

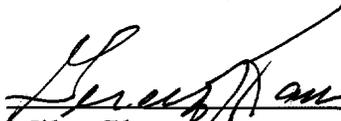
Nuclear Studies
with Intermediate Energy Probes

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Final Technical Report

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The bulk of the research work supported by Grant # DE-FG05-87ER40364 was carried out at the following laboratories:

- 1) the Nationaal Instituut voor Kernfysica en Hoge-Energiefysica (NIKHEF) in Amsterdam, Holland;
- 2) the Saskatchewan Accelerator Laboratory (SAL) in Saskatoon, Saskatchewan, Canada;
- 3) the Brookhaven National Laboratory (BNL);
- 4) the Thomas Jefferson National Accelerator Facility (TJNAF); and
- 5) the Triangle Universities Nuclear Laboratory (TUNL).

Additional theoretical design work on related topics in Accelerator Physics was carried out independently of these facilities.

The results of the research carried out have been reported in 57 articles appearing in refereed journals; 26 invited talks, seminars, and colloquia; and 32 conference proceedings. In addition, 5 PhD degrees have been awarded on the basis of this research. Some data obtained while we were supported by this grant are still being analyzed and the results will appear in the near future.

The work initiated under this grant is being continued with the support of US DOE Grant # DE-FG02-97ER41025.

NIKHEF

The research performed at NIKHEF can be divided into three components: experiments in the EMIN experimental hall using the beam from the Medium Energy Accelerator (MEA), experiments with internal targets in the Amsterdam Pulse Stretcher (AmPS), and studies of electron beam physics.

The first experiments we performed in the EMIN hall while supported by this grant were of inelastic electron scattering from ^{42}Ca and ^{44}Ca . These measurements were analyzed in conjunction with parallel measurements of intermediate energy proton scattering measurements from these nuclei previously carried out at the Indiana University Cyclotron Facility (IUCF)

and the Los Alamos Meson Physics Facility (LAMPF). The combined analyses enabled us to determine simultaneously both the proton and neutron transition densities, thereby placing stringent constraints on models of these nuclides. The results of these measurements appeared in articles 4, 9, and 13 in the following list and were the basis for the PhD thesis of H.P. Karen (2).

The next experiments involved measurements of the reactions ${}^6\text{Li}(e,e'd){}^4\text{He}$ and ${}^{12}\text{C}(e,e'd){}^{10}\text{B}$ to examine the degree of nucleon correlations present in nuclei. The results of these measurements were presented in article 3.

The last set of experiments we performed in the EMIN hall were of threshold electroproduction of neutral pions from the proton via the coincidence reaction $p(e,e'p)\pi^0$. These measurements refuted earlier claims of a violation of the low energy theorems and were a sensitive test of the predictive power of Chiral Perturbation Theory. The results of these measurements appeared in articles 14, 20, and 35 in the following list; were presented in talks 8, 9, 11, and 12; and were the basis of the PhD dissertation of T.P. Welch (1).

Starting in 1989 we worked closely with C.W. de Jager on the development of an internal target capability in the AmPS electron storage ring (see talks 1 and 5). In addition to working on the early conceptual design of the facility we worked on novel techniques for producing efficient gas jets for use as targets. For this purpose we looked into highly asymmetric nozzles which provided excellent focusing in one (important) direction at the expense of defocusing in the orthogonal (unimportant) direction. The results of this work appeared in article 23 and in conference proceedings 8.

In preparation for the internal target research program we worked on the development of an electron spectrometer. In particular, we constructed a large, diffusely reflective Cerenkov detector to be used with it. We also worked on the development of a polarized deuterium gas target and a Compton polarimeter with which to measure the longitudinal polarization of the stored electron beam. This development work is described in articles 37, 46, 51, 52, and 53 and appeared in conference proceedings 12, 19, 23, 25, 27, 28, and 29.

The experimental program carried out with the internal target facility focused on polarization observables in the scattering of polarized electrons

from polarized ^2H and ^3He . Reactions studied included $^2\text{H}(e,e)d$, $^2\text{H}(e,e'p)n$, $^2\text{H}(e,e'n)p$, $^3\text{He}(e,e)^3\text{He}$, $^3\text{He}(e,e'p)$, $^3\text{He}(e,e'n)$, and $^3\text{He}(e,e'^3\text{H})\pi^+$. Of particular note are our results on T_{20} for ^2H and on the electric form factor of the neutron. The results of these measurements are described in articles 36, 49, 50, 57, and 58; were presented in talks 20, 22, 23, 25, and 26; appeared in conference proceedings 11, 13, 14, 18, 20, 21, 24, 30, 31, and 32; and were the basis of the PhD dissertation of D.W. Higinbotham (5).

Saskatchewan Accelerator Laboratory (SAL)

At SAL we used a tagged gamma beam to measure the photoproduction of charged pions from p-shell nuclei. Of particular note was the iso-elastic reaction $^{14}\text{C}(\gamma, \pi^-)^{14}\text{N}_{1+,2,3\text{MeV}}$, our studies of which established that the failure of theories to predict the cross sections for such photoproduction reactions stems from a failure to describe the basic process rather than from details of nuclear structure, final state interactions, etc. The results of these measurements are described in articles 36, 48, 49, 56, and 57; were presented in talks 20, 22, 23, 25, and 26; appeared in conference proceedings 11, 13, 14, 18, 20, 21, 24, 30, 31, and 32; and were the basis of the PhD dissertation of D.W. Higinbotham (5).

Brookhaven National Laboratory (BNL)

Our activities at BNL were as members of the Laser Electron Gamma Source (LEGS) collaboration. We participated in studies of photo-reactions on nuclei and began preparations for the later development of equipment for double polarization measurements on ^1H and ^2H , work which continued beyond the period covered by this grant. The results of our work with the LEGS collaboration are described in article 40; were presented in talk 24; and appeared in conference proceedings 15 and 26.

Thomas Jefferson National Accelerator Facility (TJNAF)

During the period of this grant our activities at TJNAF were centred on measurements of deep inelastic structure functions of light nuclei and the development of a high intensity, polarized gamma source based on Compton back-scattering of laser light from the facility's electron beam. The results of the former work are described in articles 55 and 56. The latter project, which never came to fruition, was presented in talks 10, 14, 15, 16, 17, 18, and 19 and appeared in conference proceedings 7.

Tri-Universities Nuclear Laboratory (TUNL)

Development of a high intensity, low energy polarized gamma source ($2 \text{ MeV} \leq E_\gamma \leq 220 \text{ MeV}$) based on the storage ring Free Electron Laser (FEL) of the Duke Free Electron Laser Laboratory (DFELL) was begun in collaboration with H. Weller of TUNL. The goal of this (recently commissioned) project was a facility dedicated to measurements of deuteron photodisintegration and the Gerasimov-Drell-Hearn Sum Rule, threshold pion photoproduction, nucleon polarizabilities, and reactions of astrophysical significance. This work is described in articles 28 and 45 and was presented in talks 19 and 21. Work at this new facility has become a major focus of the activities of our group.

Accelerator Physics

Drawing on experience gained earlier in the development of the proposal for what is now TJNAF the P.I. worked on a variety of projects in the field of accelerator physics. These included

- 1) development of techniques for extracting a parasitic beam from multi-TeV proton accelerators for use in fixed target experiments (art. 19; conf. proc. 1 and 2);
- 2) design of an electron storage ring synchrotron radiation source (art. 16);
- 3) studies of asymmetric e^+e^- colliders for use as "flavor factories" (talk 13; conf. Proc. 3; PhD dissertation of K.D. Cromer, 4);
- 4) feasibility studies for a high energy $\mu^+ \mu^-$ collider (art. 32, 33, and 34; conf. proc. 9, 10, 16, and 17);
- 5) electron polarization in storage rings (to be published).

Publications:

Entries dated after the end of the grant period were based on previous work funded by the grant.

- 1) "Electroexcitation of 4^- States in ^{16}O " B.E. Norum with C.E. Hyde-Wright *et al.*, Phys. Rev. **C35** (1987) 880.
- 2) "High-Resolution Inelastic Electron Scattering from ^{17}O ," B.E. Norum with D.M. Manley *et al.*, Phys. Rev. **C36** (1987) 1700.
- 3) "Deuteron Formation in the Reaction $^{12}\text{C}(e,e'd)^{10}\text{B}_{T=1}$," B.E. Norum with R. Ent *et al.*, Phys. Rev. Lett. **62** (1989) 24.
- 4) "Density Dependence in the Two-Nucleon Effective Interaction at 135 MeV," B.E. Norum with J.J. Kelly *et al.*, Phys. Rev. **C39** (1989) 1222.
- 5) "Electroexcitation of Rotational Bands in ^{18}O ," B.E. Norum with D.M. Manley *et al.*, Phys. Rev. **C41** (1990) 448.
- 6) "Effective Interaction for $^{16}\text{O}(p,p')$ at $E_p = 318$ MeV," B.E. Norum with J.J. Kelly *et al.*, Phys. Rev. **C43** (1991) 1272.
- 7) "Electron Scattering from ^9Be ," B.E. Norum with J.P. Glickman *et al.*, Phys. Rev. **C43** (1991) 1740.
- 8) "Structure of ^9Be from Proton Scattering at 180 MeV," B.E. Norum with S. Dixit *et al.*, Phys. Rev. **C43** (1991) 1758.
- 9) "Empirical Density-Dependent Effective Interaction for Nucleon-Nucleus Scattering at 500 MeV," B.E. Norum with B.S. Flanders *et al.*, Phys. Rev. **C43** (1991) 2103.
- 10) "Electroexcitation of Negative-Parity States in ^{18}O ," B.E. Norum with D.M. Manley *et al.*, Phys. Rev. **C43** (1991) 2147.
- 11) "Neutron and proton transition densities from $^{32,34}\text{S}(p,p')$ at $E_p = 318$ MeV I. Isoscalar densities for ^{32}S ," B.E. Norum with J.J. Kelly *et al.*, Phys. Rev. **C44** (1991) 1963.
- 12) "Neutron and proton transition densities from $^{32,34}\text{S}(p,p')$ at $E_p = 318$ MeV II. Neutron densities for ^{34}S ," B.E. Norum with M.A. Khandaker *et al.*, Phys. Rev. **C44** (1991) 1978.
- 13) "Effective interaction for $^{40}\text{Ca}(p,p')$ at $E_p = 318$ MeV," B.E. Norum with J.J. Kelly *et al.*, Phys. Rev. **C44** (1991) 2602.
- 14) "Electroproduction of π^0 on the Proton near Threshold," B.E. Norum with T.P. Welch *et al.*, Phys. Rev. Lett. **69** (1992) 2761.

- 15) "Effective Interaction for $^{16}\text{O}(p,p')$ and $^{40}\text{Ca}(p,p')$ at $E_p = 200$ MeV," B.E. Norum with H. Seifert *et al.*, Phys. Rev. **C47** (1993) 1615.
- 16) "A Synchrotron Radiation Facility for Canada," L. Dallin, D. Skopik, and B. Norum, Physics in Canada **49** (1993) 167.
- 17) "Neutron transition densities for ^{48}Ca from proton scattering at 200 and 318 MeV," B.E. Norum with A.E. Feldman *et al.*, Phys. Rev. **C49** (1994) 2068.
- 18) "Inelastic electron scattering from ^{18}O at backward angles," B.E. Norum with R.M. Sellers *et al.*, Phys. Rev. **C51** (1994) 1926.
- 19) "Extraction from TeV-range accelerators using bent crystal channeling," B.E. Norum with R.A. Carrigan *et al.*, Nucl. Instrum. Meth. in Phys. Res. **B90** (1994) 128.
- 20) "Neutral-Pion Electroproduction on the Proton near Threshold," B.E. Norum with H.B. van den Brink *et al.*, Phys. Rev. Lett. **74** (1995) 3561.
- 21) "The $^{13}\text{C}(\gamma, \rho\pi^-)^{13}\text{N}$ reaction at $E_\gamma \approx 184$ MeV ($T_\pi \approx 41$ MeV)," B.E. Norum with H.B. van den Brink *et al.*, Nucl. Phys. **A587** (1995) 657.
- 22) "Negative pion photoproduction from ^{15}N in the Region of the Δ Resonance," B.E. Norum with J. Shaw *et al.*, Phys. Rev. **C52** (1995) 199.
- 23) "Supersonic gas jets as internal targets at NIKHEF," B.E. Norum with T. Botto *et al.*, Nucl. Instrum. Meth. in Phys. Res. **A362** (1995) 26.
- 24) "Measurements of of the $(e,e'p\pi^-)$ reaction on nuclei in the nucleon resonance region", A. Cichocki and K. Wang with L. Elouadrhiri *et al.*, Phys. Rev. **C50** (1994) R2266.
- 25) "Multiple hadron production by 14.5 GeV electron and positron scattering from nuclear targets", K. Wang with P. Degtyarenko *et al.*, Phys. Rev. **C50** (1994) 541.
- 26) "Comparison of the (e,e') , $(e,e'p)$ and (γ,p) reaction on ^{10}B ", A. Cichocki and K. Wang with L.J. de Bever *et al.*, Prog. Part. Nucl. Phys. **34** (1995) 383.
- 27) "Reaction $^{13}\text{C}(n,p)^{13}\text{B}$ at 65 MeV", K. Wang *et al.*, Phys. Rev. **C53** (1996) 1718.
- 28) "The TUNL-DFELL Inverse Compton γ -ray Source as a Nuclear Physics Facility," B.E. Norum with T.S. Carman *et al.*, Nucl. Instrum. Meth. **A378** (1996) 1.
- 29) "Precision measurement of $R = \sigma_I/\sigma_T$ on hydrogen, deuterium, and beryllium targets in deep inelastic electron scattering", K. Wang with L. H. Tao *et al.*, Z. Phys. **C70** (1996) 387.

- 30) "Reaction $^{13}\text{C}(n,p)^{13}\text{B}$ at 118 MeV," K. Wang with C.J. Martoff *et al.*, Phys. Rev. **C53** (1996) 1717.
- 31) "Photo-production of Negative Pions on ^{15}N Using $E_\gamma \approx 148$ MeV Tagged Photons," B.E. Norum with H.T. Chung *et al.*, Journal of the Korean Physical Society **29** (1996) 581.
- 32) "Muon Collider Design," B. Norum with R. Palmer *et al.*, Nucl. Phys. **B51A** (1996) 61.
- 33) "Polarized Beams in a Muon Collider," D. Cline, B. Norum, and R. Rossmanith, Nucl. Phys. **B51A** (1996) 191.
- 34) " $\mu^+\mu^-$ Collider: Feasibility Study," B.E. Norum with The $\mu^+\mu^-$ Collider Collaboration, BNL Report BNL-52503 (1996).
- 35) "Electroproduction of neutral pions on the proton," B.E. Norum with H.B. van den Brink *et al.*, Nucl. Phys. **A612** (1997) 391.
- 36) "Measurement of Tensor Analyzing Powers for Elastic Electron Scattering from a Polarized ^2H Target Internal to a Storage Ring," D.W. Higinbotham with M. Ferro-Luzzi *et al.*, Phys. Rev. Lett. **77** (1996) 2630.
- 37) "A Large-Acceptance Detector System for Electron Scattering from Polarized Internal Targets," D.W. Higinbotham with J.F.J. van den Brand *et al.*, Nucl. Instrum. Meth. in Phys. Res. **A387** (1997) 471.
- 38) "A Measurement of the Proton and Deuteron Spin Structure Function g_1 in the Resonance Region," R.A. Lindgren with K. Abe *et al.*, Phys. Rev. Lett. **78** (1997) 815.
- 39) "Evidence for Nuclear Tensor Polarization of Deuterium Molecules," D.W. Higinbotham with J.F.J. Van den Brand *et al.*, Phys. Rev. Lett. **78** (1997) 1235.
- 40) "Spin Asymmetries from $^{16}\text{O}(\gamma^-, p\pi^-)$ near Δ Resonance Energies," A. Cichocki, R.A. Lindgren, B.E. Norum, and K. Wang with K. Hicks *et al.*, Phys. Rev. **C55** (1997) R12.
- 41) "Pion Scattering to 6^- Stretched States in ^{32}S ," R.A. Lindgren with B.L. Clausen *et al.*, Phys. Rev. **C55** (1997) 625.
- 42) "Pion-Nucleus Spin-Flip Strength at Low and Resonance Energies," R.A. Lindgren with B.G. Ofenloch *et al.*, Phys. Rev. **C55** (1997) 1295.
- 43) " $2s_{1/2}$ occupancies in ^{30}Si , ^{30}P , and ^{32}S ," R.A. Lindgren with J. Wesseling *et al.*, Phys. Rev. **C55** (1997) 2773.

- 44) "Deuteron threshold electrodisintegration at high momentum transfer," K. Wang with W.M. Schmitt *et al.*, Phys. Rev. **C56** (1997) 1687.
- 45) "Gamma-Ray Production in a Storage Ring Free-Electron Laser," B.E. Norum with V.N. Litvinenko *et al.*, Phys. Rev. Lett. **78** (1997) 4569.
- 46) "Instrumentation for Δ photoproduction experiments on nuclei with high energy resolution," D.W. Higinbotham with G. van der Steenhoven *et al.*, Nucl. Instrum. Meth. **A399** (1997) 160.
- 47) "A monochromatic neutron facility for (n,p) reactions," K. Wang with S.S. Hanna *et al.*, Nucl. Instrum. Meth. **A401** (1997) 345.
- 48) "Investigation of the $^{10}\text{B}(\gamma, p)$ reaction using tagged photons," K. Wang with L.J. de Bever *et al.*, Phys. Rev. **C58** (1998) 981.
- 49) "Coherent neutral pion electroproduction on ^4He in the delta region," D.W. Higinbotham, B.E. Norum, and K. Wang with M.J.M. van Sambeek *et al.*, Nucl. Phys. **A631** (1998) 545c.
- 50) "Spin Effects in Medium-Energy Electron- ^3He Scattering," D.W. Higinbotham and B.E. Norum with J.F.J. van den Brand *et al.*, Nucl. Instrum. Meth. **A402** (1998) 268.
- 51) "The optical properties of the BigBite spectrometer at NIKHEF," D.W. Higinbotham with D.J.J. de Lange *et al.*, Nucl. Instrum. Meth. **A406** (1998) 182.
- 52) "Diffusely Reflective Aerogel Cherenkov Detector Simulation Techniques," D.W. Higinbotham, Nucl. Instrum. Meth. **A414** (1998) 332.
- 53) "A Compton Backscattering Polarimeter for Measuring Longitudinal Electron Polarization," D.W. Higinbotham and B.E. Norum with I. Passchier *et al.*, Nucl. Instrum. Meth. **A414** (1998) 444.
- 54) "Measurements of the proton and deuteron spin structure functions g_1 and g_2 ," R.A. Lindgren with K. Abe *et al.*, Phys. Rev. **D55** (1998) 112003.
- 55) "Measurements of the Deuteron Elastic Structure Function $A(Q^2)$ for $0.7 \geq Q^2 \geq 6.0$ $(\text{GeV}/c)^2$ at Jefferson Laboratory," R.A. Lindgren with L.X. Alexa *et al.*, Phys. Rev. Lett. **82** (1999) 1374.
- 56) "Inclusive Electron-Nucleus Scattering at Large Momentum Transfer," R.A. Lindgren with J. Arrington *et al.*, Phys. Rev. Lett. **82** (1999) 2056.
- 57) "Measurement of T_{20} in Elastic Electron-Deuteron Scattering," D.W. Higinbotham with M. Bouwhuis *et al.*, Phys. Rev. Lett. **82** (1999) 3755.

58) "The Charge Form Factor of the Neutron from the Reaction ${}^2\text{H}^-(e^-, e'n)p$," D.W. Higinbotham, B.E. Norum, and K. Wang with I. Passchier *et al.*, Phys. Rev. Lett. **82** (1999) 4988.

Invited Talks, Seminars, and Colloquia:

Entries dated after the end of the grant period were based on previous work funded by the grant.

- 1) "Proposed Internal Target Project for the Saskatoon Electron Stretcher Ring," B.E. Norum, Topical Conference on Electronuclear Physics with Internal Targets, SLAC, January, 1989.
- 2) "High Duty Factor Electron Accelerators for Nuclear Physics," B.E. Norum, Seminar, Indiana University, March 31, 1989.
- 3) "Polarized Electrons for Internal Target Experiments at AmPS (Amsterdam Pulse Stretcher)," B.E. Norum, Workshop on Internal Target Physics at NIKHEF-K, NIKHEF-K (Amsterdam), September 29, 1989.
- 4) "Who Cares About Quarks? The CEBAF Question," B.E. Norum, Colloquium, Vrije Universiteit (Amsterdam), December 6, 1989.
- 5) "Test of an Internal Target at the Saskatchewan Accelerator Laboratory," B.E. Norum, Bates Linear Accelerator Center, January 31, 1990.
- 6) "Tickling Quarks at CEBAF," B.E. Norum, Colloquium, University of Saskatchewan, February 6, 1990.
- 7) "Photoproduction of Charged Pions from Nuclei," B.E. Norum, Seminar, Vrije Universiteit (Amsterdam), April 17, 1990.
- 8) "Threshold Production of Neutral Pions," B.E. Norum, Colloquium, NIKHEF-K (Amsterdam), May 3, 1990.
- 9) "Electromagnetic Production of Low Energy Pions," B.E. Norum, Landelijke OIO-Bijeenkomst, NIKHEF-K (Amsterdam), May 11, 1990.
- 10) "Polarized Electron Sources for Stretcher/Storage Rings," B.E. Norum, Workshop on the Future of Nuclear Physics in Europe with Polarized Electrons and Photons, Institut de Physique Nucleaire (Orsay, France), July 5, 1990.
- 11) "Electroproduction of Neutral Pions near Threshold," B.E. Norum, Seminar, CEBAF, April 29, 1992.
- 12) "Testing QCD at Low Energies," B.E. Norum, Seminar, National Institute for Standards and Technology (Boulder, CO), February 26, 1993.
- 13) "Studies of a Linac-Ring B Factory," B.E. Norum, Workshop on Asymmetric Flavor Factory Concepts, Center for Advanced Accelerators, UCLA, April 2, 1993.

- 14) "Compton Scattering at CEBAF: Polarized Gammas and Electron Polarimetry," B.E. Norum, Seminar, Hampton University, April 8, 1993.
- 15) "Nuclear/Particle Physics with Polarized Photons at CEBAF," B.E. Norum, Seminar, University of Maryland, December 6, 1993.
- 16) "Polarized Photons for Nuclear and Particle Physics," B.E. Norum, APS Div. of Nucl. Phys. Meeting, Williamsburg, VA, October 26, 1994.
- 17) "A Backscattered γ^- beam at CEBAF," B.E. Norum, TUNL-FELL Workshop on the Development of a Polarized Gamma-Ray Beam at TUNL, Durham, NC, December 16, 1994.
- 18) "Physics with Polarized γ 's at CEBAF", B.E. Norum, Seminar, Rensselaer Polytechnic Institute, Rensselaer, NY, February, 1995.
- 19) "The Long and Short of Photo-Nuclear Physics," B.E. Norum, Seminar, George Washington University, October 1996.
- 20) "Results from Recoil Detection with Polarized Nuclei," D.W. Higinbotham, Second Workshop on Electronuclear Physics with Internal Targets, MIT, May 1998.
- 21) "Physics with the TUNL/DFELL Polarized Photon Source," B.E. Norum, Workshop on Physics with Polarized Photons, El Paso, TX, October 1998.
- 22) "The Internal Target Physics Program at NIKHEF (Amsterdam)," D.W. Higinbotham, Seminar, University of Virginia, October 1998.
- 23) "The Electric Form Factor of the Neutron from the Reaction $^2\text{H}^-(e^-,e'n)$," D.W. Higinbotham, Seminar, University of Virginia, May 1999.
- 24) " ^{16}O Results from $(\gamma,2\text{N})$ at LEGS," R.A. Lindgren, Fourth Workshop on Electromagnetically Induced Two-Hadron Emission, Grenada, Spain, May 1999.
- 25) "The NIKHEF Measurements of the Charge Form Factor of the Neutron," D.W. Higinbotham, Seminar, MIT, July 1999.
- 26) "The NIKHEF Measurements of the Charge Form Factor of the Neutron," D.W. Higinbotham, Seminar, The George Washington University, July 1999.

Conference Proceedings:

Entries dated after the end of the grant period were based on previous work funded by the grant.

- 1) "Report of the Super Fixed Target Beauty Facility Working Group on Progress towards the SFT at the SSC," B.E. Norum with H. Brown *et al.*, Proceedings of the 1990 Summer Study on High Energy Physics, Snowmass (1990) 373.
- 2) "Laser Induced Extraction from the LHC or SSC," B.E. Norum and R. Rossmanith, Proc. Third European Particle Accelerator Conference, Berlin (1992) 336.
- 3) "Studies of a Linac-Ring B Factory," B.E. Norum, Proc. Workshop on Asymmetric Flavor Factory Concepts, Center for Advanced Accelerators, UCLA, April, 1993.
- 4) "Experimental Study of Chiral Anomaly with Polarized Photons", K. Wang and B.E. Norum, Proc. Workshop on Chiral Dynamics, Cambridge, Massachusetts, 1994.
- 5) "Cross Section and Asymmetry Measurements for $^{16}\text{O}(\gamma^-,pn)$ and $^{16}\text{O}(\gamma^-,pp)$ using Tagged Polarized Photons," R.A. Lindgren with A. Cichocki, V. Gladyshev, B.E. Norum, T. Gresko *et al.*, Proc. SPIN 94, Bloomington, Indiana, September 1994.
- 6) "Exclusive Pion Production from ^{16}O using Polarized Photons," A. Cichocki, V. Gladyshev, R.A. Lindgren, B.E. Norum, T. Gresko, with K. Hicks *et al.*, Proc. SPIN 94, Bloomington, Indiana, September 1994.
- 7) "Polarized Photons for Nuclear and Particle Physics," B.E. Norum, Proc. Workshop on Spin degrees of Freedom in Electromagnetic Nuclear Physics, Williamsburg, Virginia (1994) 123.
- 8) "Gasjet Target from a Rectangular Nozzle," B.E. Norum with R.L.J. van der Meer *et al.*, Proc. 19th Symposium on Rarefied Gas Dynamics, Oxford, UK (1994).
- 9) "Polarized Beams in a Muon Collider," B.E. Norum and R. Rossmanith, Proc. of the 3rd Workshop on Physics Potential and Development of Muon-Muon Colliders, San Francisco, California, December 1995.
- 10) "Muon Collider Design," B.E. Norum with R. Palmer *et al.*, Proc. of the 3rd Workshop on Physics Potential and Development of Muon-Muon Colliders, San Francisco, California, December 1995.
- 11) "Electron scattering off tensor-polarized deuterium," D.W. Higinbotham with K. de Jager for the 91-12 Collab., Proc. 9th Amsterdam Mini-Conference, February 1996.
- 12) "Diffusely reflective aerogel cherenkov detector simulation technique," D.W. Higinbotham, Prog. North-West Europe Nucl. Phys. Conf., April 1996.

- 13) "Electron scattering off tensor-polarized deuterium," D.W. Higinbotham with H. de Vries for the 91-12 Collab., Prog. North-West Europe Nucl. Phys. Conf., April 1996.
- 14) "Absolute measurement of T_{20} on the deuteron," D.W. Higinbotham with M. Bouwhuis for the 91-12 Collab., Prog. North-West Europe Nucl. Phys. Conf., April 1996.
- 15) "SASY: The Spin ASYmmetry Detector for the Measurement of the Spin Structure of the Nucleon," A. Cichocki, R.A. Lindgren, B.E. Norum, and K. Wang with C. Thorn for the LEGS-Spin Collaboration, Proc. PANIC XIII, Williamsburg, Virginia, April 1996.
- 16) "Polarized Beams in a Muon Collider," D. Cline, B. Norum, and R. Rossmannith, Proc. of 1996 European Particle Accelerator Conference, Barcelona, Spain (1996).
- 17) " $\mu^+\mu^-$ Collider: A Feasibility Study," B.E. Norum with R. Palmer *et al.*, FNAL Conf. Proc. 96-092, BNL Report 52503, LBNL Report 38946 (1996).
- 18) "Electron scattering off tensor-polarized deuterium," D.W. Higinbotham with K. de Jager for the 91-12 Collab., Proc. 9th Amsterdam Mini-Conference, February 1996.
- 19) "Diffusely reflective aerogel cherenkov detector simulation technique," D.W. Higinbotham, Proc. North-West Europe Nucl. Phys. Conf., April 1996.
- 20) "Electron scattering off tensor-polarized deuterium," D.W. Higinbotham with H. de Vries for the 91-12 Collab., Proc. North-West Europe Nucl. Phys. Conf., April 1996.
- 21) "Absolute measurement of T_{20} on the deuteron," D.W. Higinbotham with M. Bouwhuis for the 91-12 Collab., Prog. North-West Europe Nucl. Phys. Conf., April 1996.
- 22) "SASY: The Spin ASYmmetry Detector for the Measurement of the Spin Structure of the Nucleon," The LEGS-Spin Collaboration, Proc. PANIC XIII, Williamsburg, Virginia, April 1996.
- 23) "A Compton Backscattering Polarimeter for Electron Beams below 1 GeV," D.W. Higinbotham with I. Passchier *et al.*, Proc. 12th International Symposium on High-Energy Spin Physics, September 1996.
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- 26) "The DHG Sum Rule Measured with Medium Energy Photons," A. Cichocki, R.A. Lindgren, B.E. Norum, and K. Wang with K. Hicks *et al.*, Proc. Conf. Exciting Physics with New Accelerator Facilities, Hyogo, Japan (1997) 65.
- 27) "Polarization of Deuterium Molecules," D.W. Higinbotham with J.F.J. van den Brand *et al.*, AIP Conference Proceedings 421, 1998.
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- 3) "Studies of a Linac-Ring B Factory," B.E. Norum, Proc. Workshop on Asymmetric Flavor Factory Concepts, Center for Advanced Accelerators, UCLA, April, 1993.
- 4) "Experimental Study of Chiral Anomaly with Polarized Photons", K. Wang and B.E. Norum, Proc. Workshop on Chiral Dynamics, Cambridge, Massachusetts, 1994.
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Dissertations supervised:

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