Jefferson Lab
and SBIR/STTR Program

Drew Weisenberger
DOE-NP SBIR/STTR Exchange Meeting Aug 8-9 2017
Outline

• Jefferson Lab Overview and Mission

• Scientific and Technical Capabilities

• JLab and the NP SBIR/STTR Program—A Synergistic Involvement
JLab Overview
Jefferson Lab At-A-Glance

- Created to build and operate the Continuous Electron Beam Accelerator Facility (CEBAF), a world-unique user facility for Nuclear Physics:
  - Mission is to gain a deeper understanding of the structure of matter
    - Through advances in fundamental research in nuclear physics
    - Through advances in accelerator science and technology
  - In operation since 1995
  - 1,530 Active Users
  - 181 Completed Experiments to-date (3 full, 3 partial from 12 GeV era)
  - Produces ~1/3 of US PhDs in Nuclear Physics (531 PhDs granted to-date; 195 in progress)

- Managed for DOE by Jefferson Science Associates, LLC (JSA)

- Human Capital:
  - 699 FTEs
  - 26 Joint faculty; 28 Post docs; 9 Undergraduate students; 39 Graduate students

- K-12 Science Education program serves as national model

- Site is 169 Acres, and includes:
  - 72 Buildings & Trailers: 880K SF
  - Replacement Plant Value: $415M

FY 2016:
Total Lab Operating Costs: $184.1M
Non-DOE Costs: $6.3M
12 GeV CEBAF Upgrade

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

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

"With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized"
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, hyper-nuclear physics, future new experiments (e.g., MOLLER and SoLID)
NP Data Acquisition

• All four halls base their DAQ off CODA (CEBAF Online Data Acquisition) - a suite of software and hardware components for building DAQ systems

• Data is read from the detector by embedded VME CPUs running Linux.

• Switched network transfers data to servers running Linux.
  – Use “high end” multi-core servers to maximize throughput per server.
  – Network for Event Builder is 40 Gbit/s InfiniBand.
  – CODA can Run multiple EB and ER in parallel.

• GLUEX in hall-D high luminosity running (2019 onward)
  – 16 kByte events at 90 kHz ~ 1.5 GByte/s
  – GLUEX DAQ tested at 2.7 GByte/s with two Event Builders
  – GLUEX will generate 7 Pbyte of raw data in 2019.
Scientific & Technical Capabilities
Instrumentation, Detection Systems & Techniques
Photon Detector Characterizations

- Temperature effects
- B-field effects
- Rad hard (AmBe $10^{11}$ n/cm²)
- Timing
- Linearity
- Spatial uniformity of response
- Crosstalk

-Microchannel plate based photomultiplier tubes (MCP/PSPMT)
-Large area picosecond photon detector (LAPPD)
-Silicon photo multipliers (SiPM)
-Single Photon Avalanche Photo Diodes (SPADs)

Hamamatsu- Japan
Photonis- France
Photek- UK
ANL/Incom (Boston)
Voxtel
Silicon Photomultipliers & Radiation Hardness

- Silicon Photomultipliers (SiPMs) offer the advantage of high B field immunity
- But have key disadvantages at present
  - Do not have the *single photon* timing resolution offered by MCP-PMTs
  - Numerous studies indicate damage threshold \( \sim 10^{10} \text{n}_{eq}/\text{cm}^2 \)
  - Some alleviation possible through low temperature operation and offline high temperature annealing
- For EIC applications, latest studies indicate that dose levels are tolerable (\( \sim 10^{10}-10^{11} \text{n}_{eq}/\text{cm}^2 \))
- Commercial SiPMs continue to improve in higher photodetection efficiency and lower noise, but radiation damage data is for discontinued models in most cases
- Need to re-evaluate current commercial models to assess suitability of SiPMs

Ketek WB
Hamamatsu S13360
SensL J
Advansid NUV
Multichannel ASIC-based Readout

**Microchannel PMTs & SiPM arrays**

- **SiPM array**
  - 3x3 mm² pixels
  - 256 channels
  - 5x5 cm² area

- **MCP-PMT**
  - 6x6 mm² pixels
  - 64 channels
  - 5x5 cm² area

Address needs of modern detector setups involving high channel counts and small pixel readout – extend success with MaPMT (CLAS12 RICH) to microchannel PMTs (giving high timing precision) and SiPMs (compactness, low voltage operation, magnetic-field immunity)

- In collaboration with Fast Electronics Group (F. Barbosa, B. Raydo, C. Dickover), will adapt existing solutions to these photodetectors

- Use results to leverage further development to address unique capabilities and challenges imposed by these detectors

Both sensors and ASIC chips on site
SRF R&D Activities

- SRF R&D
  - High Q0
  - High gradient
  - Surface doping
  - Thin films

- SPP
  - LCLS-II
  - FRIB
  - HZB
  - CERN
## Major Projects Underway

<table>
<thead>
<tr>
<th>Description</th>
<th>LCLS II</th>
<th>FRIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 GeV superconducting linac in existing SLAC tunnel</td>
<td>New user facility at MSU for rare isotope studies</td>
<td></td>
</tr>
</tbody>
</table>

| Collaboration | ANL, Cornell, FNAL, LBNL, SLAC, Jefferson Lab | MSU, State of Michigan, DOE SC, Jefferson Lab |

<table>
<thead>
<tr>
<th>Jefferson Lab Scope</th>
<th></th>
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<tbody>
<tr>
<td>Cryoplant design and acquisition</td>
<td>• Cryogenic system design, procurement, fabrication, and integration</td>
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</tr>
<tr>
<td>Cryomodule and cavities for half of linac</td>
<td>• Cryomodule engineering and design finalization</td>
<td></td>
</tr>
<tr>
<td>Qo R&amp;D, LLRF, machine physics</td>
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<table>
<thead>
<tr>
<th>Status</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>✓ CD 2/3A complete</td>
<td>✓ FDR for 2K cold compressors complete</td>
<td></td>
</tr>
<tr>
<td>✓ First two cryoplant procurements placed</td>
<td>✓ Beta 0.041 design complete</td>
<td></td>
</tr>
<tr>
<td>✓ Prototype cryomodule complete and tested,</td>
<td>✓ Beta 0.29 design complete</td>
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<tr>
<td>✓ Production cryomodule assembly started, string 6 completed.</td>
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</table>
LCLS-II Cryoplant Schematic showing Cryogenic Distribution System (CDS)

Cryoplant (JLab- ½ linacs & cryo plant)

CDS (Fermilab- CDS piping)
Boron Nitride Nanotubes (BNNT) based Neutron Detector

Radioisotope Based Molecular Imaging for Plant Biology

3-D Breast Cancer Detector

Handheld Gamma Camera for Surgeons

Scintillation Web Detector for Radioisotope Imaging of 32P Uptake in Plant Roots

BNNT based neutron detector

Plant biology studies with $^{11}\text{O}_2$

VASH installed on Dilon Technologies gamma camera

SiPM based detector

Plastic scintillator coupled to wavelength shifting fiber
Novel Gamma Camera Development: SiPM Based

SiPM based Low Profile Imager in collaboration with Dilon Technologies

Two of twelve SiPM Arrays with passive temperature compensation on mother board. Total height ~ 1.0 cm

Allows for thinner lighter cameras. Facilitates a dual headed system and advanced collimators

Leveraging original SiPM development for Hall D
Nuclear Physics Emerging Initiatives
High power (~100 kW) electron accelerators are well suited for the production of some important isotopes for medical and industrial applications.

Method: generate bremsstrahlung photons, using a radiator, which in turn irradiates the target.

- LERF at Jefferson Lab (FEL) can deliver >100 kW of beam power
- Electron beam energy & current are tunable
- Use it to produce $^{67}\text{Cu}$ with the bremsstrahlung
Technical Challenge

Target system which can handle high power (50 kW)
For $^{67}\text{Cu}$ production, gallium is a potential isotope target
  - Solid below $\sim 30^0 \text{ C}$
  - Boiling Point $\sim 2200^0 \text{ C}$

VCU will perform separation of $^{67}\text{Cu}$ from irradiated gallium
Decade of Experiments Approved
First 12 GeV Science Experiment Complete!

Electron Ion Collider
The Next QCD Frontier

- Confinement
- Hadron Structure
- Nuclear Structure and Astrophysics
- Fundamental Symmetries

2015 NSAC Long Range Plan
Strong support for TJNAF program

- Role of Gluons in Nucleon and Nuclear Structure

Exploring the Glue that Binds Us All
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

Jones Report:
EIC R+D lead to SBIR call for simulation of spin tracking, beam-beam effects, EIC

energy range:
e-: 3-10 GeV
p : 20-100 GeV

Cooling strategy:
• DC cooler in booster
• Bunched beam cooler in Ion collider ring

Collaboration with SLAC, LBNL, ANL, BNL
JLab and the NP SBIR/STTR Program
Synergistic involvement
– Accelerator Technology
– Simulation Software and Data Management
– Nuclear Physics Isotope Science & Technology
– Instrumentation, Detection Systems & Techniques
## SBIR Partners

<table>
<thead>
<tr>
<th>Partner</th>
<th>Project</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Laboratories</td>
<td>Processing Methods for Superconducting Materials</td>
<td>Charlie Reece</td>
</tr>
<tr>
<td>Microdynamics Inc</td>
<td>Continued evolution of the operational performance characteristics of the “CYCLOPS” cavity internal inspection and topography characterization system</td>
<td>Charlie Reece</td>
</tr>
<tr>
<td>MuPlus</td>
<td>Design and Optimization of Muon Cooling Channel</td>
<td>Mike Spata</td>
</tr>
<tr>
<td>SVT</td>
<td>GaAsSb/AlGaAs Superlattice High-Polarization electron source</td>
<td>Matt Poelker</td>
</tr>
<tr>
<td></td>
<td>Construct and operate a compact photocathode preparation chamber with a microMott polarimeter, with true load-lock capability</td>
<td>Matt Poelker</td>
</tr>
<tr>
<td>Alameda</td>
<td>Nb-on-Cu cavities for 700-1500 MHz SRF accelerators</td>
<td>Charlie Reece</td>
</tr>
<tr>
<td></td>
<td>Viability of Cathodic Arc Nb coatings on electro-hydro-formed copper cavities</td>
<td>Charlie Reece</td>
</tr>
<tr>
<td>Faraday</td>
<td>Investigate and accelerate the development of the FARADAYIC HF-FREE Electro-Polishing process (aka cathodic electropolishing (CEP) for SRF Niobium cavities</td>
<td>Charlie Reece</td>
</tr>
</tbody>
</table>
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<tr>
<td>Radiabeam</td>
<td>Nb Nano-Patterned Cathode</td>
<td>Fay Hannon</td>
</tr>
<tr>
<td></td>
<td>BNNT Wire Scanner</td>
<td>Joe Gubeli</td>
</tr>
<tr>
<td>Muons Inc</td>
<td>Test two 13kW, CW magnetrons built by Muons Inc</td>
<td>Haipeng Wang</td>
</tr>
<tr>
<td></td>
<td>Lossy Beam Pipe HOM Load Ceramics with DC Conductivity</td>
<td>Frank Marhauser</td>
</tr>
<tr>
<td>Surmet</td>
<td>Provide cryogenic testing of ten (10) wedge samples to be provided by SURMET for testing</td>
<td>Jiquan Guo</td>
</tr>
<tr>
<td>Electrodynamic</td>
<td>Non-Invasive Spin Polarization Monitoring</td>
<td>Matt Poelker</td>
</tr>
<tr>
<td>Xelera Research*</td>
<td>A Magnetized Electron Source for Ion Beam Cooling</td>
<td>Fay Hannon</td>
</tr>
<tr>
<td>Q-Peak*</td>
<td>High Power, High Repetition Rate, 700-850nm Pulsed Laser</td>
<td>Shukui Zhang</td>
</tr>
</tbody>
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* At DOE for Approval
Accelerator Technology
Jefferson Lab actively seeks opportunities with **Industrial Partners** to conduct research that is aligned with our Strategic Plan.

Laboratory staff work with the **SBIR Program Manager** to edit topical areas for the different Funding Opportunity Announcements.

Solicitations received from Industry cover a broad spectrum of potential opportunities.

Jefferson Lab provides a **prioritized list of supported proposals** to the SBIR Program Manager.

We then monitor awards for potential synergies with our Strategic Plan.

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**SBIR Letters of Support Over Last Two Years**

- Accelerator Physics: 13
- Computational Physics: 1
- Detectors: 2
- Diagnostics: 5
- Electronics: 1
- Isotopes: 4
- Magnets: 2
- Polarimeters: 2
- RF Power: 1
- Sources: 4
- SRF: 2
- Targets: 6
- Vacuum: 2

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*Jefferson Lab*
SRF R&D

JLab SRF has benefitted from various SBIR collaborations, including RF source development, new **SRF processes**, new **materials**, new **tuners** and other cavity fabrication-related activities and **EM simulation tools**.

**What we need now:**

- High efficiency RF sources (>70%), including magnetrons, for JLEIC (952.6MHz) and as replacement for the old CEBAF klystrons (1497 MHz)
- SRF compatible microwave absorbing materials for HOM loads at cryogenic temperatures.
- Low loss, reliable RF windows and couplers, capable of 13 kW to 500 kW operation.
- Low-impedance, particle free bellows for high currents.
- Novel fabrication techniques for seamless cavities.
- Novel support structures or vibration isolation techniques to counter microphonics.
- New materials or process especially for high Q’ and HF(acid)-free recipes
- New high Tc SRF materials.
- New cavity diagnostics and inspection methods.
- Novel crab (deflecting mode) cavity designs.
High efficiency at low cost: ingot Nb

Medium-purity ingot Nb is a good material to build SRF cavities operating at medium gradients with higher efficiency and potentially lower cost (~1/3) than standard high-purity, fine-grain cavities.

Chosen for new “C75” cells

G. Ciovati et al., SRF’15, MOPB001 (2015).
**Improved efficiency: JLab Nb$_3$Sn 5-cell progress**

**G. Eremeev early career award**

The new configuration was commissioned up to 1250 °C on May 4, 2017.

New 17” OD x 40” furnace insert

- Nb$_3$Sn grain structure
- Looking from the top

Reasonable low-field $Q_0$, but a strong $Q$-slope, similar to the one measured in 5-cell cavity coated at Wuppertal University. Medium field $Q$-slope is likely due to equator features. Nb$_3$Sn coating is present, but is not uniform. The top of the cavity seems “shinier” than the bottom.

**More 5-cell cavity tests coming soon!**
**Nb/Cu Thin Film Cavity - HIPIMS**

**Upgraded Deposition System**
- Tripled Pulse Power Capability
- Permanent Vertical System Operation

**Small Samples**
- Very low surface roughness
- Bulk-like crystal structure
- Hetero-epitaxial Growth

**Cavities**
- Cavity RF performance shows larger Q than bulk at low field
- Excellent film adhesion
- Continuing to converge on a high quality copper surface for film deposition

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**PE-01 - Niobium single cell (C100 end Cell type)**

**Nb/Nb, Preliminary**

- More Cu cavity tests coming soon!

Matt Burton, Larry Phillips, et. al.
HF-Free Electropolishing Niobium

Pulse-reversed process demonstrated effective on single cell cavity by Faraday Technology using sulfuric acid alone

**JLab** is providing detailed electrochemical analysis and process characterization with varied concentration and pulse structure

Completed setup of first vertical EP cabinet for HF-free cavity processing

E.J. Taylor et al., SRF2013
A.M. Rowe et al., SRF2013

H. Tian, et. al.

First cavity processed this way somewhere other than Faraday Technology. 10% sulfuric acid
Injectors and sources R&D

CEBAF Injector and JLEIC R&D

- Bunchlength monitor and fast kicker using harmonically-resonant cavity, harmonic arbitrary waveform generator and amplifier (SBIR-related)
- Non-invasive electron beam polarimeter, RF-cavity to detect polarization, and/or to monitor Stern-Gerlach deflection (SBIR-related)
- High Polarization and High QE Photocathodes (SBIR-related)
- Improving vacuum to -13 Torr (funded via Research and Development for Next Generation Nuclear Physics Accelerator Facilities)
- Thermionic gun with RF time structure, for generating magnetized beam (SBIR-related, JLEIC)
- Powerful drive laser for photoguns, wavelength near 532 and/or 780 nm, with variable repetition rate, ~ 50ps laser pulses via gain-switching (SBIR-related)
Enhanced absorption occurs only at specific laser wavelengths.

**Benefits of Distributed Bragg Reflector**

- **non-DBR Photocathode**: absorption in the GaAs/GaAsP superlattice < 5%
  - Most light passes into the substrate leading to unwanted heating
- **DBR photocathode**: absorption in the GaAs/GaAsP superlattice > 20%
  - Less light required to make required beam, less light means less heat
- Great for high current initiatives like polarized positrons at CEBAF and EIC

<table>
<thead>
<tr>
<th></th>
<th>GaAs</th>
<th>5 nm</th>
<th>p=5E19 cm⁻³</th>
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<tbody>
<tr>
<td>GaAs/GaAsP SL</td>
<td>(3.8/2.8 nm) x14</td>
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<td>p=5E17 cm⁻³</td>
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<tr>
<td>GaAsP₀.₃₅</td>
<td>2750 nm</td>
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<td>p=5E18 cm⁻³</td>
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<tr>
<td>Graded GaAsPₓ</td>
<td>(x = 0~0.35)</td>
<td>5000 nm</td>
<td>p=5E18 cm⁻³</td>
</tr>
<tr>
<td>GaAs buffer</td>
<td>200 nm</td>
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<td>p=2E18 cm⁻³</td>
</tr>
<tr>
<td>p-GaAs substrate</td>
<td>(p&gt;1E18 cm⁻³)</td>
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<td>p=5E17 cm⁻³</td>
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<tr>
<td>GaAsP₀.₃₅ spacer</td>
<td>750 nm</td>
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<td>p=5E18 cm⁻³</td>
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<tr>
<td>GaAsP₀.₃₅/ AlAsP₀.₄ DBR</td>
<td>(54/64 nm) x12</td>
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<tr>
<td>GaAsP₀.₃₅</td>
<td>2000 nm</td>
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<td>p=5E18 cm⁻³</td>
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<td>Graded GaAsPₓ</td>
<td>(x = 0~0.35)</td>
<td>5000 nm</td>
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</tr>
<tr>
<td>GaAs buffer</td>
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<td>p-GaAs substrate</td>
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**Photocathode without DBR**
- Non-DBR photocathode

**Photocathode with DBR** (57 layers!)
- DBR photocathode

SVT Associates phase 2
World Record: QE from High Polarization Photocathode

Others have tried…but very difficult to obtain QE enhancement at the laser wavelength that also provides high polarization, CEBAF lasers operate at ~ 776 nm (doubled-telecom lasers)

- Standard strained-superlattice
  - QE = 0.89%
  - Polarization = 92%
- DBR
  - QE = 6.4%
  - Polarization = 84%
- The highest reported QE of any high polarization photocathode
- Excellent candidate for mA operations, will test at CEBAF this shutdown
- SBIR partnership

SVT Associates phase 2
Harmonically resonant cavity as selective energy booster

- Drive **harmonically resonant cavity** with RF to create powerful, short-lived E-field
- Set laser rep rate to 1247.5 MHz, kicker driven at 1497 MHz plus harmonics
- Use, Wien filter, chopper and/or 1D spectrometer to measure energy boost

Electrodynamic, Phase 2 SBIR
RF cavities for JLEIC

- JLEIC Collider Rings
- 476.3 MHz electron-ring (NCRF PEP-II)
- 952.6 MHz crab (SCRF)
- 952.6 MHz ion-ring (SCRF)
- 952.6 MHz cooler ERL (SCRF)
- 952.6 MHz booster (SCRF)
- Electron Injector
- 12 GeV CEBAF
- Halls A, B, C
- ODU
- Crab
- i-SRF + NCRF
- Cooling
- Booster
- SRF Linac
- Ion Source
- Harmonic Fast kicker for cooling ring
LDRD Magnetized Electron Source

- $K_2$CsSb Photocathode Preparation Chamber, Gun, Solenoid and Beamline are all operational

- Replace photogun with rf-pulsed thermionic gun (Xelera phase2)
EIC R&D Areas Ripe for SBIR

- Magnetized electron sources
- Polarized proton sources and polarimeters
- Charge Strippers for heavy ions
- Magnet R&D for: 1) fast cycling 3-4 T SC magnets, 2) high field-high aperture IR magnets, 3) 1-2T long solenoid (20m) for e-cooling
- Advanced simulations and modeling for: 1)bunched beam electron cooling, 2)beam-beam, 3)space-charge and 4) spin tracking
Simulations and Data Management
SBIR Topics in Modeling/Simulations

• Study of non linear dynamics in the presence of beam beam interactions
  – Effect of beam beam in the presence of non-linearities
  – Effect of coherent and incoherent beam beam on the working point
  – Implications of utilizing a multi bunch scheme (gear changing) for synchronization
  – Effect of crab crossing in the presence of beam beam, synchro-betatron resonances
• Chromaticity compensation and dynamic aperture optimizations in the presence of higher order multipoles and magnet non-linearities
• Ion beam generation, acceleration, injection into the booster ring in the presence of space charge
• Estimation of electron cloud effects in the ion ring
• Design of a cooler for bunched beam cooling for the ion beam
• Development of a GPU accelerated code for beam cooling simulation
a) Experiments in nuclear, high energy and astrophysics require hundreds to thousands of recording channels capable of fast data acquisition and signal processing.

b) Proposal to design and make commercially available the “ASoC”: a low-cost, low power and high density System-on Chip (SoC) capable of analog signal conditioning, 4 Gigasample/sec waveform sampling and integrated readout and signal processing capabilities.

c) The ASoC device will also have a deep sampling buffer making it suitable for large nuclear physics experiments with potentially long trigger delays. Design and development of the advanced ASoC chip which is built based on the existing IRSX chip by integrating into one SoC (i) analog signal conditioning circuits, (ii) an optimized version of IRSX, and (iii) digital readout and signal processing block capabilities (triggering, sparsification and data reduction).
New Tech Center Adjacent to Jefferson Lab

- Located on 50 acres adjacent to Jefferson Lab
- Follows the proven business model at Virginia Tech Corporate Research Center (VTCRC)
- 1 million square feet of research and office space
Conclusions

• Successful track record of synergy between the SBIR program and JLab

• JLab is committed in to continuously supporting & enhancing the SBIR/STTR program at JLab especially in Accelerator, Detector & Isotope R&D

• We are in particularly interested in exploring the SBIR/STTR opportunities towards EIC directed R&D, and we welcome the opportunity to support future proposals.
Thank You
Design and fabrication of the “SiREAD”- Silicon photomultiplier REadout, Automated calibration and Detection: A low power, low noise and high performance waveform sampling chip for high channel NaLu Awarded Phase I - $150k funding

1. Proposal to design and make commercially available the “SiREAD”: a low-cost, low power and high density System-on Chip (SoC) capable of analog signal conditioning, fast waveform sampling and integrated readout and signal processing capabilities.

2. The SiREAD device will also have calibration and monitoring circuitry in addition to a deep sampling buffer making it suitable for large Nuclear Physics experiments with potentially long trigger delays.

3. Design and development of the advanced SiREAD chip which is built based on the existing TARGET chip by integrating into one SoC (i) analog signal conditioning circuits and bias monitoring, (ii) an optimized version of TARGET, and (iii) digital readout and signal processing block capabilities (triggering, sparsification and data reduction).
Readout implementations for EIC eRD14 PID
Consortium from Nalu Scientific

- mRICH (Georgia State) prototype will use the 256 channel (3x3 mm\(^2\) pixels) H13700 PMT (update to Hamamatsu H9500)

- Use available TARGETX ASIC – 16 channels - developed originally for SiPM readout in BELLE II

- Each H13700 will have adapter board that handles 8 plug-in cards (2 ASICs/card) + separate FPGA card for readout of one PMT – all 256 channels

- Goal is to eventually use SiREAD ASIC – now in SBIR Phase II development – as core ASIC for photodetector (MCP-PMT, SiPM, LAPPD) readout
One single cell cavity was used for the study to explore the low temperature nitrogen infusion. The baseline test is limited by Q-slope ~40MV/m and conventional 120 C bake improved the gradient and quenched at 46.5 MV/m. After low temperature N2 infusion, best result is observed with cavity baked at 140C/48hours in Nitrogen environment with $Q_0= 2 \times 10^{10}$ at 35 MV/m. The study is ongoing...

P. Dhakal et. al.
JLEIC High Energy Electron Cooler

High Energy Electron Cooler

- Ion beam cooling solenoid (B<0)
- Magnetization flip cooling solenoid (B>0)
- Injector
- Beam dump
- Linac
- ERL Ring
- Fast extraction kicker
- Fast injection kicker
- Dechirper
- Vertical bend to CCR
- Injected bunches
- Exchange septum
- Circulating bunches
- Extracted bunches
- Vertical bend into ERL
- Rechirper

12 GeV CEBAF

100 meters
JLEIC super-ferric magnet R&D

Texas A&M developed 2 approaches to winding cable:

**NbTi Rutherford cable**

**Pros:**
- Uses mature cable technology (LHC).

**Cons:**
- Ends tricky to support axial forces.

**NbTi Cable-in-Conduit**

**Pros:**
- Semi-rigid cable makes simpler end winding.
- Semi-rigid round cable can be precisely located.
- Cryogenics contained within cable.

**Cons:**
- Cable requires development and validation.
Improving SRF Cavity Efficiency via Doped Materials

Learning how to minimize SRF losses (maximize cavity $Q$) via Nitrogen Doping of Niobium

- Collaborated with FNAL and Cornell to **validate High-$Q$ process for LCLS-II**
  - Enabled >50% reduction in cryo-load compared with previous methods
  - Now transferring the protocols to vendors
- Systematically studying the doping protocols, material effects, and SRF properties
  - Involving university collaborators (including graduate students) in **detailed material characterization**
  - Beginning to interpret new RF performance in terms of latest basic SRF theory
Collaboration with CERN on SRF for FCC

Collaboration on 802 MHz SRF for FCC-eh (CERN’s electron-ion option)
- Cavity design and prototype
- Joint study on cryomodule

Cryomodule based on SNS

ERL cavity

HOM spectrum looks good
High Polarization Photocathodes

90% polarization!! Need to shift QE resonance peak for CEBAF lasers

Sample# 75102 (DBR) vs. 75303 (Sb, non-DBR)

Distributed Bragg Reflector (DBR) enhancement designed @760nm

Need to shift DBR resonance to 780nm!

Partners with SVT Associates: 3 phase-2 SBIR proposals

GaAsSb/AlGaAsP not bad, need to test at high voltage
Construction of a Ring Imaging Cherenkov (RICH) detector to replace two sectors of the LTCC in CLAS12. Each sector has an entrance window of \( \sim 4.5 \text{ m}^2 \) and an exit window of \( \sim 8 \text{ m}^2 \).

**Goal:** ID of kaons vs \( \pi \) and \( p \) with momentum 3-8 GeV/c with a \( \pi/K \) rejection factor 1:500

Hybrid solution: proximity gap plus focusing mirrors

Two elements extend the current "state-of-the-art" in the technology:

a) Spherical mirror
b) Aerogel
Ten spherical mirror
  total surface \(\sim 3.6 \text{ m}^2\) mounted on a supporting structure attached to the RICH module

Four frontal planar mirror
  total surface \(\sim 3 \text{ m}^2\) mounted on the frontal closing panel they hold the aerogel tiles

Six lateral planar mirrors
  total surface \(\sim 1.4 \text{ m}^2\) mounted on the lateral panel

One bottom mirror
  surface \(\sim 0.2 \text{ m}^2\) mounted on the lower panel

**Spherical mirrors requirements:**

- low material budget
- **surface roughness** below 3 nm RMS
- **surface accuracy** below 6 \(\mu\text{m}\) P-V
- **radius accuracy** better than 1%

Only one company within USA and Europe is able to fulfill the above requirements
Aerogel is the only known material whose index of refraction is correct for Kaon ID in the desired momentum range.

One layer of 2cm thickness and $n=1.05$ radiator for $\theta<13^\circ$ and two layers of 3cm thickness and $n=1.05$ radiator for $\theta>13^\circ$ will be used.

**Aerogel requirements:**
- Refractive index: 1.05
- Area: 20x20 cm$^2$ (large tiles)
- Thickness: 3 cm
- Scattering Length: greater than 50 mm (high transmission length)

Only one company in the world is able to fulfill the above requirements
Hall B – HDice Target for transverse configuration

• Solid HD material placed into a frozen spin state - requires only modest (~1 T) short (~15 cm) field to hold spin in-beam (MgB2 magnesium diboride)

• Operating performance with electrons beams requires further beam tests ➔ plan to use upgrade of the injector test facility: $E_e = 5 – 10$ MeV (~10 MeV beam will test the HD performance at 11 GeV!)

Modifications required to operate the target in transverse polarization mode in the CLAS12 Solenoid, whose strong long. magnetic field must be locally repelled.

Status of ongoing work:

• Transport design for 10 MeV rastered ITF beam

• R&D for a new “passive” SC diamagnetic shield to hold spin transverse to beam within solenoid

• Improving NMR system for target polarization measurement

• Design and build new HD gas purification factory

Patrizia Rossi
Gamma Camera for Breast Cancer Detection

Drew Weisenberger

**Dilon Technologies, Inc.** Newport News, VA
~20 employees, >250 units sold internationally imaging performed on >250,000 patients

**Nuclear physics detector technology used in the Dilon camera** - helps detect breast cancers that conventional mammograms may miss, saving lives.

Recently: CRADA with Hampton University, Dilon & JLab initiated to enhance gamma camera performance using NP *silicon photomultiplier technology.*
Learning how to grow high quality Superconductor/Insulator/Superconductor films

- Multi-layer SIS films may be a path to support very high surface RF fields
- Now producing high quality NbTiN/AlN/Nb films by multi-target sputter deposition
  - Candidate system to test the SIS SRF theory
  - Showing excellent progress in avoiding parasitic losses
  - Initial results are consistent with theory

<table>
<thead>
<tr>
<th></th>
<th>Thickness [nm]</th>
<th>$H_{c1}$ [mT]</th>
<th>$T_c$ [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NbTiN/MgO</td>
<td>2000</td>
<td>30</td>
<td>17.25</td>
</tr>
<tr>
<td>NbTiN/AlN/AlN ceramic</td>
<td>145</td>
<td>135</td>
<td>14.84</td>
</tr>
<tr>
<td>NbTiN/AlN/MgO</td>
<td>148</td>
<td>200</td>
<td>16.66</td>
</tr>
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</table>
High Gradient: New Results and Next Steps

Purpose: achieve high gradient with high efficiency, at a low cost and high reliability
Approach: Low-Surface-Field Shape + Large-grain Niobium material + advanced processing

JLAB SRF 1-Cell 1.3 GHz Large-Grain Niobium Cavity G2

- 1.3GHz 1-cell
- TTF shape
- Large-grain Nb
- In-house built
- In-house proc.

Prototypes:
- Two each 1-cell built and tested
- Two each 3-cell and one each 9-cell in process of fabrication.

Future cavities: LSF cavity

R. Geng

E_{acc} [MV/m]
JLEIC Magnet R&D

• Existing collaboration with Texas A&M for the design and prototyping of super-ferric magnets for the ion collider ring and for the booster
• Design and prototyping of high field, large aperture, compact superconducting magnets for the collider Interaction Regions and Final Focus
• Design of long solenoids (15-30m) for bunched beam cooling

Example: design of a large-aperture high-pole-tip-field superconducting quadrupole with modest yoke thickness

Type: Quadrupole
Length 2.4 m
Max Field Gradient 51 T/m
Aperture/bore radius 11.8-17.7
Max outer size 43 cm (on one side)
Field uniformity <10^-4 at 25mm radius
Detector Development for Plant Biology with Triangle Universities
Nuclear Laboratory / Duke University

Duke University Phytotron plant research facility with environmentally controlled growth chambers for plant ecophysiological and microbial research using radionuclides

Radioisotope generation using TUNL tandem Van de Graaff

Drew Weisenberger
Positron emission tomography (PET) detector systems to image the process of carbon transport through plants during photosynthesis under different conditions, using the PET radioisotope $^{11}\text{C}$. 

Leaf cuvette for $^{11}\text{CO}_2$

PhytoPET detector modules

Corn seedling leaf

PhytoPET-Duke University/Jefferson Lab

Drew Weisenberger
• Measured vertical emittance after every pass
Strategy for High Luminosity and Polarization

**High Luminosity**
- Based on **high bunch repetition rate CW colliding beams**
  \[ L = f \frac{n_1 n_2}{4\pi\sigma_x \sigma_y} \sim f \frac{n_1 n_2}{\varepsilon \beta_y} \]
- KEK-B reached > 2x10^{34} /cm²/s
- However new for proton or ion beams

**High Polarization**
- All rings are in a figure-8 shape  
  ➔ critical advantages for both beams
  - Spin precessions in the left & right parts of the ring are exactly cancelled
  - Net spin precession (spin tune) is zero, thus **energy independent**
  - Spin can be controlled & stabilized by small solenoids or other compact spin rotators

**Beam Design**
- High repetition rate
- Low bunch charge
- Short bunch length
- Small emittance

**IR Design**
- Small $\beta^*$
- Crab crossing

**Damping**
- Synchrotron radiation
- Electron cooling

**Excellent Detector integration**
- Interaction region is designed to support
  - **Full acceptance** detection (including forward tagging)
  - Low detector **background**
## Calculated Yields and Contaminants

*(Full Absorption target)*

<table>
<thead>
<tr>
<th>Energy of Electron Beam [MeV]</th>
<th>Natural Gallium Target</th>
<th>$^{71}$Ga Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.5</td>
<td>40</td>
<td>100</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nuclide &amp; dominant production reaction</th>
<th>$T_{1/2}$</th>
<th>Calculated Yield [ mCi / (50 kW - h) ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{67}$Cu $^{71}$Ga($\gamma$,n)$^{67}$Cu</td>
<td>61.8 h</td>
<td>1.4  13  18  3.5  32  44</td>
</tr>
<tr>
<td>$^{64}$Cu $^{69}$Ga($\gamma$,n)$^{64}$Cu</td>
<td>12.7 h</td>
<td>298  521</td>
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<tr>
<td>$^{71m}$Zn $^{71}$Ga($\bar{n}$,p)$^{71m}$Zn</td>
<td>4 h</td>
<td>0.1  0.8  0.2  1.1</td>
</tr>
<tr>
<td>$^{69m}$Zn $^{69}$Ga($\gamma$,np)$^{69m}$Zn</td>
<td>13.8 h</td>
<td>0.1  17  45  0.1  40  109</td>
</tr>
<tr>
<td>$^{69}$Zn $^{69}$Ga($\gamma$,np)$^{69}$Zn</td>
<td>56 m</td>
<td>0.7  181  494  1  434  7</td>
</tr>
</tbody>
</table>
# Calculated Yields and Contaminants

(Full Absorption target)

<table>
<thead>
<tr>
<th>Energy of Electron Beam [MeV]</th>
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<td>T₁/₂</td>
<td>Calculated Yield [ mCi / (50 kW - h) ]</td>
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<tr>
<td>⁷²Ga</td>
<td>14.1h</td>
<td>43</td>
</tr>
<tr>
<td>⁷¹Ga(n, γ)⁷²Ga</td>
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<tr>
<td>⁷⁰Ga</td>
<td>21 m</td>
<td>8.5</td>
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<tr>
<td>⁷¹Ga(γ, n)⁷⁰Ga</td>
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<td></td>
</tr>
<tr>
<td>⁶⁹Ga(n, γ)⁷⁰Ga</td>
<td></td>
<td></td>
</tr>
<tr>
<td>⁶⁸Ga</td>
<td>68 m</td>
<td>4.4 x ¹⁰⁴</td>
</tr>
<tr>
<td>⁶⁹Ga(γ, n)⁶⁸Ga</td>
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<td></td>
</tr>
<tr>
<td>⁶⁷Ga</td>
<td>3.26 d</td>
<td>2.9 x ¹⁰⁴</td>
</tr>
<tr>
<td>⁶⁹Ga(γ, 2n)⁶⁷Ga</td>
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<td></td>
</tr>
<tr>
<td>⁶⁶Ga</td>
<td>9.5 h</td>
<td>6.2</td>
</tr>
<tr>
<td>⁶⁹Ga(γ, 3n)⁶⁶Ga</td>
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<td></td>
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