OVERVIEW OF E159, E160, E161
D.O.E. Review April 3, 2001
P. Bosted

• A cohesive program of three fixed target photoproduction experiments.

• Significant overlaps in beam, target, and detectors; maximizes physics output for investment needed.

• Approved at Nov. 2000 EPAC meeting.

• Plan to run several calendar months each.
  2003: E160 $A$-dependence of $J/\psi$
  2004: E161 $\Delta G(x)$ from Open Charm
  2005: E159 GDH Sum Rule

• Experiments joined together to form Real Photon Collaboration
REAL PHOTON COLLABORATION

- UCLA
- INFN Frascati, Italy
- Jefferson Lab
- University of Liverpool
- Los Alamos
- University of Massachusetts
- Saclay, France
- 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
E160: MEASUREMENT OF THE $\Lambda$-DEPENDENCE OF $J/\psi$ AND $\psi'$ PHOTOPRODUCTION

K Griffioen, P. Bosted, D. Crabb co-spokespersons

Planned to run in 2003

http://www.slac.stanford.edu/exp/e160/

- Goals:
  - Learn about creation and interaction of $J/\psi$ and $\psi'$ in nuclei.
  - Understand why VMD and geometrical expectations for $\sigma_{N}^{\psi}$ are at odds.
  - Constrain causes for $J/\psi$ suppression in relativistic heavy-ion collisions by using simpler probe in same energy region.
Measurement:

- Reconstruct $J/\psi$ from $\mu^+\mu^-$ pairs.
- Identify quasi-elastic events with fit to $p_t$-distribution
- Use Be, Al, Cu, Pb targets
- Use 15, 25, and 35 GeV photons

Anticipated Results:

- $t$-distributions
- $\alpha$ from $\sigma_A \propto A^\alpha$ at 15, 25, 35 GeV
- $\psi$-nucleon cross section $\sigma_{\psi N}^{\text{tot}}$ at 15, 25, 35 GeV with much smaller errors than previous experiments.
- First look at $\psi'$-nucleon cross section $\sigma_{\psi N}^{\text{tot}}$
E160 Spectrometer

- 29D32 Dipole Magnet $\int B \cdot dl = 22$ kG-m
- 70D43 LASS Dipole Magnet $\int B \cdot dl = 25$ kG-m.
- 2.2 m alumina ($\text{Al}_2\text{O}_3$) absorber with tungsten core.
- 3 planes of scintillator hodoscopes.
Photon Intensity (Energy Weighted Flux) and Acceptance-Weighted $J/\psi$ Rate Versus Photon Energy for 3 Settings
Length Scales

- \( l_c \) and \( l_F \)
- \( L \) (nuclear radius)

**Graph:**
- X-axis: Energy (GeV)
- Y-axis: length (fm)
- Lines:
  - Pb radius
  - Al radius
  - NN separation
  - Coherence length
  - Formation length
**ψ – N Cross Sections**

- **Data:** nucl-th/9806023 review

- **Glauber:**
  \[
  \frac{\sigma^{pA \to \psi}}{A\sigma^{pN \to \psi}} = e^{-L\rho_0\sigma_{\text{tot}}^{\psi N}}.
  \]

  in which \( L \) is the length of absorption trajectory, \( \rho_0 \) is nuclear density. If \( L \propto A^{1/3} \) then \( \sigma_{\text{tot}}^{\psi N} \propto A^\alpha \). \( \sigma_{\text{tot}}^{\psi N} \approx 6 \text{ mb}, \alpha \approx 0.92 \).

- **Vector Meson Dominance:** \( \sigma_{\text{tot}}^{\psi N} \propto \frac{d\sigma}{dt}(\gamma N \to \psi N)|_{t=0} \) by the optical theorem.

  \( \sigma_{\text{tot}}^{\psi N} \leq 1 \text{ mb} \).

- **Geometry:** \( \sigma_{\text{tot}}^{\psi N} \) is proportional to the square radius. \( \sigma_{\text{tot}}^{\psi N} = 2 - 5 \text{ mb} \).
Projected Results

Photoproduction

\[ \alpha \]

\[ E_\gamma \text{ (GeV)} \]

- SLAC (17 GeV); FNAL (120 GeV)
- E160 estimated errors
Error Estimates on $\sigma_{\psi N}^{\psi N}$

Total Cross Sections

![Graph showing error estimates on total cross sections](image-url)

Error Estimates on $\sigma_{\psi N}^{\psi N}$

![Graph showing error estimates on total cross sections](image-url)
E161

MEASUREMENT OF

GLUON SPIN DISTRIBUTION
IN NUCLEONS
USING POLARIZED OPEN CHARM PHOTOPRODUCTION

S. Rock, D. Crabb, P. Bosted co-spokespersons

Planned to run in 2004

http://www.slac.stanford.edu/exp/e161/
WHY MEASURE
THE GLUON POLARIZATION?

1. FUNDAMENTAL SUM RULE
   \[ \frac{1}{2} = \frac{1}{2} \cdot \Delta \Sigma + \Delta G + L_z \]
   - \( \Delta \Sigma \sim 0.23 \pm 0.07 \) (from quarks)
   - \( \Delta G \) (from Gluons)
   - \( L_z \) includes quarks and gluons. Possible to measure it.

2. pQCD CONSISTENCY FOR ALL REACTIONS
   - \( g_1 \) FROM DIS (SLAC, SMC, EMC, 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
WHAT WE KNOW

POLARIZED PARTON DISTRIBUTIONS FROM pQCD EVOLUTION EQUATIONS.

THE FIT OF
Gluck, Reya, Stratmann and Vogelsang (1999)

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

\[ \Delta g \text{ ONLY APPEARS in NLO} \]
HOW TO MEASURE $\Delta g(x, Q^2)$ DIRECTLY

POLARIZED PHOTON BEAM
POLARIZED LiD TARGET
PHOTON-GLUON FUSION

Photon-Gluon Fusion
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>fraction of $\mu^+$ (%)</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>$D^0$</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>fraction of $\mu^-$ (%)</td>
<td>40</td>
<td>53</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

BACKGROUNDS

- $\mu$ FROM K and $\pi$ DECAY (Long Lifetime)
- Bethe-Heitler $\mu$ PAIRS
- $J/\psi$ DECAY (Small)
- VECTOR MESON DECAYS (Small)
- ASSOCIATED PRODUCTION (Small)
- FINAL STATE INTERACTIONS (Small)
- DIFFRACTIVE PRODUCTION (Small)
EXPERIMENTAL STRATEGY

• HIGH POLARIZATION TARGET

• HIGH POLARIZATION BEAM

• MEASURE MOMENTUM of $\mu$
  – High Field Magnet
  – Fine Grain Hodoscopes
  – Good Time Resolution

• ABSORB K and $\pi$ BEFORE DECAY
  – $\sim$ 10 Interaction Lengths (38 R.L.)
  – 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)
  – Calculate Based on Pairs and Known $\sigma$
NORMAL MODE

SPECTROMETER
EXPECTED RESULTS
for Asymmetry in Cross Sections with photon/nucleon Spins parallel or anti-parallel
COMPARISON OF EXPERIMENTS

ESTIMATED PROJECTED ERRORS

COMPASS 3 YEARS
\( \gamma g \) fusion

STAR and PHENIX

HERMES
(REAL DATA)

\( \Delta G/G \)

X

0.0
0.1
0.2
0.3
0.4

0.0
0.25
0.50
0.75
1.00
Proposal to Measure $\Delta \sigma^{\gamma N}(k)$ and the High Energy Contribution to the Gerasimov-Drell-Hearn Sum Rule

P. Bosted, D. Crabb co-spokespersons

Planned to run in 2005

http://www.slac.stanford.edu/exp/e159/
INTRODUCTION

- Total photoabsorption cross section $\sigma^{\gamma N}(k)$ depends only on photon energy $k$ for real photons.

- Can be decomposed into spin 1/2 and 3/2 final states $\sigma_{3/2}$ and $\sigma_{1/2}$, corresponding to helicity of photon aligned or anti-aligned with spin of nucleon.

- Spin-averaged $\sigma^{\gamma N}(k) = (\sigma_{1/2} + \sigma_{3/2})/2$ well-measured (including SLAC early 1970’s). Roughly constant at 120 $\mu$b.

- We propose to measure

$$\Delta \sigma^{\gamma N}(k) = \sigma_{3/2} - \sigma_{1/2}$$

using circularly polarized photons and longitudinally polarized nucleons.
The GDH SUM RULE

- Relates integral over $\Delta\sigma(k)$ to anomalous magnetic moment $\kappa$ of target with spin $S$ (composite or elementary).

$$\int_{k=\pi}^{\infty} \frac{dk}{k} \Delta\sigma^N(k) = \frac{2\pi^2 \alpha \kappa^2}{M^2} \quad (1)$$

- Follows from general principles of causality, universality, Lorentz and electromagnetic gauge invariance.

- One assumption: that unsubtracted dispersion relation can be used for $f_2(\nu)$.

- Scale of convergence gives scale of highest spin-flip excitations of target.

- $\Delta\sigma^N(k)$ must decrease with $k$ at high $k$ for integral to converge. Contrast to $\sigma^N(k)$, known to increase with $k$ at high energies.
bullet Direct measurements only exist up to 800 MeV for proton, but various resonance region multi-pole analyses have made estimates of integrals.

<table>
<thead>
<tr>
<th>target</th>
<th>$2\pi^2\alpha\kappa^2/M^2$</th>
<th>Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton</td>
<td>204 $\mu$b</td>
<td>257 to 289 $\mu$b</td>
</tr>
<tr>
<td>neutron</td>
<td>232 $\mu$b</td>
<td>169 to 189 $\mu$b</td>
</tr>
<tr>
<td>isoscalar $(p+n)/2$</td>
<td>219 $\mu$b</td>
<td>213 to 239 $\mu$b</td>
</tr>
<tr>
<td>isovector $(p-n)/2$</td>
<td>-15 $\mu$b</td>
<td>34 to 65 $\mu$b</td>
</tr>
</tbody>
</table>

bullet Large discrepancy, especially isovector case.

bullet **Non-resonant** contribution important?

bullet **High energy** contributions important?

bullet Need **data** on both proton and neutron to find out.

bullet Worldwide program at Mainz, Bonn, GRAAL, SPIN8, LEGS, Jefferson Lab, TUNL, other, but limited to 5 GeV.
LOW ENERGY BEHAVIOR OF $\Delta\sigma(k)$

Preliminary data from Mainz on proton. Resonant excitations are evident (especially $\Delta(1232)$).
EXPERIMENTAL OVERVIEW

- Coherent bremsstrahlung provides circularly polarized photons $4 < k < 40$ GeV.

- Subtract incoherent contributions to obtain $\Delta \sigma(k)$ at discrete values of $k$.

- Longitudinally polarized $NH_3$ and $ND_3$ targets.

- Measure total cross section asymmetry with large calorimeters.

- Reject E.M. backgrounds with cuts, longitudinal segmentation of detector, and/or calculations

- Measure in Counting Mode for lower systematic error (each hadronic interaction is individually counted)

- Use Flux Integration Mode for smaller statistical errors (total hadronic energy summed over many interactions).
Target and Detectors

Target:
- 5 T Field
- NH3 / ND3
- 140 GHz Microwaves
- Dynamic Nuclear Pol.
- 90% proton pol.
- 40% deuteron pol.
- nitrogen unpolarized

Large-Theta Detector

Small-Theta Detector

Coils

Cross Section of one layer

Alternating planes of horizontal and vertical scintillator strips

27 EM and 53 Had layers summed with longitudinal wave-shifter bars
EXPECTED ERRORS FOR PROTON

Systematic errors (not shown) expected to be 6% to 8% (relative).

EXPECTED ERRORS FOR NEUTRON
SUMMARY OF E159

- A fundamental experiment, providing baseline for studies of spin structure of nucleon.
- Test convergence of isovector and isoscalar GDH Sum Rule.
- Connections to $g_1$ at low $x$, Bjorken Sum Rule.
- No existing data: surprises possible!
- Study QCD in non-perturbative regime with one of simplest possible interactions.
- SLAC is only place experiment can be done $5 < k < 40$ GeV.
- Energy range extends factor 8 beyond Jefferson Lab.
- Strong collaboration with experience and resources needed to do experiment.
SUMMARY OF REAL PHOTON EXPERIMENTS

• Unique opportunity: experiments cannot be done elsewhere (even if Jlab 12 GeV upgrade happens).

• Cost effective, using much existing equipment.

• Simultaneous operation with PEP-II will be possible.

• Interesting physics shedding light on charm, quark-gluon plasma, and spin structure of the nucleon.