Jefferson Lab
12 GeV Science Program

R. D. McKeown
Jefferson Lab

QCD Evolution
May 12, 2014
A Laboratory for Nuclear Science

Nuclear Structure

Structure of Hadrons

Fundamental Forces & Symmetries

Medical Imaging

Accelerator S&T

Quark Confinement

Hadrons from Quarks

Theory and Computation
12 GeV Upgrade Project

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

Upgraded is designed to build on existing facility: vast majority of accelerator and experimental equipment have continued use.

The completion of the 12 GeV Upgrade of CEBAF was ranked the highest priority in the 2007 NSAC Long Range Plan.
12 GeV Upgrade Project Schedule

16-month installation
May 2012 - Sept 2013

Accelerator commissioning start
Oct 2013

Hall A commissioning start
Feb 2014

Hall D commissioning start
Oct 2014

Halls B & C commissioning start
Jan/Feb 2016

Project Completion
September 2017

Re-baseline Approved
September 4, 2013
12 GeV Project Highlights

Hall D

Hall B

Hall C
CHL1, CHL2 operational Linacs at 2K
North Linac – 1090 MeV
South LINAC – 1090 MeV
CEBAF 2.214 GeV
Optics, Magnets great

KPP: machine capable of 12 GeV
1 pass at 2.2 GeV/pass for 8 hours
with acceptable trip rate (50% uptime)
May 7, 2014

- 5.5 Passes
- 10.5 GeV
- Transported to Hall D Tagger Dumplet
- Completes CD4a Project milestone
# Three Year Plan

## Jefferson Lab Three-Year Schedule

<table>
<thead>
<tr>
<th>Dec 2013</th>
<th><strong>Jefferson Lab Three-Year Schedule</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calendar Year</strong></td>
<td><strong>2014</strong></td>
</tr>
<tr>
<td><strong>Fiscal Year</strong></td>
<td><strong>2014</strong></td>
</tr>
</tbody>
</table>

### CEBAF
- Activity Beam: Commissioning
- 2014: Commissioning
- 2015: Physics
- 2016: Physics

### Hall A
- Activity Beam: Const.
- 2014: Const.
- 2015: Physics
- 2016: Physics

### Hall B
- Activity Beam: CLAS12 Construction/Installation Non-CLAS12 Ops
- 2014: CLAS12 Construction/Installation Non-CLAS12 Ops
- 2015: Comm.

### Hall C
- Activity Beam: SHMS Construction/Installation
- 2014: SHMS Construction/Installation
- 2015: Comm.

### Hall D
- Activity Beam: GlueX Installation
- 2014: GlueX Installation
- 2015: Comm.
- 2016: Physics

Legend:
- **Beam for Commissioning**
- **Beam for Physics**
- **Non-CLAS12 Ops**
JLab: 21st Century Science Questions

• What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?

• Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?

• Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?

• What is the relation between short-range N-N correlations and the partonic structure of nuclei?

• Can we discover evidence for physics beyond the standard model of particle physics?
## 12 GeV Approved Experiments by Physics Topics

<table>
<thead>
<tr>
<th>Topic</th>
<th>Hall A</th>
<th>Hall B</th>
<th>Hall C</th>
<th>Hall D</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>3</td>
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<tr>
<td>The transverse structure of the hadrons (Elastic and transition Form Factors)</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td>10</td>
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<tr>
<td>The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td></td>
<td></td>
<td>11</td>
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<td>The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td></td>
<td>13</td>
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<tr>
<td>Low-energy tests of the Standard Model and Fundamental Symmetries</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>6</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>18</td>
<td>19</td>
<td>18</td>
<td>4</td>
<td>2</td>
<td>61</td>
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### 12 GeV Approved Experiments by PAC Days

<table>
<thead>
<tr>
<th>Topic</th>
<th>Hall A</th>
<th>Hall B</th>
<th>Hall C</th>
<th>Hall D</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)</td>
<td></td>
<td>119</td>
<td>320</td>
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<td>439</td>
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<td>The transverse structure of the hadrons (Elastic and transition Form Factors)</td>
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<td>85</td>
<td>102</td>
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<td>356</td>
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<tr>
<td>The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)</td>
<td>65</td>
<td>230</td>
<td>165</td>
<td></td>
<td></td>
<td>460</td>
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<tr>
<td>The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)</td>
<td>409</td>
<td>872</td>
<td>161</td>
<td></td>
<td></td>
<td>1442</td>
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<tr>
<td>Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)</td>
<td>159</td>
<td>120</td>
<td>179</td>
<td>14</td>
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<td>472</td>
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<tr>
<td>Low-energy tests of the Standard Model and Fundamental Symmetries</td>
<td>547</td>
<td>205</td>
<td>79</td>
<td>60</td>
<td></td>
<td>891</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>1324</td>
<td>1631</td>
<td>607</td>
<td>424</td>
<td>74</td>
<td>4060</td>
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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** – form factors, future new experiments (e.g., SoLID and MOLLER)
Beyond 12 GeV Upgrade

- Super BigBite Spectrometer (FY13-16 construction)
  - high $Q^2$ form factors
  - SIDIS

- MOLLER experiment (MIE – FY15-18?)
  - Standard Model Test

- SoLID
  Chinese collaboration
  CLEO Solenoid ✓

- Enhancements of equipment in B, C, D
  (Leverage external investments)
Quantum Numbers of Hybrid Mesons

Quarks

\( S = 0 \)
\( L = 0 \)
\( J^{PC} = 0^{--} \)
like \( \pi, K \)

\( S = 1 \)
\( L = 0 \)
\( J^{PC} = 1^{--} \)
like \( \gamma, \rho \)

Excited Gluon Field

\( J^{PC} = \begin{cases} 1^{--} \\ 1^{++} \end{cases} \)

Hybrid Meson

\( J^{PC} = \begin{cases} 1^{--} \\ 1^{++} \\ 0^{+-} \end{cases} \)

Exotic

Gluonic excitation (and parallel quark spins) lead to exotic \( J^{PC} \)
States with Exotic Quantum Numbers

$2^{+-}$

$0^{+-}$

$1^{--}$

$1^{++}$

Dudek et al.
The Incomplete Nucleon: Spin Puzzle

\[ \frac{1}{2} = \frac{1}{2} \Delta \Sigma + L_q + J_g \]

[X. Ji, 1997]

- DIS → \( \Delta \Sigma \approx 0.25 \)
- RHIC + DIS → \( \Delta G \ll 1 \)
- \( \rightarrow L_q \)
Unified View of Nucleon Structure

\[ W_p^u(x, k_T, r) \] Wigner distributions

\[ d^3r \]

\[ d^2k_T \, dr_z \]

TMD PDFs
\[ f_1^u(x, k_T), \ldots h_1^u(x, k_T) \]

GPDs/IPDs

3D imaging

\[ d^2k_T \]

\[ d^2r_T \]

\[ dx \] & Fourier Transformation

PDFs
\[ f_1^u(x), \ldots h_1^u(x) \]

1D

Form Factors
\[ G_E(Q^2), G_M(Q^2) \]
SIDIS Electroproduction of Pions

- Separate Sivers and Collins effects

- **Sivers** angle, effect in distribution function: \((\phi_h - \phi_s)\)
- **Collins** angle, effect in fragmentation function: \((\phi_h + \phi_s)\)

- Previous data from HERMES, COMPASS
- New landscape of TMD distributions
- Access to orbital angular momentum
SIDIS Studies with 12 GeV at JLab

- **CLAS12 in Hall B**
  General survey, medium lumi

- **SHMS- HMS in Hall C**
  L-T studies, precise $\pi^+/\pi^-$ ratios

- **SBS in Hall A**
  High x, High $Q^2$, 2-3D

- **SOLID in Hall A**
  High Lumi and acceptance – 4D
Parity Violation at JLab

- Nucleon Strangeness Form Factors (complete)
  - HAPPEX (Hall A)
  - G0 (Hall C)

- Neutron Skin
  - PREX
  - CREX

- Precision Tests of Standard Model
  - Qweak (Under analysis)
  - MOLLER
  - SoLID
Cosmology and Dark Matter

- Dark sector is new physics, beyond the standard model
- Many direct searches for dark matter interacting with sensitive detectors (hints, no established signal yet...)

- Controversial evidence for excess astrophysical positrons...
PAMELA Data on Cosmic Radiation

Surprising rise in $e^+$ fraction

But not $\bar{p}$

- Could indicate low mass $A' (M_{A'} < 1 \text{ GeV})$?
- Or local astrophysical origin??
PAMELA Data on Cosmic Radiation

- Surprising rise in e+ fraction
- But not p
- Could indicate low mass $A'$ ($M_{A'} < 1$ GeV)
- Or local astrophysical origin??
New Opportunity: Search for A’ at Jefferson Lab

- BNL “g-2” expt: $\Delta a_\mu (\text{expt-thy}) = (295\pm88) \times 10^{-11}$ (3.4 $\sigma$)
- No evidence for SUSY at LHC (yet)
- Another solution: A’, a massive neutral vector boson

- also useful for dark matter models

- 3 Jefferson Lab proposals:
  - APEX test run (Hall A) – published
    PRL 107, 191804 (2011)
  - HPS test run (Hall B) – complete
  - DarkLight test run (FEL) – complete
Medium Energy EIC@JLab

JLab Concept

Initial configuration (MEIC):
- 3-11 GeV on 20-100 GeV ep/eA collider
- fully-polarized, longitudinal and transverse
- luminosity: up to few $\times 10^{34}$ e-nucleons cm\(^{-2}\)

Upgradable to higher energies
- 250 GeV protons + 20 GeV electrons
Jefferson Lab: Today and Tomorrow

• The Jefferson Lab electron accelerator is a unique world-leading facility for nuclear physics research - 12 GeV commissioning well underway

• 12 GeV upgrade ensures at least a decade of excellent opportunities for discovery
  – New vistas in QCD
  – Growing program Beyond the Standard Model
  – Additional equipment: SBS, MOLLER, SoLID

• EIC moving forward:
  – Strong science case, much builds on JLab 12 GeV program
  – MEIC design well developed – time scale following 12 GeV program is “natural”
  – NSAC Long Range Plan Imminent