The Jlab 12 GeV Upgrade

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The physical origins of quark confinement (GlueX, meson and baryon spectroscopy)

The spin and flavor structure of the proton and neutron (PDF’s, GPD’s, TMD’s…)

The quark structure of nuclei

Probe potential new physics through high precision tests of the Standard Model

Defining the Science Program:

– Four Reviews: Program Advisory Committees (PAC) 30, 32, 34, 35
– 2006 through 2010
– Results: 32 experiments approved; 13 conditionally approved
– PAC36 scheduled August 2010: continue rankings

Exciting slate of experiments for 4 Halls planned for initial five years of operation!
Upgrade is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use

**Add arc**

**Enhanced capabilities in existing Halls**

**Add 5 cryomodules**

**20 cryomodules**

**20 cryomodules**

**Add 5 cryomodules**

**CHL upgrade**

**New Hall**

**Upgrade arc magnets and supplies**

Maintain capability to deliver lower pass beam energies: 2.2, 4.4, 6.6...

Scope of the project includes:
- Doubling the accelerator beam energy
- New experimental Hall and beamline
- Upgrades to existing Experimental Halls
12 GeV Scientific Capabilities

Hall D – exploring origin of confinement by studying exotic mesons

Hall B – understanding nucleon structure via generalized parton distributions

Hall C – precision determination of valence quark properties in nucleons and nuclei

Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments (e.g. PV and Moller)
# Quantum Numbers of Hybrid Mesons

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Excited Flux Tube</th>
<th>Hybrid Meson</th>
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| $S = 0$
$L = 0$
$J^{PC} = 0^{-+}$
*like $\pi, K$* | $J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$ | $J^{PC} = \begin{cases} 1^{--} \\ 1^{++} \end{cases}$ |
| $S = 1$
$L = 0$
$J^{PC} = 1^{--}$
*like $\gamma, \rho$* | $J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$ | $J^{PC} = \begin{cases} 0^{--} \\ 1^{++} \\ 2^{+-} \\ 0^{+-} \end{cases}$ |

Flux tube excitation (and parallel quark spins) lead to exotic $J^{PC}$
Lowest mass expected to be $\pi_1(1^{+-})$ at $1.9 \pm 0.2$ GeV.
Proton Spin Puzzle

\[ \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G(Q^2) + L_q(Q^2) + L_g(Q^2) \]

- \( \text{DIS} \rightarrow \Delta \Sigma \approx 0.25 \)
- \( \text{RHIC + DIS} \rightarrow \Delta g \ll 1 \)
- \( \rightarrow L_q \)

[X. Ji, 1997]

D. de Florian et al., PRL 101 (2008) 072001
Unified View of Nucleon Structure

6D Dist.

\[ W^u_p(x,k_T,r) \] Wigner distributions

\[ d^3r \]

\[ d^2k_T \, dr_z \]

TMD PDFs
\[ f^u_1(x,k_T), \ldots, h^u_1(x,k_T) \]

GPDs/IPDs

3D imaging

\[ d^2k_T \]

\[ d^2r_T \]

PDFs
\[ f^u_1(x), \ldots, h^u_1(x) \]

1D

Form Factors
\[ G_E(Q^2), \quad G_M(Q^2) \]

dx & Fourier Transformation

"take out" "put back"

GPD

\[ x - \xi \quad x + \xi \]

R. McKeown – Hadron Workshop - Beijing
Kinematics Coverage of the 12 GeV Upgrade

Study of high $x_B$ domain requires high luminosity.

The 12 GeV Upgrade is well matched to studies in the valence quark regime.
Extraction of GPD’s

Cleanest process: Deeply Virtual Compton Scattering

\[ A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta \sigma}{2 \sigma} \]

\[ \xi = x_B / (2 - x_B) \]

Polarized beam, unpolarized target:

\[ \Delta \sigma_{LU} \sim \sin \phi \{F_1 H + \xi (F_1 + F_2) \tilde{H} + kF_2 E \} d\phi \]

Unpolarized beam, longitudinal target:

\[ \Delta \sigma_{UL} \sim \sin \phi \{F_1 \tilde{H} + \xi (F_1 + F_2) (H + \xi / (1 + \xi) E) \} d\phi \]

Unpolarized beam, transverse target:

\[ \Delta \sigma_{UT} \sim \sin \phi \{k (F_2 H - F_1 E) \} d\phi \]
Quark Angular Momentum

\[ J^q(t) = \int_{-1}^{1} dx x [H^q(x, \xi, t) + E^q(x, \xi, t)] \]

→ Access to quark orbital angular momentum

JLab Hall A
n-DVCS

\[ J_d + \frac{J_u}{5.0} = 0.18 \pm 0.14 \]

GPDs from:
Code VGG (Vanderhaeghen, Guichon and Guidal)

Thomas Jefferson National Accelerator Facility
R. McKeown – Hadron Workshop - Beijing
Experimental DVCS program E12-06-119 was approved for the 12 GeV upgrade using polarized beam and polarized targets.

High luminosity and large acceptance allows wide coverage in $Q^2 < 8$ GeV$^2$, $x_B < 0.65$, and $t < 1.5$ GeV$^2$.
**SIDIS Electroproduction of Pions**

- Separate Sivers and Collins effects
  - **Sivers** angle, effect in distribution function:
    - $(\phi_h - \phi_s) = \text{angle of hadron relative to initial quark spin}$
  - **Collins** angle, effect in fragmentation function:
    - $(\phi_h + \phi_s) = \pi + (\phi_h - \phi_s') = \text{angle of hadron relative to final quark spin}$
SIDIS SSAs depend on 4 variables ($x$, $Q^2$, $z$ and $P_T$).

Large angular coverage and precision measurement of asymmetries in 4-D phase space are essential.
Hall A Transversity Projected Data

- Total 1400 bins in $x$, $Q^2$, $P_T$ and $z$ for 11/8.8 GeV beam.
- $z$ ranges from 0.3 ~ 0.7, only one $z$ and $Q^2$ bin of 11/8.8 GeV is shown here. $\pi^+$ projections are shown, similar to the $\pi^-$.

![Graph showing projected data for $2 < Q^2 < 3$ and $0.40 < z < 0.45$]
High x spin dependent DIS

REQUIRES:
- High beam polarization
- High electron current
- High target polarization
- Large solid angle spectrometers
Measure 2-body decay
• High resolution
• High yield

\[ A^{-1} \Lambda Z \rightarrow A^{-1}(Z + 1) + \pi^- \]
12 GeV Upgrade Schedule

- Two short parasitic installation periods in FY10
- 6-month installation May-Oct 2011
- 12-month installation May 2012-May 2013
- Hall A commissioning start October 2013
- Hall D commissioning start April 2014
- Halls B and C commissioning start October 2014
- Project Completion June 2015
12 GeV Construction

- Accelerator: Major Procurements (>\$500K) nearly complete
  - beam transport magnets; helium refrigerator; power supplies; etc...

4m Dipole Magnet at JLab

Beam Transport Quadrupole Magnets (50 of 114 total) at JLab
Physics Equipment Construction

Hall B – Region II Drift Chamber Frame Assembly

Hall D – Barrel Calorimeter Module

Hall C – Wire Stringing Jig for Drift Chamber
Civil Construction: Hall D Complex 2009-2010

Excavation – Sept 2009

Nor’easter – Nov 2009

Floor Slab – Jan 2010

Walls – June 2010
Jlab 12 GeV Upgrade

An exciting scientific opportunity
- Explore the physical origins of quark confinement (GlueX)
- New access to the spin and flavor structure of the proton and neutron
- Reveal the quark/gluon structure of nuclei
- Probe potential new physics through high precision tests of the Standard Model

Strong User community involvement
- NSF MRI and NSERC funding to universities for detector elements
- Strong international collaborations
- 32 PAC-approved experiments

Accel-Civil-Physics scope leverages the existing facility

Construction is well underway!
- Accelerator nearing completion on major procurements; hardware arriving
- Detector assembly ramping up
- Civil construction on track

New Proposals and collaborations are welcome