G0 backward angle

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Hall C Users group meeting

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Motivation

Strange quark contribution to the electro-magnetic properties of the nucleon

\[ P = uud + u\bar{u} + d\bar{d} + s\bar{s} + g + .... \]

\[ \langle \text{sea} \rangle \]

- s quark: cleanest candidate to study the sea:

- Momentum: \[ \int_0^1 x(s(x) + \bar{s}(x))dx \sim 4\% \] (DIS)
- Mass: \[ m_s \langle N | s\bar{s} | N \rangle \sim 30\% \] (pion-N)
- Spin: \[ \langle N | \gamma^{\mu} \gamma^5 s | N \rangle \sim 10\% \] (Polarized DIS)

- Charge and current Contribution to the Nucleon: \[ \text{?? Form Factors } G_E^s, G_M^s \]
Strange Quark Contribution to the Nucleon Properties

Polarized electrons, unpolarized target ->

\[ A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[ \frac{-G_F Q^2}{4\pi\alpha \sqrt{2}} \right] \frac{A_E + A_M + A_A}{\sigma_p} = 2 \]

\[ A_E = \varepsilon(\theta) G_E^Z G_E^\gamma \]
\[ A_M = \tau G_M^Z G_M^\gamma \]
\[ A_A = -(1 - 4\sin^2 \theta_W)\varepsilon' G_A^e G_M^\gamma \]

Suppose charge symmetry:

\[ G_{E,M}^Z (Q^2) = (1 - 4\sin^2 \theta_W)(1 + R_A^p)G_{E,M}^p - (1 + R_A^n)G_{E,M}^n - G_{E,M}^s \]
\[ G_A^e (Q^2) = -G_A^e + (\eta F_A^\gamma + R_e) + \Delta s \]

Separation \( \rightarrow \) Requires 3 measurements
## Experiments

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>$Q^2$ (GeV/c)^2</td>
<td>0.04, 0.1</td>
<td>0.48</td>
<td>0.1</td>
<td>0.1, 0.23</td>
<td>0.12 - 1.0</td>
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<tr>
<td>Angle</td>
<td>B</td>
<td>F</td>
<td>F</td>
<td>F/B</td>
<td>F/B</td>
</tr>
<tr>
<td>Target</td>
<td>H, D</td>
<td>H</td>
<td>H, $^4$He</td>
<td>H</td>
<td>H, D</td>
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<tr>
<td>Separation</td>
<td>$G_M^s$, $G_A^{(p+n)}$</td>
<td>$G_E^s$, $G_M^s$, 0.4</td>
<td>$G_E^s$, $G_M^s$</td>
<td>$G_E^s$, $G_M^s$</td>
<td>$G_E^s$, $G_M^s$, $G_A^{(p+n)}$</td>
</tr>
</tbody>
</table>

- New proposal for Happex III at 0.6 GeV^2
- Full A4 program within the 3 next years
- GO full program March. 2007
G0 Measurements

Program to separate the 3 form factors,
3 # measurements are needed:

- Forward angle $e^+ p$ (elastic).... 2004
- Backward angle $e^+ p$ (elastic)...Oct 2006
- Backward angle $\vec{e} + d$ (quasi-elastic)...Underway

Other physics topics from G0 data:

- Inelastic electron scattering: N-$\Delta$ axial form factor (Carissa)
- Transverse polarization asymmetries: 2-$\gamma$ exchange (Sarah)
- Pion production asymmetries
G0 Backward Collaboration


PhD students

Stephanie Bailey**: W&M, USA
Carissa Capuano**: W&M, USA
Alexandre Coppens: Manitoba, Canada
Colleen Ellis: Maryland, USA
Juliette Mammei *: Virginia Tech. USA.
Mathew Muether: Illinois, USA
John Schaub: NMSU, USA.
Maud Versteegen: LPSC, France.
G0 Backward Angle

- Electron Beam: 362 and 687 MeV → $Q^2$: 0.23 and 0.62 GeV$^2$

• Turn-around the magnet, change polarity.
• LH2 or LD2 target, electron detection: $\Theta = 108^\circ$.
• Add Cryostat Exit Detectors (9 CEDs per Octant)→ separate elastic and inelastic electrons in the CED*FPD space.
• Aerogel Cerenkov for $\pi/e$ separation ($p_\pi < 380$ MeV/c)
Polarimetry and Target

- Polarimetry

- Laser upgraded; Strained-superlattice GaAs In Gun2 (“new” material) ~ 85% Polarization

- Mott Measurements: Aceelerator

- Moeller Measurement: Gaskell, Horn

- Moller 85-86% is consistant.
- Mott ~82-85 %
- Systematic offset of ~5% between Moeller&Mott.

- Target: Smith

- Good performance
- 1000 W !!!
G0 Backward Schedule

Running Periods

March – May 06   LH2 687 MeV.
May 06 (tests)   LD2 362 MeV.
July-Aug         LH2 362 MeV.
Sep-Oct 06       LH2 687 MeV.
Nov-Dec 06       LD2 687 MeV.
Jan-Feb 07,      LD2 362 MeV.
Mar 07           LD2 687 MeV.

Total accumulated charge:
LH2 (687 MeV) -> ~100 C
LH2 (362 MeV) -> ~90 C
LD2 (687 MeV) -> ~37 C ... need more data 😞
LD2 (362 MeV) -> ~28 C ... In progress.

- LD2 → high singles rates in Cerenkov PM tubes from neutrons, replace w/ quartz face tubes, therefore 3 more requested weeks were granted.
Beam Specifications

- 2 ns beam structure, ~85% polarization
- Beam Energy (Jones)

<table>
<thead>
<tr>
<th>Beam Parameter</th>
<th>Achieved (IN-OUT)/2</th>
<th>“Specs”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge asymmetry</td>
<td>0.09 +/- 0.08</td>
<td>2 ppm</td>
</tr>
<tr>
<td>x position difference</td>
<td>-19 +/- 3</td>
<td>40 nm</td>
</tr>
<tr>
<td>y position difference</td>
<td>-17 +/- 2</td>
<td>40 nm</td>
</tr>
<tr>
<td>x angle difference</td>
<td>-0.8 +/- 0.2</td>
<td>4 nrad</td>
</tr>
<tr>
<td>y angle difference</td>
<td>0.0 +/- 0.1</td>
<td>4 nrad</td>
</tr>
<tr>
<td>Energy difference</td>
<td>2.5 +/- 0.5</td>
<td>34 eV</td>
</tr>
<tr>
<td>Beam halo (out 6 mm)</td>
<td>&lt; 0.3 x 10^-6</td>
<td>10^-6</td>
</tr>
</tbody>
</table>

Two helicity states: IHWP in and out

Apr 17th 2006  685.57 +/- 0.92 MeV
Sept 27th 2006 684.86 +/- 0.92 MeV
Dec 19th 2006  689.61 +/- 0.93 MeV
Low energy: (e-p from HallA)

Parity quality; Data from December

Suleiman, Bailey, Schaub, Pitt.
Mammei: BCM&BPM calibrations
Electronics

- Customized CED*FPD coincidence boards: Louisiana Tech. & Grenoble.
  - Read Scalers for each CED*FPD combination -> Build the coincidence matrix.
- G0 backward uses 2 kinds of Trigger:
  - Electron trigger: CED*FPD*Cerenkov
  - Pion trigger: CED*FPD no Cerenkov
CED-FPD Matrix Pattern

LH2, LD2 687 MeV: $Q^2 = 0.62 \text{ (GeV/c)}^2$

- Elastic band: $e^+p \rightarrow e^+p$
- Inelastic band: $N-\Delta$
- Dalitz: $e^+p \rightarrow \pi^0 + p \rightarrow 2\gamma \rightarrow e^+e^-$
- Super-elastic: no physics

LH2, LD2 362 MeV: $Q^2 = 0.23 \text{ (GeV/c)}^2$

- Quasi-elastic band: $e^+d \rightarrow e^+X \ (X=p \text{ or } n \text{ in } D)$
- Inelastic band: $N-\Delta$
- Dalitz: $e^+p \rightarrow \pi^0 + p \rightarrow 2\gamma \rightarrow e^+e^-$,
  $e^+n \rightarrow \pi^0 + n \rightarrow 2\gamma \rightarrow e^+e^-$, etc..
- Super-elastic: no physics

Locus determination: Field scans: Muether
Simulations: Beise
Yields Along the Matrix

LH2, 678 MeV

LH2, 362 MeV

LD2, 678 MeV

LD2, 362 MeV
Analysis Strategy for $G_0$

Blinding Fatcor (Mult.)

LH2, LD2 Raw Asymmetries, $A_{meas}$

Instrumental & Beam corrections:
- Electronic Deadtime/Randoms
- Helicity-correlated beam properties
- Beam polarization

Background corrections:
- Dilution Factors
- Background from target
- Pion Contamination

Previous experiments $G_{E}^{s}+\eta G_{M}^{s}$

Unblinding

LD2 $A_{phys}$  LH2 $A_{phys}$

Q2 Determination

$G_{e}^{s}$  $G_{m}^{s}$  $G_{A}^{e}$
Raw Asymmetries

LH2, 687 MeV

LD2, 687 MeV

LH2, 362 MeV

LD2, 362 MeV

In progress

Figures made by Meuthers.
Preliminary Raw Elastic Asymmetries

LH2, 687 MeV

LD2, 687 MeV

LH2, 362 MeV

LD2, 362 MeV

in progress
Deadtime/Randoms Corrections

- Dead Time corrections:
  Simulated the complete electronics chain (P. Pillot)

  LH2, 687 MeV, 60 uA  ~7%
  LH2, 362 MeV, 60 uA  ~6%
  LD2, 687 MeV, 30 uA  ~9%
  LD2, 362 MeV, 35 uA  ~10%

  (work in progress)

- Random corrections:

  - LH2, randoms are small.
  - LD2 target, randoms important
    In the inelastic band:
    -> change in the electronics (Breuer)
Other corrections

- Linear regression (slope corrections): Stephanie, John

- Target windows: Flys water, Al, Radiator, etc… -> 3~4% (Alex)

- Contaminations: pions in electrons, vice versa -> Cerenkov efficiencies (Alex, Maud)

- Physics Contaminations: (Background & inelastic) under elastic, etc.. (Muether)

- Transverse Polarization

- Leakage test: Not much! 😊

- other tests…
Expected G0 Results

- Statistical -> goal: maximum statistics
- Systematic experimental: backgrounds
- Systematic from the nucleon form factors
Backup Slides
Transverse Asymmetries
362MeV, LH$_2$

Transverse Asymmetries (blinded)
Data Quality

**Elastic**
- A_oct1_ela_elec IHW Out
  - Entries: 1545926
  - Mean: -32.07
  - RMS: 1.919e+04

- A_oct1_ela_elec IHW In
  - Entries: 1545926
  - Mean: 41.53
  - RMS: 1.909e+04

**Inelastic**
- A_oct1_ine_elec IHW Out
  - Entries: 1545926
  - Mean: -33.74
  - RMS: 2.724e+04

- A_oct1_ine_elec IHW In
  - Entries: 1545924
  - Mean: 37.49
  - RMS: 2.707e+04

**Sup.elastic**
- A_oct1_sup_elec IHW Out
  - Entries: 1545926
  - Mean: +1.863
  - RMS: 3.013e+04

- A_oct1_sup_elec IHW In
  - Entries: 1545924
  - Mean: -17.75
  - RMS: 2.996e+04
Pion Data, 687 MeV

Inelastic, LH2

Elastic, LH2

LH2

LD2
Backgrounds and Shielding Design
(Breuer)

Open detector geometry $\rightarrow$ put shielding near sources of background (mostly g’s, n’s, GHz rate)

Optimize to minimize rate from existing sources without introducing new sources!

Significant geometry constraints (cryostat, crane access, detector frame, etc.)

Solution:

custom Al/Pb tubular insert strategically placed Pb/steel/ concrete

Example simulation of $\gamma$’s striking a detector ($E_\gamma > 10$ keV)
Beam Quality

LH2 Summer

LH2 Fall

LD2 Fall

LD2 Winter
Nucleon Form factors

PRELIMINARY
Simulation of Physics data, backgrounds

- LH2 elastic, inelastic rates and asymmetries
- LD2 quasielastic rates and asymmetries
  → implementation of calculation from R. Schiavilla that includes 2-body effects (w/ J. Hood)
- $\pi^+/$/$\pi^-$ production from H, D and Al windows, C solid targets
- $\pi^0$ production in LH2, LD2, Al $\rightarrow e^+/e^-$ rate
- Detector yields vs beam position/angle: needed for validation of removal of false asymmetries (w/ S. Toplosky)
- Detector yields vs magnetic field: used for validation of background subtraction (w/ M. Muether, UIUC)
- Acceptance vs z-position: used for Al window subtraction (w/ A. Coppens, Manitoba)
- Inelastic electron simulation (w/ S. Wells, LaTech, C. Capuano, W+M)
Cell by cell Asymmetry quality, Octant6
run 33502 (LD2 362MeV)
Cell by cell Yield quality, Octant6
run 33502 (LD2 362MeV)
Data Acquisition for G0 Backward

- ROC1
  - NA Scalar Data
- ROC4
  - NA Scalar Data
- ROC2
  - NA ARS
  - NA Scaler
- ROC3
  - SDMCH
- ROC7
  - CED-FPD board
  - Fr C Scaler
  - Fr ARS
- ROC8
  - NA Singles
- ROC5
  - TDC+ADC
- ROC31
  - INJ crate
- ROC13
  - DC (F1 TDC)
- ROC14
  - DC (F1 TDC)

Event Builder

Event Recorder

@gzerofile

G0 Analyser

Online

Offline

DataBase

Histos

Forward angle DAQ

Additions for the Backward DAQ

Hall C DAQ
- Dead Time corrections:
  Simulated the complete electronics chain (P. Pillot)

  LH2, 687 MeV, 60 uA  ~7%
  LH2, 362 MeV, 60uA  ~6%
  LD2, 687 MeV, 30 uA  ~9%
  LD2, 362 MeV, 35uA  ~10%

  (work in progress)

- Random corrections:
  LD2 case,
  change in the Electronics.
Forward +Happex results
Results from the Forward angle

Preferred model:

\[ G_E^s + \eta G_M^s = \frac{4\pi\alpha\sqrt{2}}{G_F Q^2} \left( G_E^p \left( 1 + R_V^{(0)} \right) \right) \left( A_{\text{phys}} - A_{\text{ANVS}} \right) \]

A non null strange quark contribution?

- R. Michaels talk tomorrow. (Results from Happex)

Need of backward measurements for complete separation.
e+d -> e' +X where X can be p + n broken up (either at threshold or quasielastic)
inelastic is similar: in both of these cases the physics is the same as
in LH2, except that one can scatter from neutron as well, and the nucleons are moving
also elastic e+D -> e' --- this is small compared with quasielastic, but has yet to be simulated -- the asymmetry is very sensitive to GMs so there may be a tiny correction.

e+p(in D)->pi0+ p -> 2gamma->e+e-
e+n(in D)->pi0 + n -> 2gamma->e+e-
e+d -> pi0 + d -> 2gamma->e+e-
Spin Dance

\[ P_{\text{meas}} = P_e \cos(\eta_{\text{Wien}} - \phi) \]

- For the left graph:
  - \( P_e = 86.33 \pm 0.39\% \)
  - \( \phi = 89.33 \pm 0.73\text{ degrees} \)

- For the right graph:
  - \( P_e = 85.47 \pm 0.57\% \)
  - \( \phi = 90.92 \pm 0.59\text{ degrees} \)
Cerenkov Efficiency

- 31 MHz data, separate pions from electrons.
- Maud, Alex; Analysis of 31 MHz data, independent analysis

LD2 NOV 2006 687 MeV Multiplicite 3 (Old PMTs)

<table>
<thead>
<tr>
<th>oct</th>
<th>eff</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53.95 +- 0.85</td>
</tr>
<tr>
<td>2</td>
<td>42.92 +- 0.94</td>
</tr>
<tr>
<td>3</td>
<td>44.31 +- 1.14</td>
</tr>
<tr>
<td>4</td>
<td>26.36 +- 0.51</td>
</tr>
<tr>
<td>5</td>
<td>31.23 +- 1.36</td>
</tr>
<tr>
<td>6</td>
<td>42.63 +- 0.60</td>
</tr>
<tr>
<td>7</td>
<td>30.32 +- 0.98</td>
</tr>
<tr>
<td>8</td>
<td>36.98 +- 0.62</td>
</tr>
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</table>

LD2 JANV 2007 360 MeV Multiplicite 2 (New PMTs)

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<th>oct</th>
<th>eff</th>
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<tbody>
<tr>
<td>1</td>
<td>86.32 +- 0.07</td>
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<tr>
<td>2</td>
<td>80.51 +- 0.04</td>
</tr>
<tr>
<td>3</td>
<td>81.97 +- 0.24</td>
</tr>
<tr>
<td>4</td>
<td>69.42 +- 0.04</td>
</tr>
<tr>
<td>5</td>
<td>76.21 +- 0.05</td>
</tr>
<tr>
<td>6</td>
<td>85.18 +- 0.03</td>
</tr>
<tr>
<td>7</td>
<td>72.83 +- 0.08</td>
</tr>
<tr>
<td>8</td>
<td>79.89 +- 0.04</td>
</tr>
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</table>
Physics contaminations
Dilution factors

(Muether)
Axial Anapole form factor

- Neutral weak vector charge of the electron
- Anapole effects,
- Electroweak radiative corrections

- Deuteron; effect will cancel, if one ignores final state interactions, etc…assume charge symmetry. (p-n) u,d quarks.
Contamination by Target Al windows

Counting rates for on CED as a function of FPD number (in kHz/uA):

- LH2 @ 687 MeV
- Total Al windows - Entrance + Vacuum Window - Exit Window

~4% @362 and 687MeV

Al data Asymmetries:

@362MeV:
Elastic : -18 +/- 29ppm
Inelastic : 21 +/- 41ppm

@687MeV:
Elastic : -48 +/- 72ppm
Inelastic : -2 +/- 41ppm

- LH2 @ 687 MeV
- Total Al windows
- Entrance + Vacuum Window
- Exit Window