Opportunities with JLab energy and luminosity upgrade

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Santa Margherita Ligure (Italy) Oct 17 – 21, 2022







Jefferson Lab

 Beam delivered to the 4 halls simultaneously at different energies and currents

- CW electron beam
- E_{max} = 12 GeV
- Pol_{max} ~ 90%
- High intensity tagged photon beam at 9 GeV
- Experiments at ultra-high luminosities, up to 10³⁹ e-nucleons /cm⁻²/ s⁻¹

- Explore the fundamental nature of confined states of quarks and gluons → Non-perturbative regime of QCD
- Discover evidence for physics beyond the standard model



Today and Tomorrow



The 12 GeV Experimental Program is in full swing 33 Experiments completed out of 91 approved



~8 years at ~30 weeks/year



CEBAF & Jefferson Lab



Energy Upgrade: the 'Big Picture'



CEBAF FFA Upgrade - 'Currently under Study'

- Starting with 12 GeV CEBAF as a baseline
- NO new SRF (1.1 GeV per linac)
- New 650 MeV recirculating injector
- Remove the highest recirculation pass (Arc 9 & A) and replace them with two FFA arcs including time-of-flight chicanes
- Recirculate 4+4 times to get to about 18 GeV
- Install a secondo pair of FFA arcs 'on the floor below Arc 9&A
- Recirculate 3 times to get about 24 GeV

Pass Arithmetic: **5** -1 + 4 + 3 = **11**

• Recirculate 4 + 6 times to get to about 22 Ge

Pass Arithmetic: **5** -1 + 6 = **10**



Courtesy Alex Bogacz



Multi-Energy Beam Dynamics in FFA Arc

CBET January 2022



Stephen Brooks BNL

Jefferson Lab

Future Opportunities at CEBAF

- **Higher energy**
- Positron beam
- **High Luminosity**

https://indico.jlab.org/event/520/

J-FUT	UR	APC ⁻ Oppc
March 28, 2022 - March 30), 2022 • Messina	Jul 18 – 3 APCTP, I Asia/Seoul tim
TOPICS		Overvier Timetab Participa
- Physics opportunities - Hadron spectroscopy - Nucleon structure	ORGANIZERS	

OBJECTIVE:

Starts Jul 18, 2022, 9:00 AM Ends Jul 23, 2022, 1:00 PM

eam capabilities

APCTP, Pohang

https://indico.knu.ac.kr/event/566/

The electroproduction of mesons and photons has been shown to be a powerful tool for studies of the interaction of elementary particles and their dynamics at short and long distances. In particular, studies of the orbital motion of partons encoded in transverse space and momentum distributions of partons, like Generalized Parton Distributions (GPDs) and Transverse Momentum Distributions

(TMDs), have been widely recognized as key objectives of the JLab 12 GeV program. Studies of azimuthal distributions of hadrons and photons in exclusive and semi-inclusive DIS (SIDIS) provide access to variety of observables widely recognized as key objectives of the COMPASS

neasurements, various activities at RHIC and KEK, the LHC fixed target projects (LHC spin SMOG2@LHCb) and a driving force behind the construction of the future Electron Ion Collider (EIC). Studies of the ground and excited nucleon state structure in terms of nucleon elastic form factors, PDFs, and the N→N* (nucleon to nucleon resonances) transition electro-excitation amplitudes offer unique complementary opportunity to explore the evolution of active components in the structure of

the ground and excited state nucleons at distances where the transition from quark-gluon confinement to the perturbative OCD regime is expected and where the dominant part of hadron

mass emerges. These studies are of particular importance to address key open problems of the Standard Model on emergence of hadron mass and quark-gluon confinement. The upgraded to 24

GeV JLab, with much wider kinematical coverage, in particular at large Q^2 , will be crucial to extend all ongoing projects at JLab, in particular studies of the 3D structure of hadrons and hadronization, pin down interaction dependent parts, providing missing deeper access to quark- gluon dynamics and

P Focus Program in Nuclear Physics 2022: Hadron Physics tunities with JLab Energy and Luminosity Upgrade

gather theorists and experimentalists to discuss the physics opportunities and technical options for each of the possible upgrade scenarios: energy, positron, luminosity 8

Physics with CEBAF at 12 GeV and Future Opportunities

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Abstract

202 Nov 30

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We summarize the ongoing scientific program of the 12 GeV Continuous Electron Beam Accelerator Facility (CE-BAF) and give an outlook into future scientific opportunities. The program addresses important topics in nuclear, hadronic, and electroweak physics including nuclear femtography, meson and baryon spectroscopy, quarks and gluons in nuclei, precision tests of the standard model, and dark sector searches. Potential upgrades of CEBAF are considered, such as higher luminosity, polarized and unpolarized positron beams, and doubling the beam energy Keywords

Progress in Particle and Nuclear Physics: In Press

https://www.ectstar.eu/workshops/opportuniti es-with-jlab-energy-and-luminosity-upgrade/

OPPORTUNITIES WITH JLAB ENERGY AND LUMINOSITY UPGRADE



High Energy Workshop Summer Series 2022



The Next Generation of 3D Imaging



https://www.jlab.org/conference/hews22#

Science at Mid x: Antishadowing and the Role of the Sea





Probe the science that would be opened up by a 20+ energy electron beam

- initially utilize largely existing or alreadyplanned Hall equipment
- leverage the unique capabilities of luminosity and precision possible at JLab in the EIC era
- 1. flagship measurements that can be done only with 20+ GeV (uniqueness)
- flagship measurements with 20+ GeV that can extend and improve the 11 GeV measurements, (enrichment)
- measurements with 20+ GeV that can set the bridge between JLab12 and EIC (complementarity)
- Working on a white paper document





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Hadron Spectroscopy

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- Tetraquark candidates observed in B decays, e⁺e⁻ colliders
- Significant theoretical interest and progress, but internal structure not yet understood
- Never directly produced using photon/lepton beams

- Photoproduction provides an alternative mechanisms to study such states
- Initial simulations from GlueX and CLAS12 demonstrate the capabilities of the existing detectors to measure these reactions



P.(4380)

Pc(4312)

Zrs(3985)

Z_c(4200) Z_c(4020)

Z,(3900)

J/ψ and ψ' photoproduction

Golden processes to pin down:

- a) existence/confirmation of pentaquark resonances
- b) nucleon structure (mass, gluon distribution...)



3D Imaging: Enhancement of $Q^2 \& P_T$ range





- Q² evolution studies possible
- More cleanly separate pure twist-2 CFFs

insight into the problem

 Significantly increase of the relevant Q² range for the Qⁿ scaling test – Not yet proven at 12 GeV

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Gluon polarization



Accessing Gluon Polarization

SU(2) - SU(3) - SU(3) + pos

0.1

 \boldsymbol{x}

0.5

How well do we know the gluon polarization in the proton?

Y. Zhou,^{1,2,3,4,5} N. Sato,⁵ and W. Melnitchouk⁵

 $Q^2 = 10 \text{ GeV}^2$

0.4

0.2

0.0

-0.2

-0.4

0.01

arXiv:2201.02075v2

 $x \Delta g$

Gluon polarization still elusive in the valence region

- First simultaneous global QCD analysis (JAM Coll.), including data from unpolarized and polarized hadron collisions (STAR&PHENIX)
- Polarized jet data cannot discriminate between >0 & <0 solutions
- In the large P_T region: solid theoretical framework based on the collinear factorization (For 0.1<x<0.3 phase space with large P_T)



SIDIS at Large x



SIDIS at Large x : JLab domain!

- At large x fixed target experiments are sensitive to ALL Structure Functions
- For EIC, observables surviving the $\epsilon{\rightarrow}1$ limit (F_{UU}, F_{UL}, Transversely pol. F_{UT})







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Anti-Shadowing



JLab at ~22 GeV is an anti-shadowing regime machine !



~22 GeV

What is needed

- High precision \rightarrow high luminosity
- e-A (x, Q²) range accessible
- Ability to change targets quickly,...
- Pol./unpol. mapping across A, N, Z,
- Nuclear tagging \rightarrow links between nuclear dynamic & quark structure 15

- Region extremely interesting, near-equally dominated by valence quarks, sea-quarks, and gluons → many many models!!
- Anti-Shadowing is the least studied nuclear structure function effect exp.
 - flavor and spin dependence essentially uncharted
 - no tagged measurements
- The transition between shadowing and the EMC regimes → a testing ground for different descriptions





Physics Beyond the Standard Model



Торіс	Presenter	Highlight/Comment
SoLID PVDIS on deuteron	A. Emmert	Prelim. Study \rightarrow reduced uncertainty in sin ² θ_{W}
BSM in PVDIS experiments	S. Mantry	$e \rightarrow \mu$ study underway
Primakov effect experiments	L. Gan	γ + e $\rightarrow \pi$ +e, new gauge boson searches
BDX experiment	M. Spreafico	Prelim. Study → expanded reach
BSM with secondary beams	M. Bondi	Competitive with current hadron facilities

π^0 Primakoff production off an electron target: eliminate nuclear bkg





Many more...

- Electroproduction of N* resonances with increased Q² range to explore emergence of hadron mass
- DDVCS for direct probe of GPDs away from the $x=\pm\xi$ line.
- Parity-violating DIS for unambiguous access to Strange Quark
- Hadron Formation using Nuclei
- Nuclear forces at extreme dynamics: investigation of Nuclear Repulsive Core
- Search for sub-GeV dark scalars and pseudoscalars

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Science at the Luminosity Frontier: JLab at 22 GeV

Next Workshop : Jefferson Lab – January 23-25, 2023

[Cuga] ***Save the Date*** "Science at the Luminosity Frontier: Jefferson Lab at 22 GeV" Jan. 23-25, 2023- a message from Thia Keppel and David Dean \leftarrow \leftarrow \leftarrow

First Circular

Mark your calendars for "Science at the Luminosity Frontier: Jefferson Lab at 22 GeV", a workshop to explore the science made possible by an energy upgrade to the CEBAF accelerator. The workshop will take place at the laboratory from Monday, January 23, to Wednesday, January 25, 2023. This workshop will encompass the broad spectrum of topics in medium energy physics enabled by the potential upgrade, and will feature theoretical advances as well as recent and potential results. Concrete projections for experiments are encouraged. Topics will include:

- Hadron spectra as probes of QCD
- Transverse structure of the hadrons
- Longitudinal structure of the hadrons
- 3D structure of the hadrons
- Hadrons and cold nuclear matter
- Low-energy tests of the Standard Model and Fundamental Symmetries

All sessions will take place at the CEBAF Center auditorium. In-person attendance is strongly encouraged, but the meeting will likely have a hybrid connection. Morning registration and an evening reception will be held on Monday, January 23.

Further announcements will be sent along with the organizing committee, as well as guidelines for requesting a presentation. For now, please reserve the date and plan to attend!

David Dean

Deputy Laboratory Director and Cynthia Keppel Associate Director for Physics Thomas Jefferson National Accelerator Facility

Conclusions

- CEBAF 22 GeV upgrade capitalizes on existing investments
 - Scientific program with existing Hall equipment
 - Leverage new FFA accelerator technology with resistive magnets
- Strong science case for JLab energy upgrade in <u>development</u>
 - Unique measurements at the luminosity frontier
 - Complementary to EIC
 - Leverages precision capabilities of Jefferson Lab
- Support for energy upgrade development
 - Users
 - Lab support, including LDRD investment
 - DOE encouragement to develop the science reach and technical aspects of an upgrade

