Abstracts

Office of Nuclear Physics SBIR/STTR Exchange Meeting

Note: The ordering of the abstracts matches the ordering of the talks.

Meeting Day1: August 23, 2022

Keynote Speaker

SBIR/STTR Program Overview

Michelle Shinn
DOE, Office of Nuclear Physics

Radiation Hardened Infrared Focal Plane Arrays

Yong Chang, Epir, Inc., IL

Grant Title: Radiation Hardened Infrared Focal Plane Arrays

NP SBIR/STTR Topic: Instrumentation

The goal of the project is to design and fabricate prototype high energy neutron radiation-tolerant infrared cameras with a 5 μm cut-off wavelength using sensor arrays made from HgCdTe materials. We work to achieve this goal through improving material quality and redesigning the focal plane array and camera architectures. A combination of approaches to improve material growth, post-growth annealing, and device architecture was employed in this work. HgCdTe material and process conditions have been optimized to fabricate infrared focal plane arrays with predictable, reliable performance under neutron irradiation conditions. We designed the infrared device material structures and conducted the molecular beam epitaxy growth for mid-wavelength-infrared HgCdTe samples. The growth that we conducted as well as the characterization and validation procedures ensured material availability for the subsequent project steps including device fabrication process development for small and large-scale 1280×720 focal plane arrays. We also conducted nuclear physics and device physics simulations to finalize the device structure design and fabricate the necessary photomasks. We included multiple test structures and small arrays in the mask design to enable proper assessment of the device and the neutron radiation effects on those devices. Neutron radiation-hardened infrared detector fabrication, including the process evaluation chips has been conducted. We are currently working on fabrication procedure optimization, especially on identifying proper fabrication conditions for small area p-region formation in HgCdTe material, such as dose and thermal processing conditions. EPIR also worked with the neutron application team from Fermilab on material, device and camera modeling and we completed the Monte Carlo MCNP simulations for the design improvements of our neutron radiation-hardened cameras.

Boron Nitride Nanotube Vibration Damping for SRF Structures

Roy Whitney, BNNT Materials, LLC, VA

Grant Title: Boron Nitride Nanotube Vibration Damping for SRF Structures

NP SBIR/STTR Topic: Accelerator

Boron nitride nanotubes (BNNTs) can significantly enhance the performance of SRF structures used for particle accelerators by damping and/or isolating microphonics that result in length oscillations of the accelerating structures. BNNT viscoelastic behavior is observed over a temperature range from 2 K to 700 K (-271°C to 427°C). BNNT damping reduces expensive RF power capital and operating costs that would be above what is otherwise required for accelerating the particles to keep the SRF cavities on resonance. Results to date have demonstrated the BNNT damping of microphonics in a Jefferson Lab CEBAF C100 two cavity cryounit at 2 K and in two LCLS-II cavities at 2 K in a production cryomodule. Currently BNNT damping is being installed in a full C100 cryomodule.

Update on the NHanced CMOS Integrated With Float Zone Pixel Sensor Program

Robert Patti, NHanced Semiconductors Inc, NY

Grant Title: CMOS Integrated With Float Zone Pixel Sensor

NP SBIR/STTR Topic: Electronics

Sensors fabricated from high resistivity float zone silicon material have been the basis of vertex detectors and trackers in High Energy Physics (HEP) for the last 30 years. HEP has a growing need for accurate particle tracking devices. One major challenge of charged particle tracking at low momenta is to build good single point resolution sensors that can perform in environments strongly limited by multiple Rutherford scattering. To minimize elastic interaction, the focus has been to decrease the radiation length by thinning the sensors and using low mass and low Z support structures. Decreasing the sensor's active thickness also lowers the occupancy, which can be a limiting factor for thick sensors and high-angle tracks. It is important to maintain a low power budget so as to minimize heat generation, because cooling imposes additional radiation length issues. A low power budget also keeps the power supply conductor material to a minimum. Another obvious requirement is a relatively fast readout rate to limit event pileup. Of course, all of this must be resolved within tight budget constraints.The solution addressed with this SBIR is a 3D Advanced Hybrid Sensor (3D-AHS). In this solution, the hybrid pixel arrays are built on separate wafers from the ROICs, but tightly integrated using the NHanced Direct Bond Interconnect (DBI®) process. Using two substrates avoids the difficulties presented by MAPS.DBI provides the following advantages for the AHS:1. Improved time resolutionDBI offers high volume manufacturability at pitches down to 3μm as opposed to 12μm for leading edge high volume micro-bump technologies. The roadmap for DBI technology aims for 1μm interconnect pitches in the near future.This is extremely beneficial in systems where the timing resolution is dominated by noise-associated jitter. To achieve good time resolution we want to maximize signal to noise, minimize rise times, maximize gm (which is related to the frontend transistor current), and minimize capacitance. The load capacitance scales roughly with the square of the pixel dimension; therefore, if we employ small pixels (~25μm), we will dramatically reduce the front-end noise.2. Reduced silicon mass3D assembled layers will interface with one another through DBI connections, which have very few mechanical weaknesses. In fact, 3D devices display robustness similar to a counterpart monolithic 2D part.

DBI technology is also hermetic and offers better long term reliability as oppose to micro-bump connections, which are subject to environmental factors (e.g. moisture exposure). The improved wafer robustness will allow us to lower the silicon mass even further. We envision thinning the silicon detector to 20μm for our Phase II prototype. Such extreme thinness will require engineering care for bow corrections, but should not affect the mechanical integrity of the structure, even for 200mm wafers.

Fast Multi Harmonic Kickers

Brock Roberts, Electrodynamic, NM

Grant Title: Fast Multi Harmonic Kickers

NP SBIR/STTR Topic: Accelerator

Electrodynamic has developed techniques to superimpose multiple harmonic RF signals to create high power, fast, and accurate bunch kicking waveforms. A description of these techniques and progress toward building a driver for JLAB's Harmonic Kicker Cavity will be presented.

High Rate Picosecond PhotoDetector (HRPPD) Development

Michael Foley, Incom Inc., MA

Grant Title: Large Area Multi-Anode MCP-PMT for High Rate Applications

NP SBIR/STTR Topic: Instrumentation

Project Abstract: The development of the High Rate Picosecond Photon Detector (HRPPD) was initiated by Incom Inc. under DOE NP Phase I SBIR project (award DE-SC0020578) to fulfill specific requirements on photosensors to support the need for devices to detect, analyze, and track photons, charged particles, and neutral particles such as neutrons, neutrinos, and single atoms. We will discuss a novel device with various pixelated signal boards (as small as 2-3 mm pads). Other design features are that it can perform at high rates (200 kHz/cm2) in a 2-3 Tesla magnetic field with high gain, low intrinsic background, and high photocathode efficiency to support the high rates found in noisy radiation environments. as exemplified by the EIC collaboration, and other NP programs. Realization of these features in 20 cm x 20 cm form factor LAPPD™ currently being commercialized by Incom Inc. is rather challenging although LAPPD has already demonstrated picosecond timing, high gain, low noise and high Quantum Efficiency (QE). In order to meet these needs, a new direct readout anode was demonstrated in Phase I to offer improved signal to noise compared to alternative approaches. Because of the complexity the technical development for this novel anode, it was decided to prototype it initially using a smaller 10 cm x 10 cm form before scaling up to full size (20 cm X 20 cm) LAPPD size. We have demonstrated feasibility of directly coupled 3 mm x 3 mm anode readout; developed 10 cm x 10 cm ALD functionalized MCPs with 10-micron pores for better timing and magnetic field tolerance and tested a fully functional open face High Rate Picosecond Photo Detector (HRPPD) package. The first year this Phase II project has been to demonstrate fully functional sealed HRPPD suitable for pilot production, test and evaluate prototype HRPPD in practical beamline trials (BNL). Three mains areas will be discussed: Performing multiple HRPPD sealing trials with a complete MCP stack. Multiple sealing trials were performed with complete detector package to find optimal sidewall geometry and metallization methodology in a dedicated Integration and Sealing Tank. These fully functioning detectors will have a standard bi-alkali photocathode, a pair of 10-micron pore ALD-GCA-MCPs, and a pixelated capacitively coupled

readout. Directly coupled anode versions will also be fabricated.Development of a reliable production process for large area 10-micron pore MCPs. As mentioned above under Phase I project, 108 mm x 108 mm 10-micron ALD-GCA-MCPs have been produced. However, the production yield for these GCA-ALD-MCPs was rather low due to the need to refine the production of large format 10-micron pore. In this Phase II we will increase yields and quality of larger format 10-micron pore MCPs by improving GCA fusing process and optimizing ALD process. Characterization of HRPPD/ Magnetic Field Tolerance. In order to characterize the HRPPD, a dedicated readout board will be designed. Quantum Efficiency, gain, timing and spatial resolution, and the high-rate capability of HRPPD will be measured in a dedicated setup. HRPPD performance at high magnetic fields (up to 3T) will be evaluated.

Digital Data Acquisition with High Resolution

Wojtek Skulski, SkuTek Instrumentation, NY

Grant Title: Digital Data Acquisition with High Resolution and Linearity

NP SBIR/STTR Topic: Electronics

We are working on improving the integral nonlinearities (INL) of digitizers based on the pipelined ADC technology. This ADC architecture causes semi-periodic nonlinearities due to imperfect matching of the ADC stages forming a signal sampling pipeline. Nonlinearity is impacting resolution in high precision experiments, whose prime example was the Majorana Demonstrator. We will review the INL determination reported in the Demonstrator paper. We will then describe how the method can be automated with the calibration circuits integrated into the digitizer design. We will present the progress of this project.

High-Quality, Conformal Bellows Coatings Using Ultra-Fast HiPIMS with Precision Ion Energy Control

Thomas Houlahan, Starfire Industries, IL

Grant Title: High-Quality Conductive Bellows Coatings Using Conformal Ionized PVD To Replace Unreliable Electroplating Processes

NP SBIR/STTR Topic: Accelerator

In this work, we demonstrate a replacement for traditional 'wet' chemical deposition processes using a vacuum, ionized PVD process that results in a conformal metal film. The process is capable of coating complex, convoluted parts that are common in modern particle accelerators (e.g., bellows, RF cavities). While these coatings are typically electroplated, there is an abundance of literature expressing the difficulties with these films, and there is a further desire to move away from ‘wet’ electrochemical processing due to the generation of hazardous waste streams. The method developed in this work relies on the combination of two technologies: 1) a novel, compact, radial magnetron specifically designed for coating the inner surface of complex parts, and 2) the deposition and etching that are achieved using ultra-fast high-power impulse magnetron sputtering (HiPIMS) coupled with precision control of the ion energy using a positive voltage reversal. Under the right conditions, this process will result in a conformal film and has been used to coat both test coupons and bellows sections sized for the LCLS-II and CEBAF. The resulting Cu films, which are 5—10 μm in thickness, exhibit excellent adhesion, even in the face of extreme plastic deformation. Further, they have been shown to tolerate temperature extremes ranging from a vacuum bakeout at 400 C down to 77 K (LN2). The magnetron design, HiPIMS operation, and resulting Cu film properties will be presented and discussed.

High Granularity in Low-Gain Avalanche Detectors

Rafiqul Islam, Cactus Materials, Tempe AZ

Grant Title: A New Approach to Achieving High Granularity in Low-Gain Avalanche Detectors

NP SBIR/STTR Topic: Electronics

The past five years has seen the development of low-to-moderate gain (x10-50) silicon avalanche diodes (LGADs)i, motivated by a desire to achieve a time-stamp resolution of 30 ps for tracks arising from proton-proton collisions at the LHC. The critical enabling development is the ability to create a region in the sensor for which the field is high enough to induce impact ionization by electrons, but still low enough that the holes don't multiply. This leads in turn to a limited, tightly controlled avalanche that avoids the cross-talk and recovery-time limitations experienced by Silicon Photo-Multipliers and Avalanche Photodiodes. Progress in the development of LGADs has allowed them to become a baseline option for both the CMS and ATLAS detectors for the high-luminosity (HL-LHC) upgrade of the LHC, with commissioning planned for 2026. Here, we present a proprietary novel approach to LGAD design and fabrication with a carefully tuned doping profile and wafer bonding approach. LGAD will offer a range of critical applications in several fields, including 4D-tracking approaches in proton-proton and electron-ion colliding beam instrumentation, nuclear physics applications, ultrahigh frame-rate instrumentation for photon science and diagnostics for accelerator physics.

Energy Recovery Linac Designs and Studies for Electron Cooling of Hadron Beams

Colwyn Gulliford, Xelera Research LLC, Ithaca, NY

NP SBIR/STTR: Accelerator

The baseline scheme for hadron beam cooling in the Electron Ion Collider (EIC) calls for Coherent electron Cooling (CeC) of the hadrons with non-magnetized electrons at high energy (150 MeV electrons), and additional cooling via conventional bunched beam cooling using a precooler system. The electron beam parameters for these concepts are at or beyond the current state of the art, with electron bunch charges of the order of 1 nC and average currents on the order of 100 mA and require an Energy Recovery Linac (ERL)-based accelerator to produce such beams. Using specifications provided by BNL and Jefferson Lab, physicists and engineers at Xelera Research are working on a complete design of an ERL system capable of satisfying such a cooler. This work includes designs for the injector, merger, multi-pass Linac, merger into the cooling section, demerger into the return line (which includes 180-degree arcs), and final extraction of the energy-recovered beam, beam breakup simulations, tolerance studies, start-to-end simulations, and beam halo studies.

LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD)

Ethan Hull, PHDS Co., TN

Grant Title: LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD) FOR LOW-BACKGROUND COUNTING ARRAYS AND RADIOPURITY-ASSAY

NP SBIR/STTR Topic: Instrumentation

DOE Nuclear Physics missions include the ongoing search for rare processes including neutrinoless double-beta decay. Arrays of high-purity germanium detectors are being used to pursue this research. A new Ring Contact Detector (RCD) design is being investigated as a complement to the successful point contact and inverted point-contact detector designs. RCDs will provide the largest overall volume of depleted germanium per volt of applied bias voltage. The RCD detector design is being experimentally researched through novel germanium detector processing and high-purity germanium crystal growth.

Keynote Speaker

DOE SBIR/STTR Diversity, Equity, and Inclusion Activities

Eileen Chant

DOE, SBIR/STTR Office

High Performance Glass Scintillators for Nuclear Physics Experiments

Tanja Horn, Scintilex, LLC, VA

NP SBIR/STTR Topic: Instrumentation

High performance scintillator materials are needed for particle identification and measurements of energy and momentum of electromagnetic particles in mode

Trigger Detection for the sPHENIX Experiment via Bipartite Graph Networks with Set Transformer

Yu Sun, Sunrise Technology, Inc, NY

NP SBIR/STTR Topic: Software

Trigger (interesting events) detection is crucial to high-energy and nuclear physics experiments because it improves data acquisition efficiency. It also plays a vital role in facilitating the downstream offlinedata analysis process. The sPHENIX detector, located at the Relativistic Heavy Ion Collider in Brookhaven National Laboratory, is one of the largest nuclear physics experiments on a world scale and is optimizedto detect physics processes involving charm and beauty quarks. These particles are produced in collisions involving two proton beams, two gold nuclei beams, or a combination of the two and give critical insights into the formation of the early universe. This paper presents a model architecture for trigger detection with geometric information from two fast silicon detectors. Transverse momentum is introduced as an intermediate feature from physics heuristics. We also prove its importance through our training experiments. Each event consists of tracks and can be viewed as a graph. A bipartite graph neural network is integrated with the attention mechanism to design a binary classification model. Compared with the state-of-the-art algorithm for trigger detection, our model is parsimonious and increases the accuracy and the AUC score by more than 15%.

An ASIC with a Low Power Multichannel ADC for Energy and Timing Measurements

Anton Karnitski, Pacific Microchip Corporation, CA

Grant Title: An ASIC with a Low Power Multichannel ADC for Energy and Timing Measurements

NP SBIR/STTR Topic: Electronics

Pacific Microchip Corp. has previously developed an ASIC with a low power multichannel ADC for energy and timing measurements. It includes 32 independent 12-bit 200Ms/s ADCs with integrated digital backend for event detection and recording. Within the Phase IIB project, the prototype chip being redesigned to improve ASIC performance and fix discovered issues.

Radiation Hardened Opto-Atomic Magnetometer (RHOM) Progress Update

Chris Hull, Hedgefog Research, CA

Grant Title: Radiation Hardened Opto-atomic Magnetometer (RHOM)

NP SBIR/STTR Topic: Instrumentation

Hedgefog Research Inc. (HFR) is continuing the development of a Radiation Hardened Opto-atomic Magnetometer (RHOM) for magnetic field monitoring in high radiation environments, including its targeted implementation at the DOE's new Facility for Rare Isotope Beams (FRIB). Utilizing a unique radiation-hardened optical probe, RHOM allows for long term real-time magnetic field measurements even in the presence of high radiation flux. During the initial Phase II period, HFR has performed studies to assess the radiation resistance of the RHOM probe module, with a focus on the effects of high radiation dose on the transmission properties of optical fibers used for connecting with the sensor. The successful completion of these fiber radiation tests was a critical milestone in demonstrating this novel technology. Lessons learned in Phase II are now guiding the development of the RHOM product prototype in Phase IIA.

Updates on High Density Digitizer System-on-Chip (HDSoC) Design and Testing

Luca Macchiarulo, Nalu Scientific, HI

Grant Title: Design and Fabrication of the HDSoC- High Density Digitizer System-on-Chip

NP SBIR/STTR Topic: Electronics

We will present some detail of the design and measurements of the performance of the first revisions of the HDSoC, a waveform sampling ASIC optimized for high density photo-detectors, such as Silicon Photomultiplier (SiPM) or MA-PMTs. The first revision of HDSoC is operating at 1 Gigasample/sec waveform sampling (current measurement evaluating operation to 2 Gsps) with the ability to service 32 channels. The second revision will be submitted imminently and planned to cover 64 channels. The HDSoC is a System-on-Chip with built-in SiPM biasing, input TIA, with internally controlled digitization via a digital core that allows independent operation of each of the channels permitting low latency and high data rate, as well as multiple acquisition modes including dead timeless operation within a rate limit. Besides general evaluation of the features of the fabricated chips, we will present preliminary results on the digitization of fast signals from high channel density SiPM arrays, the estimation of energy (using the digitized signals) corresponding to the SiPM dark counts and timing uncertainty between the input channels of the digitizer.

Meeting Day 2: August 24, 2022

HOM Absorber Design for eRHIC ERL Cavity

Tom Schultheiss, TJS Technologies, NY
NP SBIR/STTR Topic: Accelerator

The Office of Nuclear Physics long range plans include allocation of resources to develop technology for a polarized electron-ion collider. Early BNL effort of their Electron Ion Collider (EIC) included an Energy Recovery Linac design that would provide for significant upgrade in luminosity. One of the components that requires significant development is the high current ERL SRF cavity. To preserve the beam and its characteristics it requires higher order mode absorbers both in-line and cavity damped. This SBIR focuses on the design and development of an HOM absorber module to be used with a multi-cell cavity and in-line beampipe. In Phase 1 TJS Technologies provided analysis to show that it has the proper material and geometry to absorb the required HOMs at the expected power level. We then developed an HOM manufacturing plan, design, and cost. BNL also requested a beamline design using a similar core of tile and backer. In Phase II we manufactured a waveguide and a beamline prototype assembly. Both are at BNL and are planned to be tested when they have available funds and personnel. In Phase IIA TJS Technologies performed low power RF tests of the waveguide assembly. BNL has provided equipment and personnel to perform high power absorption tests of tile assemblies. A second waveguide assembly is presently planned for crab cavity HOMs. This absorber will include lighter weight tile/backer assemblies and a light weight housing

Highly Transparent Aerogel with Refractive Index <1.01 for High Energy Particle Detection

Tanja Horn, Scintilex, LLC, VA
NP SBIR/STTR Topic: Instrumentation

Aerogel of high optical quality is needed for hadron identification in nuclear physics experiments in the momentum range 3 8 GeV/c, where other techniques are not effective. The large-volume aerogel Cherenkov detectors for the Electron-Ion Collider (EIC) and those in three halls at the Jefferson Lab require aerogel material. This project addresses the need for high-quality, hydrophobic aerogels with a refractive index as low as 1.008 to identify particles at higher momenta and for large tile sizes up to 20 x 20 x 3 cm3 while maintaining good optical and hydrophobic properties.

Low-cost and Efficient Cooling of on-Detector Electronics Using Conformal Thermoelectric Modules

Giri Joshi, Nanohmics, Inc., TX
NP SBIR/STTR Topic: Electronics

Thermoelectric coolers (TECs) are a well-established technology. Solid-state TECs have no moving parts and provide more consistent, uninterrupted, maintenance-free, and environmentally-friendly cooling when compared to traditional cooling systems such as vacuum-based refrigeration compressors. However, high costs and a slightly lower Coefficient of Performance (CoP < 1.0) relative to compression refrigeration have limited traditional TECs to niche applications such as automotive seat cooling, portable coolers, and biotech applications, though the total TEC market in 2019 exceeded $1B USD. Furthermore, conventional

methods used in TE cooler manufacturing do not provide a means for production of large-area, conformal TECs to break into mainstream refrigeration, air conditioning, medical and commercial markets that include niche areas such as on-detector spectrometer electronics cooling needed desired by Department of Energy facilities such as the Thomas Jefferson National Accelerator Facility (TJNAF) and Relativistic Heavy Ion Collider (RHIC) of Brookhaven National Lab.

To address the limitation, **Nanohmics Inc., working in collaboration with Prof. Mona Zebarjadi, Dr. Drew Wiesenberger, and Capstan Technologies, has been developing a novel large-area, conformal TEC technology using high-throughput, automated process and demonstrate the utility of the method for high-performance Bi_2Te_3-based thermoelectric cooling devices through construction of an electronics cooling prototype system at the end of the Phase II program.** Nanohmics team has designed an alpha-prototype conformal, large-area and efficient TEC cooling system during the Phase II through low-cost tape &reel based manufacturing process. These TEC system includes modular TEC units connected through novel stretchable and conformal mechanically compliant electrical connectors and performs competitively compared to commercially available TECs. The device CoP and cooling power compared favorably to other competitive cooling systems such as vacuum compressors and Rankine coolers. Furthermore, price per modular unit (20mm x 41mm) of these TECs will be on the order of ~$5, in the range of commercial TEC cost with significant added benefits for potential applications such as therapeutic and wearable cooling. When considering all the stated advantages, the proposed technology becomes cost-competitive compared to all other alternatives and immediately impact both cooling/heating (such as aerospace and defense, electronics, automotive, and biomedical cooling) as well as waste heat recovery markets (such as automotive and industrial waste heat).

Low RF Loss DC Conductive Ceramic for High Power Input Coupler Windows for SRF Cavities

Ben Freemire, Euclid Tech Labs,
NP SBIR/STTR Topic: Accelerator

Ceramic RF windows used in power couplers for superconducting cavities are prone to accumulate volume and surface charges. The electric field generated by charging grows until the trapped electrons discharge, with the resultant arc damaging or destroying the window. Euclid Techlabs has developed a new ceramic composition that exhibits low loss at high frequencies and is conductive at DC. This allows electrons to drain rather than being accumulated in the material, which was confirmed via a beam charging test of both conductive and non-conductive versions of the ceramic. Windows made of this conductive ceramic were fabricated for use in 1.5 GHz and 650 MHz RF couplers at JLab and FNAL. A waveguide window has successfully been tested in air up to 11 kW CW power. Several brazing and soldering techniques have been investigated, with two successful options identified. Additional window assemblies are in production, with high power vacuum tests of pairs of windows scheduled at JLab and FNA

Cold Spray Technology Applications for SRF Cavity Thermal and Mechanical Stabilization

Roman Kostin, Euclid Techlabs, IL
NP SBIR/STTR Topic: Accelerator

The overall objective for the proposed program is to apply the cold-spray technology for the improvement of SRF cavity parameters. In Phase IIA of the project, this new technology was used for SRF cavity

fabrication to provide mechanical and thermal stability in its application for conduction-cooled industrial SRF-based accelerators.

Two cavities have been coated with copper: a cavity with Nb3SN layer and a pure Nb cavity. The first cavity was coated for conduction cooling experiments, the second one for Lorentz Force Detuning studies (LFD). It was demonstrated that LFD can be significantly reduced (factor of two) by the copper cold spray reinforcement without sacrificing cavity flexibility for tuning. Two issues were identified: annealing of the cavity resulted in cracking of the copper layer which was associated with the trapped gasses in the powder; frequency shift during the deposition process. Work has been started on resolving these issues.

Radiation Hard High Speed Camera System for Accelerator Beam Diagnostics

Esko Mikkola, Alphacore Inc., AZ

NP SBIR/STTR Topic: Instrumentation

Alphacore Inc. has been developing a radiation-tolerant, triggerable, high speed imaging chip and a complete camera system for investigating rapidly occurring phenomena in radiation environments. One of the main applications is beam monitoring in particle accelerator facilities. Additional focus has been made to optimize the technology to increase its commercial viability.

Continuous Acquisition TDC FPGA synchronized over packet network

Radu Radulescu, Radiabeam Telluric Labs, NJ

NP SBIR/STTR Topic: Software

Event reconstruction is presently achieved through hardware distribution of optical or electrical synchronization pulses to synchronize timing at the frontend electronics.

In alternative, we developed a numerical event reconstruction system based on an FPGA TDC for both detector events and for data packets of the embedded 25GE ports. The timestamps are packetized, transported, and processed by our General Timing Synchronization protocol and algorithms providing software timing synchronization with picoseconds accuracy, for both the Detector and the Accelerator, within tens of miles. The system uses COTS boards and provides more that 2G timestamps/s for each TDC channel with configurable precision from 8 ps to 200fs. The high throughput and precision allow the TDC to be converted into a Gsps ADC through addition of a PWM frontend circuit, for unprecedented functional flexibility.

Machine Learning Techniques and Interfaces for Improved Accelerator Operations

Jonathan Edelen, RadiaSoft LLC, CO

Grant Title: A browser based toolkit for improved particle accelerator controls

NP SBIR/STTR Topic: Accelerator

Our project has been focused on developing machine learning methods to improve tuning of accelerator beamlines and for anomaly detection to improve diagnostic capabilities. Additionally we have been developing improved browser based tools for switching between online models and control settings. This talk will provide a high level overview of our objectives followed by a status update on each of these research efforts.

High Performance Scintillator and Advanced Beam Monitoring System

Peter Friedman, Integrated Sensors, LLC, OH

Grant Title: High Performance Scintillator and Beam Monitoring System

NP SBIR/STTR Topic: Instrumentation

The High-Performance **S**cintillator **B**eam **M**onitoring System (SBM) is a novel ionizing-particle beam imaging monitor designed for a variety of applications and can provide advanced, precise beam tuning, imaging, position location and profile analysis, continuously in real-time (≤1 Hz) for particle beams up to **~10^{11} pps/cm^2** as well as visualization of **single-ion** signals with **10-20 µm** spatial resolution. The SBM uses a magazine of thin to ultra-thin scintillator targets, movable into/out of the beam (remotely) without breaking vacuum. Two proprietary and novel scintillators are used: (1) a semicrystalline polymer-film material (PM) tested over a thickness range of ~1-190 µm, which yields stronger signals than all other commercial plastic scintillators tested; and (2) a thin (~100-400 µm) opaque sheet consisting of inorganic crystals in a polymer hybrid matrix (HM). Both PM and HM are highly radiation damage resistant, non-hygroscopic, have low outgassing, and produce minimal secondary reflections. HM produces order-of-magnitude larger signals than single-crystal CsI(Tl). The scintillator targets are coupled by very fast, low f-number (<1.0) optics to high sensitivity, low-noise or ultra-low noise machine vision cameras. The SBM was successfully demonstrated in 2021 at the Facility for Rare Isotope Beams (FRIB) on the ReA3 beamline for real-time beam imaging/tuning using a relatively low-intensity Kr-86 ion-beam (2.75 MeV/u) from *single-particles* up to ~10^6 pps. The SBM has a small footprint and can be configured to occupy less than 6-inches of beamline space. Because of its extremely large dynamic range of **~11 orders-of-magnitude**, a single SBM can measure beam currents that are now determined at FRIB by four (4) different devices: Faraday cup, MCP detector, Si-detector, and a calibrated beam attenuator. The SBM signal/response linearity was demonstrated at FRIB to be more than 5 orders-of-magnitude and can image and analyze individual pulses as short as 2 ns. Depending on the particle energy and beam intensity, the SBM can operate as a nearly "**transparent**" beam monitor and has demonstrated this capability at FRIB. It has now been tested at 4 different particle beam laboratories with the HM scintillator's extraordinary performance verified by BNL. Applications are also being developed for conventional particle beam therapy as well as the newly emerging cancer treatment known as FLASH radiotherapy (RT), which delivers approximately four (4) orders-of-magnitude higher dose rates than conventional RT.

Progress on Design and Development of the All in One Digitizer System on a chip: AODSChip

Isar Mostafanezhad, Nalu Scientific, LLC, HI

Grant Title: Design and Development of the All in One Digitizer System on a chip (AODS)

NP SBIR/STTR Topic: Electronics

We will present progress on design and development of the All-in-One Digitizer System-on-chip "AODS": a low-cost, low power, low-noise and low channel-count Application Specific Integrated Circuit (ASIC) with a high dynamic range option specialized for reading out both Photomultiplier (PMT) and Silicon PhotoMultiplier (SiPM) type light detectors. The ASIC will be capable of analog signal conditioning and up to 2 Gigasample/sec waveform sampling with the ability to service up to 4 channels. NSL's AODS device will also have a deep sampling buffer making it suitable for a range of large and mid-high rate NP experiments such as the experiments carried out at the Relativistic Heavy Ion Collider, JLab's 12 GeV line and the ones possible at the future Electron Ion Collider.

Purification of Lutetium 177

John Moses, CF Technologies, Inc., MA

Grant Title: Supercritical Fluid Separation and Purification of Rare Earth Elements, particularly Lanthanides including 177-Lu, to Lower Energy Consumption and Reduce Waste

NP SBIR/STTR Topic: Isotopes

The process to separate Lutetium 177 from Ytterbium 176 was developed with cold mixtures of Lutetium and Ytterbium. In the past year we have irradiated Ytterbium 176 and Lutetium 176, to produce Lutetium 177. With the hot Lu 177, we have tested the process, and made modifications to overcome issues that arose with the hot materials.

Long-Term Radiation Rugged Rotary Vacuum and Water Seals in Heavy-Ion Accelerators

Jennifer Lalli, NanoSonic, Inc., VA

Grant Title: Long-Term Radiation Rugged Rotary Vacuum and Water Seals in Heavy-Ion Accelerators

NP SBIR/STTR Topic: Accelerator

The Nuclear Physics community has identified a need for materials that will survive high radiation environments to support next generation rare isotope beam facilities. Specifically, long-lifetime, rotary vacuum and water seals are needed to survive 0.5 – 15 MGy/month. Current gaskets and seals do not offer the combined mechanical and radiation survivability needed for years of service, and organic paraffin ferrofluidic carriers break down at doses of ~2MGy. Advanced nanocomposites were developed and exposed to harsh irradiation alongside candidate commercial seal materials for a durability study. Mechanical, thermal, and thermomechanical testing were conducted prior to and post irradiation on a representative rotating shaft. The new material is being integrated within a commercial seal housing for transition to MSU's FRIB.

Low Cost Data Acquisition Synchronization for Nuclear Physics Applications

Wojtek Skulski, SkuTek Instrumentation, NY

Grant Title: Data Acquisition Integration with GRETA and Digital Gammasphere Environment

NP SBIR/STTR Topic: Electronics

We are working on interfacing and synchronizing SkuTek digitizers with the digital acquisition framework at Argonne National Laboratory. The project will bring significant improvements of the digitizer architecture, readout speed, and online control. The digitizer will provide 32 channels of low noise digitization with 14 bits at 100 MSPS, suitable for both scintillators and high resolution semiconductor detectors. The trigger and timing control link (TTCL) will be based on fast point-to-point serial links compatible with Gamma Ray Tracking Array (GRETA). The event readout will be performed over copper Ethernet at 1 Gbps, or optical fiber Ethernet at 10 Gbps. Digitizer setup, control, and monitoring will be handled with embedded Linux single board computer (SBC) running the modern version of embedded Linux for the ARM processor. We will review the project and present the progress achieved during the last year.

Automated Preparation Of 211AT For Targeted Alpha Therapy Applications

Graham Marshall, Global FIA, Fox Island, WA: Matthew O'Hara, PNNL, WA

NP SBIR STTR Topic: Isotopes

At-211 has shown great promise for targeted radiotherapy employing its two high-energy alpha emissions. It's use for this purpose is presently constrained by limited availability. In this project the goal is to isolate research- and therapeutic-quantities of ^{211}At in a rapid, automated, and safe manner. To achieve this goal, an automated wet chemical procedure has been outlined and a system envisaged comprising several sequential unit operations that would begin with an irradiated target and end with a salt containing the ^{211}At suited for transportation or a radio-labeled patient-ready therapeutic. In this report, the work undertaken on the titration step and the trigger for the final purification step using a size-exclusion column is described.

In particular, conditions have been established for titrating 10M nitric acid eluent with 10M sodium hydroxide. This necessitated using a titration procedure that registered the end point before the level of sodium reached levels that caused the so-called "sodium-effect" on the pH electrode.

Flow conditions for separating proteins from salt using size exclusion chromatography and a set of sensors for tracking the separation are also described.

Meeting Day 3: August 25, 2022

Modeling Plasma Discharge Cleaning of SRF Cavities

Jarrod Leddy, Tech-X Corporation, CO

NP SBIR/STTR Topic: Accelerator

Superconducting radio frequency (SRF) cavities are utilized for acceleration in particle accelerators, and therefore must sustain large electromagnetic fields. Impurities on the surface of the cavity can cause arcing and therefore lower the maximum obtainable fields inside the cavity. One method being pursued for removing these impurities is to treat the cavity surface with a plasma for both mechanical and chemical removal, but the formation of this plasma is not well understood.We have performed electromagnetic particle-in-cell simulations using VSim to investigate the plasma formation via ionization cascade using a Monte Carlo collision framework. The energy to sustain this ionization is provided via electromagnetic modes excited within the cavity; these modes are well described in vacuum via pure EM simulation (ie. without particles). To model plasma formation, a background gas is included along with impact ionization, electron scattering, and recombination. With this full set of physics requirements, we have explored the EM power threshold for plasma ignition at experimentally relevant background gas pressures and compared them with experimental data.We will discuss other features we have developed and implemented to move towards full cavity simulation of the plasma discharge cleaning, including surface reactions, a hybrid and neutral fluid models, and reaction diagnostics. Finally, we will show results from simulations that were performed to directly address physics questions from collaborators performing experiments at JLAB.

Radhard DWDM Tb Photonics Integrated Circuit for Continuous Readout

Radu Radulescu, Telluric Labs LLC, NJ

NP SBIR/STTR Topic: Software

The Continuous Flow TTDAQ is the next generation triggerless, continuous readout DAQ for Pbps transfer rates. It provides two orders of magnitude increase in data bandwidth for each fiber, for a fraction of the modulation signal amplitude, power, size and weight compared with current readout systems. This is made possible by the development of a DWDM radhard, Photonic Integrated Circuit (Tb PIC), remotely illuminated by lasers outside the radiation zone. Tb PIC is designed to be used in both digital and linear (analog) signal transport.

Internal structure is based on MicroRing Resonators (MRR) used for both modulation and demodulation, using a novel photonics circuit topology and architecture, which provides stability and high immunity to noise. MRR have several advantages, featuring native wavelength filtering, high sensitivity, small dimensions (~10um), tunability, low power, lower cost.

The second revision of our PIC uses 200G and 100G ITU scale and can be upgraded for the denser 50G grid.

Scintillating Bolometer Crystal Growth and Purification for Neutrinoless Double Beta Decay Experiments

Joshua Tower, Radiation Monitoring Devices Inc., MA

Grant Title: Scintillating Bolometer Crystal Growth and Purification for Neutrinoless Double Beta Decay Experiments

NP SBIR/STTR Topic: Instrumentation

Phase IIA will continue the successful collaboration between RMD and MIT working with the international CUPID Interest Group. Phase IIA research will optimize crystal growth of ultra-pure lithium molybdate, scale up crystal size, and implement procedures that maintain the radio-purity throughout processing. Detector crystals will be sent to MIT and the CUPID Group to evaluate detector performance. The final step will be to incorporate enriched 100Mo into our processes and provide crystals for a demonstration experiment to qualify the material. The ultimate goal is to enable full-scale production of detector crystals and become a qualified U.S. supplier of crystals for the CUPID experiment.

Digital Data Acquisition with High Resolution and Linearity

Wojtek Skulski, Sku Tek Instrumentation, NY

NP SBIR/STTR Topic: Instrumentation

We are working on improving the integral nonlinearities (INL) of digitizers based on the pipelined ADC technology. This ADC architecture causes semi-periodic nonlinearities due to imperfect matching of the ADC stages forming a signal sampling pipeline. Nonlinearity is impacting resolution in high precision experiments, whose prime example was the Majorana Demonstrator. We will review the INL determination reported in the Demonstrator paper. We

will then describe how the method can be automated with the calibration circuits integrated into the digitizer design. We will present the progress of this project.

The event readout will be performed over copper Ethernet at 1 Gbps, or optical fiber Ethernet at 10 Gbps. Digitizer setup, control, and monitoring will be handled with embedded Linux single board computer (SBC) running the modern version of embedded Linux for the ARM processor. We will review the project and present the progress achieved during the last year.

Status Report 1497 MHz AM magnetron

Michael Neubauer, Muons, Inc., IL

Grant Title: A novel injection-locked amplitude-modulated magnetron at 1497 MHz

NP SBIR/STTR Topic: Accelerator

Test results are presented. The tube has been shipped to JLAB for additional testing and to establish the configuration for a vertical slice test.

Distributed digital data acquisition system with network time synchronization

Wolfgang Hennig, XIA LLC, CA

NP SBIR/STTR Topic: Software/Data

As radiation detector arrays in nuclear physics applications become larger and physically more separated, the time synchronization and trigger distribution between many channels of detector readout electronics becomes more challenging. Among applications requiring the highest precision are time-of-flight measurements which try to determine the time difference in two or more related particle interactions in two or more separate detectors to sub-nanosecond precision, ideally in the tens of picoseconds. Clocks and triggers are traditionally distributed through dedicated cabling, but newer methods such as the IEEE 1588 Precision Time Protocol and its high accuracy profile (White Rabbit) allow clock synchronization through the exchange of timing messages over Ethernet. We report here the use of White Rabbit, implemented in the Pixie Net XL detector readout electronics, to synchronize multiple modules that read out separate detectors. The timing performance is characterized both coincident gamma rays from 22Na and a split pulser signal. Time resolutions are about 300 ps full width half maximum for 22Na and about 90 ps for the pulser, compared to ~15 ps for 2 channels on the same module using the pulser.

A Multi-channel Radiation-tolerant, Low power, High-speed, and Resolution Analog-to-Digital Converter for Nuclear Physics Detectors

Ping Gui, TallannQuest LLC DBA Apogee Semiconductor, TX

NP SBIR/STTR Topic: Electronics

In this presentation we will report the design and measurement results of three generations of GS/s 12-bit ADCs developed (1st chip in 65nm and 2nd and 3rd chips in 28nm CMOS) during this project, along with

radiation (Total Ionization Dose (TID), Single-Event Effects (SEE) and Neutron Displacement Damage) test results.

Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

Alexander Smirnov, Radiabeam Technologies, LLC, CA

NP SBIR/STTR Topic: Accelerator

The ionization scattering of the electron beam with residual gas molecules causes ion trapping in the electron rings, both in the collider and electron cooling system. The trapped ions may cause emittance growth, tune shift, halo formation, and coherent coupled bunch instabilities. Therefore, the beam temporal structure needs gaps to clear the ions to prevent them from accumulating turn after turn. Typically, the gap in the bunch train has a length of a few percent of the ring circumference. In those regions, extraction electrodes are introduced with pulsed voltages applied. In this paper, we present the design of a high voltage pulsed kicker hardware, that includes the vacuum device and the pulsed voltage driver. By design, the system must show over 3 kV of deflecting voltage amplitude, rise and fall times of less than 10ns, 100ns flat-top duration at 1.4 MHz repetition rate.

Novel methods for in-situ high-density surface cleaning (scrubbing) of ultrahigh vacuum long (100m or longer) narrow tubes to reduce secondary electron yield and outgassing

Ady Herschovitsch, Poole Ventura, Inc. CA

NP SBIR/STTR Topic: Accelerator

Electron clouds in existing accelerators limit machine performance through dynamical instabilities and associated vacuum pressure increases. Bare metal vacuum walls have shown to prevent electron cloud formation. Proper scrubbing of stainless steel, copper, or niobium vacuum walls can mitigate the problems of electron clouds and increase accelerator luminosity. Present scrubbing by ion beams and plasmas has resulted in unsatisfactory surface cleaning by not scrubbing all surfaces and poor debris pumping-out due to low-density plasma generation. Novel plasma discharge cleaning techniques and tools are being developed for *in-situ* scrubbing long, small diameter tubes by generating high-density plasmas to completely affect each exposed surface. One technique involves high plasma density magnetron mole, the other is based microwave plasma injection that generates high-density plasma. High-density plasma scrubbing in the viscous gas flow range can reach all surfaces and pump out all debris effectively.

An RF beam Sweeper for Purifying In-Flight Produced Rare Isotope Beams

Alexander Smirnov, Radiabeam Technologies, LLC, CA

Grant Title: An RF beam Sweeper for Purifying In-Flight Produced Rare Isotope Beams

NP SBIR/STTR Topic: Accelerator

Radioactive ion beams (RIB) are produced via two-step processes and several production techniques have been developed. At ATLAS, the production of such beams is provided via in-flight method and grants access to more than 100 short-lived isotopes in the mass range up to A∼60. However, after traversing the production target, the primary beam is energy degraded and acquires a long low-intensity energy tail from the multiple-scattering processes in the target material. For low intensity RIB, these tails can easily dominate the total delivered beams. To handle the large divergence and energy spread of the in-flight produced beam, an in-flight

radioactive beam separator, named AIRIS, is being commissioned. First, the secondary beam passes through momentum achromat. Its first step is magnetic achromat while the second must consist of an RF sweeper. In response to this problem, RadiaBeam has proposed to develop an RF sweeper operating at two frequencies (6 and 12 MHz) providing with 150 kV kick that is able to triple the voltage achieved with the existing ATLAS sweeper. In Phase II we have significantly advanced the engineering design and started the sweeper fabrication to be completed by the end of the phase. At the same time, the complexity of the design, initially proposed for Phase II has increased significantly due to the requirements for RF power, reliability, fabrication feasibility of large vacuum vessel and the development frequency switch, and highly efficient solid-state RF power sources for two frequencies (initially planned only for a single frequency). The current Phase IIA continuation of this project is to finalize the design and fabrication all auxiliary components, which are essential for the sweeper operation, including high power switch and full-power RF power sources for both frequencies.

Keynote Speaker

Update on the Department of Energy SBIR/STTR Program, Q/A

Manny Oliver
DOE SBIR/STTR Office