Outline

- The 12 GeV Era at Jefferson Lab
- Other future opportunities
- Future EIC
JLab: A Laboratory for Nuclear Science

Nuclear Structure

Medical Imaging

Cryogenics

Structure of Hadrons

Fundamental Forces & Symmetries

Nuclear Astrophysics

Accelerator S&T

Theory & Computation
12 GeV CEBAF Upgrade

- Double maximum Accelerator energy to 12 GeV
  - Ten new high gradient cryomodules
  - Double Helium refrigerator plant capacity
  - Civil construction and upgraded utilities
- Add 10th arc of magnets for 5.5 pass machine
- Add 4th experimental Hall D
- New experimental equipment in Halls B, C, D

Total Project Cost = $338M
Estimate to Complete = $1.2M
Hall D – exploring origin of confinement by studying exotic mesons

Hall B – understanding nucleon structure via generalized parton distributions and transverse momentum distributions

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

Hall A – short range correlations, form factors (SBS), hyper-nuclear physics, future new experiments (e.g., SoLID and MOLLER)
12 GeV Upgrade – Path to Completion

- **Accelerator**
  - Full 12 GeV energy achieved
  - Full luminosity demonstrated
  - Simultaneous multi-hall beam delivery achieved

- **Hall C** – Key Performance Parameter demonstrated
  - SHMS installed, commissioned with beam
  - March 2017

- **Hall B** – Key Performance Parameter demonstrated
  - CLAS12 installed, commissioned with beam
  - February 2017

- **Remaining Scope** = Solenoid Magnet for Hall B
  - Final phase of assembly at vendor completed in June 2017
  - Delivered to Jefferson Lab June 27
  - Installation and acceptance tests underway

*Project Completion September 2017*
Future Projects

- MOLLER experiment
  (Possible MIE – FY19-23)
  - CD-0 approved
    (project paused due to budget uncertainty)
  - Standard Model Test
  - DOE science review (September 2014) – strong endorsement
  - Director’s review held December 15-16, 2016
    Technical, cost & schedule

- SoLID
  - SIDIS and PVDIS
  - CLEO Solenoid ✓
  - International collaboration
  - Director’s review (Feb. 2015)
    → new pre-CDR almost complete
Jefferson Lab @ 12 GeV Science Questions

- What is the role of gluonic excitations in the spectroscopy of light mesons?

- Where is the missing spin in the nucleon? Role of orbital angular momentum?

- Can we reveal a novel landscape of nucleon substructure through 3D imaging at the femtometer scale?

- 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>
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<td>24</td>
<td>23</td>
<td>5</td>
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<td><strong>Total Experiments Completed</strong></td>
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<td>1.1</td>
<td>0</td>
<td>0.4</td>
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<td>22.9</td>
<td>23.0</td>
<td>4.6</td>
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## A Decade of Experiments
Gluonic Excitations and the Mechanism for Confinement

States with Exotic Quantum Numbers

Searching for the rules that govern hadron construction
M. R. Sheperd, J. J. Dudek, R. E. Mitchell

Also baryons – see talk by A. D’Angelo
The Incomplete Nucleon: Spin Puzzle

- \( \text{DIS} \rightarrow \Delta \Sigma \approx 0.25 \)
- \( \text{RHIC} + \text{DIS} \rightarrow \Delta G \approx 0.2 \)
- \( \rightarrow L_q \)

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

[X. Ji, 1997]
**Imaging the Nucleon**

- **Transverse Momentum Dist. (TMD)**
  - Confined motion in a nucleon (semi-inclusive DIS)

- **Generalized Parton Dist. (GPD)**
  - Spatial imaging (exclusive DIS)

- **Requires**
  - High luminosity
  - Polarized beams and targets
  - Sophisticated detector systems

**Major new capability with JLab @ 12 GeV**
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
Measuring the Neutron “Skin” in the Pb Nucleus

\[ Q_{W}^{p} = (1 - 4 \sin^2 \theta_{W}) \]
\[ Q_{W}^{n} = -1 \]

Weak interaction selects neutrons

- Parity violating electron scattering
- Sensitive to neutron distribution

Applications: Nuclear Physics, Neutron Stars, Atomic Parity, Heavy Ion Collisions
Testing the Standard Model at JLab

Projected JLab data:

- MOLLER
- SoLID
- Qweak

Data:

- Q_{W}(p)
- Q_{W}(e)
- eDIS
- NuTeV
- Tevatron
- LEP 1
- SLC
- LHC

(from PDG 2014)
Charmonium Pentaquark

LHCb
2 $P_c$ states needed to describe results:
- narrow: $P_c(4450)$
- wide: $P_c(4380)$
CEBAF Program FY15-17

Experimental Hall A
- DVCS/GMP
- Argon Experiment
- Marathon

Experimental Hall B
- HPS
- P-Rad
- Key Performance Parameter
- Engineering Run
- Run Group A

Experimental Hall C
- Key Performance Parameter
- SHMS Optics Run
- Commissioning Experiments

Experimental Hall D
- Photon Line/Grue-X Commissioning
- Engineering Run
- E12-06-102: Low Intensity Glue-X

Accelerator
- Scheduled Accelerator Operations
- Accelerator Development

<table>
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<th>FY-2015</th>
<th>FY-2016</th>
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<td>2017</td>
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First Published Results from 12 GeV CEBAF

The first experimental results, from data collected in the GlueX engineering run, have been published in Phys. Rev. C.

The new GlueX results show:

- For neutral pions, the reaction mechanism is dominated by pure vector coupling.
- The first data for beam asymmetry for $\eta$ production >3 GeV.
- The GlueX experiment in Hall D can produce timely results.

GlueX will search for hybrid mesons, particles in which the strong gluonic field contributes directly to their properties. From the spectrum of these particles, we can learn about the gluonic field in QCD.

Bonus:

First observation of charmonium at JLab!
Heavy Photon Search – First Results

• NP-HEP Collaboration

2015 Engineering Run
1.7 PAC days @ 1.05 GeV

2 GeV data taken in 2016, under analysis

Future Program: more HPS, APEX, DarkLIGHT

1 mm gap between Si tracker detectors for passage of electron beam
Solving the Proton Radius Puzzle

- PRad: new experiment to address proton radius @ JLab
- NSF MRI: $\text{H}_2$ gas target
- DOE GEM tracking detectors
- Successful run in summer 2016!
In the near term, there are plans at JPARC and FAIR:

- **BELLE II** – super B factory, but also charm spectroscopy
- **JPARC Hadron Hall Extension** with K, \( \pi, \bar{p} \) up to 10 GeV
- **PANDA at FAIR** with stored and cooled 15 GeV/c anti-protons
SuperKEKB/Belle II

- A new international Flavor-Factory experiment at KEK
  - Super B-factory (~840 BB pairs/sec; total ~53×10^9 BB (50ab^{-1}))
  - Super charm factory (~1040 cc pairs/sec; total ~65×10^9 cc(50ab^{-1}))
  - Super tau factory (~740 \tau^{+}\tau^{-} pairs/sec; total ~46×10^9 \tau^{+}\tau^{-}(50ab^{-1}))
in clean environment of lepton collisions!

- Clean environment also enables to probe dark photons, light Dark Matter particles, exotic hadrons, ...

Rich physics program
JPARC Hadron Hall Extension

- Extend the Hadron Hall for ~105m.
- Construct 2 production targets with beam lines.

Single strangeness experiments to explore generalized baryon-baryon interaction

From discovery to measurement of K0 rare decay

Spectroscopy of multi-strangeness and charm systems

Courtesy S. Sawada
PANDA physics program:

• Strangeness: High statistics sample of unexplored territory hyperon ($\Lambda^*$, $\Sigma^*$, $\Xi^*$, $\Omega^*$) spectroscopy
• Charm(-like): X,Y,Z-factory, high statistics allow new approach to lineshapes, transitions, nature of the states
  Heavy-light mesons unexplored high spin states, lineshape
• Nucleon Structure: highest rates at lower $q^2$ for GE, GM, TDA, WACS, TMD
• Hypernuclei and nuclear targets: Hyperon-potential in nuclei, excited states of $\Lambda\Lambda$- hypernuclei

Expected Physics Start: 2025
RECOMMENDATION III

Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new electron ion collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.
**JLab EIC Figure 8 Concept**

- High Polarization
- High Luminosity
- Low technical risk
- Flexible timeframe for construction consistent w/running 12 GeV CEBAF
- Cost effective operations

- Fulfills White Paper Requirements

- Collaboration with SLAC, LBNL, ANL, BNL
- Site evaluation (Virginia funds)
- User group organizing (charter, meetings)
- NAS study underway
- DOE-NP accelerator R&D program (FY17-18)
Conclusion

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

• Other new opportunities:
  – JPARC Hadron Hall Extension
  – PANDA @ FAIR

• EIC moving forward:
  – Strong science case, much builds on JLab 12 GeV program
  – JLEIC design well developed – time scale following 12 GeV program is “natural”
  – NSAC 2015 Long Range Plan recommendation