E161

MEASUREMENT OF

GLUON SPIN DISTRIBUTION
IN NUCLEONS
USING POLARIZED OPEN CHARM
PHOTOPRODUCTION

- WHY MEASURE THIS
- SOME THEORY
- EXPERIMENTAL SETUP
- PROJECTED RESULTS
- OTHER EXPERIMENTS
E161 COLLABORATION

- UCLA
- Jefferson Lab
- University of Liverpool
- Los Alamos
- University of Massachusetts
- SACLAY
- Institut fur Kernphysik, Mainz
- Old Dominion University
- Ruhr-Universität Bochum, Germany
- Smith College
- SLAC
- University of Virginia
- College of William and Mary
- Yerevan Physics Institute, Yerevan, Armenia
WHY MEASURE
THE GLUON POLARIZATION?

1. FUNDAMENTAL SUM RULE

\[ \frac{1}{2} = \frac{1}{2} \cdot \Delta \Sigma + \Delta G + L_z \]

- \( \Delta \Sigma \approx 0.23 \pm 0.07 \)
- \( L_z \) includes quarks and gluons. Possible to measure it.

2. pQCD CONSISTENCY FOR ALL REACTIONS

- \( g_1 \) (SLAC, CERN, HERMES)
- PHOTOPRODUCTION
  (COMPASS, HERMES, SLAC?)
- P-P at RHIC

3. FUNDAMENTAL PROPERTY OF NUCLEON

- 30 YEARS ON UNPOLARIZED PARTON DISTRIBUTIONS
- 10 YEARS ON POLARIZED QUARKS
UNPOLARIZED QUARK DISTRIBUTIONS

DIS LEPTON SCATTERING

SLAC  electrons  1968-1986
HERA  electrons  1992-
EMC   muons    1976-1980
NMC   muons    1981-1990
BCDMS muon     1981-1985
CCFR neutrino  1980’s
NuTeV neutrino 1995

PROTON-PROTON

DIRECT PHOTON PRODUCTION

High $P_T$ JETS
Drell-Yan
Z, W, top production

⇒ SEARCH FOR NEW PHYSICS
POLARIZED PARTON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.
THE FIT OF Gluck, Reya, Stratmann and Vogelsang (1999)

\[ \Delta q(x, Q^2) = q_i^+(x, Q^2) - q_i^-(x, Q^2) \]

\[ \Delta g \text{ ONLY APPEARS in NLO} \]
POLARIZED PARTON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.

THE FIT OF E155 COLLABORATION (2000)

\[ \Delta G = \int_0^1 g(x) \, dx = 1.6 \pm 0.8 \pm 1.1 \]

Polarized Gluon Distributions at \( Q^2 = 4 \) (GeV/c)\(^2\)
POLARIZED GLUON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.

THE FITS OF
Altarelli, Ball, Forte and Ridolfi (1998)
\( \Delta G = 1 \) to 2.2
POLARIZED GLUON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.

VARIOUS FITS

- — — — Brodsky (1995) $\Delta G = 0.7$
- — — — Sterling (1996) $\Delta G = 1.7$
- · · · Forte AR Model (1996) $\Delta G = 1.1$
- - - - Forte OS model (1996) $\Delta G = 1.0$

![Graph showing various fits for polarized gluon distributions with different models and their corresponding $\Delta G$ values.](image)
HOW TO MEASURE $\Delta g(x, Q^2)$ DIRECTLY

POLARIZED PHOTON BEAM
POLARIZED LiD TARGET
PHOTON-GLUON FUSION

Photon-Gluon Fusion

\[ \gamma \quad \text{Photon-Gluon Fusion} \]

\[ g \quad \bar{c} \]

\[ c \]

\[ \bar{c} \]
TOTAL CHARM PHOTOPRODUCTION $\sigma$

$$\sigma_{\gamma p}(k) = \int_{x_{min}}^{1} g(x, Q^2) dx \int_{-1}^{1} \sigma(\hat{s}, \cos(\theta^*)) \beta d \cos(\theta^*)$$

$$x_{min} = 4m_c^2/2Mk$$

$$s = 2Mk + M^2$$

$$\beta = \sqrt{1 - 4m_c^2/\hat{s}} \text{ is the c.m. velocity of } c, \bar{c}$$

$$\hat{s} = xs \text{ is the energy of the photon-gluon system squared}$$

$$\sigma(\hat{s}, \cos(\theta^*)) \text{ is for the hard scattering}$$

↓↑ This proposal
\[
\downarrow\uparrow N + \downarrow\uparrow N \frac{f^q d^4 H}{I} = (\gamma) d J_o / (\gamma) d J_o \nabla = (\gamma) \, \text{cc} \, \nabla
\]

\[
\frac{g' - \frac{1}{g} + \frac{1}{g} + 1}{g + 1} \, (\gamma) = \frac{s}{(s) \sin \theta} \, 6 = (\gamma) \, \nabla
\]

Integrating over \( \cos \), this becomes

\[
\left[ \frac{n}{s \gamma^{\mu \nu} - \gamma^{\mu \nu}} \right] + \left[ \frac{n}{(s) \sin \theta} \right] \frac{s}{(s) \sin \theta} \, 6 = \left( \left( \cos \theta \right) \cos \theta \right) \, \nabla
\]

Where

\[
\left( \left( \cos \theta \right) \cos \theta \right) \, \nabla = \left( \left( \cos \theta \right) \cos \theta \right) \, \nabla \int \int \int x \, r \, x \, \nabla \, \frac{\mu \mu x}{I} = (\gamma) d J_o \, \nabla
\]

\[
\downarrow\uparrow o - \uparrow\downarrow o = \nabla
\]
CROSS SECTION and $\Delta \sigma$

DEPENDENCY ON CENTER OF MASS ANGLE

![Graph showing the relationship between $\sigma(\beta,|\cos(\theta^*)|)$ and $\Delta \sigma(\beta,|\cos(\theta^*)|)$ depending on $\hat{s}$ values.]
This proposal

(I. Bojak and M. Stratmann)
also calculated by Z. Merebashvili et al.
### EXPERIMENTAL STRATEGY

**TAG CHARM WITH SINGLE DECAY $\mu$**

<table>
<thead>
<tr>
<th></th>
<th>$D^+$</th>
<th>$D^0$</th>
<th>$D_s^+$</th>
<th>$\Lambda_c^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>produced (%)</td>
<td>19</td>
<td>63</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Branching Ratio (%)</td>
<td>17</td>
<td>7</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>decay to $\mu^+$ (%)</td>
<td>37</td>
<td>47</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$D^-$</th>
<th>$\bar{D}^0$</th>
<th>$D_s^-$</th>
<th>$\Lambda_c^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>produced (%)</td>
<td>21</td>
<td>71</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>decay to $\mu^-$ (%)</td>
<td>40</td>
<td>53</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Fraction of different charmed particles produced with $k=40$ GeV photons and a deuterium target with $p_T > 0.5$ GeV generated using PYTHIA 5.7. Also shown is the percent of muons of each charge which ORIGINATED from the parent charmed particle.
BACKGROUND

OTHER SOURCES OF $\mu$

- $\mu$ FROM K and $\pi$ DECAY (Long Lifetime)
- Bethe-Heitler $\mu$ PAIRS
- J/$\psi$ DECAY (Small)
- VECTOR MESON DECAYS (Small)

PHYSICS BACKGROUND

- ASSOCIATED PRODUCTION (Small)
- FINAL STATE INTERACTIONS (Small)
- DIFFRACTIVE PRODUCTION (Small)
EXPERIMENTAL STRATEGY

- **HIGH POLARIZATION TARGET**
- **HIGH POLARIZATION BEAM**
- **MOMENTUM of $\mu$**
  - High Field Magnet
  - Fine Grain Hodoscopes
  - Good Time Resolution
- **ABSORB K and $\pi$ BEFORE DECAY**
  - $\sim 10$ Interaction Lengths
  - Monte Carlo Predicts Rates
  - Asymmetry Very Small (E155)
  - Two Absorber Setups
    - 75% and 25% of Time
  - Multiple Scattering of $\mu$ Almost the Same
- **VETO $\mu^+\mu^-$ PAIRS**
  - (B-H, J/\psi, VECTOR MESONS)
    - Some Singles Remain (Acceptance)
SIGNAL/BACKGROUND
BEFORE DECAY SUBTRACTION

K=35 GeV
K=40 GeV
K=45 GeV

10 < P_μ < 15
5 < P_μ < 10
SIGNAL/BACKGROUND

DECA Y SUBTRACTED
μ SPECTROMETER

NORMAL MODE

TOP VIEW

Return Yoke

Coil.

Lead Shielding

Alumina Absorber

Lead Shielding

Coil.

LASS DIPOLE

Front View of Plane 1
(horizontal bars, simplified)

Front View of Plane 1
(vertical bars, simplified)

Plane 1

Plane 2

Plane 3

Copper Pipe

Photon Beam

15 GeV

10 GeV

5 GeV

1 METER
BACKGROUND: $\pi, K$ DECAY
CROSS SECTION

Hadron Cross Sections from E154

Cross Section (nb/sr/GeV)

$P$ (GeV/c)

- - WISER FIT
- - PYTHIA

2.75 deg.
5.5 deg.
BACKGROUND: \( \pi, K \) DECAY

E155 HADRON ASYMMETRY 5.5°
BACKGROUND: \( \pi, K \) DECAY

E155 HADRON ASYMMETRY 2.75°
PHYSICS BACKGROUND
NORMAL HADRONIZATION

Photon-Gluon Fusion

γ
c

D
Baryonic String

N
π

N
π

Mesonic string

D

K
PHYSICS BACKGROUND
ASSOCIATED PRODUCTION

Photon–Gluon Fusion

- FACTORIZATION
- RELATIVE DETECTED CROSS SECTION (Few Percent)
- HOW DOES $c$ INTERACT WITH POLARIZED TARGET FRAGMENTS?
Mostly from $D$ (c quark) \( \Rightarrow \) No $\Lambda_c^+$

$\mu^+$ Mostly from $D$ (c quark) \( \Rightarrow \) No $\Lambda_c^+$

$\mu^-$ Mostly from $\bar{D}$ ($\bar{c}$ quark) \( \Rightarrow \) c quark can form
\( \Lambda_c^+ \) PRODUCTION INDEPENDENT OF TARGET FRAGMENT POLARIZATION

- \( \Lambda_c^+ = cud \) with ud in Spin=0 State
- Production does NOT Depend on Polarization of \( c \) Quark.
- Production Does NOT Depend on Polarization of Target Fragments.
- Decay of Polarized \( \Lambda_c^+ \): small correction

DIFFERENCE BETWEEN \( \mu^+ \) and \( \mu^- \)

- Checks These Ideas
- Can Extrapolate to Zero Associated Product
## BEAM PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Energy (GeV)</td>
<td>45.1, 48.3, 51.5 ***</td>
</tr>
<tr>
<td>Electron Current ($10^{10}$/spill)</td>
<td>2.0, 2.0, 2.0</td>
</tr>
<tr>
<td>Peak Photon Energy (GeV)</td>
<td>35.0, 40.0, 45.0</td>
</tr>
<tr>
<td>Photons ($10^7$/spill)</td>
<td>2, 1.5, 1.1</td>
</tr>
<tr>
<td>Circular Polarization</td>
<td>0.75, 0.80, 0.84</td>
</tr>
<tr>
<td>High $p_t$ Muons/day</td>
<td>160,000, 140,000, 120,000</td>
</tr>
<tr>
<td>days (at 120 Hz, 100% efficiency)</td>
<td>9, 10, 11</td>
</tr>
</tbody>
</table>

*** Use **48.3 GeV, Different Diamond Orientation**

🔥 **E155 had $3 \times 10^9$ e$^-$ into ESA**
• Polarization Data taken Simultaneously with PGF
• Pairs with $1.2 < M_{\mu\mu} < 2.8$ GeV.
• $>5$ times the PGF rate.
• Elastic (from $^6\text{Li}$), Quasi Elastic and Inelastic Contributions.
• Relative importance depends on kinematics.
• Depends on Nuclear and Nucleon Form Factors and Polarized Structure Functions.
• Asymmetry about 3% depending on Kinematics.
EXPECTED RESULTS
AVERAGE

SYSTEMATIC ERRORS $\sim 8\%$
OTHER EXPERIMENTS

COMPASS

- NEXT GENERATION SMC
  5 TIMES SMC LUMINOSITY
- $\mu + d \rightarrow c\bar{c}$ (LiD TARGET)
- DETECT $D$, $\bar{D}$
- BEAM ENERGY = 160 GeV
- MOST OF DATA AT VERY LOW $Q^2$
- ALSO USE HIGH $P_T$ JETS
- START UP JUNE 2001
- PROBABLY SLOW STARTUP
OTHER EXPERIMENTS
HERMES

- LOW ELECTRON ENERGY (27 GeV)
- LOW LUMINOSITY
- RUNNING NOW
- TWO “HIGH $P_T$ JETS”
- $0.06 < x < 0.28$
- FIRST RESULTS: $\Delta G/G = 0.41 \pm 0.18$

**RHIC**

Gluon Compton Scattering

$$g + q \rightarrow \gamma + X$$

$$A_{LL} \cdot d\sigma \sim \Sigma a \cdot \Delta q_a \cdot \Delta g \cdot d\Delta\sigma (q_a + g \rightarrow \gamma + X)$$

Gluon Fusion

$$g + g \rightarrow jet + jet$$

$$A_{LL} \cdot d\sigma \sim \Delta g \cdot \Delta g \cdot d\Delta\sigma (g + g \rightarrow X + X)$$
COMPARISON OF EXPERIMENTS

ESTIMATED PROJECTED ERRORS

COMPASS 3 YEARS
\( \gamma g \) fusion

STAR and PHENIX

HERMES
(REAL DATA)

E161
REQUEST TO SLAC

- RESOURCES TO BUILD BEAM
- RESOURCES TO BUILD DETECTOR
- RESOURCES FOR TARGET MAGNET and $\mu$WAVE HARDWARE
- 3 WEEKS CHECKOUT AT LOW REPETITION RATE
- 2 MONTHS OF DATA TAKING
  - 120 Hz Parasite on PEP-II
  - 50% Data Collection Efficiency
CONCLUSIONS

- **IMPORTANT TO MEASURE** $\Delta g/g$
- **E161 CAN MEASURE** $\Delta g/g$ **DIRECTLY**
- **PRECISION $\geq$ OTHER EXPERIMENTS**
- **COMPLEMENTARY TO OTHER EXPERIMENTS USING DIFFERENT HARD SCATTERING PROCESSES**