

Detector R&D at BNL (for experiments at colliders)

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ENERGY

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Brookhaven National Laboratory

- One of the 17 DOE US National Laboratories
 - Managed on behalf of DOE by Brookhaven Science and Associates
- Multi-program research
 - Nuclear Physics
 - High Energy Physics
 - Materials & Chemical sciences
 - Bio & environmental sciences
 - Accelerator science and technology
 - Big data and national security

Relativistic Heavy Ion Collider



Superconducting Magnet Facility



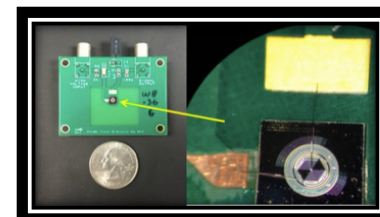
Scientific Data Computing Center



NASA Space Radiation Lab



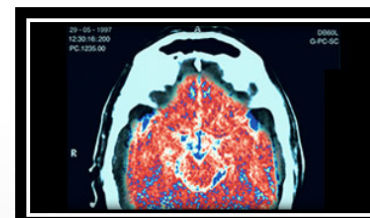
Instrumentation



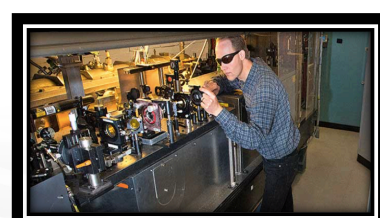
NSLS-II (Synchrotron Light Source)



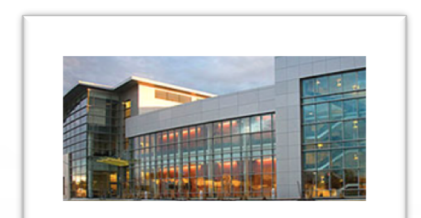
BNL Linac Isotope Producer



Accelerator Test Facility

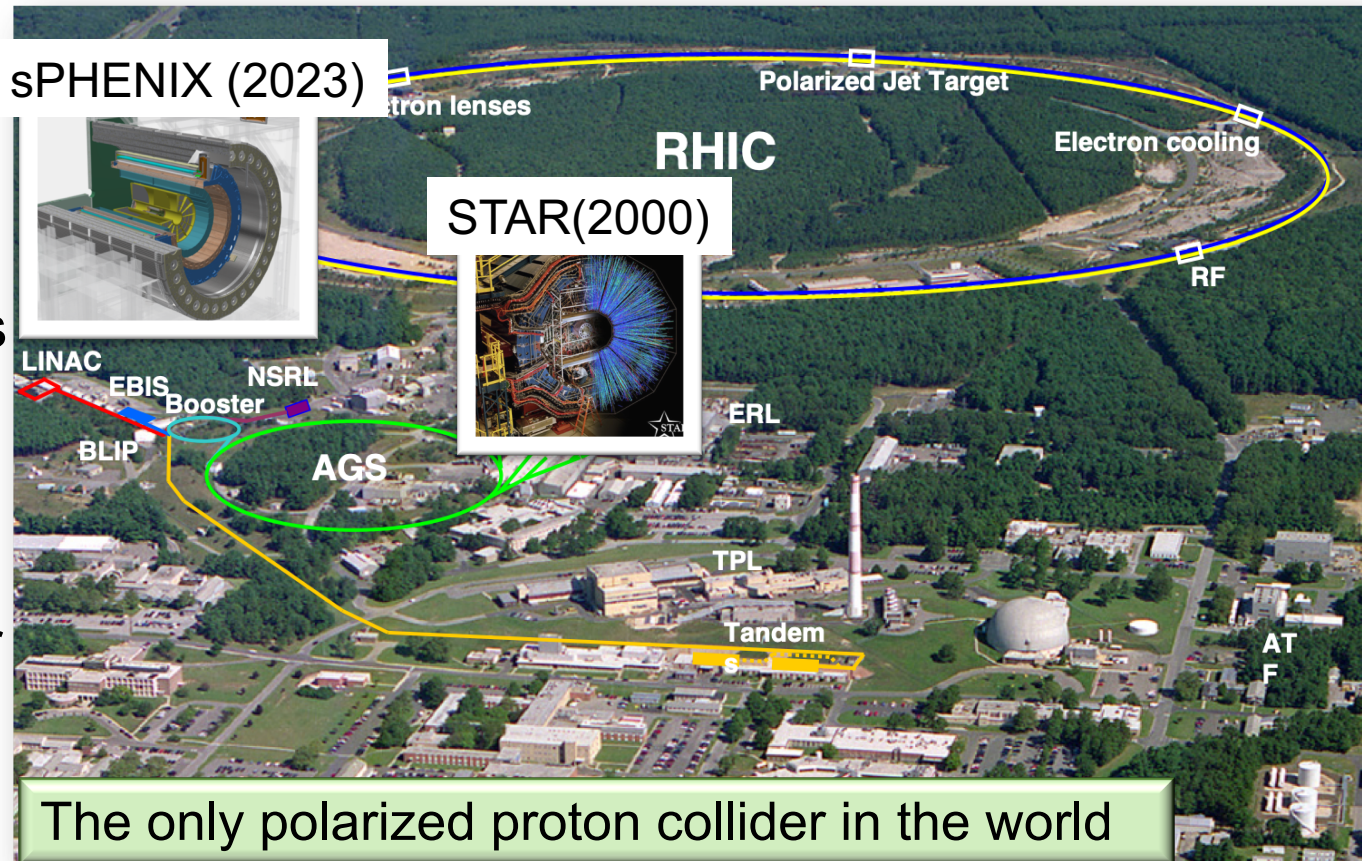


Center Functional Nanomaterials



STAR (and sPHENIX) experiments at RHIC

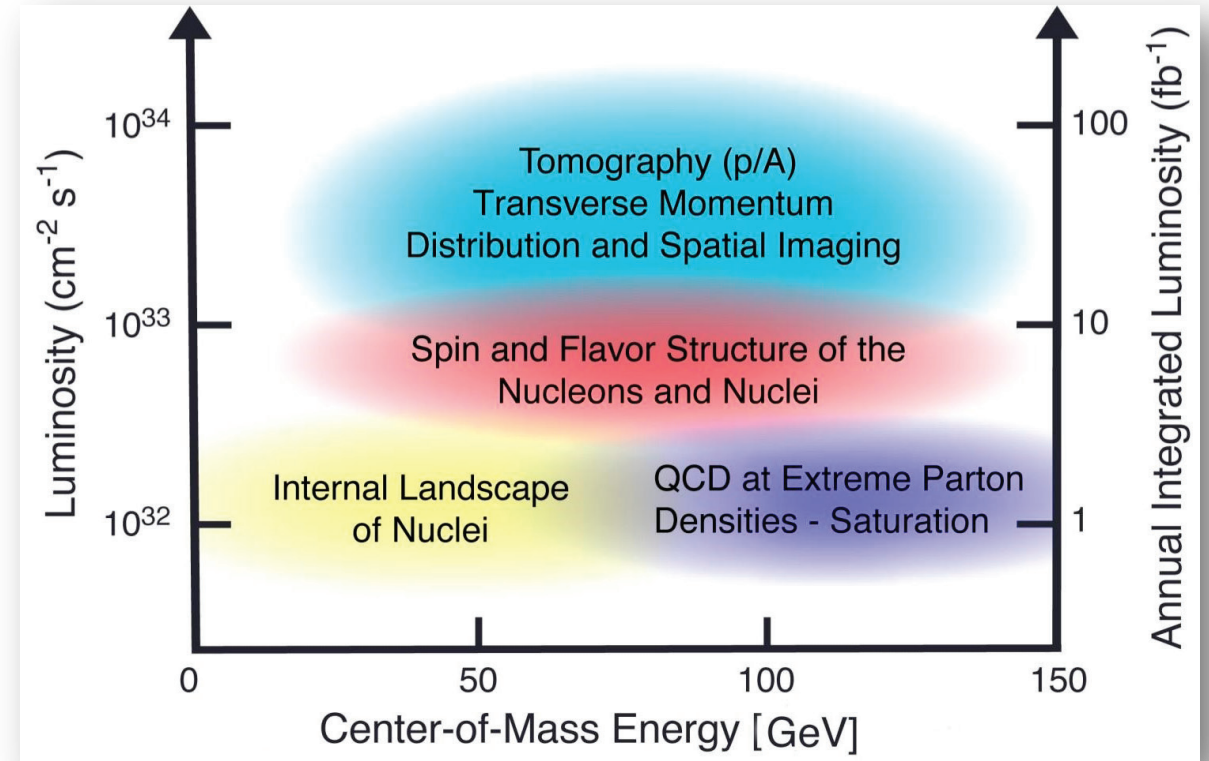
- Study the formation and characteristics of the quark-gluon plasma and spin structure of the proton
- High rapidity, multi-purpose experiments for heavy ion collisions
 - $p\uparrow$, Au, d, Cu, U, ^3He , ^{96}Zr , ^{96}Ru
 - Energy range ($\sqrt{s_{\text{NN}}} = 7 - 200 \text{ GeV}$)
- Development of state-of-the-art detector technologies, software & computing
- Key capabilities in accelerator science and technology



Path forward: US Electron Ion Collider

Site selection expected soon

- Electron-proton / electron-ion collider
- Accelerator requirements:
 - Polarized electron/proton/light nuclei
 - Heavy nuclei beams up to U
 - Luminosities up to $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 - Bunch spacing $\sim \text{ns}$
- Detector requirements:
 - Precise tracking and vertex, $\text{resol} \sim \mu\text{m}$
 - e energy resolution $\sim 1\% \sqrt{E} + 0.5\%$
 - Jet measurements
 - $\pi/K/p$ separation over a wide range
 - $|\eta| \sim 3.5$ and $0.25 < p < 50 \text{ GeV}$
 - High precision forward measurements

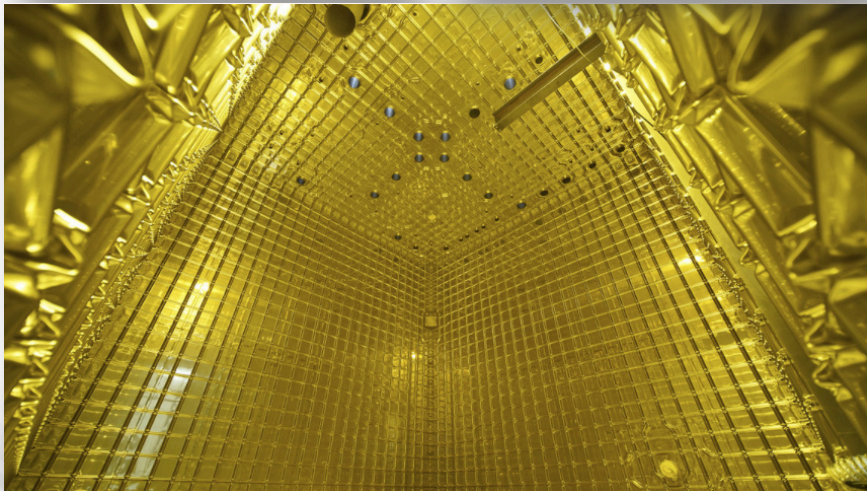
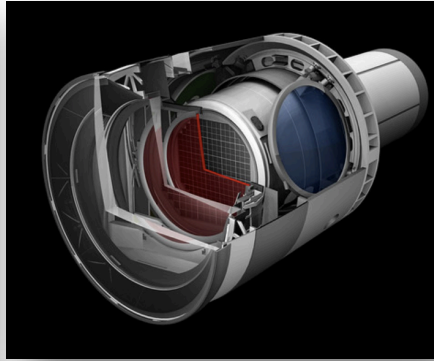
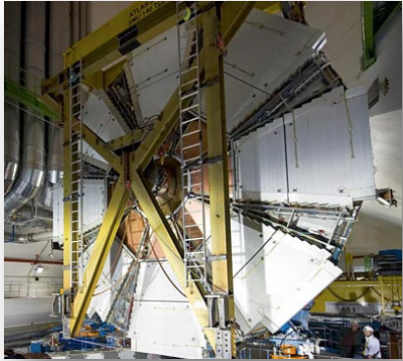


Accelerator & detector challenges very similar to HEP colliders

Generic EIC Detector R&D program

- Started in 2011
- Managed by BNL in association with JLab and DOE Office of Nuclear Physics
- EIC Detector Advisory Committee to prioritize R&D requests
- Open to international participation
- R&D areas:
 - Silicon/PID/Scintillating detectors/Software/Streaming Readout/Magnetic cloaking and MPGD
- Other efforts with beneficial impact on EIC R&D
 - Collaborations with CERN R&D programs with partial match to EIC
 - R&D for LHC experiments (R&D for phase I, ATLAS, ALICE, LHCb)
 - R&D at Belle-II and FAIR experiments

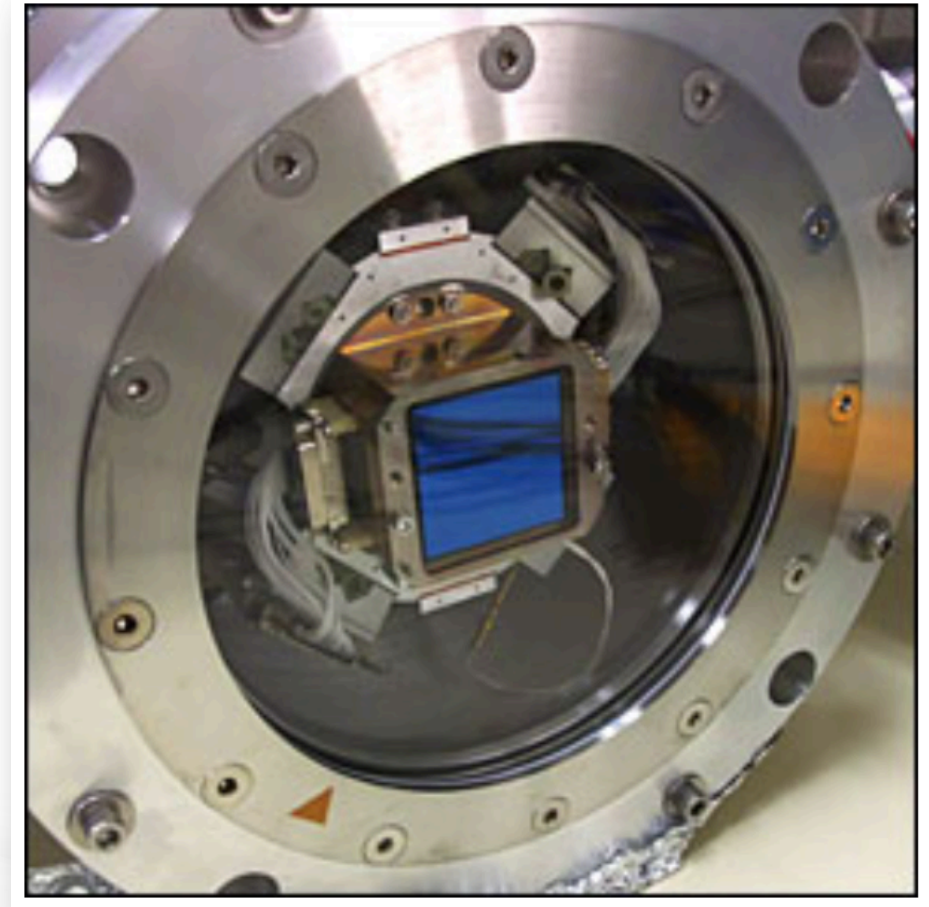
BNL contribution to HEP programs



- Collider experiments: ATLAS, Belle-2
 - BNL managing the US contribution to ATLAS HL-LHC, and US ATLAS operations program
 - Development of LAr detectors and electronics, silicon detectors, muons electronics, timing detectors, system integration, TDAQ
 - Belle2: computing
- Neutrino experiments: SBN, protoDUNE, DUNE
 - Cold electronics, TPC & feedthrough design, system integration
- Cosmic experiments: LSST
 - CCD for focal plane LSST
 - R&D for future 21cm experiment
- Computing
 - Tier0 for RHIC, Tier1 for ATLAS, Data Center Belle-2

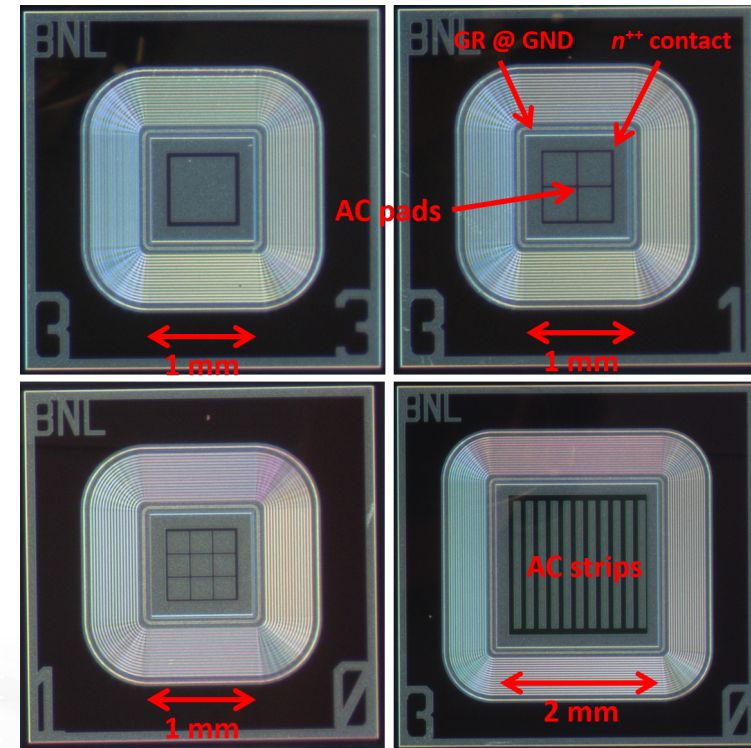
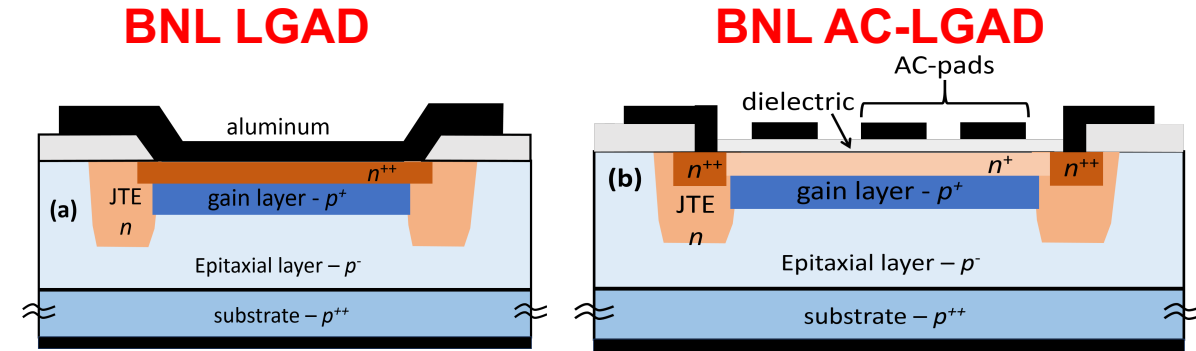
BNL capabilities

- Key capabilities enabling BNL research programs
 - Silicon Sensor Developments
 - Noble Liquid Detectors
 - ASICs Development
 - CAD
 - Microelectronics & High Density Interconnects
 - High throughput DAQ
 - System integration design
 - Software and computing



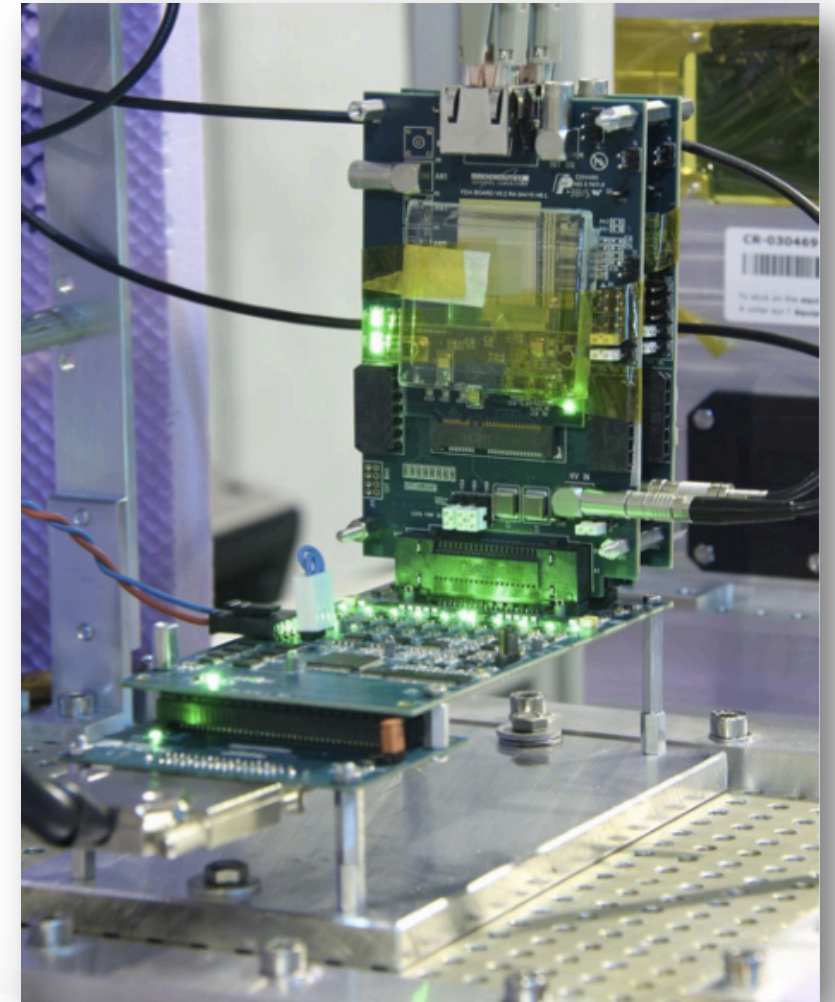
4D/5D LGADs

- BNL pursuing innovative concepts on pixelated LGADs
- Address the need of good spatial resolution and timing necessary for next generation HEP and Nuclear Physics Experiments at EIC (other applications possible)
- Looking forward:
 - Further studies to improve spatial and timing resolutions with pixelated LGADs
 - Edgeless sensors
 - Development of LGADs + HV-CMOS
 - Energy measurements



HV-CMOS sensor design & characterization

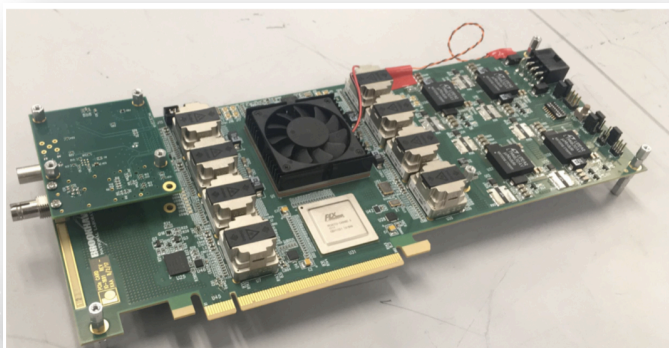
- Development of modular testing electronics for HV-CMOS characterization
- Design, manufactured and assembled readout system with DAQ integration (CaRIBOU) to characterize HV-CMOS sensors
- Validation of sensor design and performance baseline parametric measurements
- Measurements of charge collection efficiencies, time resolution and radiation tolerance



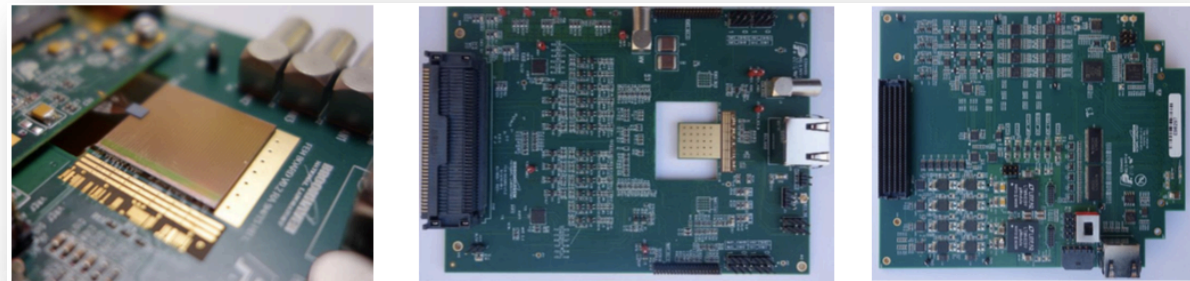
FELIX+CaRIBOU at CERN test beam

High throughput data acquisition

- Developments to factorize front-end electronics from data handling with compact, high-density, scalable, low maintenance, easily upgradeable, commodity-based solution
- High performance data acquisition, digital signal process and data collection
 - BNL leading design for FELIX, and developments for applications to other experiments: protoDUNE, sPHENIX, future cosmic experiments, future collider experiments...
- Field Programmable Gate Array (FPGA) and system integration experts, highly integrated system level data acquisition systems



Front End Link eXchange (FELIX)

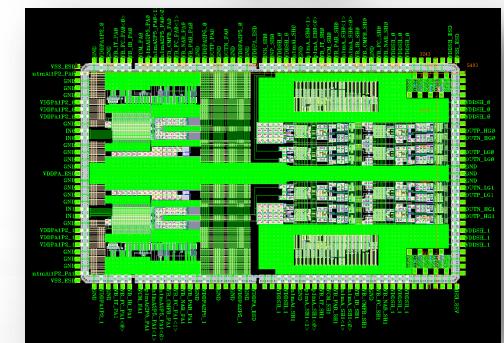
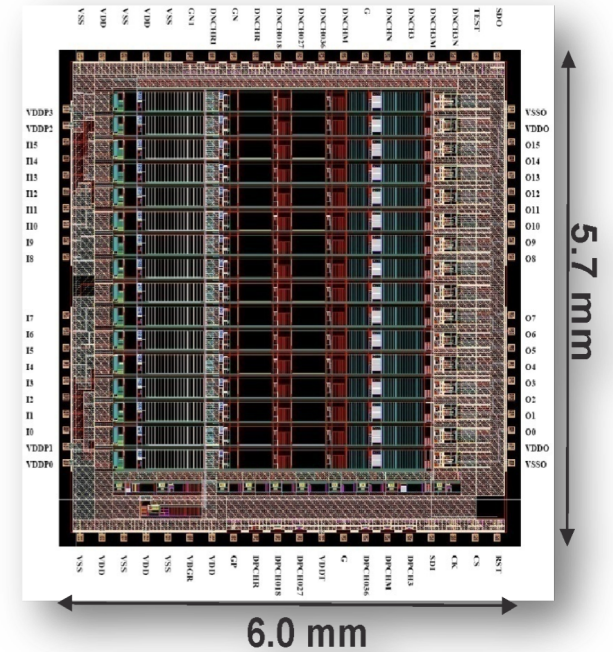


Control and readout board (CaRIBOu) in test set up for HV-CMOS characterization

ASICs & electronics

- Unique expertise for high precision/low noise analogue front end electronics
- BNL leading design for extreme environments
 - **Cryogenics:** System integration of cold readout chain - Front End ASICs, ACD ASIC and cold FPGA
 - **High radiation:** Development of radiation tolerant electronics ALFE – ATLAS LAr calorimeter Front End
- System design and custom Front Ends for diverse detector applications
- Advanced packaging options:
 - Wire bonding, bump bonding, 3D integration

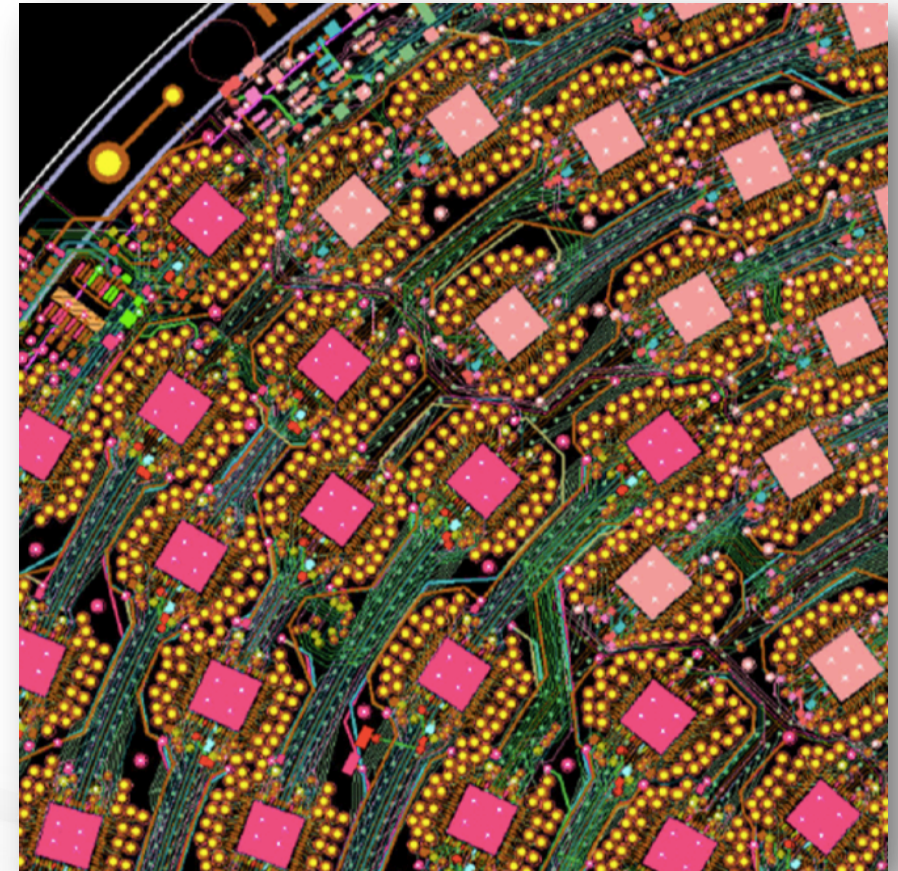
Cryogenic Analog Low-Noise Front-End ASIC
MicroBooNE, Argontube, CAPTAIN, LArIAT, SBND, 50 L
ICARUS,
DUNE 35 ton, ProtoDUNE-SP, DUNE



ALFE

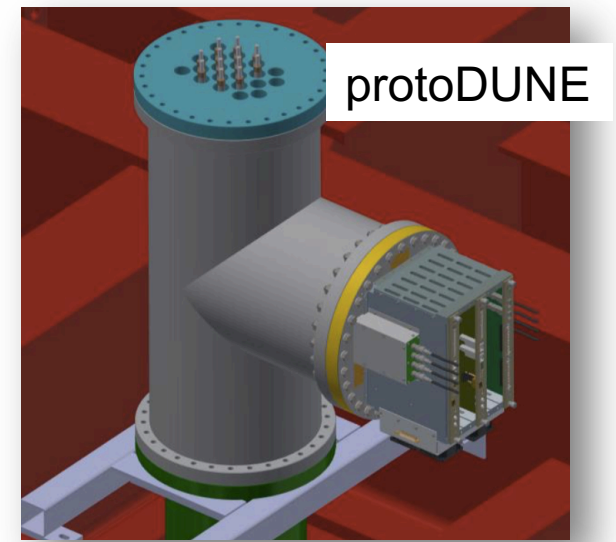
Microelectronics fabrication & assembly and High Density interconnect laboratory

- Multilayer complex design PCB capability
- Printed circuit assembly
 - Including semi-automatic pick and place assembly station
- R&D on High density interconnects
 - Gold bump and Al-wedge bonding for ASICs to high density detectors & circuit boards

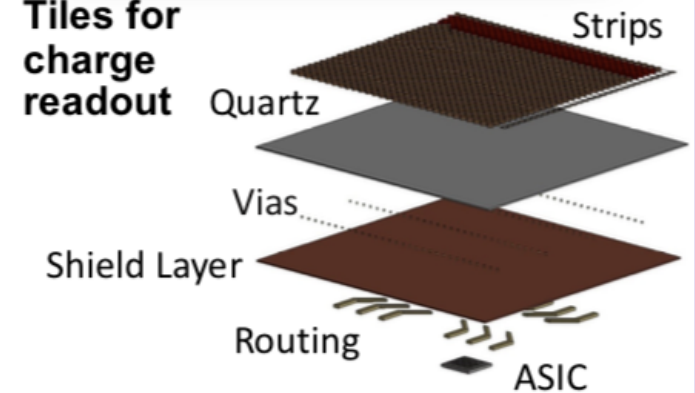


Noble liquid detectors

- Detector design for LAr TPC
 - Engineering, detector design, and full readout chain cold electronics, feedthrough, warm electronics
 - MicroBooNE, SBND, ProtoDUNE, DUNE SP
 - Exploring new charge readout schemes
- Detector design and integration for LXe TPC
 - Large ultra-low background detector
 - Scintillating and collected charge readout chain (ASICs, cold electronics, interconnect, warm electronics)
 - System design and characterization

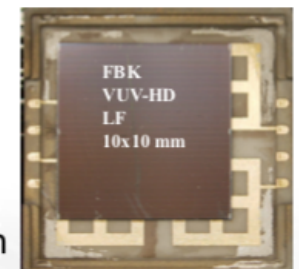


Tiles for charge readout



SiPMs for scintillation readout

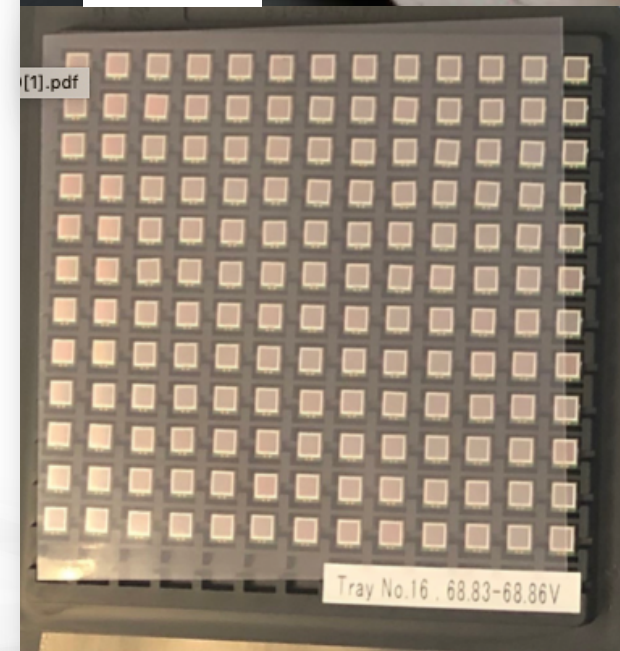
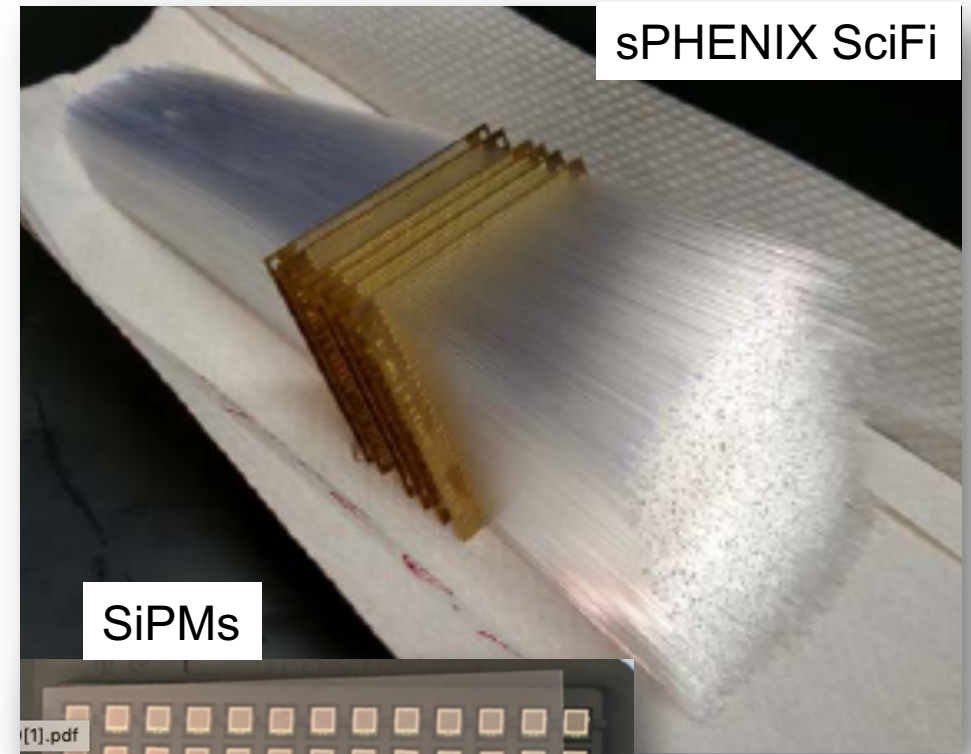
VUV-sensitive
down to ~ 175 nm



Light based detectors

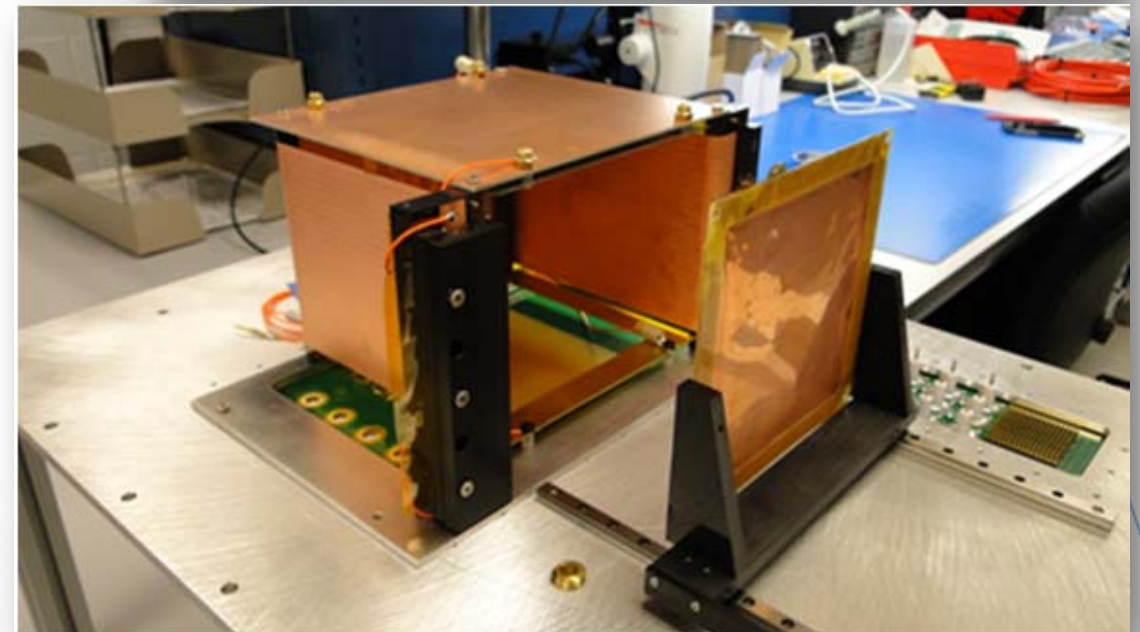
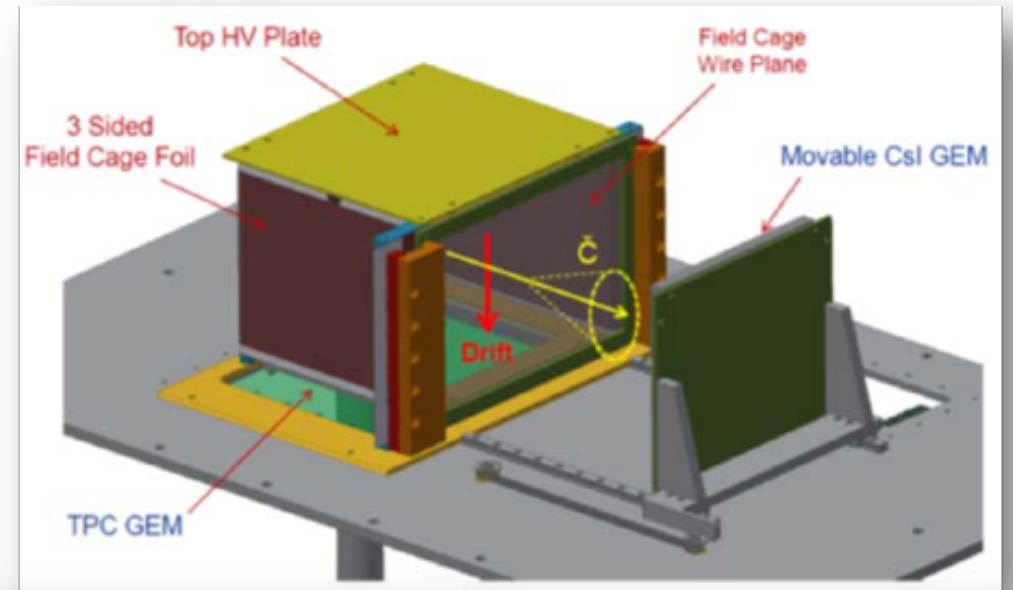
- Developments in scintillating fibers embedded in W powder
 - Very good energy and position resolution
 - SiPMs readout developments and characterization
- Applications in Heavy Ion experiments and potential interest for EIC experiments

EIC R&D program



Cherenkov TPC

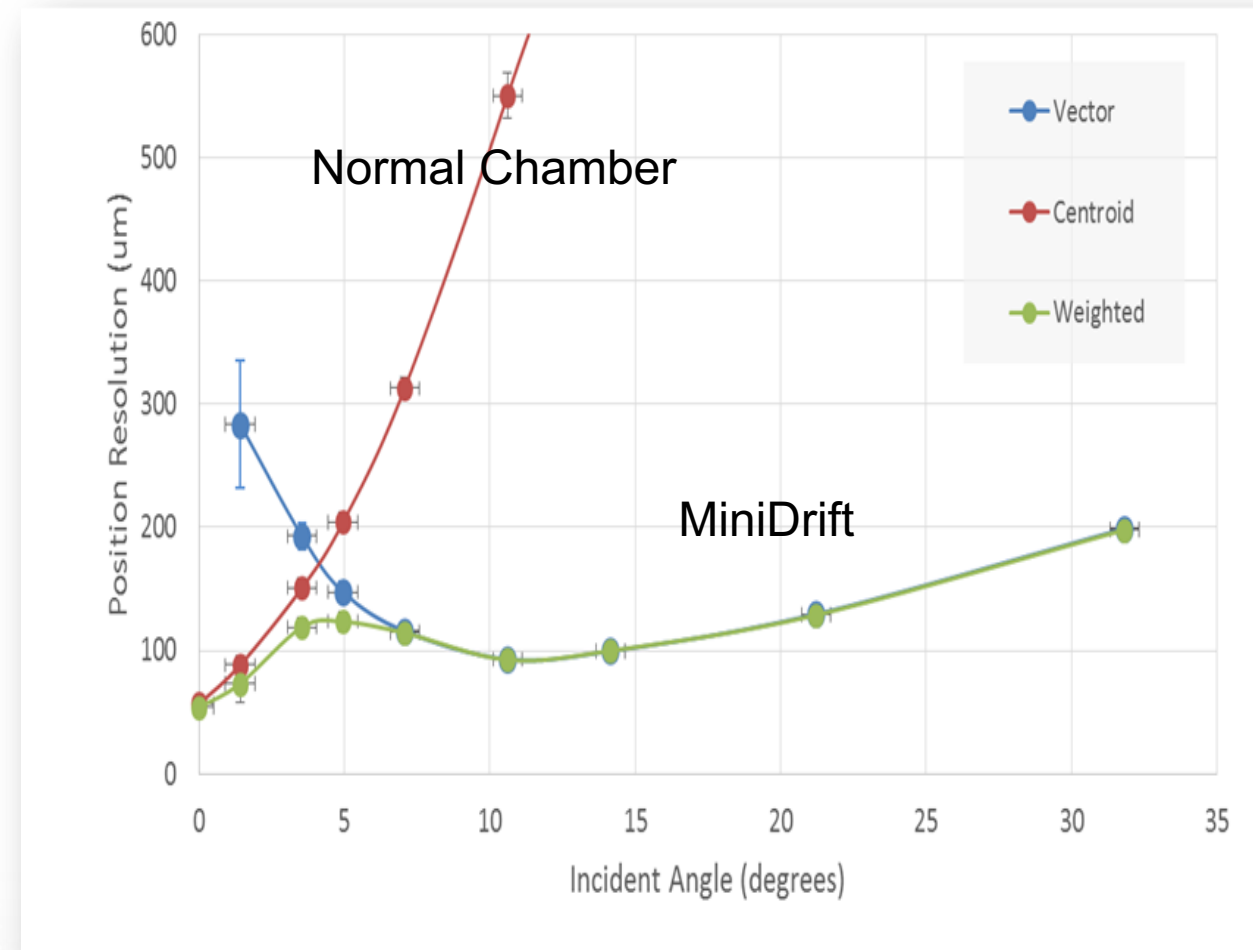
- Development to combine the functions of a TPC for charged particle tracking and a Cherenkov detector for PID in the same volume
 - TPC: 10cm drift+10x10cm² 4 layer GEM
 - Cherenkov: 3.3x3.3cm² pad arrays + 10x10cm² 4 layer GEM
- First results show good performance on track resolution and light yield



EIC R&D program

Mini-drift GEM Tracking detector

- Triple GEM stack with small drift region (mini TPC)
- Minidrift overcomes resolution degradation with incident angle for conventional GEMs tracking detectors
- Compatible with all forms of planar GEM



EIC R&D program

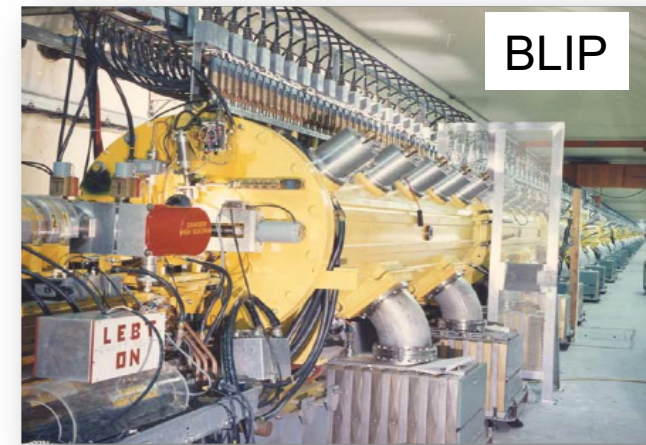
Software & Computing

- Development of faster simulations
 - Reengineering ATLAS fast simulation for GPUs
 - Machine Learning on HPC for shower simulations
- Exploring the use of ATLAS-originated common tracking software (ACTS) for reconstruction in high multiplicity environment for potential RHIC applications
- Development and implementation of Jupyter platform for multi-program data analysis
- Exploring frameworks (PanDA) to distribute workloads across various facilities and platforms
- Multi-experiment data management using Rucio (DUNE, Belle II, BNL light source)
- Development of Turnkey software stacks for EIC detector designs



Irradiation facilities

- Brookhaven Linac Isotope Producer (BLIP)
 - Beam line 200 MeV protons, 130 μA , and target area for Isotope production
 - Production of medical radio-isotopes for US, presently mainly ^{82}Sr
 - R&D of new radio-isotopes for diagnosis and therapy of metastatic cancers, ^{225}Ac
 - Possibility of proton/neutrons from BLIP for sensor irradiation studies
- Nasa Space Radiation Laboratory (NSRL)
 - Different ion beam species from H to Au, E ~few MeV up to few GeV, up to 2×10^{11} ions/spill
 - Study of cosmic radiation for human interplanetary space flights
 - R&D of ion beam cancer treatment
 - Possibility of beam time for other research applications
- Tandem Van de Graaff facility
 - Protons and ions (from a few MeV to a hundreds of MeV), flux from $1 - 10^6$ particles/cm²/sec
- Co^{60} gamma source facility for irradiation studies



Conclusions

- BNL has a vibrant R&D program to address the challenges of future detectors in HEP and Nuclear Physics
- BNL has infrastructures, facilities and skills to enable cutting edge research on key technologies for detectors
- Welcomes collaborations with other partners to develop technologies that will enable scientific breakthroughs