BROOKHAVEN NATIONAL LABORATORY
PROPOSAL INFORMATION QUESTIONNAIRE
LABORATORY DIRECTED RESEARCH AND DEVELOPMENT PROGRAM

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DEPARTMENT/DIVISION	NPP/PO - ATRO/IO	**DATE:**	**06/17/2021**
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TITLE OF PROPOSAL:	**The 'ABC' of cognizant Data Acquisitions**		
TYPE A			
PROPOSAL TERM	From **October 2021**	Through	**September 2024**

SUMMARY OF PROPOSAL

Description of Project:

We propose to address the challenge of increasing data rates at EIC and synchrotron facilities by integrating edge based AI/ML data reduction and signal processing techniques into the data acquisition system (DAQ) front end electronics.

Data rates at the LHC have reached 0.5 Pb/s and the EIC and synchrotron facilities are rapidly approaching 100 Gb/s and are anticipated to generate multiple exabytes of data per year. Conventional methods for handling such data quantities pose both engineering and scientific challenges. From the engineering perspective, large data infrastructures require sizable budgets for continuing maintenance. From a purely scientific perspective, post processing of exascale data is time consuming and delays time to publication by years.

Our AI/ML approach will provide a ~100x reduction in the data storage requirements and ~10x reduction in power consumption using two different methods. The first method will reduce data rates and power consumption by implementing deep neural networks (DNN) running on commodity FPGAs in front end electronics close to the detector to classify and filter out events that contain little useful scientific information. The second method will reduce the data storage requirements and time to publication by using both DNN based self-supervised learning for autonomous recalibration and channel classification techniques implemented in FPGAs to improve signal-to-noise.

This project is fully aligned with ongoing research at BNL as all HEP, NP and most BES experiments operated at an accelerator facility; enhancing the purity of the recorded data would optimize use of the luminosity/ brilliance of these expensive to operate facilities. The researchers involved in this LDRD have significant experience in designing and operating large collider experiments and are therefore best suited to make this LDRD a success and integrate this modern approach into other data acquisition systems.

Expected Results:

The goal of this R&D project is to provide a set of modular building blocks (software and hardware) for a cognizant DAQ easily applicable at different experiments.

- prototype electronic boards to integrate intelligence next to the detector and develop an autonomous calibration system
- software and algorithms to integrate the intelligence next to the detector
- a first case study would be to build a proof of concept based on the ATLAS Phase II Silicon Strip detector modules and staves to develop and qualify the building blocks of a cognizant and detector-aware DAQ.
- we will we will then expand the case study to a full readout chain of Monolithic Active Pixel Sensors (MAPS) based μ-vertex tracker and a calorimeter system based on a silicon photomultiplier (SiPM) photosensor readout currently in operation in STAR@RHIC will allow us to use already existing electronics boards and update them to integrate AI/ML

The results will be a combination of hardware, software, and Tensorflow or Torch models that will provide data reduction, autonomous calibration, and improved signal-to-noise ratio. The first model for data reduction will be a DNN capable of classifying whether a signal in the readout electronics should be propagated downstream for further processing or if the event should be filtered. This model will be initially trained in a supervised fashion using manually labeled datasets. The second model for triggering autonomous recalibration will be an unsupervised or self-supervised autoencoder trained to reconstruct the signal in the readout electronics. The mean-squared error between the reconstruction and input signal will increase as the detector loses calibration and a threshold tolerance on this error will trigger the recalibration routine. A variety of pretext tasks (https://arxiv.org/abs/2011.00362) such as denoising or frame based ordering will be used to encourage the autoencoder to learn a representation of the signal. Finally, the last model for increasing signal-to-noise will be a DNN based classifier that can be used to localize from which part of the detector a signal was generated. This will allow for more sophisticated component resolved signal processing; a prime example of this is the ability to mitigate the effects of detector radiation damage on the pulse thresholding by allowing for spatially resolved calibration pedestals.

Each of these models can be implemented as separate or as part of a single model. Collecting salient data for training is a challenge ubiquitous throughout the ML community. Initial efforts will alleviate this burden by using active learning approaches such as diversity and uncertainty sampling to identify training data that provides the steepest learning curves.

PROPOSAL

DAQ systems are the heart of any detector at a collider or accelerator facility. Having the possibility to enhance recorded signal purity and quality by filtering out noise and/or correcting quickly sub-detector performance issues would have several long-lasting advantages.

- improve effective use of the delivered luminosity
- reduce requisite storage space from exabyte scale by several orders of magnitude
- offline data calibration and reconstruction and such time to publication would be reduced.

This significantly enhanced data quality can be achieved if one designs a cognizant DAQ, which brings intelligence based on AI/ML from offline post processing into the detector readout electronics. This will allow for use of Deep Neural Networks (DNN) with low power consumption and latency to classify and discriminate between real signal based hits/events from false positives.

Additionally this will enhance the quality of the signal events by detecting problems in sub-detector performances by interfering and recalibrating the problematic section of the detector. The goal of this R&D project is to provide a set of modular building blocks (software and hardware) for a cognizant DAQ easily applicable at different experiments.

We propose to build first a proof of concept based on the ATLAS Phase II Silicon Strip detector modules and staves to develop and qualify the building blocks of a cognizant and detector-aware DAQ. These modules and staves are available at BNL, which are currently readout using a DAQ based on a FELIX card and firmware designed by the OMEGA group at BNL in collaboration with several international partners (NIKHEF, CERN, …). The proposed concept consists of multiple staves or modules mechanically mounted on an optical table, with one of the Strip modules acting as the device under test (DUT), attached to precise translation stages that can induce misalignments or vibrations. Using test beam facilities such as FNAL FTBF or CERN SPS H6 and H8 beamlines, data sample streams from the assemblies can be obtained to train and verify the ML/AI algorithms that reconstruct in real time the trajectories of particles crossing the reference modules and apply corrections for dynamic misalignment and vibration in the DUT.

Figure 1: a) ATLAS ITk Strip Stave and FELIX readout at BNL. (b) ATLAS ITk Strip Stave. (c) ITk Strip Sensor s-curve calibration obtained using FELIX card.

This effort will produce a working prototype suite of modular (intellectual property) IP cores that can be deployed in FPGA readout electronics across DOE facilities. The IP cores will be fed directly from the readout and provide DNN based classification capabilities for discriminating between signal classes. Some examples of these capabilities are classifying readout electronic output to determine if detector calibration is still accurate or if recalibration procedures are required, classify the type of photon (thermal, optical, gamma) from which a pulse has been generated, and provide spatial resolution by determining the pad of origin.

The initial DNNs for event filtering, autonomous recalibration, and signal-to-noise enhancement will be trained separately to show proof of concept. This simplifies the training by constraining the loss function to a single scalar. Once proof of concept for each of the DNNs has been individually demonstrated, they can be merged into a single DNN model and trained using multi-objective loss functions.

Data reduction

There are numerous potential DNN architectures (e.g. Mobilenet, Resnet, Inception) for classifying and filtering between events with signals from those without. The DNN architecture most suitable for FPGA deployment are convolutional based since the Finite Impulse Response (FIR) IP cores make efficient use of multiply-accumulate resources to implement AXI streaming with deterministic latency. The common underlying mathematics shared between FIR and ML convolutions allow for Xilinx's FIR IP core to be readily repurposed for ML convolutional layers. The natural saturation of finite precision arithmetic present in the FIR IP core provides built-in ReLU capabilities. This is in contrast to Xilinx's proprietary DPU based Vitis-AI approach which is bandwidth limited due to its focus on image processing, and requires multiple clock cycles to process a single frame.

As a starting point, we will use the fully convolutional Centernet ("Centernet") approach. Centernet is an object detection algorithm that analyzes images to generate bounding boxes, labels, and pose. Compared to previous region proposal networks (RPN) that rely heavily on an anchor, Centernet regresses the extents of the bounding boxes and labels directly. The robustness of the technique has inspired researchers in other fields to extend its application to point clouds and RF channel identification. To date, the point cloud extension of Centernet has the highest mean-average precision score on third party leaderboards ("NuScenes Leaderboard"). An open source repository ("Centernet") with a Torch implementation is available for quickly obtaining proof of concept. Adapting Centernet for application in RF signal processing is relatively straightforward; replace 2D convolutions with 1D convolutions. The heatmap output from the Centernet backbone can be binary (e.g. signal of interest, noise signal) or more elaborate (e.g. signal of interest, dark count, cosmic ray, outlier, etc…). Bounding box extents regressed by the DNN detector head can be used to trigger the readout electronics to store or filter the signal.

Collecting relevant training data will be one of the major challenges of this effort. The training data will require manually labeling of pulses as either signals of interest, dark count, background, etc. To mitigate the burden of manually collecting and labeling data, we will use active learning methodologies based on uncertainty and diversity sampling (https://arxiv.org/abs/2004.04699) to select datasets that provide the most information for training.

Autonomous recalibration

The approach used to trigger autonomous recalibration will be similar to that of autoencoder based outlier detection. Conventional outlier detection uses dimensional reduction techniques such as truncated Singular Value Decomposition (SVD), Robust-Principal Component Analysis (PCA), or autoencoder to learn a low dimensional representation of the signal. Under ideal conditions reconstructing the signal from the low dimensional representation poorly reconstructs the noise and outliers. In the absence of outliers, the mean-squared error between the reconstruction and original signal is low. During inference, the presence of outliers increases the error and is an indication that an outlier is present.

For autonomous recalibration, the uncalibrated state will be considered the outlier state and an autoencoder will be trained to reconstruct signals collected when the system is calibrated. As the system loses calibration during inference, the mean-squared error between the reconstruction and input signal will increase. A threshold on the error will be used to automatically trigger a calibration run. One of the benefits with this unsupervised approach is that a training run can be executed after each calibration procedure without having to manually label data. The DNN used for the autoencoder will be fully convolutional to allow for an AXI streaming finite impulse response implementation in the FPGA with deterministic latency. In order to encourage the system to learn a representation while keeping the number of layers small, we propose a self-supervised pretext task such denoising, deformation correction, or frame ordering (https://arxiv.org/abs/2011.00362). Deformation correction in particular will be beneficial for identifying miscalibration. In this approach the data into the autoencoder is augmented by deforming a calibrated signal to more closely resemble an uncalibrated signal. The autoencoder is then trained to regress the calibrated signal from the uncalibrated signal, increasing the mean-squared error between the reconstruction and input signal.

Channel Identification Based Signal-to-Noise Ratio Improvements

The Roman Pot detectors based on pixelated Silicon detectors have a single readout channel that is fed by multiple pads patterned on the Si wafer. The voltage threshold set to discriminate between dark counts and signals of interest is a single scalar that doesn't account for the distribution of responses of individual pads. This effect becomes more detrimental as defects from radiation damage accumulated in the Si broaden the distribution of quantum efficiency. We propose to obtain spatial resolution and provide pad resolved calibration thresholds by training a DNN to identify the pad of origin. Similar approaches have been extensively used in remote RF signal processing (https://dl.acm.org/doi/abs/10.1145/3395352.3402901) and are readily adaptable for *in-silico* application.

The initial network architecture can also be an object detector similar to Centernet. The brute force approach would be to make each heatmap layer output from the Centernet detector backbone correspond to a single pad. However, with over 3600 pads per detector, this may push the limits of FPGA resources. To mitigate the resource consumption, a single heatmap layer can provide the extents for downstream FPGA analysis pipelines to run classification. The ground truth spatial location required for training can be generated by controlled application of photons at known pad locations and measuring ADC traces from the readout electronics.

There are several major benefits to this approach. This will allow the pad pitch in the Roman Pot detector to be decreased from 500um to 3mm providing a factor 30 power reduction. This will consequently reduce the cooling infrastructure required for maintaining the detector within the operating parameters. More generally, this approach will improve the calibration by allowing for pad specific thresholds and gains to be set. Additionally, once the response from a single pad is isolated, more specific classifications such as the photon type (e.g. optical, dark count, x-ray, gamma) can be used to further classify the signal of origin and whether to filter it for data reduction.

Milestones and Success Criteria:

Year 1: Demonstrate real-time detector configuration change in response to conditions through an ML/AI tool.

- Use simulated data to select and tune AI/ML algorithm and test its application on the data

Year 2: Demonstrate real-time data calibration in response to detector conditions through ML/AI tools.

- Implement the algorithm into the FPGA

Year 3: Full chain of ML/AI tools in firmware & software to optimize data taking in response to detector conditions through ML/AI tools.

Success Criteria:

- set of modular building blocks (software and hardware) for a cognizant DAQ easily applicable at different experiments.

Intellectual Merit of the Proposal:

This LDRD proposal uses the creative concept of designing an intelligent DAQ utilizing the innovative concept to bring AI/ML from offline post processing into the detector readout electronics as close as possible to the individual subdetectors to address the challenge of increasing data rates at LHC, EIC and synchrotron facilities, see Figure 2.

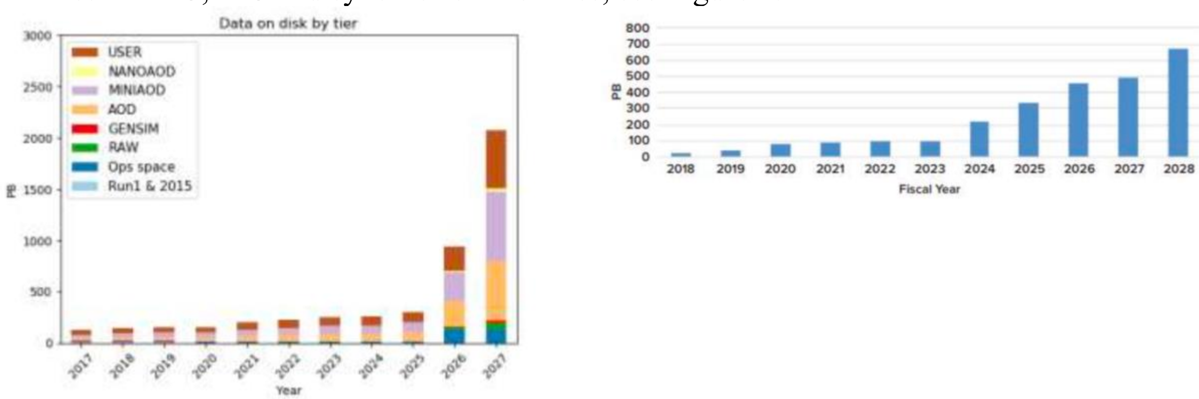

Figure 2: left: Projected data storage needs from CMS facility at LHC. right Projected aggregated data generation rates at BES light sources. From data call for DOE-BES User Facilities Data Management and Analysis Resource Needs in Advanced Scientific Computing Research.

An intelligent DAQ will increase the purity of the data through the use of Deep Neural Networks (DNN) with low power consumption and latency to classify and discriminate between real signal based hits/events from false positives and enhance the quality of the signal events by detecting problems in sub-detector performances by interrupting the data collection and recalibrating the problematic section of the detector. The enhanced purity of the recorded data allows a more effective use of the luminosity/ brilliance of these expensive to operate facilities and therefore will enhance knowledge by providing a way to reduce the offline data calibration and reconstruction and such time to publication.

The broader impacts of the proposed activity on the Laboratory:

The research of this LDRD builds on the unique capabilities of different BNL divisions combining AI/ML, electronics design and operating large experiments, all BNL core competencies, into one research direction. This combined with the complementary expertise of the researchers involved in this proposal, who all are well recognized leaders in their field of instrumentation, high energy and nuclear physics, enhances the scientific and technical vitality of the Laboratory. Addressing the operational efficiency of BES, HEP and NP experiments at collider facilities addresses both BNL and DOE SC core competencies. The fact that the PIs and the collaborators on this LDRD are already well recognized leaders in their respective communities and that the groups spans diverse complementary communities ensure without any extra effort that BNL has the relationships and visibility in the relevant community to capitalize on this investment. Of course it is part of the plan of this LDRD to raise the awareness of BNL's new competency among the relevant communities to disseminate the results at the relevant conferences in the respective communities.

Return on Investment:

This LDR provides several possibilities for significant future funding and as such excellent possibilities for a good return of the investment. The timeframe for this return is the next 10 years. In the following there are a couple of examples how this return can manifest itself.

- The success of this LDRD provides the basis that BNL can capture the design of modern DAQ systems like the one for EIC and DUNE, which are estimated to be $26M and $8M, respectively
- improved operating efficiency at colliders and light sources by enhancing the purity of the recorded data, which would give a better use of the luminosity / brilliance of these expensive to operate facilities.
  The operation cost of EIC is estimated at $40k / hour decreasing the experimental deadtime by 5% through the use of a cognizant DAQ would save $9.4M operational costs as the same data could be taken faster. This can be summarized with more data for the buck.
- The possibility for a patent for a suite of modular (intellectual property) IP cores that can be deployed in FPGA readout electronics across different facilities. This patent can be marketed and form part of an SPP.
- Using cognizant DAQs at HEP, NP and most BES experiments operated at an accelerator facility enhances the purity of the recorded data and as such leads to reduced computing storage costs. The EIC is expected to require 150 PB/yr to archive all the raw and reconstructed for storage capacity; in 2020 prices of $100k/PB, this would be $3M. Improving the signal to background in the recorded data by 10% through the use of an intelligent DAQ would lead to a $300k/year saving for archiving media.

Glossary of Acronyms:
deep neural network (DNN)
data acquisition (DAQ)
artificial intelligence (AI)
machine learning (ML)
field programmable gate array (FPGA)
intellectual property (IP)
Graphical Processing Unit (GPU)
Deep learning Processing Unit (DPU)
Advanced eXtensible Interface (AXI)
Rectified Linear Units (ReLU)
Silicon Photomultiplier (SiPM)
Analog Digital Converter (ADC)

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"NuScenes Leaderboard." *NuScenes Leaderboard*, NuScenes, https://www.nuscenes.org/object-detection?externalData=all&mapData=all&modalities=Any.
Zhou, Xingyi, et al. "Objects as Points." *arXiv*, https://arxiv.org/abs/1904.07850.

ONE-PAGE VITA FOR EACH INVESTIGATOR

VITA Dr. Elke-Caroline Aschenauer

Education and degrees:
1990 – 1994 Ph.D. Swiss Federal Institute of Technology Zürich, CH
1984 – 1989 Major in Physics at the Friedrich-Alexander-University, Erlangen, D
1986 'Vordiplom' in Physics

Career:
1994 – 1996: Human Capital and Mobility Fellowship of the European Community
1994 – 1995: Research associate at the NIKHEF-K, Amsterdam, NL
1995 – 1996: Research associate at the Department of Physics of the University of Gent, Belgium
1996 – 2001: Post-Doctoral Fellow at DESY, Germany
2001 – 2006: Staff Scientist at DESY, Germany
2007 – 2009: Senior Staff Scientist at JLAB, USA
2009 – present: Scientist at BNL, USA
2010 December: received tenure
2015 February: senior scientist

Awards and (Inter) National Service:
2004: Academic research prize of the University of Regensburg Prof.-Hess-Dozentur
2009 – 2015: member of the DESY physical review committee; (2012 to 2015 Co-Chair)
2006 – 2012: member of the BMBF (German funding agency) committee reviewing applications in nuclear physics (two 3 year periods)
2012: APS Fellow
2015: Member of the expert group for the evaluation of the FAIR Project in February 2015
2017: Humboldt-Research Award (Humboldt-Forschungspreis)
2018: BNL Science and Technology Award
2019 - today: Particle Data Group co-author for the Structure Functions Section
2020 - today: Member of the JLAB Physics Advisory Committee

Main achievements:
- 06/2020 – present: Co-Associate Director for the EIC Experimental Program
- 2020 – present Cold QCD Group Leader
- 2009 – 2019: Group Leader Medium Energy
- 2020 – present: PI STAR forward upgrade
- 2017 – 2020: STAR Upgrade Manager
- 2009 – 2017 Co-Chair BNL EIC Taskforce
- As the Hall-D Group Leader and project leader for the Hall-D part of the 12 GeV upgrade. In the two years at JLab, I build up the Hall-D scientific and technical group and stewarded the project through **all** the reviews needed for CD-2 and CD-3
- During my time at DESY, I was responsible for designing and building the photon detector for the HERMES RICH, as well as commissioning and being the local expert (1998-2006) for the detector. The HERMES RICH made a significant difference to the physics capabilities of HERMES.I was the HERMES Run-coordinator and Deputy Spokesperson from 2000-2003 and the Hermes Spokesperson from 2003-2007

Publication List
A full list of my publications can be found here
http://inspirehep.net/search?ln=en&p=find+a+aschenauer+and+tc+p&of=hb&action_search=Search&sf=earliestdate&so=d

VITA Dr. Michael Begel

Education and degrees:

2000 Ph.D. University of Rochester, Rochester NY
1993 M.A. University of Rochester, Rochester NY
1991 B.A. Reed College, Portland OR

Career:

1989-1991: Reactor Operator, Reed Reactor Facility, Portland OR
1991-1999: Research Assistant, University of Rochester, Rochester NY
1999-2007: Postdoctoral Research Associate, University of Rochester, Rochester NY
2007-present: Scientist at BNL (2013: tenured, 2020: senior)

Awards:

- 1989-1991: Licensed Nuclear Plant Reactor Operator (Senior, 1990) at the Reed Reactor Facility
- 1991-1994: Department of Education Fellow, University of Rochester, Rochester NY
- 2000: Frederick Lobkowicz Ph.D. Thesis Prize, University of Rochester, Rochester NY
- 2009: Sambamurti Memorial Lectureship, BNL
- 2018: Record of Invention BSA18-02/IP2018-003-01 S.N. 17/281,731
  High Data Throughput Reconfigurable Computing Platform
- 2019: Fellow of the American Physical Society
- 2019: Record of Invention BSA19-06/IP2019-004-02 S.N. 62/813,780
  High Bandwidth Reconfigurable Data Acquisition Card

Main achievements:

- 1991-2007: FNAL E706 Experiment, Batavia Illinois
- 1999-2008: FNAL DZero Experiment, Batavia Illinois
- various leadership roles in Top & QCD Physics, Trigger, Operations, Luminosity
- 2000-2001: Commissioning Coordinator for DZero Run II
- 2008-present: CERN ATLAS Experiment, Geneva Switzerland
- CAM in US ATLAS Phase-I and HL-LHC Upgrade Projects
- various leadership roles in Trigger & Performance
- 2016-present: Group Leader of Omega Group, Department of Physics, BNL
- 2016-present: PI for BNL HEP Energy Frontier Research Program
- 2016-present: co-PI for BNL HEP Detector Research & Development
- 2016-present: Manager for US ATLAS Center at BNL
- 2019-present: Brookhaven Council member
- 2019-present: co-convener, pQCD in Energy Frontier of 2020 HEP Community Planning Exercise (Snowmass)

Publication List

Full publication list can be found at http://goo.gl/MX2NNQ.

VITA Dr. Gabriella Carini

Education and degrees:

2006 Ph.D. University of Palermo, Italy
2001 'Lauream' cum laude, University of Palermo, Italy

Career:

2003 –2005: Research Scholar, BNL, Nonproliferation and National Security Department
2006: Research Associate, Beamline Scientist**,** BNL, Nonproliferation and National Security Dep.
2006 – 2008: Research Associate, BNL, National Synchrotron Light Source (NSLS)
2008 – 2010: Assistant Physicist, BNL, National Synchrotron Light Source (NSLS)
2010 – 2011: Associate Physicist**,** BNL, National Synchrotron Light Source (NSLS)
2011 – 2015: Staff Scientist, SLAC National Accelerator Laboratory, PPA directorate
2015 – 2018: Detectors Department Head, Staff Scientist, SLAC, Linac Coherent Light Source (LCLS)
2015 – 2018: Detectors Program Director, SLAC, Linac Coherent Light Source (LCLS)
2016 – 2018: Detectors Systems Lead/PM, LCLS-2 Instruments Development Program, SLAC
2018 – 2019: Deputy Division Head, Instrumentation Division, Brookhaven National Laboratory
2018 – present: Senior Scientist, Instrumentation Division, Brookhaven National Laboratory
2019 – 2020: Deputy Director, Instrumentation Division, Brookhaven National Laboratory
2020 – present: Director, Instrumentation Division, Brookhaven National Laboratory

Selected Honors and Awards:

2019 Oppenheimer Science and Leadership Program (DOE)
2011 Brookhaven National Laboratory Spotlight Award.
2008 IEEE Long Island Section's Outstanding Young Engineer Award for 'outstanding contributions to the advancement of semiconductor detectors for x-ray spectroscopy'
2006 Certificate of Outstanding Contributions to the field of Nuclear Radiation Measurements at the IEEE NPSS 2006 for 'investigations of the role of Te inclusions in limiting the performances of CdZnTe detectors'.
2005 Co-winner of a 2005 R&D 100 Award for 'developing a highly efficient, low-cost radiation detector: the CdZnTe Frisch-ring detector'. The detector can be used for homeland security applications, nuclear medical imaging, environmental monitoring and cleanup, galactic events studies, and nuclear-weapons safeguards.
2002 Fellowship Researcher, Training and Mobility of Researchers (TMR) European Commission Program at the French Atomic Energy Commission, Grenoble, France.

Patents:

G. Carini, S. Herrmann, R. Fahrig, "Charge Cloud Tracker: High-resolution, high DQE, photon-counting, energy discriminating X-ray detector", US Patent 9696437, July 4, 2017.
G. De Geronimo, A. Bolotnikov, G. Carini, "Method for the depth corrected detection of ionizing events from a co-planar grids sensor", US Patent 7531808, May 12, 2009.

VITA Dr. Mathieu Benoit

Mathieu **Benoit**

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Work Experience and Education

OMEGA Group, physics Department, Brookhaven National Laboratory — *Upton, NY,USA*
SCIENTIFIC ASSOCIATE — *Apr. 2020 - PRESENT*

Dept. of Particle and Nuclear Physics (DPNC), University of Geneva — *Geneva, Switzerland*
SENIOR RESEARCHER AND TEACHING COLLABORATOR — *Sept. 2014 - Feb. 2020*

European Organization for Nuclear Research (CERN) — *Geneva, Switzerland*
FELLOW ASSIGNED TO CLIC VERTEX DETECTOR R&D PROGRAM — *Sept. 2011 - Sept. 2014*

Laboratoire de L'accélérateur Linéaire (LAL), Université Paris Sud XI — *Orsay, France*
PHD CANDIDATE IN PHYSICS — *Jan. 2008 - Sept. 2011*

Study of planar pixel sensors hardened to radiation damage for the upgrade of the ATLAS vertex detector for operation at high luminosity

Université de Montréal — *Montréal, Québec, Canada*
MASTER CANDIDATE IN PHYSICS — *2007-2008*

Modeling of CdZnTe-based detectors for γ spectroscopy and imagery

Université de Montréal — *Montréal, Québec, Canada*
BACHELOR DEGREE IN PHYSICS — *Sep. 2003, Dec. 2007*

Publications

- **Roadmap toward the 10 ps time-of-flight PET challenge : Perspectives on using silicon pixel detectors for fast timing applications**, M. Benoit, Physics in Medicine & Biology, 2020, DOI 10.1088/1361-6560/ab9500
- **Development of FELIX based readout system for HV-CMOS sensor testbeam**, M. Benoit et al., J. Inst. Vol 14 issue 01 (2019), DOI 10.1088/1748-0221/14/01/P01013
- **Electrical characterization of AMS aH18 HV-CMOS after neutrons and protons irradiation**, M. Benoit et al., J. Inst. PIXEL18 proceedings (2019), arXiv:1902.05914
- **Allpix^2: A Modular Simulation Framework for Silicon Detectors**, M. Benoit et al., NIMA Vol 901 p164-172 (2018), DOI 10.1016/j.nima.2018.06.020
- **Charge collection characterisation with the Transient Current Technique of the ams H35DEMO CMOS detector after proton irradiation**, J. Anders et al., J. Inst. Vol. 13 (2018), DOI 10.1088/1748-0221/13/10/P10004
- **Development of a modular test system for the silicon sensor R&D of the ATLAS Upgrade**, M. Benoit et al., J. Inst. Vol 12 issue 01 (2017), DOI 10.1088/1748-0221/12/01/P01008
- **Test beam measurement of ams H35 HV-CMOS capacitively coupled pixel sensor prototypes with high-resistivity substrate**, M. Benoit et al., J. Inst. Vol 13 (2018), arXiv:1712.08338
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- **The FE-I4 telescope for particle tracking in testbeam experiments**, M. Benoit et al., J. Inst, Vol. 11 No. 7 (2016), DOI 10.1088/1748-0221/11/07/p07003
- **Results of the 2015 testbeam of a 180 nm AMS High-Voltage CMOS sensor prototype**,M. Benoit et al., J. Inst. Vol. 11 No. 07 (2016), DOI 10.1088/1748-0221/11/07/p07019
- **100 ps time resolution with thin silicon pixel detectors and a SiGe HBT amplifier**, M. Benoit et al., J. Inst. Vol. 11 No 03 (2016), DOI 10.1088/1748-0221/11/03/P03011
- **Test beam analysis of ultra-thin hybrid pixel detector assemblies with Timepix readout ASICs**, M. Benoit et al., CLICdp-Note-2016-001 (2016), `http://cds.cern.ch/record/2133128`

VITA Dr. Hongwei Ke

Education and degrees:

2007 – 2013 Ph.D. in Particle Physics and Nuclear Physics at Central China Normal University, Wuhan, China

2003 – 2007 Major in Physics at Central China Normal University, Wuhan, China

Career:

2020 – present: Technology Architect, BNL

2017 – 2019: Sr. Technology Engineer, BNL

2013 – 2017: Research Associate, BNL

Services and Achievements:

- 2020 – present: Co-lead of STAR Tracking Software Group
- 2014 – present: Software coordinator for STAR High-Level Trigger
- 2017 – present: Member of STAR Trigger board
- 2020 – present: Member of STAR QA board
- Led the effort of developing and operating the High-Level Trigger (HLT) system of the STAR experiment.
- Built a Linux cluster equipped with CPU, Xeon Phi coprocessors, HTCondor scheduler and Ceph storage system to support the STAR HLT and data analysis tasks.
- Led the measurement of charge asymmetry dependence of the pion event anisotropy in Au + Au collisions at STAR in the search for the chiral magnetic wave in experiment. Participate in the measurement of charge particle flow in Au + Au collisions of RHIC BES phase I and in U + U collisions at STAR.

Publication List

Full List

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2. STAR Collaboration, L. Adamczyk et al., Observation of Charge Asymmetry Dependence of Pion Elliptic Flow and the Possible Chiral Magnetic Wave in Heavy-Ion Collisions, Phys. Rev. Lett. 114, 252302 (2015)
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4. STAR Collaboration, H. Agakishiev et al., Observation of the antimatter helium-4 nucleus, Nature 473, 353 (2011)

VITA Dr. Stefania Stucci

Education and Degrees:

2012 – 2016 Ph.D. in High Energy Physics, University of Bern, Switzerland

- Co-responsible of the module reception test of stave quality check for the innermost layer of the ATLAS silicon detector installed in 2014
- Main analyst on a search for direct pair production of chargino and neutralino decaying into a Higgs boson using a multivariate approach with ATLAS Run-1 data

2007 – 2011 M.S. in Nuclear and Particle Physics, Calabria University, Italy

- Geant4 simulation and calibration of the very forward calorimeter (ZDD) installed to BESIII

Career:

2020 – present Scientific Associate, Brookhaven National Laboratory

- Silicon Strop Detector Production Manager
- ATLAS ITk Strip FELIX DAQ Coordinator
- Responsible of the electrical test of the first US ABCStar/HCCStar stave via lpGBTx EoS card
- Responsible of the electrical and functional characterization of the ITk silicon strip hybrids and modules with ABCStar and HCCStar readout ASIC

2016 – 2020 Postdoctoral Research Associate, Brookhaven National Laboratory

- Responsible of the electrical characterization of the ITk strip electrical prototype hybrids, modules and staves
- Led irradiation campaigns with gamma-rays of the ITk silicon strip detector readout ASICs
- Characterization of the heavy ions energy deposition produced in the interaction of protons in layers of GaN and Si with a detailed GEANT4 simulation
- Co-leader of the effort to build and readout the US ITk thermo-mechanical stave

Selected Publications:

A full list can be found here**:** link

1. The ABC130 barrel module prototyping programme for the ATLAS strip tracker, Journal of Instrumentation, 10.1088/1748-0221/15/09/p09004, https://doi.org/10.1088/1748-0221/15/09/ p09004
2. Stucci Stefania et al., Effect of gamma irradiation on leakage current in CMOS read-out chips for the ATLAS upgrade silicon strip tracker at the HL-LHC, TWEPP-17, PoS, 10.22323/1.313.0094https:// cds.cern.ch/record/2312291
3. Stucci Stefania et al., Effect of gamma irradiation on leakage current in CMOS read-out chips for the ATLAS upgrade silicon strip tracker at the HL-LHC, iEEE, 10.1109/NSSMIC.2017.8532840, Nov 2018, https://ieeexplore.ieee.org/document/8532840
4. T. A.,Collaboration, ATLAS Phase-II Upgrade Scoping Document, Tech. Rep. CERN-LHCC-2015-020. LHCC-G-166, CERN, Geneva, Sep, 2015
5. The ATLAS IBL collaboration, IBL Module Loading onto Stave and Quality Check, ATL-INDET-PUB- 2015-003, CERN, Geneva, Dec. 2015 https://cds.cern.ch/record/2110639

VITA Dr. Sioan Zohar

<u>Education and degrees:</u>

2004 – 2010 Ph.D. Applied Physics Columbia University, NY
1999 – 2004 Major in Physics at Yeshiva University, NY

<u>Career:</u>

2021-present: Scientist and Brookhaven national Laboratory
2020 – 2021: Research Engineer at Expedition Technologies
Developed machine learning models in FPGA and embedded systems for image and signal processing applications

2016 – 2020: Research Engineer at the Stanford Linear Accelerator
Develop AXI stream signal processing modules for femto-second timing correction
Lead team of three in support of Data and Controls for LCLS user operations

2013 – 2016: Physicist at the Advanced Photon Source at Argonne National Laboratory
Develop FPGA based feedback control systems for x-ray beam stabilization

2011 – 2013: Post-Doctoral Fellow at the Advanced Photon Source at Argonne National Laboratory Investigated electronic structure of optically spin pumped III-V semiconductors using soft x-ray spectroscopy Develop novel x-ray based magnetic contrast microscopy technique for imaging of epitaxial

<u>Select Publications</u>

1. Paris, E., Nicholson, C.W., Johnston, S. *et al.* Probing the interplay between lattice dynamics and short-range magnetic correlations in CuGeO3 with femtosecond RIXS. *npj Quantum Mater.* 6, 51 (2021). https://doi.org/10.1038/s41535-021-00350-5
2. Sergii Parchenko, Eugenio Paris, Daniel McNally, Elsa Abreu, Markus Dantz, Elisabeth M. Bothschafter, Alexander H. Reid, William F. Schlotter, Ming-Fu Lin, Scott F. Wandel, Giacomo Coslovich, Sioan Zohar, Georgi L. Dakovski, J. J. Turner, S. Moeller, Yi Tseng, Milan Radovic, Conny Saathe, Marcus Agaaker, Joseph E. Nordgren, Steven L. Johnson, Thorsten Schmitt, and Urs Staub Orbital dynamics during an ultrafast insulator to metal transition *Phys. Rev. Research* 2, 023110 – Published 30 April 2020
3. Sioan Zohar and Joshua J. Turner, "Multivariate analysis of x-ray scattering using a stochastic source," *Opt. Lett.* 44, 243-246 (2019)
4. Bailey, W., Cheng, C., Knut, R. *et al.* Detection of microwave phase variation in nanometre-scale magnetic heterostructures. *Nat Commun* 4, 2025 (2013). https://doi.org/10.1038/ncomms3025
5. Zohar, S., & Yoon, C. (2020). Bi-cross validation of spectral clustering hyperparameters. *Powder Diffraction, 35*(2), 112-116. doi:10.1017/S0885715620000214

1. EQUIPMENT (Reference: DOE Order 413.2C for guidance on equipment restrictions)
Will LDRD funding be used to purchase equipment? N_____

2. HUMAN SUBJECTS (Reference: DOE Order 443.1)
Are human subjects involved from BNL or a collaborating institution?

Human Subjects is defined as "A living individual from whom an investigator obtains either (1) data about that individual through intervention or interaction with the individual, or (2) identifiable, private information about that individual".

If **yes**, attach copy of the current Institutional Review Board Approval and Informed Consent Form from BNL and/or collaborating institution. N ___________

3. VERTEBRATE ANIMALS
Are live, vertebrate animals involved? N ___________

If **yes**, attach copy of approval from BNL's Institutional Animal Care and Use Committee. N___________

4. NEPA REVIEW
Are the activities proposed similar to those now carried out in the Department/Division which have been previously reviewed for potential environmental impacts and compliance with federal, state, local rules and regulations, and BNL's Environment, Safety, and Health Standards? (Therefore, if funded, proposed activities would require no additional environmental evaluation.) Y ___________

If **no**, has a NEPA review been completed in accordance with the National Environmental Policy Act (NEPA) and Cultural Resources Evaluations Subject Area and the results documented? NA___________

(**Note:** If a NEPA review has not been completed, submit a copy of the work proposal to the BNL NEPA Coordinator for review. No work may commence until the review is completed and documented.)

5. ES&H CONSIDERATIONS
Does the proposal provide sufficient funding for appropriate decommissioning of the research space when the experiment is complete? Y___________

Is there an available waste disposal path for project wastes throughout the course of the experiment? Y ___________

Is funding available to properly dispose of project wastes throughout the course of the experiment? Y ___________

Are biohazards involved in the proposed work? If yes, attach a current copy of approval from the Institutional Biosafety Committee. N ___________

____

Can the proposed work be carried out within the existing safety envelope of the facility (Facility Use Agreement, Nuclear Facility Authorization Agreement, Accelerator Safety Envelope, etc.) in which it will be performed? If **no**, attach a statement indicating what has to be done and how modifications will be funded to prepare the facility to accept the work. Y

6. TYPE OF WORK Select Basic, Applied or Development BASIC

7. ALIGNMENT WITH THE LABORATORY PRIORITIES

This proposal is aligned with the priority area "Discovery Science Driven by Human-AI-Facility Integration" and supports research in Nuclear Physics, High Energy Physics and Artificial Intelligence and Data Science.

8. POTENTIAL FUTURE FUNDING

Because of the broad applicability of the R&D several divisions (ASCR, HEP, NP, BES) in the Office of Science could provide future funding.
We anticipate that funding opportunities in this area will arise through FOAs and/or DOE National Laboratory Announcements. In 2021 there have been for example FOA calls for

1. Data Reduction for Science
2. Data Analytics for Autonomous Optimization and Control of Accelerators and Detectors
3. Data-Intensive Scientific Machine Learning and Analysis

The research of this LDRD would have fit to all three of these FOA calls. We think after year two we are in a good position to respond to such funding opportunities.

9. BUDGET JUSTIFICATION

The Labor cost is based on the involvement of the investigators from NPP/PO and ATRO/IO to this proposal as listed and some experts from ATRO/IO, NPP/PO and/or CSI we will contact for very specialized expert tasks. We include $36k/year for materials, which will be the necessary hardware to produce prototype readout cards and improved FELIX cards with integrated AI/ML capabilities. Further we anticipate travel cost of $13k in year-1 and $26k in year 2 and 3 for national and international travel, this involves test beams and to attend conferences to disseminate the results in the community.

Workforce:

0.1 FTE of Mathieu Benoit NPP/PO (HEP)
0.1 FTE of Stefania Stucci NPP/PO (HEP)
0.25 FTE of Hongwei Ke NPP/PO (NP)
0.05 FTE of Michael Begel NPP/PO (HEP)
0.05 FTE of Elke Aschenauer NPP/PO (NP)
0.2 FTE of Sioan Zohar ATRO/IO
0.05 FTE of Gabriella Carini ATRO/IO
0.05 FTE of Gabriele Giacomini ATRO/IO
0.2 FTE of EE ATRO/IO or NPP/PO
0.32 FTE of Sci-1 ATRO/IO or NPP/PO or CSI
Electrical Engineers to work on the project are Ch. Videbaeck, T. Camarda and J. Fried, the scientists helping with AI/ML specific algorithm questions are Yihui Ren and Meifend Lin.

10. NAME OF SUGGESTED BNL REVIEWERS

From NPP/PO:
Dr. Ante Ljubicic tonko@bnl.gov
Dr. Jamie Dunlop dunlop@bnl.gov

APPROVALS (NPP)

Business Operations Manager

Susan M. Pankowski

Department Chair/Division Manager

Hong Ma

Associate Laboratory Director for
Nuclear and Particle Physics

Haiyan Gao

APPROVALS (ATRO)

Business Operations Manager	Ken Koebel ________________________________ Kenneth Koebel
Department Chair/Division Manager	________________________________ Gabriella Carini
Cognizant Associate Lab Director/Computational Science Initiative Director/Advanced Technology Research Office Director	________________________________ David Asner

Resource Category	DESCRIPTION		Year 1		Year 2		Year 3
050	Salary - Scientific		83,356		73,639		67,858
051	Salary - Research Assoc		0		0		0
	Total FTEs		**1.07**		**0.95**		**0.90**
TOTAL SALARY/WAGE & FRINGE			**183,518**		**169,230**		**166,389**
190/191	Contract Labor		0		0		0
201	Recharge Labor see list below		101,130		104,241		107,446
TOTAL PURCHASED LABOR			**101,130**		**104,241**		**107,446**
various	Contracts - Low Value						
280	Foreign Travel		7,000		14,000		14,000
290	Domestic Travel		6,000		12,000		12,000
300	Materials		35,000		35,000		35,000
TOTAL MSTC			**48,000**		**61,000**		**61,000**
TOTAL DIRECT COSTS			**332,648**		**334,471**		**334,835**
251	Electric Distributed (Electric Power Burden)		1,835		1,692		1,664
700/701/481	Organizational Burden		22,206		20,477		20,133
TOTAL ORGANIZATIONAL BURDEN			**24,041**		**22,169**		**21,797**
745	Procurement (Material Handling)		3,360		4,270		4,270
710	G&A Burden		0		0		0
711	Adjs to G&A Burden						
720	Common Support		139,951		139,090		139,098
722	Safeguards & Security Assess		0		0		0
746	Adjs to Procurement Burden						
TOTAL LABORATORY BURDEN			**143,311**		**143,360**		**143,368**
705	LDRD Burden		0		0		0
TOTAL PROGRAM COSTS			**500,000**		**500,000**		**500,000**

Labor Band	Name	FY22 FTE	FY22 Amount	FY23 FTE	FY23 Amount	FY24 FTE	FY24 Amount
	Hongwei Ke	0.25	37,111	0.25	38,252	0.25	39,428
	Mathieu Benoit	0.10	18,518	0.10	19,087	0.10	19,674
	Stefania Stucci	0.10	14,844	0.10	15,301	0.10	15,771
	Michael Begel	0.05	12,652	0.05	13,041	0.05	13,442
	Elke Aschenauer	0.05	15,185	0.05	15,652	0.05	16,134
	TBD Elec Engineer	0.20	29,689	0.15	22,951	0.15	23,657
	TBD Sci1	0.32	55,519	0.25	44,946	0.20	38,283
		1.07	183,518	0.95	169,230	0.90	166,389

Instrumentation Recharge Labor (on 201)	
S. Zohar	0.20
G Carini	0.05
Giacomini	0.05