The Jlab 12 GeV Upgrade

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12 GeV Science Program

- 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.

**12 GeV Upgrade Project**

- Add arc
- Add 5 cryomodules
- CHL upgrade
- Upgrade arc magnets and supplies
- New Hall
- 20 cryomodules

**Enhanced capabilities in existing Halls**

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

**Maintain capability to deliver lower pass beam energies:** 2.2, 4.4, 6.6, etc.
### Overview of Technical Performance Requirements

<table>
<thead>
<tr>
<th>Hall D</th>
<th>Hall B</th>
<th>Hall C</th>
<th>Hall A</th>
</tr>
</thead>
<tbody>
<tr>
<td>excellent hermeticity</td>
<td>luminosity $10 \times 10^{34}$</td>
<td>energy reach</td>
<td>installation space</td>
</tr>
<tr>
<td>polarized photons</td>
<td>hermeticity</td>
<td>precision</td>
<td></td>
</tr>
<tr>
<td>$E_\gamma \sim 8.5-9$ GeV</td>
<td></td>
<td>11 GeV beamline</td>
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<tr>
<td>$10^8$ photons/s</td>
<td></td>
<td>target flexibility</td>
<td></td>
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<tr>
<td>good momentum/angle resolution</td>
<td></td>
<td>excellent momentum resolution</td>
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<tr>
<td>high multiplicity reconstruction</td>
<td></td>
<td>luminosity up to $10^{38}$</td>
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R. McKeown - MENU10
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)
Super Bigbite project:

- large dipole magnet
- GEM trackers (~100,000 channels)
- hadron and EM calorimeter
- Trigger and DAQ

operating in open geometry at a luminosity of $10^{38} \text{ cm}^{-2}\text{s}^{-1}$
PV Moller Scattering:
• Precision test of SM
• Custom Toroidal Spectrometer
• 5kw LH Target

SOLID:
• High Luminosity on LD2 and LH2
• Better than 1% errors for small bins
• Large $Q^2$ coverage
• $x$-range 0.25-0.75
• $W^2 > 4 \text{ GeV}^2$
- **New Super High Momentum Spectrometer (SHMS)**
  Horiz. Bender, 3 Quads + Dipole
  \( P \rightarrow 11 \text{ GeV/c} \)
  \( \Delta P/P = 0.5 \, \text{–} \, 1.0 \times 10^{-3} \)
  Acceptance: 5msr, 30%
  \( 5.5^\circ < \theta < 40^\circ \)

- **High Momentum Spectrometer (HMS)**
  \( P \rightarrow 7.5 \text{ GeV/c} \)
  \( \Delta P/P = 0.5 \, \text{–} \, 1.0 \times 10^{-3} \)
  Acceptance: 6.5msr, 18%
  \( 10.5^\circ < \theta < 90^\circ \)

- Minimum opening angle: 17°
Quantum Numbers of Hybrid Mesons

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Excited Flux Tube</th>
<th>Hybrid Meson</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = 0$, $L = 0$, $J^{PC} = 0^{-+}$</td>
<td>$J^{PC} = \begin{cases} 1^{--} \ 1^{++} \end{cases}$</td>
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<td>$S = 1$, $L = 0$, $J^{PC} = 1^{--}$</td>
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<td>$J^{PC} = \begin{cases} 0^{++} \ 1^{--} \ 2^{++} \ 0^{++} \ 1^{--} \ 2^{++} \end{cases}$</td>
</tr>
</tbody>
</table>

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

Lattice Calculations

- $\pi_1(1^{--})$ at $1.9$ GeV
- $b_0(0^{+-})$ at $2.1$ GeV
- $b_2(2^{+-})$ at $2.3$ GeV
Decay of Exotic Mesons

Possible daughters:

$L=1$: a, b, h, f, ...
$L=0$: $\pi, \rho, \eta, \omega, ...$

The angular momentum in the flux tube stays in one of the daughter mesons ($L=1$) and ($L=0$) meson, e.g:

Example: $\pi_1 \rightarrow b_1 \pi$

$\omega \pi \rightarrow (3\pi)\pi$

or $\omega \pi \rightarrow (\pi\gamma)\pi$

simple decay modes such as $\eta\pi, \rho\pi, ...$ are suppressed.
Unified View of Nucleon Structure

6D Des.

\[ W_{p}^{u}(x,k_{T},r) \quad \text{Wigner distributions} \]

\[ d^{3}r \quad d^{2}k_{T} \, dr_{z} \]

TMD PDFs
\[ f_{1}^{u}(x,k_{T}), \ldots, h_{1}^{u}(x,k_{T}) \]

GPDs/IPDs

3D imaging

1D

Form Factors
\[ G_{E}(Q^{2}), \quad G_{M}(Q^{2}) \]

PDFs
\[ f_{1}^{u}(x), \ldots, h_{1}^{u}(x) \]

dx & Fourier Transformation

"take out" \quad "put back"
Kinematics Coverage of the 12 GeV Upgrade

The 12 GeV Upgrade is well matched to studies in the valence quark regime.

Study of high $x_B$ domain requires high luminosity.
Extraction of GPD’s

Cleanest process: Deeply Virtual Compton Scattering

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

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

<table>
<thead>
<tr>
<th>Process</th>
<th>Unpolarized beam, transverse target:</th>
<th>Unpolarized beam, longitudinal target:</th>
<th>Unpolarized beam, transverse target:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta\sigma_{LU} \sim \sin\phi{F_1 H + \xi(F_1 + F_2)\tilde{H} + kF_2 E}d\phi )</td>
<td>( \Delta\sigma_{UL} \sim \sin\phi{F_1 \tilde{H} + \xi(F_1 + F_2)(H + \xi/(1 + \xi)E)}d\phi )</td>
<td>( \Delta\sigma_{UT} \sim \sin\phi{k(F_2 H - F_1 E)}d\phi )</td>
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\( H(\xi,t) \)

\( \tilde{H}(\xi,t) \)

\( E(\xi,t) \)
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 $Q^2 < 8 \text{ GeV}^2$, $x_B < 0.65$, and $t < 1.5 \text{ GeV}^2$. 

$e^+ p \rightarrow e^+ \gamma$
DVCS at 12 GeV
SIDIS Electroproduction of Pions

- Separate Sivers and Collins effects

- **Sivers** angle, effect in distribution function:
  - \((\phi_h - \phi_s)\) = angle of hadron relative to *initial* quark spin

- **Collins** angle, effect in fragmentation function:
  - \((\phi_h + \phi_s) = \pi + (\phi_h - \phi_s')\) = angle of hadron relative to *final* quark spin
A Solenoid Spectrometer for SIDIS

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 $P_T$ vs $x$ with various data points and fits for different regions of $Q^2$ and $z$.]
High x spin dependent DIS

REQUIRES:
- High beam polarization
- High electron current
- High target polarization
- Large solid angle spectrometers
$^2H(\vec{e}, e'n)^1H$ via Recoil Polarimetry
### 12 GeV Upgrade Schedule

**Activity Name**

<table>
<thead>
<tr>
<th>Activity Name</th>
<th>FY 04/05</th>
<th>FY 06</th>
<th>FY 07</th>
<th>FY 08</th>
<th>FY 09</th>
<th>FY 10</th>
<th>FY 11</th>
<th>FY 12</th>
<th>FY 13</th>
<th>FY 14/15</th>
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<td>Accelerator including Civil</td>
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<td>4A</td>
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<td>Hall D including Civil</td>
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- 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 – PCAL Test Extrusions w/ Optical Fibers

Hall C Superconducting Magnet Q1 Coil

Hall D – Forward Drift Chamber in Test Stand
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
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, Collaborators, Contributions($,€,¥...) welcome!

Thanks:

<table>
<thead>
<tr>
<th>A. Lung</th>
<th>K. de Jager</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. Ent</td>
<td>V. Burkert</td>
</tr>
<tr>
<td>L. Cardman</td>
<td>S. Wood</td>
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<tr>
<td>X. Qian</td>
<td>E. Chudakov</td>
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