Jefferson Laboratory Theory Group
Science and Technology Review
July 15, 2002
Rocco Schiavilla
Interim Theory Group Leader

• People

• Science: Research program (broad overview)
  Selection of recent accomplishments
  Productivity and impact

• Support for JLab (current and planned) experimental programs

• Nurturing postdocs and graduate students

• Summary

• Appendices: Profiles of senior staff
  List of publications in 00-01
JLab Theory Group: Staff

• 4 full-time senior staff (4 FTE)
  Robert Edwards (lattice gauge theory)
  David Richards (lattice gauge theory)
  Distinguished Visiting Fellow: Yuri Simonov (ITEP), Oct 01-Apr 02
  Stan Brodsky (SLAC), Jan 03-Jun 03
  Theory Group Leader (to be filled, R. Schiavilla acting)

• 7 senior staff with joint appointments (3.5 FTE)
  Ian Balitsky (ODU)
  Jose Goity (Hampton)
  Franz Gross# (W&M)
  Anatoly Radyushkin (ODU)
  Winston Roberts (ODU)
  Rocco Schiavilla (ODU)
  Wally Van Orden (ODU)

• 3 JLab postdoctoral fellows (3 FTE)
  Deirdre Black (Ph.D. 01, Syracuse) - from Oct 01 to present
  Igor Musatov (Ph.D. 99, ODU) - from Oct 01 to present
  Wally Melnitchouk& (Ph.D. 93, Adelaide) - from Aug 01 to Sep 02
  George Fleming (Ph.D. 00, Columbia) - from Oct 02

  # retires from W&M in 02, but stays on 1/2 time at JLab
  & after Sep 02, supported 25% by Theory, 75% by Halls A, B, C in FY 03
JLab Theory Group: Associate Staff

• 4 active senior staff (100% university support, 0 FTE)
  Carl Carlson (W&M)  Marc Sher (W&M)
  Chris Carone (W&M)  Peter Agbakpe (NSU)

• 3 sabbatical visitors (supported by JLab)
  Peter Blunden (Manitoba) - from Sep 02 (one year)
  Carl Carlson (W&M) - from Jul 02 (one year)
  John Tjon (Utrecht) - from Aug 02 (six months) and from Aug 03 (six months)

• 2 postdoctoral fellows (supported by external funding)
  Carlos Schat# (Hampton/Argentina-CONICET/JLab) from Sep 00
  Bogdan Mihaila (W&M, Gross’ DOE grant) from Oct 02

• 5 graduate students (3 supported by JLab) and 1 visiting graduate student (supported by external funding)

#At Duke after Sep 02 as a Postdoctoral Fellow
The JLab Theory Group Expansion

- JLab has followed through with a commitment to expand Theory Group

- In FY 01-02, 4 new FTE:
  - 1 Distinguished Visiting Fellow – to broaden the group’s research interests and to collaborate with Theory Group members#
  - 2 senior staff scientists – to lead the Lattice Hadron Physics Collaboration (LHPC)
  - 1 postdoctoral fellow – to support and encourage young theorists entering the field

- In FY 03-04, 1 new FTE:
  - 2 joint positions with W&M in hadronic and nuclear theory
  - Nathan Isgur Distinguished Postdoctoral Fellow, funded by SURA (possibly a theorist)

# case in point: Simonov-Gross and Simonov-Musatov collaborations; Simonov’s mini-lecture series (3 lectures) and study group on the QCD correlator method (6 lectures)
JLab Theory Group Research Activity: An Integrated Synopsis - I

• How quarks and gluons bind together to form hadrons

  • Solving QCD in the nonperturbative regime:
    • Lattice gauge theory (Edwards, Richards, Melnitchouk)
    • Field-correlator method (Simonov)

  • Solving QCD at the boundary between the perturbative and nonperturbative regimes:
    • Sum rule techniques (Balitsky, Radyushkin)
    • Hadronic form factors, quark-gluon distribution functions, and duality (Radyushkin, Balitsky, Carlson, Melnitchouk, Musatov, Edwards, Richards)

• Understanding and modeling the mechanism of confinement and the structure and decay of hadrons:
  • Heavy-quark effective theory (Roberts, Goity)
  • Chiral dynamics and large $N_c$ QCD (Goity, Black, Carone, Gross, Roberts)
  • Relativistic and nonrelativistic quark models (Goity, Gross, Roberts, Van Orden)
**JLab Theory Group Research Activity: An Integrated Synopsis - II**

• **How nucleons bind together to form nuclei**
  • Constructing nuclear interactions and currents
    • One-boson-exchange phenomenology and similar (Gross, Schiavilla, Van Orden)
    • Effective field theory approach (Goity)

• **Understanding quantitatively the structure and reactions of nuclei from the underlying NN (and NNN) interactions and currents**
  • Relativistic approaches to nuclear dynamics (Gross, Schiavilla, Van Orden)
  • Form factors and weak transitions in few-nucleon systems (Gross, Schiavilla, Van Orden)
  • Nuclear reactions of astrophysical interest (Schiavilla)

• **The standard model and beyond** (Black, Carlson, Carone, Sher)
  • Constraints on lepton-flavor mixing from experiments
  • Effects of TeV-scale physics on low-energy parity violating observables
  • Signals for new light particles (e.g., gluinos) at JLab
JLab Theory Group Research Activity:
An Integrated Synopsis - III

How Theory Group research matches the JLab current program

Theme I: Structure and Dynamics of Hadrons

N* and Meson Properties

Few-Body Nucleon Properties (A<4)

Properties of Nuclei (A>4)

Nucleon and Meson Form Factors

Theme II: Structure and Dynamics of Nuclei

JLab Program

Strange Quarks

Theme III: Physics of the Standard Model and Beyond

Thomas Jefferson National Accelerator Facility

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Rocco Schiavilla ODU/JLab
Review of Theory Group Recent Accomplishments

Brief review of 3 recent results:

• Lattice Hadron Physics Collaboration (LHPC): Goals and Current Status
  • Lattice gauge calculation of resonance masses
  • Progress on the hardware and software components of LHPC

• Generalized Parton Distributions (GPD’s): Application to Compton scattering on the proton

• Weak-interaction effects in few-nucleon systems
Theory Group Role in the Lattice QCD Initiative

• DOE’s SciDAC program has funded a three-year (FY 02-04) National Lattice QCD Initiative at the $6M level; JLab fund allocation is $1.9M

• Within this broader initiative, a Lattice Hadron Physics Collaboration (LHPC; 24 theorists from 15 institutions), led by JLab-MIT, has been formed

• Three components to the lattice effort, with crucial roles in each played by Edwards and Richards:
  
  • **Science component** - To understand quantitatively hadron structure and interactions from the underlying quark-gluon dynamics (spectroscopy of glueballs and hybrids, moments of structure functions, ...)  
    - Relevant for experimental program and the planned Hall D for the 12 GeV Upgrade
  
  • **Software component** - to create a unified programming environment for achieving high efficiency on diverse multi-teraflop hardware
  
  • **Hardware component** - the lattice QCD strategic plan envisions JLab as one of three national centers capable of sustaining in excess of 7 Tflops/s by 2006
LHPC Progress I - Science Component

Lattice calculation of resonance masses#

- For lightest baryon masses, highly accurate quenched calculations
- Good control over systematic uncertainties associated with finite volume and finite lattice spacing
- First generation calculations of higher excited states
- Lattice calculations raising interesting challenges: nature of Roper and Lambda (1405)
- Need to extrapolate to light quark masses (pion mass) to explore chiral behavior (next slide)

#Richards et al.

J=1/2 Baryon Masses: Quenched Calculation

chiral limit
LHPC Progress II – Software and Hardware Components

• Software and algorithm developments
  • QCD-API: portable programming interface for small and large computational platforms
  • Chiral ($m_\pi \rightarrow 0$) fermions on the lattice: domain-wall construction# to remove fermion flavor-doubling problem, and restore chiral symmetry

• Hardware
  • Procurement of 128 Pentium IV computing nodes and associated network is progressing; to be upgraded to 256 nodes by end of 02
  • Substantial computational resource (250 Gflops/s by end of 02) and prototype for next-generation facility

# Edwards and Heller
Generalized Parton Distributions (GPDs) model nonperturbative quark-gluon dynamics and lead to predictions for deeply exclusive scattering (DES) processes.

DES measurements of GPDs drive one of the campaigns in the 12 GeV upgrade program.

Compton scattering process described by “handbag” mechanism#:

\[ \sum_a e_a^2 \int_0^1 F_a(x,t) \frac{dx}{x} \]

GPD \( F_a(x,t) \) parameterizes “soft” physics.

# Kroll and Radyushkin
GPDs and Wide Angle Compton Scattering on the Proton - II

Modeling $F_a(x,t)$:

i) $F_a(x,t) \rightarrow f_a(x)$ as $t \rightarrow 0$ , $f_a(x)$ DIS parton distribution function; GPD formalism provides unified description of DIS and DES processes

ii) Consider e-p elastic scattering

i) + ii) $F_a(x,t) = f_a(x)\exp[t/(2x\lambda^2)]$ with $\lambda$ from fitting proton $F_1(t)$

Compton Scattering

Polarization Transfer in Compton Scattering

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Cornell data

log$(d\sigma/dt/GeV)/n$b

$E=3$ GeV

$E=4$ GeV

$E=5$ GeV

$E=6$ GeV

$E=6$ GeV

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$K_{LL}$

$\theta_\gamma$ (deg)

JLab E99-114

handbag mechanism

pQCD hard scattering mechanism
Weak-Interaction Effects in Few-Nucleon Systems - I

- Weak interactions induce (tiny !) parity-violating (PV) components in the NN potential
- Recent work on pp elastic scattering, np radiative capture and deuteron electrodisintegration
- PV effects - longitudinal asymmetry in pp elastic scattering

\[ # \text{Carlson, Schiavilla, Brown, and Gibson} \]

\[ \text{DDH best guess prediction} \]

\[ \text{uncertainty in } v^{pc} \]

\[ \rho \quad - \quad \omega \]

\[ A \left( 10^{-1} \right) \]

\[ T_{lab} \text{ (MeV)} \]

\[ h_{pp} \]

\[ h_{\omega} \]

\[ Rocco Schiavilla ODU/JLab \]

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**Weak-Interaction Effects in Few-Nucleon Systems - II**

**PV effects - deuteron electrodisintegration in quasielastic kinematics**

\[ A = \frac{\left| \begin{array}{c} |f,PC> \\ |d,PC> \\ |d,PC> \\ |f,PC> \\ \end{array} \right| ^* \left( |d,PC> \right) + \left( |f,PC> \right) + \text{c.c.}} {2} \]

\( \gamma \)-induced asymmetry due to:
- PV components in w.f.'s
- PV components in EM current
- PV wave functions

\( \gamma \)-induced asymmetry due to:
- PV components in w.f.'s
- PV components in EM current
- PV wave functions

\# Carlson and Schiavilla

Asymmetries at Quasi–Elastic Peak

\[ |A(Q^2)| \]

\[ Q^2 [(GeV/c)^2] \]

\(-\) γ–Z interference

\(-\) PV wave functions

\(-\) anapole moment

\(-\) PV

\(-\) PV
Research Productivity and Impact
(Senior Staff and Postdoctoral Fellows Only)

• Publications listed in the 2001 Annual Report:
  • 24 publications in refereed journals and 2 (commissioned) review articles
  • 28 publications in conference proceedings (most invited)
  • 24 unpublished invited talks at major conferences/workshops
  • 21 seminars/colloquia at universities and labs around the world

• Active program of seminars, workshops, short- and long-term visitors (listed in the 2001 Annual Report)
JLab Theory Group: Support for the Experimental Program at JLab

- Strong theoretical support for the current experimental program(s) at JLab - from proposal to publication!

- Strong theoretical support for the 12 GeV upgrade proposal
  - Generalized Parton Distributions (GPDs) co-developed by Radyushkin
  - Study of hybrid hadrons proposed by the late Nathan Isgur

- Few-Body Initiative and Excited-Hadron Discussion Group# - joint theoretical/experimental seminars/informal meetings on few-body and hadron physics

- Mini-lecture Series - 3 lectures for experimentalists and graduate students on a topic relevant to the experimental program:
  - I. Aznauryan - Electro-production of pions (in support of the N* Program) (Aug 01)
  - J.-M. Laget - High energy meson photo-production and GPDs (Oct 01)
  - Yu. Simonov - The QCD vacuum and its imprint on normal and hybrid hadrons (Nov 01)
  - O. Benhar - Scaling in DIS and proton response (Mar 02)
  - Planned in 02/03: J. Tjon, C. Carlson and S. Brodsky

- Input to TAC and PAC on theory behind JLab experimental proposals

# W. Melnitchouk played pivotal role
JLab Theory Group: Nurturing Postdocs and Graduate Students

• Good environment for postdocs and students, strengthened by the strong visitor and seminar programs, mini-lecture series, ...

• People who have completed their postdocs in the last three years:
  
  J. Forest → “two-body problem”, stay at home mom at present  
  S. Jeschonnek → Asst. Prof. (tenure-track), Ohio State University at Lima  
  R. Lebed → Asst. Prof. (tenure-track), Arizona State University  
  W. Melnitchouk → Physics Division Research Fellow at JLab

• Nine Ph.D.’s in the last four years (five of them in academic positions):
  
  D. Krioukov, ODU 98 → Software company  
  M. Uzzo, W&M 98 → Research Scientist-Harvard Smithsonian Center for Astrophysics  
  L. Zhang, Hampton 98 → Oracle Corporation  
  I. Grigentch, ODU 99 → Software company  
  I. Musatov, ODU 99 → Postdoctoral Fellow, JLab Theory Group  
  P. Agbakpe, Hampton 00 → Asst. Prof. (tenure-track), Norfolk State University  
  L. Marcucci, ODU 00 → Researcher (tenure-track), University of Pisa, Italy  
  A. Rakotovao, ODU 00 → Back to Madagascar ?  
  Z. Batiz, W&M 01 → Postdoctoral Fellow, CFIF-Lisbon, Portugal

• Five students currently working towards their Ph.D.’s
JLab Theory Group: Summary

- Theory Group carries out a broad program of research in nuclear and hadronic physics with a number of different “tools”
  - Three themes: structure and dynamics of hadrons (1) and nuclei (2), and physics of the Standard Model and beyond (3)
  - Recent “tool” addition: lattice gauge theory
  - Best gauge of scientific quality is the research carried out so far#

- Theory Group actively supports the present and planned experimental program at JLab
  - Few-Body and Excited-Hadron Initiatives, and mini-lecture series
  - Its broad research program beneficial to other labs as well

- Theory Group provides a nurturing environment for postdocs and graduate students in both experiment and theory
  - Seminars, mini-lecture series, study groups
  - Strong program of short- and long-term visitors

- JLab provides strong support for theory (see slide 4).

# see Appendices with senior staff profiles and publication list in 00-01
Appendix: Profiles of Senior Staff-1

Ian Balitsky

- Ph.D., St. Petersburg, 1981
- Researcher, St. Petersburg Nuclear Physics Institute, 1980-1989
- Senior Researcher, St. Petersburg Nuclear Physics Institute, 1989-1992
- Postdoctoral Fellow, Penn State University, 1992-1995
- Research Scientist, MIT, 1995-1996
- Senior Staff/Assoc. Prof., JLab/ODU, 1996-present

- Author of 60 publications

- Research Highlights:
  - BFKL pomeron (B \rightarrow Balitsky)
  - Sum rules for static hadronic properties
  - Nonlocal operator product expansion and light-cone sum rules
  - Valley method for instanton interactions
  - Spin structure of the proton
  - Small-x evolution in high density QCD
Appendix: Profiles of Senior Staff-2

Robert Edwards

- Ph.D., New York University, 1989
- Postdoctoral Research Scientist, SCRI-FSU, 1989-1992
- Assistant Research Scientist, SCRI, 1992-1997
- Associate Research Scientist, SCRI, 1997-1999
- Senior Staff, JLab, 1999-present

- Honors: Gordon Bell Prize for Price Performance SC98 for the QCDSP Supercomputer, 1998

- Author of over 50 publications

- Research Highlights:
  - Spectroscopy studies in lattice QCD
  - Hadronic structure in lattice QCD
  - Chiral fermion development and studies in chiral symmetry breaking in gauge theories
  - Hardware and software development
Appendix: Profiles of Senior Staff-3

Jose` Goity

- Ph.D., University of Munich, 1985
- Postdoctoral Fellow at:
  - Max Planck Institute, 1984-1985
  - CNRS-Institute of Theoretical Physics, Marseilles, 1985-1986
  - Bern University, 1986-1988
  - Paul Scherrer Institute, 1988-1991
  - CEBAF, 1991-1993
- Senior Staff/Asst. Prof., JLab/Hampton, 1993-1998
- Senior Staff/Assc. Prof., JLab/Hampton, 1998-present
- Author of 50 publications
- Research Highlights:
  - Chiral perturbation theory with heavy quark symmetry
  - Chiral perturbation theory for light baryons
  - Strangeness in exchange currents using effective Lagrangians
  - Large $N_c$ limit
Appendix: Profiles of Senior Staff-4

Franz Gross

• Ph.D., Princeton University, 1963
• Instructor-Research Associate, 1963-1966
  Asst. Prof., Cornell University, 1966-1969
  Assoc. Prof., Cornell University, 1969-1970
  Prof., W&M, 1976-1986
  Senior Staff/Prof., JLab/W&M, 1985-present
• Honors: Sporn Award, Fullbright Fellow, Woodrow Wilson Fellow, Fellow of the American Physical Society
• Author of 122 publications and 1 book
• Research Highlights:
  • Relativistic theory of few body systems
  • Relativistic boson-exchange model of nuclear forces
  • Elastic and inelastic e-d scattering
  • Covariant calculations of three body bound states
  • Quark models for mesons
  • Exact solutions of field theories using the Feynman-Schwinger technique
Appendix: Profiles of Senior Staff-5

Anatoly Radyushkin

- Ph.D., Moscow State University, 1978
- Junior Scientist, JINR-Dubna, 1978-1983
  Senior Scientist, JINR-Dubna, 1983-1988
  Leading Scientist, JINR-Dubna, 1988-1992
  Senior Staff/Prof., JLab/ODU, 1992-present
- Honors: Two Annual Awards at JINR-Dubna, Fellow of the American Physical Society, ODU Eminent Scholar, Alexander von Humboldt Award
- Author of 132 publications
- Research Highlights:
  - Factorization for hard inclusive processes and elastic form factors in QCD
  - QCD sum rules for form factors
  - Wilson loop/renormalization group approach to infrared behavior of QCD
  - Nonlocal condensate formalism in QCD sum rules
  - Deeply virtual exclusive processes in QCD and generalized parton distribution functions
Appendix: Profiles of Senior Staff-6

David Richards

• Ph.D., University of Cambridge, 1984
• Postdoctoral Fellow:
  • Southampton University, U.K., 1984-1986
  • Argonne National Laboratory, 1986-1988
  • University of Edinburgh, Scotland, 1988-1993
• PPARC Advanced Fellow, University of Edinburgh, Scotland, 1993-1999
• Senior Staff/Visiting Asst. Prof., JLab/ODU, 1999-2001
• Senior Staff, JLab, 2001-present

• Author of 59 publications

• Research Highlights:
  • Energy-energy correlations in QCD
  • Two-gluon exchange models of the pomeron and diffractive scattering
  • Spectroscopy of excited baryons from lattice QCD
  • Lattice QCD calculations of weak-interaction matrix elements and quark
distribution amplitudes
  • Nucleon-nucleon interaction in lattice QCD
Appendix: Profiles of Senior Staff-7

Winston Roberts

- Ph.D., University of Guelph, 1988
- Visiting Researcher, Institut des Sciences Nucleaires, Grenoble, France, 1988-1989
- Postdoctoral Fellow, Harvard University, 1989-1991
- Senior Staff/Asst. Prof., JLab/ODU, 1991-1997
- Senior Staff/Assc. Prof., JLab/ODU, 1997-present
- NSF Program Manager for “Mathematical Physics” and “Nuclear Theory,” 1998-2000

- Honors: Canada NSERC Postdoctoral Fellowship, NSF National Young Investigator Award (1994-1999)

- Author of 44 publications

- Research Highlights:
  - Expansion in $1/m_Q$ in heavy quark effective theory
  - Application of heavy quark symmetry to charm beta decay
  - Baryon resonances in the 3P0 decay model and the search for missing resonances
Appendix: Profiles of Senior Staff-8

Rocco Schiavilla

- Ph.D., University of Illinois at Urbana-Champaign, 1987
- Postdoctoral Fellow at:
  - DPhN/HE Saclay, 1987-1988
  - CEBAF, 1988-1990
  - Argonne National Laboratory, 1990-1992
- Staff Scientist, INFN-Lecce, 1992-1993
- Senior Staff/Asst. Prof., JLab/ODU, 1993-1999
- Senior Staff/Assoc. Prof., JLab/ODU, 1999-2002
- Senior Staff/Prof., JLab/ODU, 2002-present
- Honors: Enrico Fermi Scholar, Argonne Nat. Lab., 1990-1992
- Author of 78 publications
- Research Highlights:
  - Nuclear interactions and currents
  - Electro-weak structure and response of light nuclei
  - Weak and radiative capture reactions of astrophysical interest
  - Hamiltonian approach to relativistic dynamics
  - Exact quantum Monte Carlo methods for nuclei
Appendix: Profiles of Senior Staff-9

Wally Van Orden

- Ph.D., Stanford University, 1978
- Postdoctoral Fellow, University of Maryland, 1978-1981
  Asst. Prof., University of Maryland, 1981-1987
  Staff Scientist, CEBAF, 1987-1990
  Senior Staff/Ascc. Prof., JLab/ODU, 1990-1998
  Senior Staff/Prof., JLab/ODU, 1998-present
- Author of 46 publications
- Research Highlights:
  - Relativistic models for elastic and quasi-elastic scattering from light nuclei
  - Covariant model for nucleon-nucleon scattering and application to elastic and
    quasi-elastic ed scattering
  - Relativistic constituent quark model of heavy mesons
  - Relativistic three-body systems