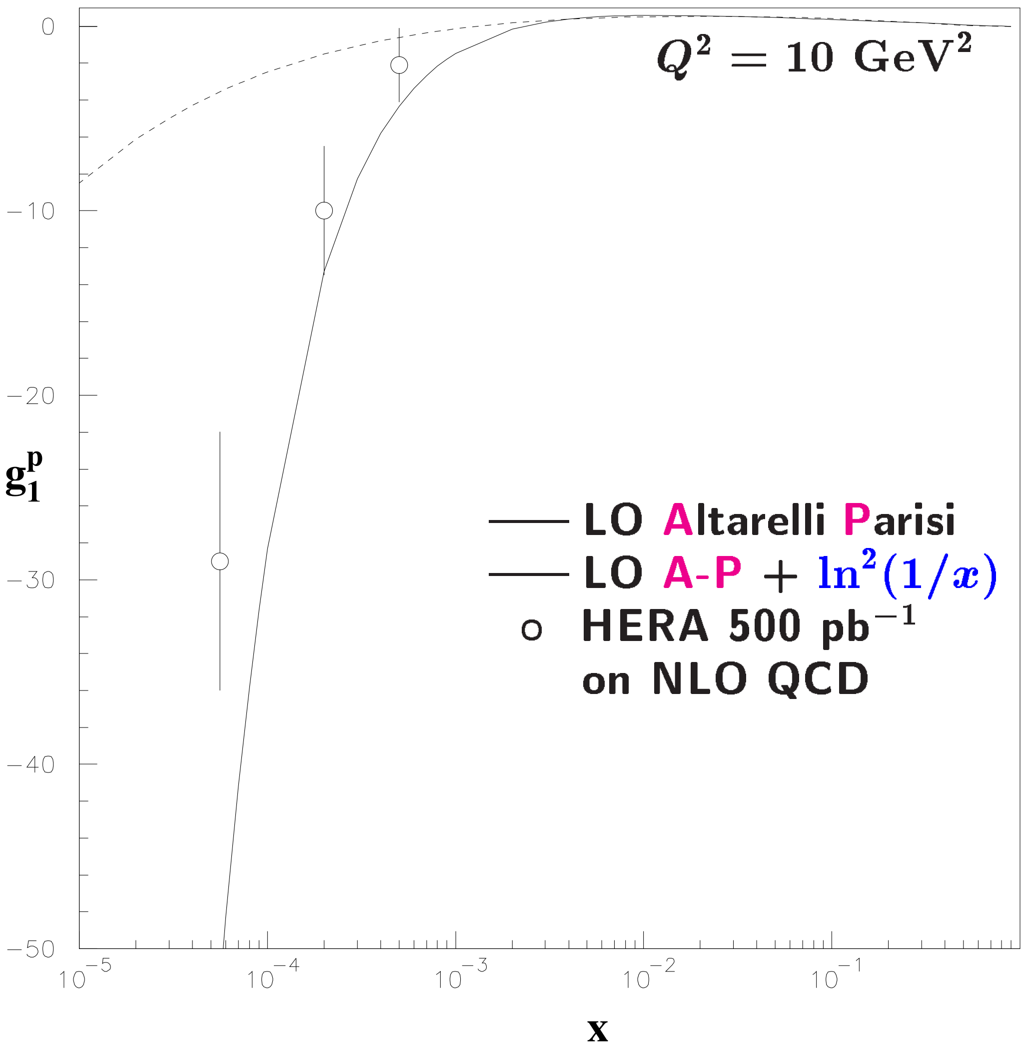
Low x Resummation

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

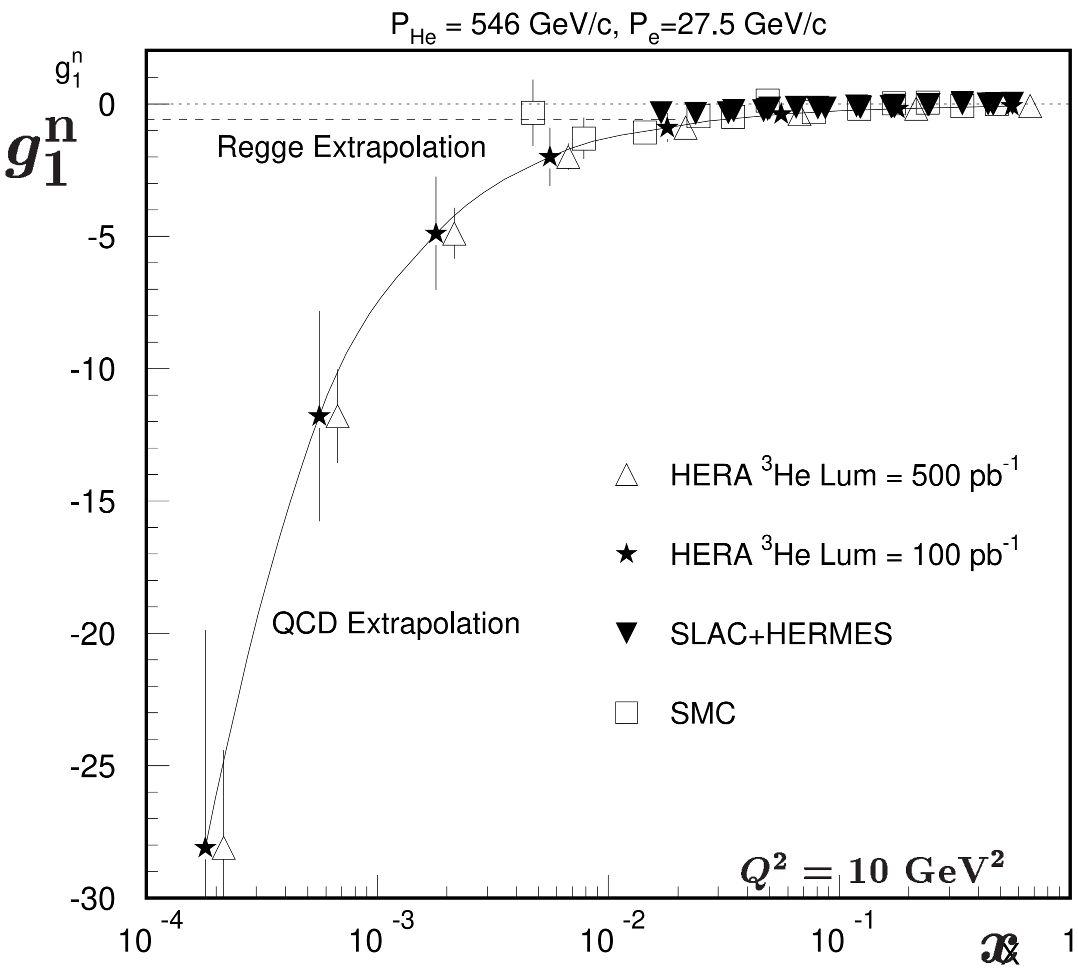


Data at HERA can differenciate between various scenarios. Particularly Interesting Possibility: Linear Collider + Polarized Protons@HERA

Neutron Spin Structure Function g_1^n

A. Deshpande, V. W. Hughes, J. Lichtenstadt

- g_1^n measurement possible if
  $\Longrightarrow$ $^3\mathrm{He}^{+2}$ can be accelerated in HERA
  $\Longrightarrow$ High intensity $^3\mathrm{He}$ source available
- Nucleon momentum $[(Z/A) \times 820] \sim 550$ **GeV**
- Useful to detect the scattered electron and the remnant proton system $\Longrightarrow$ Improves dilution factor

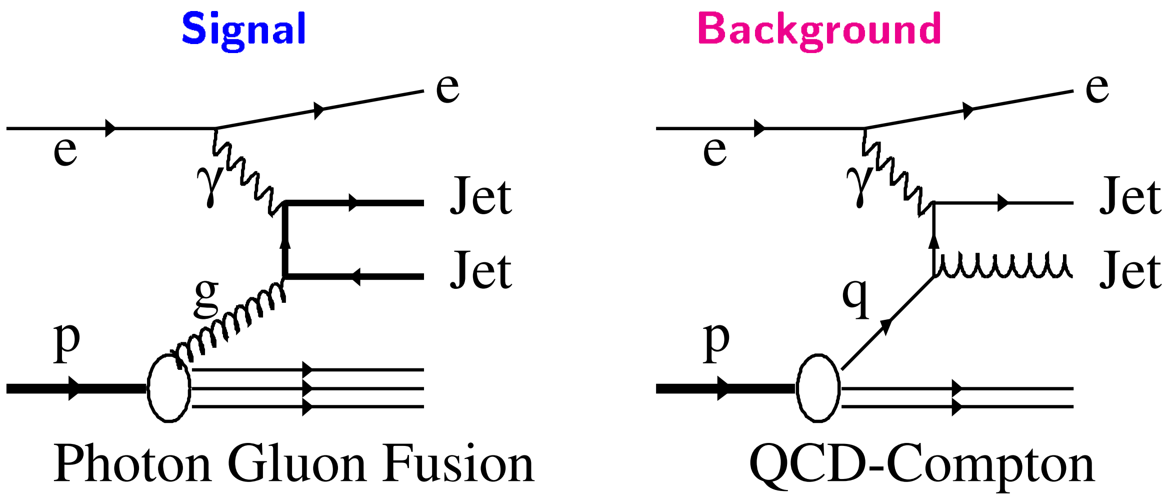


A unique and significant measurement possible!

Measurement of $\Delta G(x, Q^2)$ and its first moment...

Numerous approaches possible at HERA

- "Indirect Determination": ΔG from NLO fits to g_1
- "Direct Determination": Photon Gluon Fusion in DIS
  ΔG appears at LO



- ΔG from 2-Jet Events (LO) in DIS
- ΔG from 2-High-p_T tracks with opposite azimuthal angle in DIS
- ΔG from combined QCD fit of g_1 and Jets in DIS

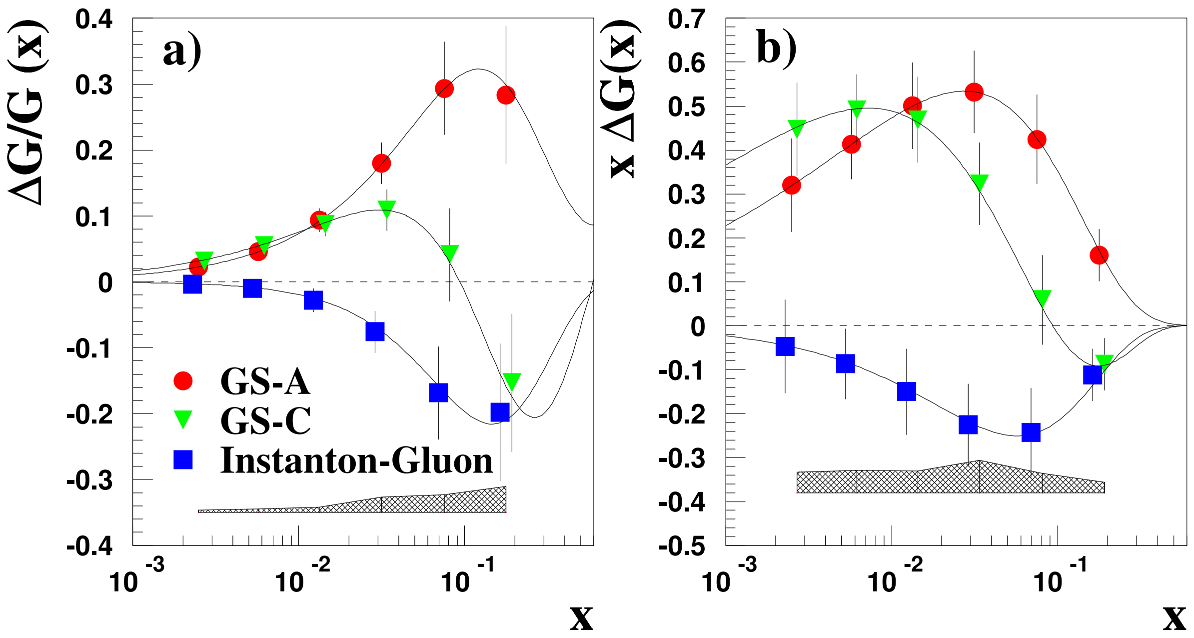
- ΔG from Jets & High-p_T in photoproduction

ΔG from Di-Jet Production

A. De Roeck, M. Maul, G.Rädel

- **MC Simulation:** signal + background; hadronization, higher order effects via parton showers
- **Event Selection:**
  $\Longrightarrow 5 \leq Q^2 \leq 100\ \mathrm{GeV}^2$
  $\Longrightarrow 0.3 \leq y \leq 0.85$
  $\Longrightarrow p_T^{\mathrm{Jet}} \geq 5\ \mathrm{GeV}$
  $\Longrightarrow |\eta_{\mathrm{Lab}}^{\mathrm{Jet}}| \leq 2.8;\qquad \eta_{\mathrm{Lab}}^{\mathrm{Jet}} = -\ln\left[\tan(\theta^{\mathrm{Jet-p}}/2)\right]$
- **Detector effects** included

Gluon extracted at Leading Order at $Q^2 = 20\ \mathrm{GeV}^2$
assuming integrated luminosity $\mathcal{L} = 500\ \mathrm{pb}^{-1}$



Di-Jets analysis will measure the polarized gluon distribution accurately

It will map the region: $0.002 \leq x_g \leq 0.2$

Next to Leading Order Corrections Small: $\sim 10\%$

E. Mirkes & S. Willfahrt

Comparison with RHIC and HERA-$\vec{N}$

T. Gehrmann

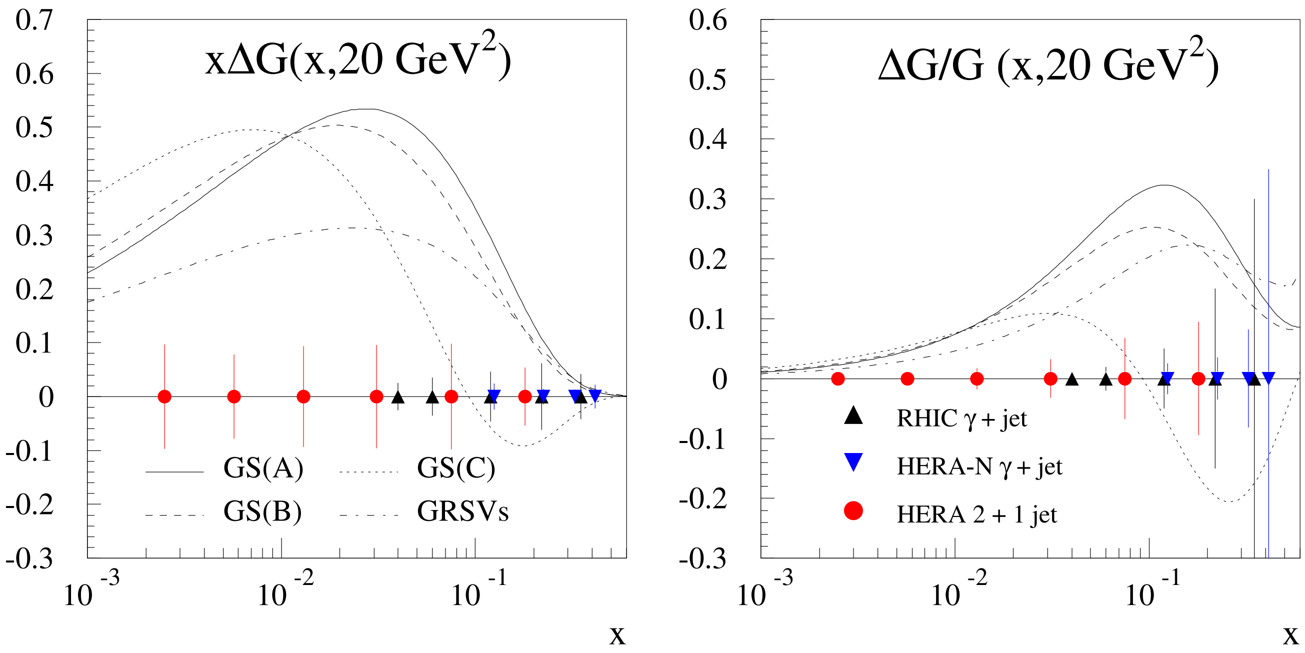
- Pol. HERA: $820\ \mathrm{GeV/c}\ \vec{p}\ (\times)\ 27\ \mathrm{GeV/c}\ \vec{e}$
- RHIC Spin: $250\ \mathrm{GeV/c}\ \vec{p}\ (\times)\ 250\ \mathrm{GeV/c}\ \vec{p}$
- HERA-$\vec{N}$: $820\ \mathrm{GeV}\ \vec{p}\ (\times)$ Stationary $\vec{p}$

HERA will measure x dependence in range

$0.002 \leq x_g \leq 0.2$

First moment measurement uncertainty

$\delta(\int \Delta G) \sim \pm 0.2$



- 2-Jet measurements at HERA cover about $\sim 75\%$ of the $\Delta G(x)$ at $Q^2 = 20\ \mathrm{GeV}^2$
- HERA-$\vec{N}$ and RHIC-Spin: Better accuracy at high x_g but limited measurement range

Complimentary AND Essential

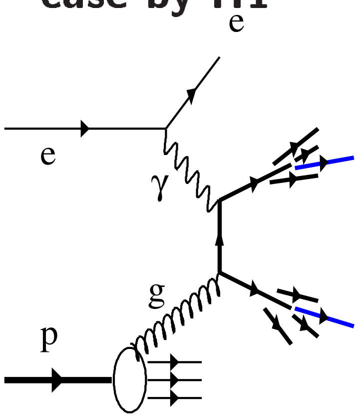
ΔG From 2 High-p_{T} Hadrons

- Analysis philosophy **similar to Di-Jet Analysis:**
  - Use of **Boson Gluon Fusion** to access ΔG
  - Instead of “Jets”, look for two “hadron tracks” back to back in azimuthal angles.

- **COMPASS Experiment** at CERN

  A. Bravar, D. von Harrach, A. Kotzinian, hep-ph/9710266

- Experimental feasibility demonstrated in **unpolarized** case by H1



Leading Hadron

$\mathcal{S}$

Leading Hadron

$$x_g = x\left(1 + \frac{\mathcal{S}}{Q^2}\right)$$

QCD Compton Background

Advantages with respect to the Jet analysis:

- $\Uparrow$ Different systematic error sources
- $\Uparrow$ No effect of Calorimeter energy scales
- $\Uparrow$ Possible to go to lower $\mathcal{S} \longrightarrow x_g$

Disadvantages:

- $\Downarrow$ Involves Fragmentation functions $D_q(x)$
- $\Downarrow$ Large smearing $\Longrightarrow \mathcal{S}_{\mathrm{meas}} \ll \mathcal{S}_{\mathrm{true}}$
- $\Downarrow$ NLO Correction?

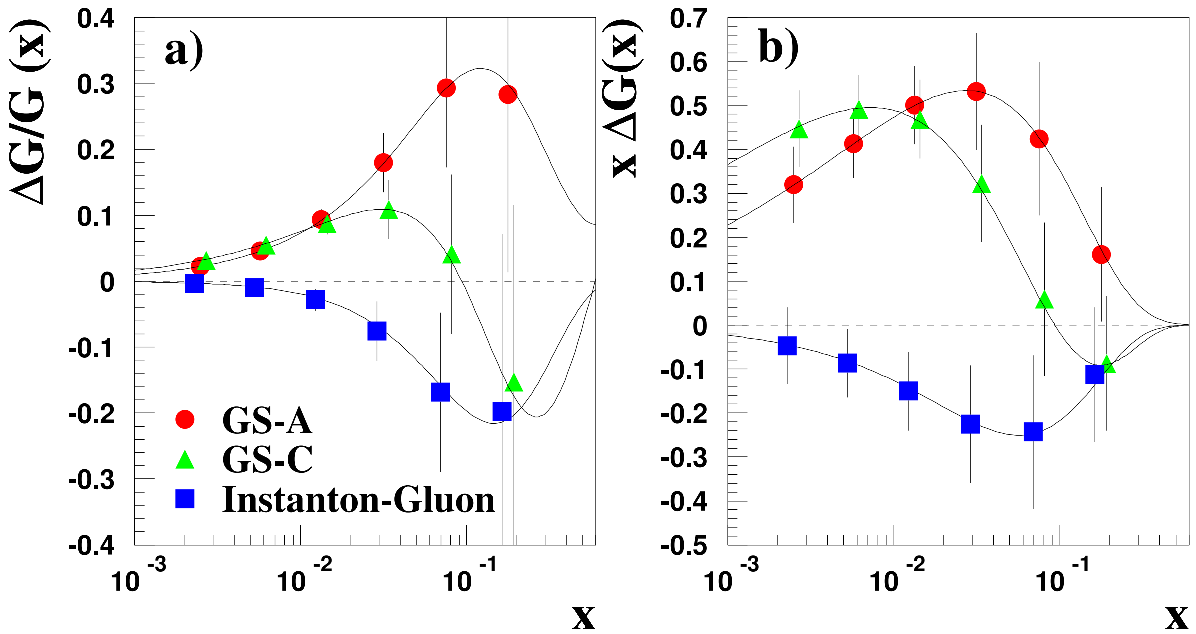
ΔG From High-p_T Hadrons at HERA

A. De Roeck, G. Rädel

Event Selection:

- $5 \leq Q^2 \leq 100$ GeV^2
- $0.3 \leq y \leq 0.85$
- $p_T^{had} > 1.5$ GeV
- $-1.5 < \eta_{Lab}^{had} < 2.5$
- $|\eta_{had1} - \eta_{had2}| < 2$
- $|\phi_{had1} - \phi_{had2}| < 60^o$

Gluon extracted at Leading Order at $Q^2 = 20$ GeV^2
assuming integrated luminosity $\mathcal{L} = 500$ pb^{-1}



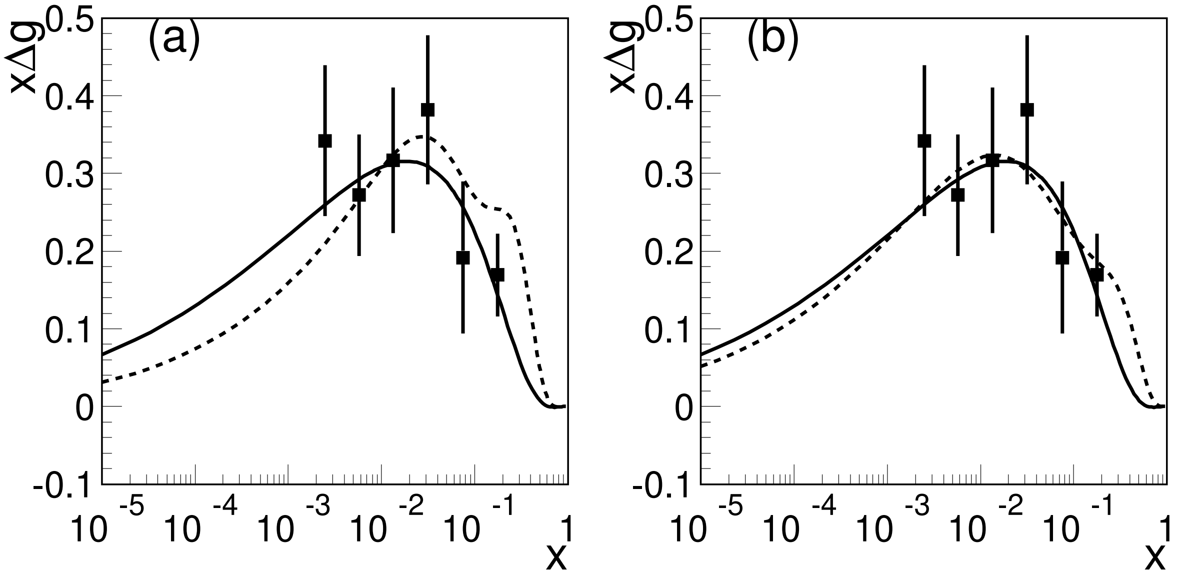
- Results similar to Di-Jet analysis
  - Worse at high x: Can be improved??
  - Reaches lower x
- 2-Jet/2-Hadron event sample overlap $\sim 40\%$

ΔG from Combined Analysis $g_1 + \mathrm{Jets}$

A. De Roeck, A. Deshpande, V. W. Hughes, J. Lichtenstadt, G. Rädel

- Different sources of uncertainties:
  - NLO pQCD analysis of g_1
  - Di-Jet Analysis (photon gluon fusion process)
- Impact different aspect of ΔG determination
  At Q_0^2:
  - $g_1 \Longrightarrow$ First moment of $\Delta G(x)$ $\Longrightarrow \int \Delta G(x) \mathrm{d}x$
  - Di-Jet Analysis $\Longrightarrow$ Shape of $\Delta G(x)$

Jet Analysis Not Used | Jet Analysis Used



Data Used		$\delta \int (\Delta G)_{\mathrm{Exp}}$
1997 Fixed Target Data g_1	$\Longrightarrow$	30%
+ HERA $g_1^{\mathrm{p}}(x, Q^2)$	$\Longrightarrow$	20%
+ HERA Di-Jet	$\Longrightarrow$	10%

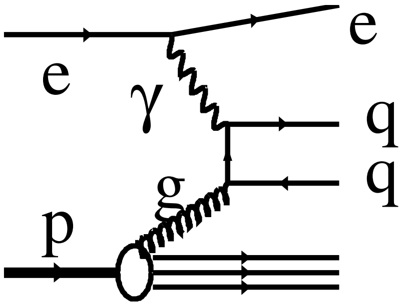
Significant improvement in $\delta(\int \Delta G)\mathrm{Exp}$
and constraint on shape of $\Delta G(x)$

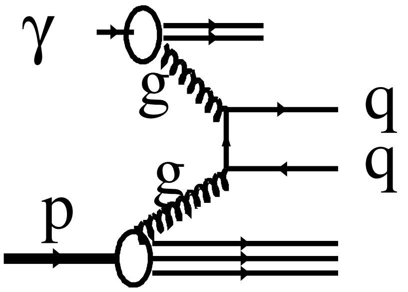
Photoproduction ($Q^2 \approx 0$)

J. Butterworth, N. Goodman, M. Stratmann, W. Vogelsang

High-p_T Jet/Hadron Production:

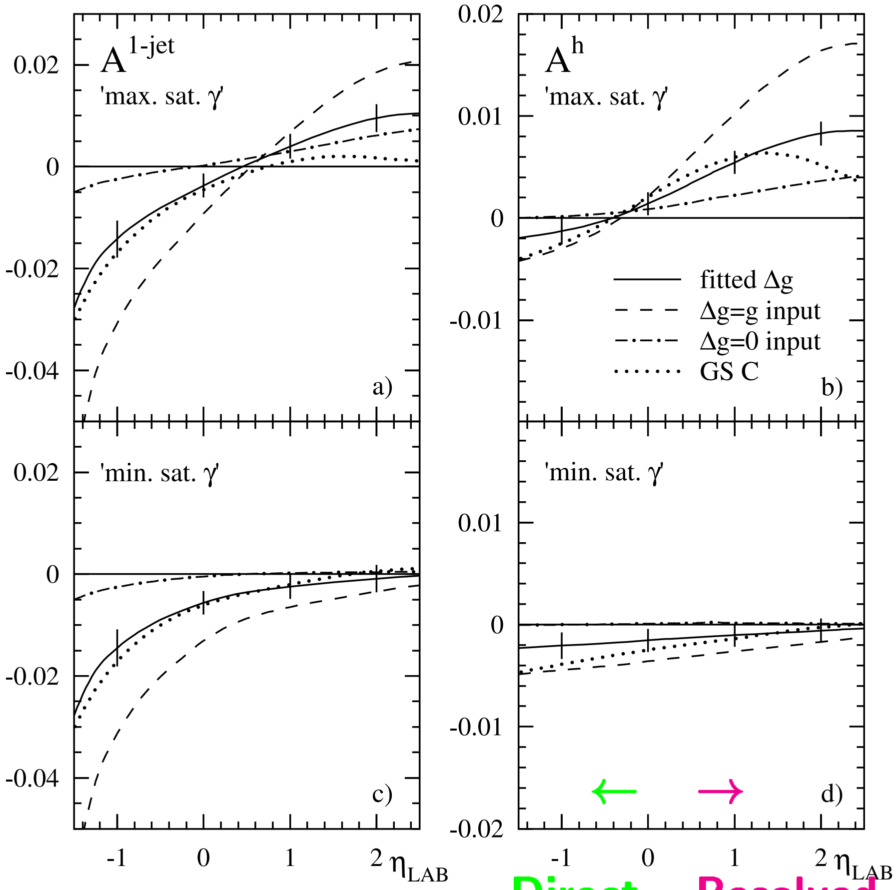
Direct Photon | **Reseolved Photons**





Inclusive asymmetries for single jets and hadrons

Cuts: Jets: $p_T > 8$ GeV Hadrons: $p_T > 2$ GeV



Direct **Resolved**

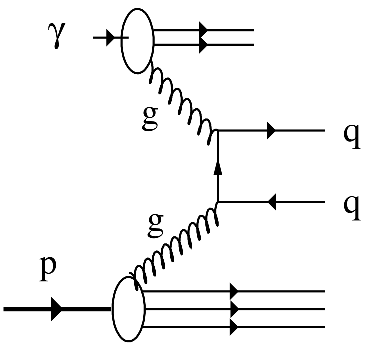
$\mathcal{L} = 100\text{pb}^{-1}$

Information on Δq^γ unique to HERA

Sensitivity to ΔG and Δq^γ

Photoproduction of Di-Jets

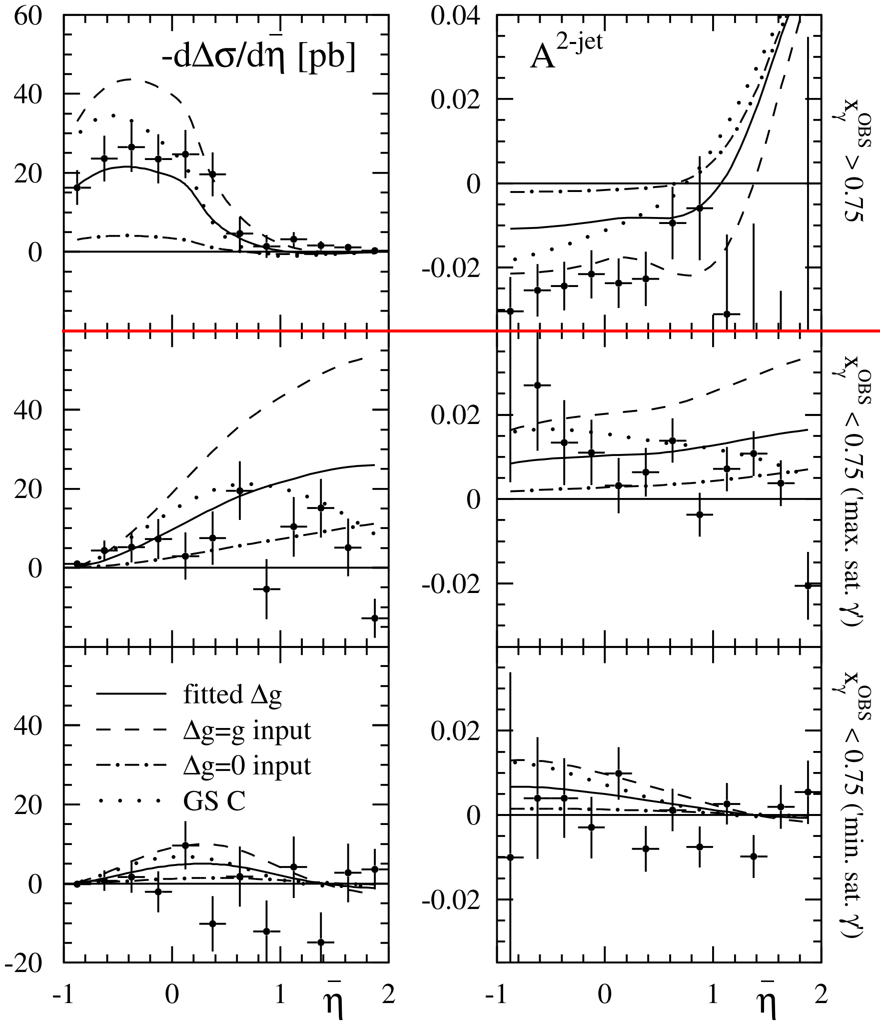
For 2-Jet events a complete reconstruction of parton kinematics possible (at leading order)



$$x_\gamma^{Obs} = \frac{\sum_{\mathrm{Jets}} p_T^{\mathrm{Jet}} e^{-\eta_{\mathrm{Jet}}}}{2yE_e}$$

$$y = E_\gamma / E_e$$

Detector level study performed with $\mathcal{L} = 50\mathrm{pb}^{-1}$



$x_\gamma > 0.75$

Sensitivity to ΔG

$x_\gamma < 0.75$

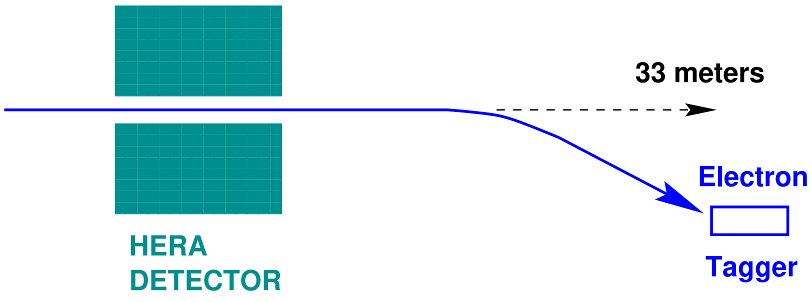
Input Assumption $\Delta q^\gamma = q^\gamma$

$\Delta q^\gamma = 0$

Sensitivity to Δq^γ

Inclusive Photoproduction Measurements

S. Bass, M. Brisudova, A. De Roeck



Electron Tagger

$Q^2 = 10^{-8} - 10^{-2}\mathrm{GeV}^2$

$\sqrt{s} \sim 60 - 250\mathrm{GeV}$

$\sigma \sim 150\mu b$

Drell-Hearn-Gerasimov Sum Rule:

$$\int_{\nu_{th}}^{\infty} \frac{\mathrm{d}\nu}{\nu}(\sigma_{\uparrow\downarrow}^{\gamma p} - \sigma_{\uparrow\uparrow}^{\gamma p})(\nu) = -\frac{4\pi^2\alpha\kappa^2}{2m_p^2}$$

- At HERA $\nu \to 10 - 40$ TeV
- Although small contribution to sum rule
  - Explore energy dependence of the cross section

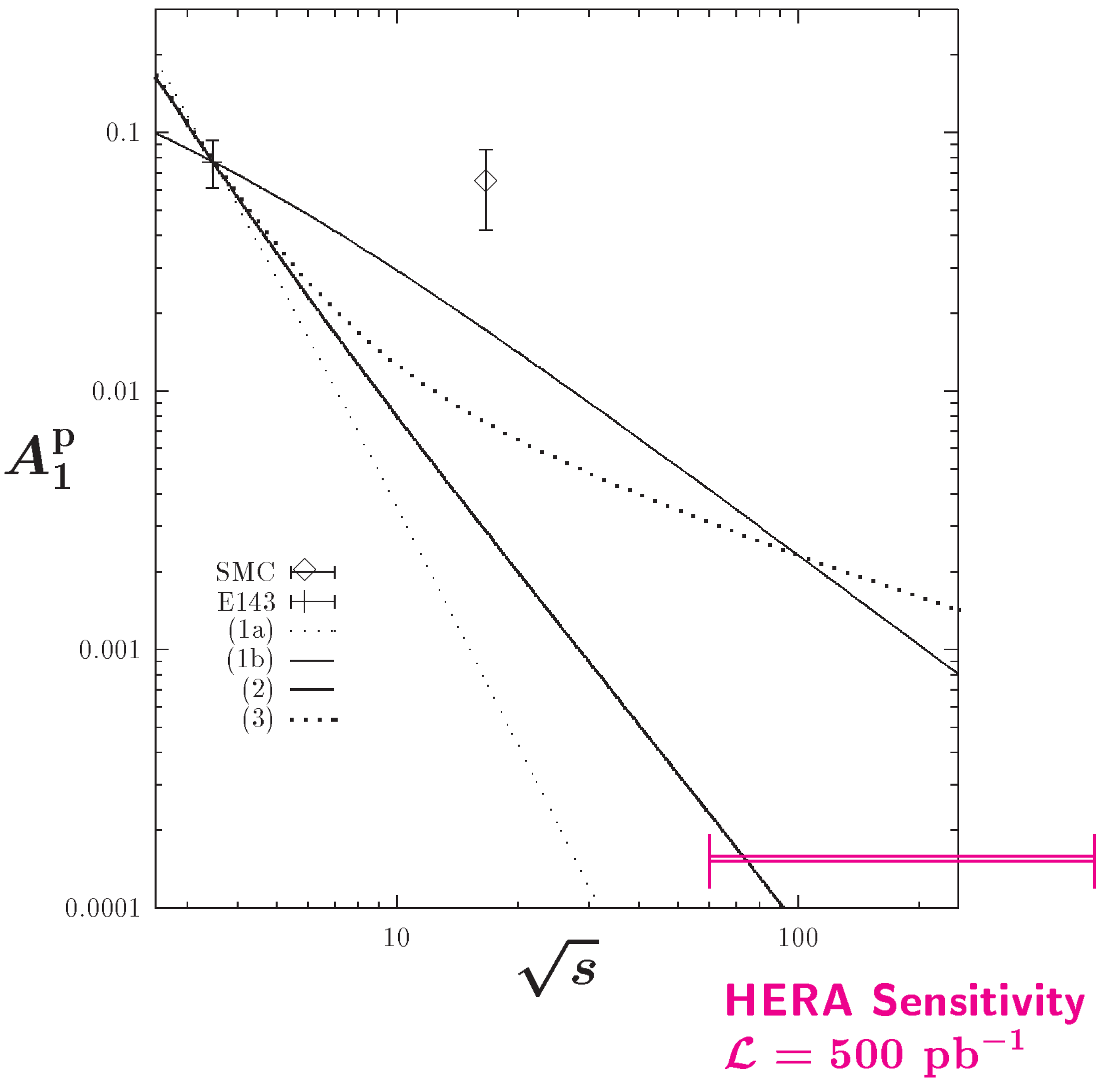
$$\Delta\sigma \sim N_3 s^{\alpha_{a1}-1} + N_0 s^{\alpha_{f1}-1} + N_g \frac{\ln(s/\mu^2)}{s} + N_{pp}\frac{1}{\ln^2(s/\mu^2)}$$

(1) (2) (3) (4)

- Large effect on $\Delta\sigma$ expected
- Asymmetry for different regge behavior

Inclusive Photoproduction Measurements.... (Continued)

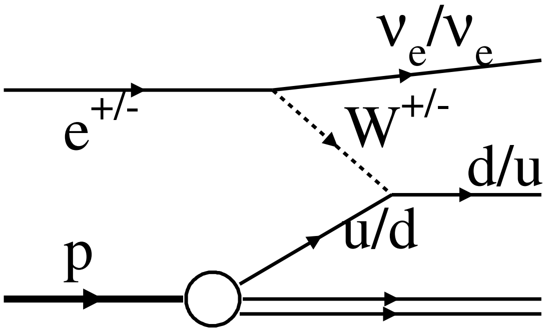
S. Bass et al.



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

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

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

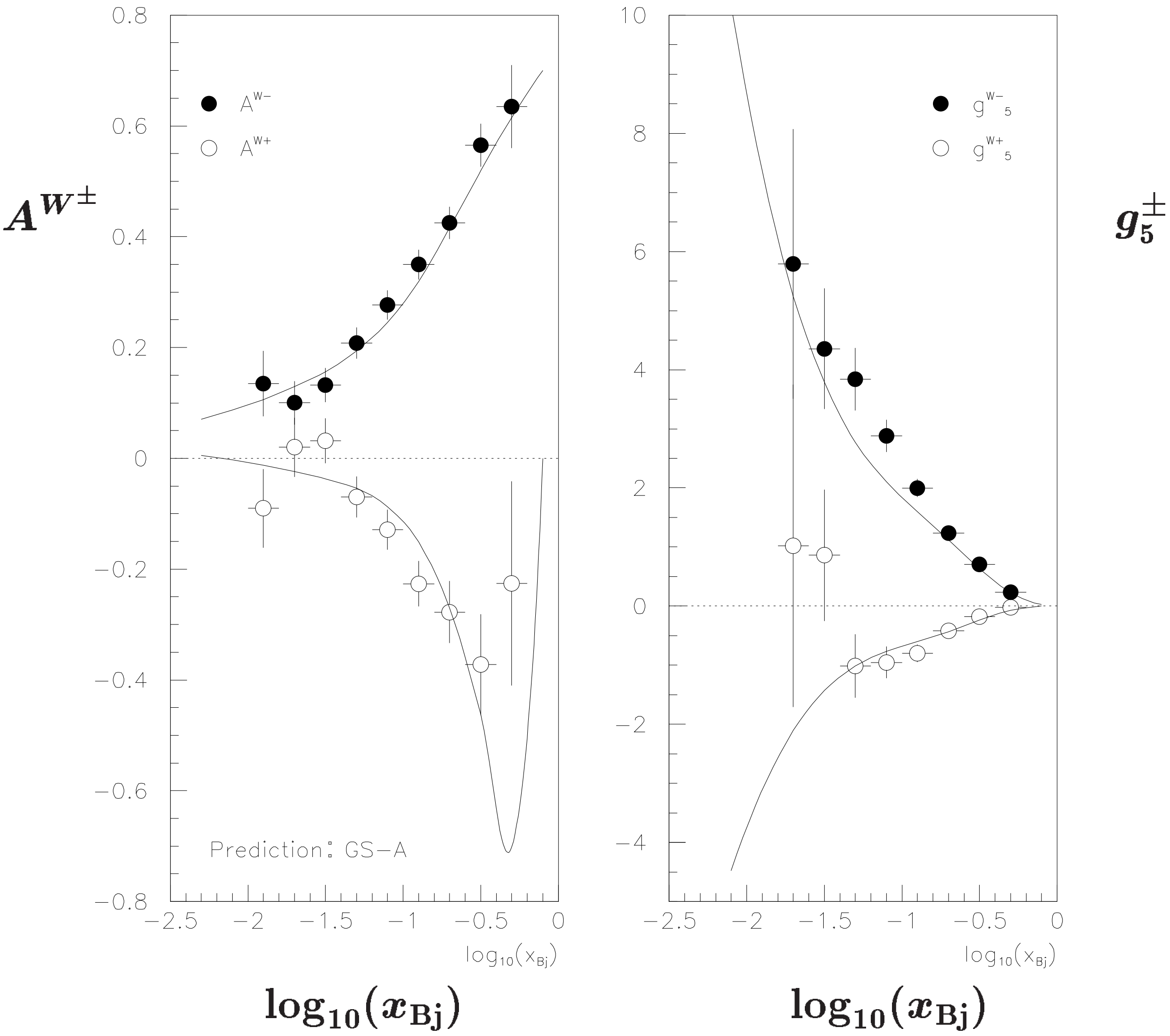
$$\text{Asymmetries}: \quad A^{W^\pm} \approx \frac{g_5^{W^\pm}}{F_1^{W^\pm}}$$

Selection

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

Assumption

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

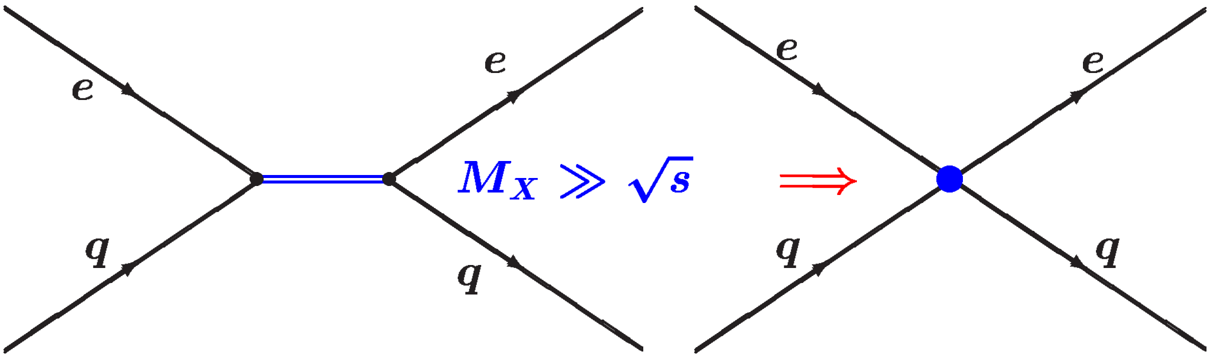


High Q^2 region and Polarization

- 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
    - $A_{\mathrm{Instanton}} = \frac{\sigma^{\uparrow\downarrow}-\sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow}+\sigma^{\uparrow\uparrow}} \longrightarrow -1$
    - $A_{\mathrm{pQCD}} \longrightarrow +1$
- J. Ellis et al.: Strange Stop Production - R Parity violating interactions: Phys. Lett. B408 (1997) 252
  - $e\ d \rightarrow \tilde{\mathrm{t}}$
    - $\sigma(e_R^+\ p_R) \ll \sigma(e_R^+\ p_L)$
  - $e\ s \rightarrow \tilde{\mathrm{t}}$
    - $\sigma(e_R^+\ p_R) < \sigma(e_R^+\ p_L)$
    - $\sigma(e_R^-\ p_L) < \sigma(e_L^+\ p_R)$
- Experimental Aspects that will need attention!
  - $e^\pm$ beam divergences in going from $e_L^\pm \Longleftrightarrow e_R^\pm$
  - Frequency of above change
  - False asymmetries
  - May learn to do this: Electroweak physics program after luminosity upgrade

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

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

$\Longrightarrow$ 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
- $200 < Q^2 < 5 \times 10^4\ \mathrm{GeV}^2$
- 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

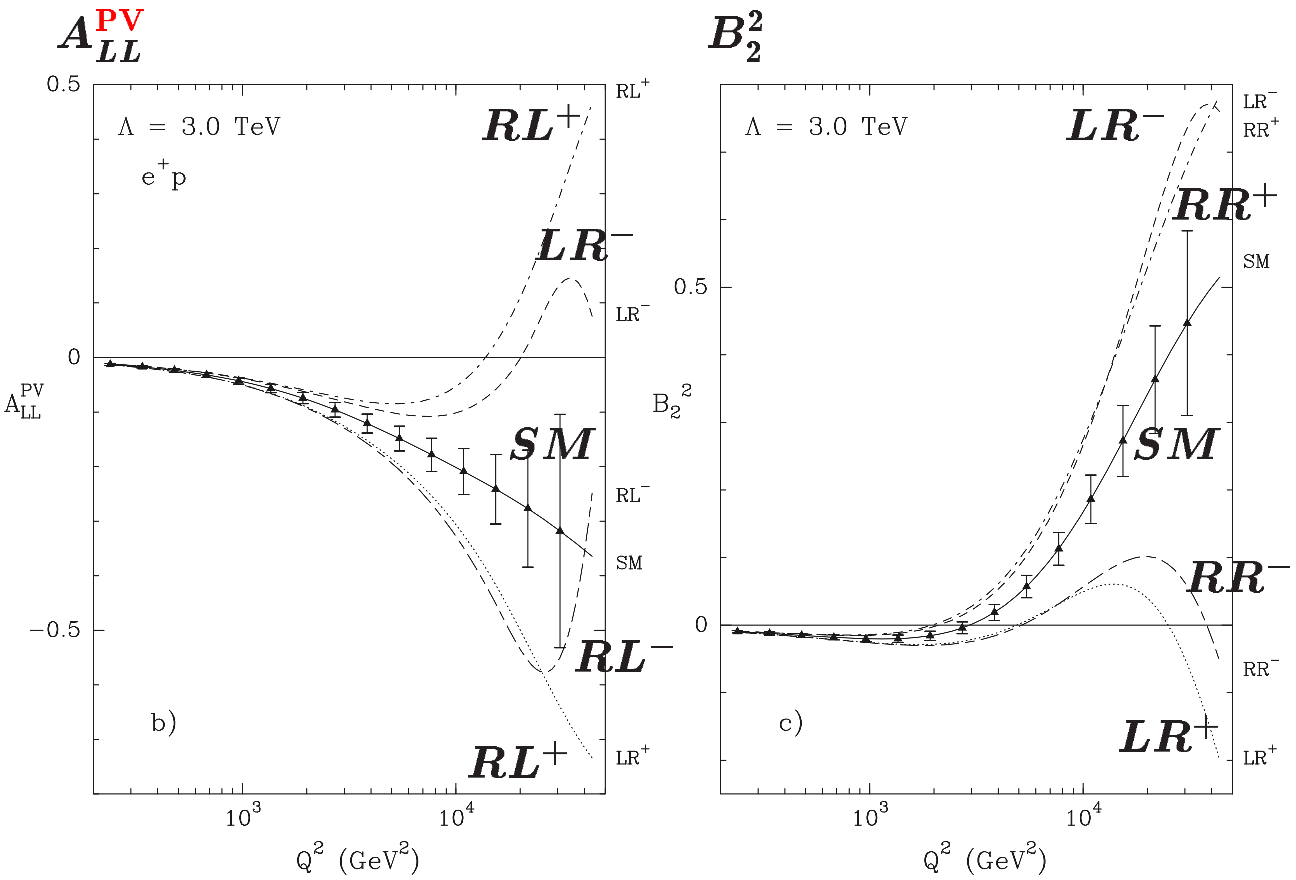
Partity Violating

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

“Mixed”

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

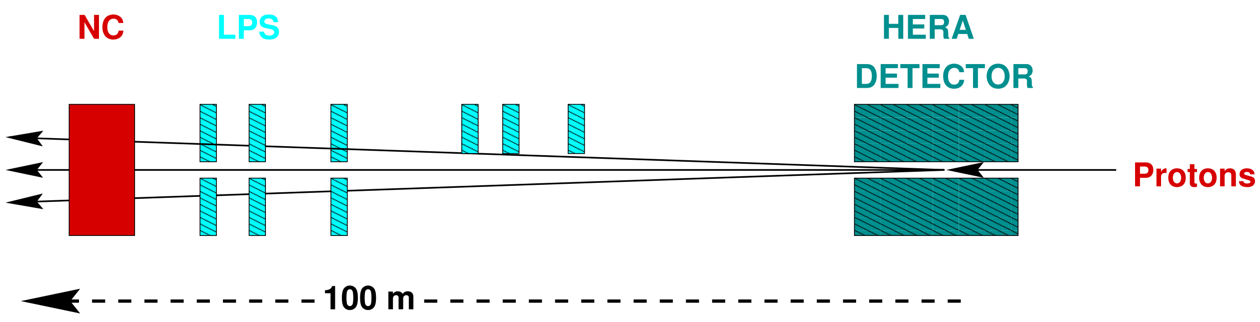
Helicity structure sensitivity up to scales ~ 7 TeV



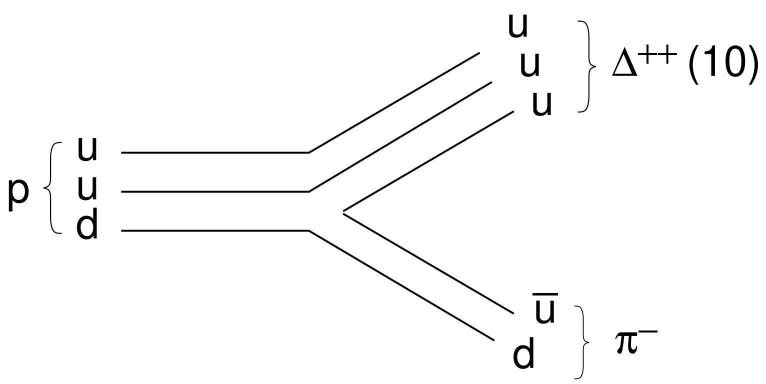
Helicity structure of the new interaction could be probed/resolved

Target Fragmentation Region

D. De Florian, G.M.Shore, G. Veneziano



- Leading proton spectrometer (LPS) & Neutron Counters (NC)
  $\Longrightarrow$ Access target fragmentation region
- Origin of Ellis-Jaffe sum rule violation
  $\Longrightarrow$Target independent charge screening (?)
  - Semi-inclusive process where a hadron carries most of nucleon's energy $\approx$ inclusive process on a different target



Measure $g_1^{\Delta^{++}}$

Detect π^-

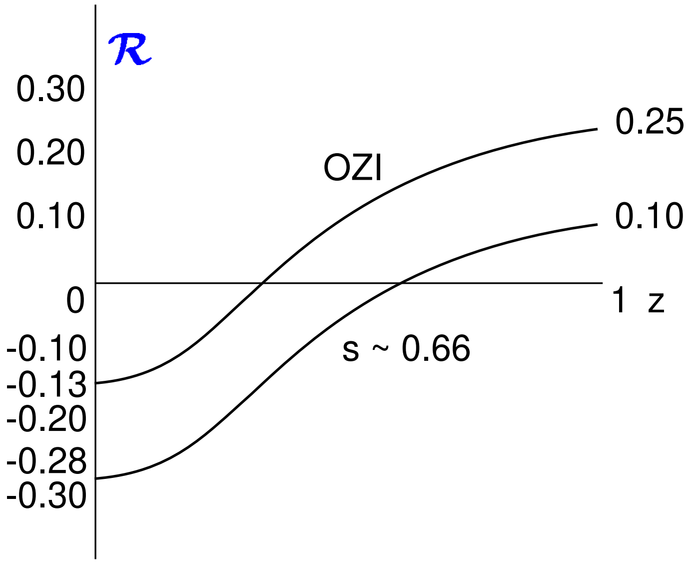
Target fragmentation region (continued)...

D. De Florian et al.

$$\mathcal{R}\left(\frac{ep \to e\pi^- X}{en \to e\pi^+ X}\right) = \frac{2s+2}{2s-1}$$

R sensitive to different assumptions:

- ○ Target independence
- ○ Simple valence quark model (OZI, $s = 1$)



$$z = \frac{p_h \cdot q}{p_N \cdot q}$$

$z \longrightarrow 1$: Target Fragmentation region

Experimental Measurement: Detection of positive & negative hadrons with large z

- Increase acceptance in forward region:
  $\Longrightarrow$ Detect positive as well as negative particles
  $\Longrightarrow$ Add new detectors (?)
- Provide Particle ID
- Use ^{3}He beam as neutron target

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

A Case For Polarized HERA

- Behavior of $g_1(x, Q^2)$ at lowest x and highest Q^2 range $\Longrightarrow$ unique
- Measurement of $\Delta G(x, Q^2)$ in the largest x_g range using many approaches
- Polarized parton distributions in photons from photo-production $\Longrightarrow$ unique
- Direct determination of $\Delta q_V = \Delta q - \Delta \bar{q}$ via charged current events
- Spin Physics beyond standard model... and more
- $N\vec{N}$ and $\vec{N}\vec{N}$ scattering at $\sqrt{s} \sim 40$ GeV with HERA-$\vec{N}$
- Measurements complementary to other future spin experiments

We have at HERA

- High energy electron and proton beams and people who know them!
- Electron beam already polarized! Polarization measurement $\Delta P/P \leq 5\%$
- Two working collider detectors and people who know them!

It would be unfortunate not to polarize the proton beam!

Linear Collider @ DESY on Polarized HERA

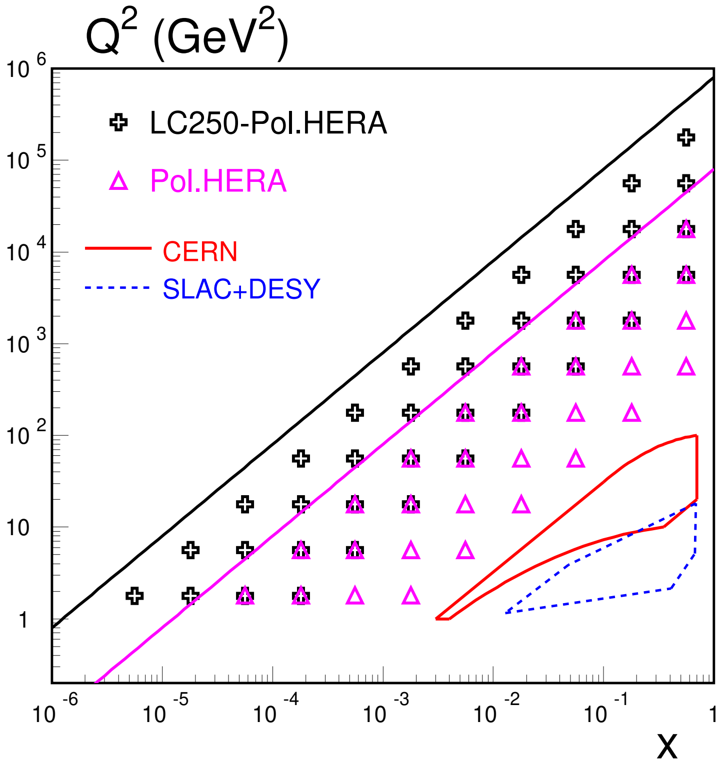
A. Deshpande

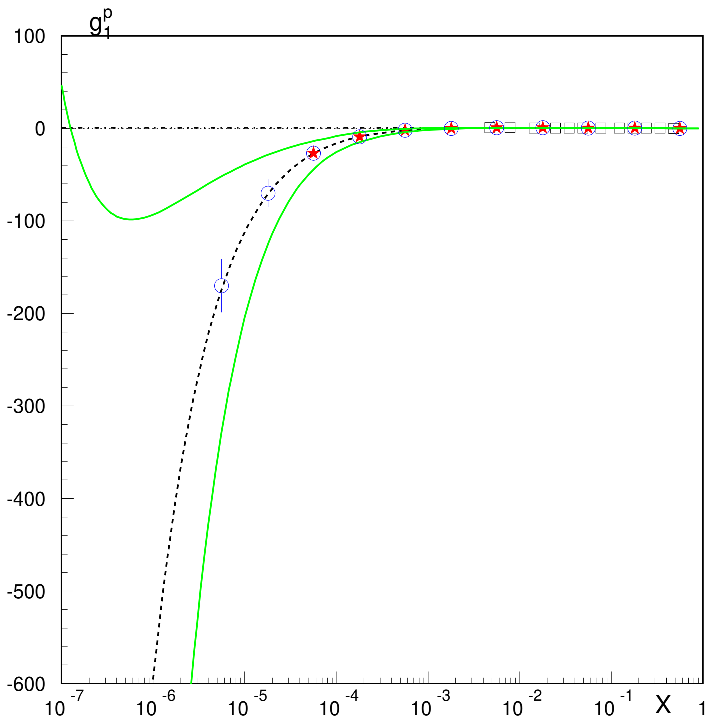
Next Linear Collider Project @ DESY:

- $e^+ \cdot e^-$ 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

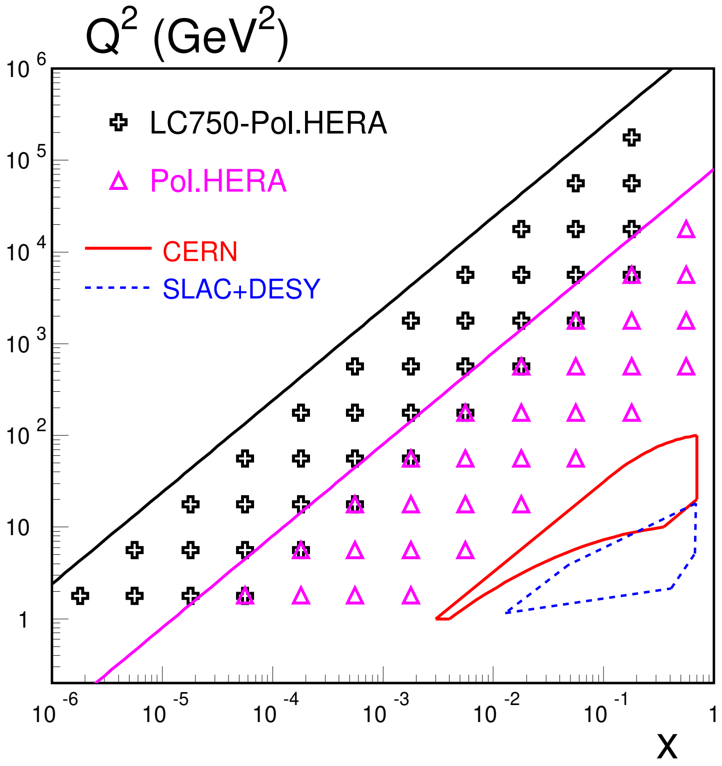
A. Deshpande

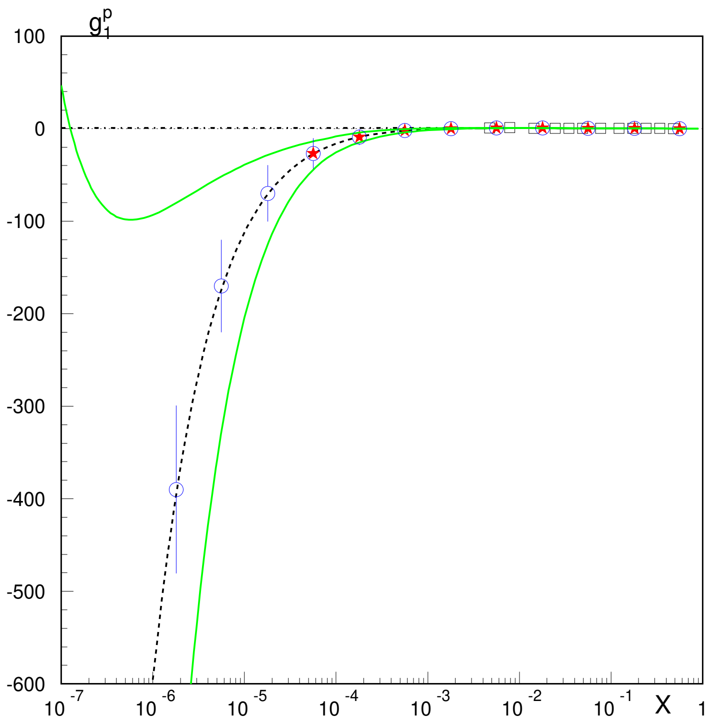




Linear Collider on Polarized HERA

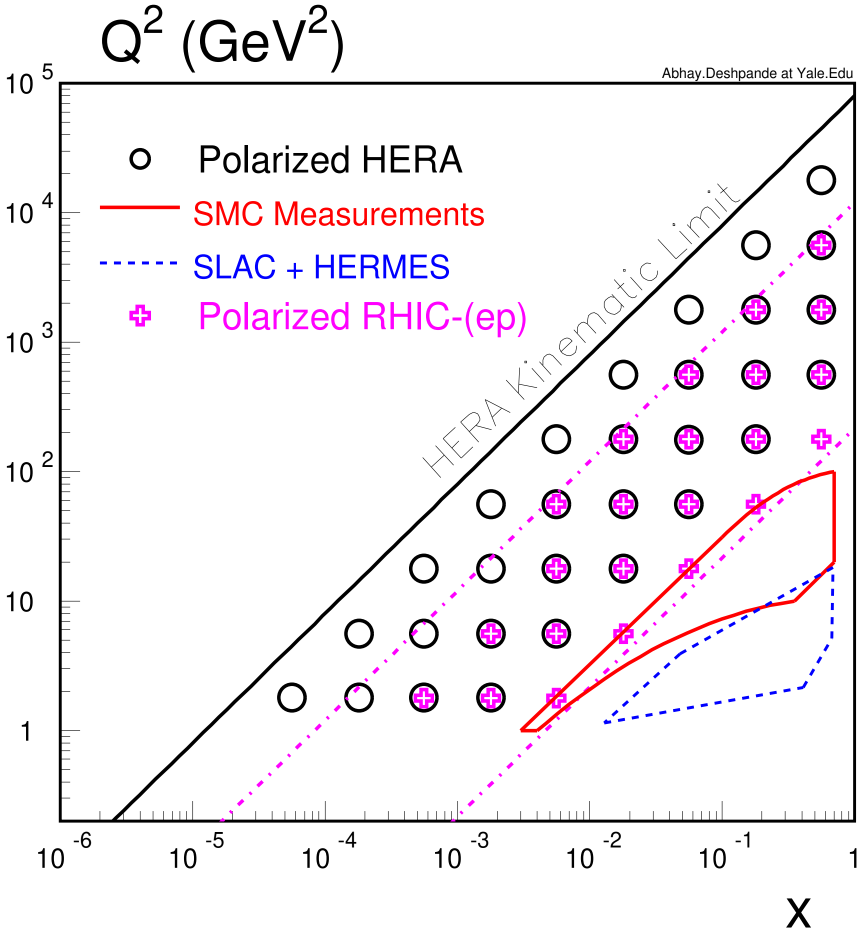
A. Deshpande





An Electron Ring in RHIC Tunnel

- Possible **10-12 GeV** electron ring in RHIC tunnel (??)
- Will enable $e \cdot A$ and $\vec{e} \cdot \vec{p}$ scattering
- $\vec{e} \cdot \vec{p}$ Collisions with $\sqrt{s} \sim 100$ GeV $\Longrightarrow$ **A Mini-Hera**
  Recall for HERA $\sqrt{s} \sim 300$ GeV



- Physics program similar to Polarized HERA: but **somewhat limited** **Is this enough?**
  Luminosity issues might be crucial
- e-p beam energy imbalance similar to HERA $\longrightarrow$ New detector?
- **Dedicated studies needed**