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

PRINCIPAL INVESTIGATOR	**Kevin Brown**	**PHONE**	**4409**
DEPARTMENT/DIVISION	**NPP/C-AD and ATRO/AF**	**DATE**	**6/17/2021**
OTHER INVESTIGATORS	**Stephen Brooks, George Mahler, François Meot, Mark Palmer (ATRO), Stephen Peggs, Deepak Raparia, Zhi Zhao, Sandra Biedron (Univ. NM), Salvador Sosa Guitron (Univ. NM)**		
TITLE OF PROPOSAL **TYPE A**	**3D laser cooling of low energy ions for ultra-low emittance beams**		
PROPOSAL TERM (month/year)	From **10/1/2021**	Through **9/30/2024**	

SUMMARY OF PROPOSAL

Description of Project:
We seek to develop a new method of 3D laser cooling of low energy ions. Such beams can be used as probes to better understand space charge phenomena [1], residual gas interactions, emittance growth through the acceleration process, intra-beam scattering phenomena, and the creation of crystalline beams. Crystalline beams, when cooled sufficiently using laser cooling techniques, will form ion Coulomb crystals. In this regime, thermal vibrations are small enough to distinguish the external quantum modes of the crystalline structure and to minimize any micromotion from the rf confining the ions. These external quantum modes are key to establishing entanglement between ions and forming quantum gates used for quantum algorithms. Simultaneously confining and 3D laser cooling using an electrostatic wiggler is a novel approach that could be developed first at BNL.

This proposal aligns with the BNL and NPP strategic long-term plans and DOE mission by aiming to develop higher quality beams and improving our understanding of complex beam dynamics in developing low emittance, high brightness beams. This work potentially benefits EIC, NASA Space Radiation Laboratory (NSRL), and is a key technological component to storage ring-based quantum computer (SRQC).

Expected Results:
The end-product of this project is a prototype for a new device, including the expected ranges of key performance parameters, a projected cost estimate and schedule to build and install such a device, and an analysis of how small emittance probes can help improve our understanding of the beam dynamics in the chain of accelerators that pre-accelerate beams for RHIC and eventually the EIC. The prototype will also explore potential methods for measuring the 6D emittance/temperature reduction of the beam. Various methods can be employed to measure the momentum spread, transverse beam sizes, different plasma parameters (e.g., comparing mean kinetic energy to mean particle distances), and low intensities using sensitive imaging techniques. These studies will help in our understanding of how to make brighter low energy beams.

These studies will benefit development of ion Coulomb crystals (i.e., crystalline beams) for quantum information systems. The techniques developed in this project will directly be applicable in the SRQC system [2].

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

PROPOSAL

Creating brighter particle beams is a never-ending endeavor in the study of particle beam dynamics. The benefits are multifold, increasing luminosity from colliding beams, reducing losses in the beam transport, and even making accelerators less expensive by reducing the aperture of the beam pipe and magnet gaps, given smaller beams can be created. Since the beams are generated in ion sources that exploit some high temperature process (hot cathodes or ablation plasmas), the beam sizes are correspondingly large with low densities. The only way to make the beams smaller and denser is to reduce the temperature of the beams. This is a primary motivation of this work. Understanding how to cool ions at low energies and studying the space charge forces, residual gas interactions, and other diffusion processes that tend to prevent the creation of brighter beams at low energies will inform future efforts to improve the quality and brightness of particle beams. This ultimately could benefit the EIC and other programs, such as the NSRL by producing higher quality, cleaner, and more dense beams. This work is of general interest in particle beam dynamics where 3D cooling is an active area of research. It is also of great interest in learning how to create ultra-low temperature beams to create ion Coulomb crystals, or crystalline beams, that can be used in quantum computing. An RFQ electrostatic wiggler could provide 3D cooling that would enable exploration of high-density beams and be an important innovation to the SRQC.

Minimizing the growth of the beam emittance through the injector chain of accelerators is a challenging and poorly understood set of processes. At low energy the emittance growth can be caused by space charge, residual gas interactions, and heating from non-adiabatic processes (e.g., RF noise). Space charge compensation systems are complex and can only reduce the growth. To reduce the emittance the temperature of the beam needs to be reduced. Emittance at the ion source is limited by the plasma temperature and, in EBIS, the field in the solenoidal trap. Given that the plasma is created by direct heating of some material (e.g., laser ablation), the temperatures can be quite high. To experimentally study processes with ultra-low emittance beams the temperature of the beams needs to be reduced. Collimation of the ion beams will reduce the beam size but not increase the density.

Space charge growth is very strong at low energies.

$$\frac{\epsilon_f}{\epsilon_i} \propto \left[1 + q^2 \frac{\mathcal{C}\cdot N}{\gamma^3 mc^2 \epsilon_i^2}\right]^{\frac{1}{2}},$$

where at low energies the relativistic factor, γ, is effectively one. Here, q is the charge, N is the number of particles in the beam, ϵ_i is the initial emittance, ϵ_f is the final emittance, and m is the particle mass, and the parameter, $\mathcal{C}$, contains scaling and geometric constants. To overcome space charge requires strong focusing. Space charge and compensation schemes can be nonlinear. Experimental studies using lower emittance, higher particle density beams can be useful for comparing to theory and simulations.

One process, for example, that could be studied with ultra-low emittance beams is the residual gas interaction cross section. As the temperature of the beam becomes smaller, the beam size and angular spread of the ions becomes smaller. How do the elastic and inelastic interactions change? If the ions become ordered and form a crystal, they no longer interact with other ions except their nearest neighbors in the crystal structure. How does this effect the single and multiple Coulomb interaction cross sections? Another interesting process that could be studied, if ions are cooled before injection into the EBIS trap solenoid, is the electron impact ionization rates. Can we find ways to preserve the small emittance until γ is large enough to reduce the space charge growth? Without a way of cooling the low energy ions we have no way to experimentally explore these questions.

Doppler laser cooling uses the resonant force coherent light exerts on atomic two-level systems in repeated absorption and spontaneous emission. The absorption changes the momentum of the atomic system by the photon momentum $\hbar\vec{k}$, for wavenumber k, while the recoil momentum from the spontaneous emission averages out in many cycles. The random character of the recoil photon emission limits the attainable temperatures, T_D. Generally, $k_B T_D = \hbar\Gamma/2$, where Γ is natural line width, or inverse of the decay rate. For ions traveling with some non-zero velocity, the longitudinal velocity components are readily accessible using lasers that provide beams that are parallel with the velocity of the ions. Longitudinal cooling is therefore relatively straight forward.

Intensity effects on the effectiveness of Doppler cooling of low energy beams have been studied theoretically [3], but experimental studies are limited. Laser cooling of bunched beams did explore limits in bunch length versus intensity [4]. Laser detuning needs to be scanned, even beyond the optimum detuning. This is a topic to explore further. For the low energy beams, space charge does not heat the beams but influences the particle trajectories. Intrabeam scattering (IBS) is a diffusion process and causes heating of the beam. It will therefore set a limit to the cooling (will counteract the cooling process as temperature decreases) as a function of intensity and rms momentum spread.

The main difficulty with transverse cooling for a non-stationary beam is the transverse velocity components are not easily accessible. To expose them requires adding some method of kicking the ions tangentially, as in sympathetic cooling, electron cooling, or even stochastic cooling, or finding a way to expose the transverse components to a longitudinal laser pulse. Applying a laser pulse tangentially, as in 3D sideband cooling, is difficult because the ions are flying past the laser pulse and only get exposed for a very short time. We would employ the well-established technique of Doppler laser cooling for free ions using two counter-propagating laser beams that are parallel to the forward motion of the ions. In this process photons excite transitions that bring the ion's internal state back to the ground state. With continued excitations, on average the spread in velocity distributions are reduced. An example of exposing the transverse velocity components to the axial laser beam is shown in Fig. 1. Here the ions are placed onto a helical path, exposing the transverse components by an angle α.

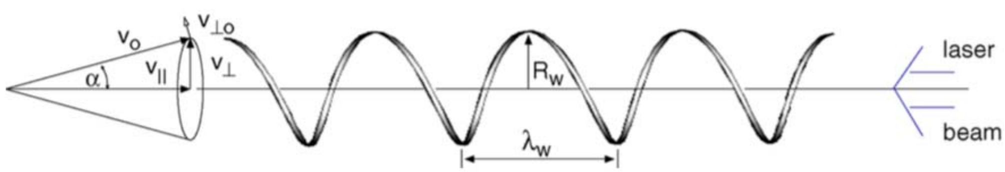

Figure 1- Exposing transverse velocity components to the longitudinal cooling lasers. (from ref. [5])

There are a couple of ways to do this. A solenoid will put the beams into such a trajectory but may only be able to achieve small angles. A helical wiggler can achieve larger angles. Such a device bends the ion beam onto a helical path with constant tilt angle as sketched in Fig. 1. It usually consists of a series of strong dipole magnets (field B_0), perpendicular to the beam axis which rotate around this axis with a (mechanically) given pitch λ_w. The radius of the helix R_w is given as a function of the dipole bending radius R_B

$$R_w = \frac{(\lambda_w/2\pi)^2}{R_B}$$

where $R_B = \gamma m v_{||} / eqB_0$ (see diagram for meaning of symbols). Here, eq is the charge and γ the relativistic factor.

As an example, consider the properties of a helical wiggler suitable for transverse laser cooling of a $^9Be^+$ beam at a velocity of $\beta = 0.041$. For a magnetic field strength of $B_0 = 0.5T$, and a mechanically defined pitch of $\lambda_w \approx 0.25\ m$, the radius of the helical trajectory amounts to $R_w \approx 0.7\ mm$. The angle α between the initial direction of the ion motion and the actual direction inside the wiggler amounts to $\tan \alpha = v_\perp/v_{||} \sim v_\perp/v_0 \approx 2\pi R_w/\lambda_w \approx 0.018$. The direction of the initially transverse thermal motion ($v_{\perp 0} \approx 1500\ m/s$, which corresponds to an initial transverse temperature of $T_\perp = 1200\ K$) is consequently tilted with the same constant angle α. Inside the wiggler, the fraction $(v_{\perp 0})_{||} = v_{\perp 0} \sin \alpha \approx 30\ m/s$ of the random transverse motion is projected into the longitudinal direction and can be reduced by the longitudinal laser force according to $\Lambda_\perp \approx \alpha \Lambda_c$, where Λ_c is the longitudinal cooling rate, and $T_\perp \approx T_{min}/\alpha^2$, where T_{min} denotes the minimum temperature achievable with laser cooling. Optimistically assuming the efficient reduction of $(v_{\perp 0})_{||}$ to 1-m/s, the overall transverse thermal velocity can be reduced to $v_{\perp 0} \approx 30 m/s$, which corresponds to a transverse temperature of the order of 0.5 K. The longitudinal velocity is reduced by $v_0(1\text{-}\cos\alpha) \approx 2000\ m/s$ inside the wiggler. Thus, the frequency of the additional cooling laser beam has to be tuned into resonance with this shifted velocity, while the frequency of the original laser beam addresses the resonance outside the wiggler.

In the electrostatic wiggler, possibly as part of a Circular Radio-Frequency Quadrupole (CRFQ), we will investigate using the drift tubes to act as a wiggler in a straight section. This would avoid having to add magnetic elements to the structure. This means we need to study the design of the drift tubes systematically and with precision. A preliminary look at this suggests we can achieve a $\lambda_w \approx 0.02\ m$ with fairly large α. A simple layout is shown in figure 2, with a cross section of the RFQ shown in figure 3, and a simplified calculation of the equilibrium orbit and ion axis rotation angle are shown in figure 4. These are naïve calculations that are just meant to demonstrate how such a device might perform.

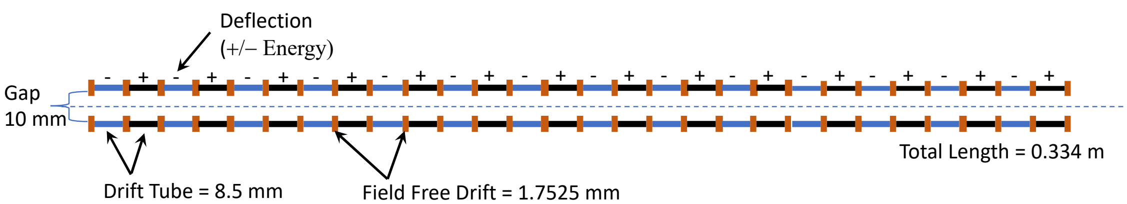

Figure 2 - Cartoon layout of a simple electrostatic wiggler. This device is contained in an RFQ for beam confinement.

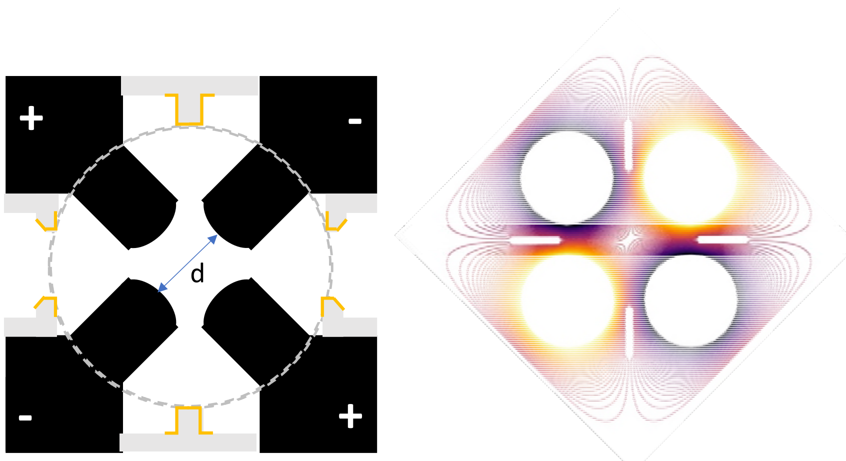

Figure 3 - Cross section of the RFQ on the left. The diameter will be on the order of 10 mm. The yellow structures on the gray ceramic holders are electrodes for exciting transverse or longitudinal motion of the ions. On the right is an example of using VSim™ to model the IBEX Paul Trap at Oxford, showing addition of octupole field components (from IPAC 2021 Poster, TUPAB234, "Exploring Accelerators for Intense Beams with the IBEX Paul Trap", Jake Flowerdew).

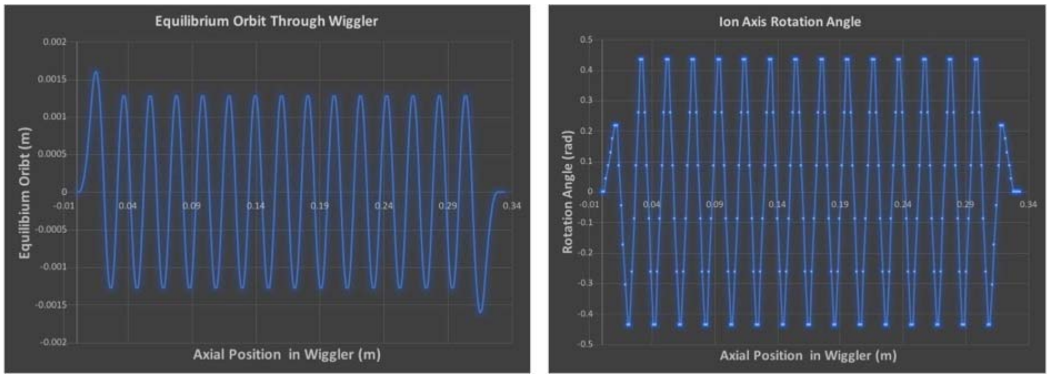

Figure 4 - Simple example to demonstrate the concept.

To measure the effectiveness of the cooling, simple measures of changes in the beam sizes can be made. A longitudinal distribution can be derived using Faraday Cups. Transverse beam sizes can be measured using slits or scraping or even using pepper pots, perhaps. Measuring ion fluorescence would require lasers to excite and scatter light and camera systems to image the ions. This will be investigated.

We feel it is important to point out that laser cooling can be applied to higher energy beams, where the counter force to the laser can come from an RF potential. Such a technique was explored at GSI [6]. The techniques developed in this proposal could be translated and developed further to cool beams in the AGS Booster and possibly in the AGS, potentially providing brighter beams for the EIC.

High Level Deliverables:

1. design for a new device, including the expected ranges of key performance parameters
2. build a prototype of such a device for purpose of proof of principle
3. analysis of how small emittance probes can help improve our understanding of the beam dynamics
4. analysis of potential methods for measuring the 6D emittance/temperature reduction of the beam

Materials List:

1. simple radio frequency quadrupole (RFQ)
    a. aluminum rails/electrodes
    b. ceramic holders
    c. supports and interconnects
    d. electrode plating on ceramic holders (6, 8.5 mm long per section, sections separated by 1.75 mm), the electrodes will act to create wigger helical trajectory [figures 2, 3, & 4]
    e. vacuum vessel, feedthroughs, and windows
    f. potentially include two end electrodes to contain ions for longer than single pass
2. vacuum pumps and monitoring
3. resonant RF power supply for RFQ
4. DC HV power supplies (100 – 200 volt) for electrodes. Likely need at least 3 PSs
5. 2 - CW tunable diode lasers (wavelength TBD) supports and any optics
6. Source of ions (test EBIS?)
7. Faraday cup to measure #ions and longitudinal profile
8. Scanning slit, pepper pot, or other method to measure transverse profile
9. Camera system to measure ion fluorescence (option)

Project Plan:

The basic project plan follows the schedule show below to meet the high-level deliverables. Since this is a new concept, many details need to be studied. The final goal is to develop a prototype device that can be tested and fine-tuned and then deployed for beam experiments.

	Duration*	Year 1				Year 2				Year 3			
Activity	[Months]	1	2	3	4	1	2	3	4	1	2	3	4
Theoretical work and Calculations	18												
Preliminary parameters & goals defined	1												
Preliminary Physics Design	1												
(C)RFQ characteristics	1												
First RF field simulations	3												
First particle tracking simulations	3												
Preliminary cooling simulation	3												
Beam injection design and simulation	1												
Beam ejection design and simulation	1												
acceptance model	1												
improved 3D rf fields simulation	4												
drift tube design	3												
wiggler configurations	3												
use 3D rf fields for particle tracking model	4												
laser cooling in Vsim	4												
improve rf model to include drift tubes	4												
review/critique design concept	1												
document/publish design/simulations	1												
Engineering Design	21												
Physics Design parameters finalized	1												
Vacuum vessel design requirements	1												
vacuum design	2												
purchase vacuum components	1												
Develop ceramic holders and (C)RFQ design	2												
Develop drift tube designs	2												
purchase long lead items (materials for RFQ)	1												
preliminary instrumentation requirements	1												
Develop specifications for instrumentation	2												
Orbit correction algorithms (wiggler)	2												
Develop specifiications for rf power supply	1												
purchase rf power supplies	1												
Develop specifications for laser cooling	2												
Laser Cooling systems Design	2												
purchase laser system parts	1												
Develop design of camera/floresence detector	2												
Review cost estimate to build	1												
document/publish design	1												
Build device, test, measure, experiments	21												
Develop measurement program	1												
Purchase final materials	1												
Fabrication & Assembly	4												
Vacuum vessel material and fabrication	2												
PS acceptance & integration	2												
Faraday cup & Instrumentation	3												
Cables, enclosures, etc.	3												
Integration and testing with CRFQ	1												
Field measurements	2												
purchase final laser system parts	1												
purchase camera systems	1												
build enclosures for lasers	2												
build ion injection systems	2												
Vacuum tests	1												
HV Feedthrough tests	1												
PS test on actual load & any RF Conditioning	1												
Beam Experiments plan	1												
obtain approval to run with beams (Safety review)	2												
begin beam tests	1												
demonstrate basic cooling	6												
document/publish	2												
	* Note: Not full time effort												

Figure 5 - Outline of draft schedule. Details can change based on progress.

References

[1] ICFA Beam Dynamics Panel Newsletter, 2020 JINST 15, https://iopscience.iop.org/journal/1748-0221/page/ICFA_Beam_Dynamics_Panel_Newsletters_Special_issue

[2] K.A. Brown and T. Roser, *Towards storage rings as quantum computers*, Phys. Rev. Accel. Beams 23, 054701 (2020) Published 13 May 2020, K.A. Brown and T. Roser, U.S. Patent Application Serial No. 16/864,332.

[3] Lewin Eidam, Oliver Boine-Frankenheim, Danyal Winters, *Cooling rates and intensity limitations for laser-cooled ions at relativistic energies*, Nuclear Inst. and Methods in Physics Research, A 887 (2018) 102–113

[4] J.S.Hangst, J.S.Nielsen, O. Poulsen, P. Shi, and J.P. Schiffer, *Laser Cooling of a Bunched Beam in a Synchrotron Storage Ring*, Phys. Rev. Letters, 74:22, 4432-4435, (29 May 1995)

[5] U. Schramm and D. Habs, *Crystalline ion beams*, Progress in Particle and Nuclear Physics, V. 53 583-677 (2004)

[6] D. Winters, et al., *Laser cooling of relativistic heavy-ion beams for FAIR*, Phys. Scr. T166 (2015) 014048, https://doi.org/10.1088/0031-8949/2015/T166/014048

ONE-PAGE VITA FOR EACH INVESTIGATOR
Kevin A. Brown, Physicist

Education and Training:
B.S. Physics, June 1983
Earth and Space Science (double major),
SUNY at Stony Brook, NY

M.S. Computer Science, December 2000
SUNY at Stony Brook, NY
Research Advisor: Prof. Tzi-cker Chiueh

Research and Professional Experience:

Brookhaven National Laboratory - Collider-Accelerator Department

Manager III / Physicist	2014 - present
Physicist	2003 - 2014
Physics Associate I	1996 - 2003
Project Engineer II	1988 –1995
Staff Engineer	1984 - 1987
Guest Research Assistant (Univ. of Michigan)	1983 - 1984

Supervisory Experience
Head of C-AD Controls Systems Groups, 6/30/2009 - present

Professional Outreach and Professional Society Service

Conference Chair, ICALEPCS 2019 New York, NY	2019
International Organizing Committee, ICFA Workshop on Slow Extraction, FNAL (July)	2019
International Organizing Committee, ICFA Workshop on Machine Learning, Paul Scherrer Institute	2019
International Organizing Committee, ICFA Workshop on Slow Extraction, CERN (November)	2017
International Executive Committee Member, ICALEPCS 2017 Barcelona, Spain	
International Scientific Committee Member, ICALEPCS 2015 Melbourne, Australia	2014
Co-Editor PAC 2011 New York, NY	2011
Organizing & Scientific Chair 14th ICFA mini-workshop on Septa Devices in Accelerators BNL, Upton, NY	2005
Organizing & Scientific Chair 10th ICFA mini-workshop on Slow Extraction BNL, Upton, NY	2002

Committee Service
Committee member, LLNL Computational Directorate review, August 28-30, 2018
Chair of Fermilab Mu2e Accelerator Oversight Committee, September 2015 - 2020
Chair of Fermilab Mu2e Experiment Directors Review Committee, FNAL, August 2015
Member of Fermilab Mu2e Experiment Directors Review Committee, FNAL, May 2011 and April 2012

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

Dr. Stephen J. Brooks
Brookhaven National Laboratory, Collider-Accelerator Department, Building #911B,
Upton, NY 11973-5000 631-344-8844 sbrooks@bnl.gov

Education

D.Phil.	Particle Physics, 2010 (University of Oxford)
M.Math.	Mathematics, 2003 (University of Oxford)
B.Sc.	Mostly Applied Mathematics, 2001 (The Open University)

Employment History

Physicist (C-AD, BNL) 10/1/2017 – present
Magnetic calculations and tuning for the production run of permanent magnets for the CBETA accelerator during 2018. Future: design of permanent magnet accelerators for other applications.

Associate Physicist (C-AD, BNL) 10/2015 – 09/2017
Magnet cell design and field-map tracking simulation for the CBETA multi-pass energy recovery linac being built at Cornell. Construction of a series of 12 novel Halbach-derived magnets using 3D printed moulds and a new shimming technique to achieve accelerator-level field quality at low cost. Application of these magnet types to the CBETA machine and construction of a small prototype FFAG arc test at the BNL Accelerator Test Facility.

Assistant Physicist (C-AD, BNL) 10/2013 – 09/2015
Design and simulation of BNL's proposed eRHIC particle accelerator and related prototype accelerators and magnets. First ever beam dynamics studies for a new sort of "3D" cyclotron.

Accelerator Physicist (Rutherford Appleton Laboratory) 09/2003 – 10/2013
Research topics included: beam dynamics and magnetic field simulations in FFAG (fixed-field) particle accelerators; heat deposition and yield of particle beam targets. Previously worked on the Neutrino Factory "muon front end" design, including setting up a public distributed computing project to run the simulations and optimise the design automatically.

Associate Lecturer in Physics (The Open University) 2007 - 2009
Tutored the course "S357: Space Time and Cosmology" for two years at distance learning university, with ~20 students. Syllabus included classical mechanics, special and general relativity and cosmology.

Vacation Studentships (Rutherford Appleton Laboratory) Summer 2000 – Easter 2003
Developed graphics for interactive particle beam transport simulations.

Research and Professional Accomplishments
From 2009-2014, performed the first computer simulations of fixed-field accelerators with vertical orbit excursion, including an invited talk at the IPAC'14 conference. Another invited talk was at the IPAC'18 conference. During the summer of 2017, built and demonstrated the highest ever energy range in a "non-scaling" fixed-field accelerator (a factor of 3.8), using beam from ATF-1 and magnets from CBETA R&D. Reviewer of 4 papers for Physical Review Accelerators and Beams, and 1 paper in Physical Review Applied.

Other Skills
Physics: research topics above, plus experience with the MARS target simulation code and Poisson/Superfish magnet design code.
Computing: C/C++, scientific and numerical computing, Windows and Linux platforms, OpenGL computer graphics, PHP, website design, distributed computing, software GUI, interactive animation.

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

George Mahler, Mechanical Engineer

Education and Training:

George J. Mahler earned a Bachelor of Engineering in Mechanical Engineering from SUNY Stony Brook in 1991, a Master of Science in Nuclear Engineering from Manhattan College in 1994 and has been a New York State Licensed Professional Engineer since 1997. George J. Mahler is a mechanical engineer providing support to a variety of particle accelerator related projects as well as independent Brookhaven National Laboratory research projects. Following are some work-related links:

Research and Professional Experience:

- Portable Gamma-Ray Spectrometer, Using Compressed Xenon: Designed and developed all mechanical components. This high-pressure ionization chamber was built to ASME standards, as was the ultra-pure gas filling system. https://ieeexplore.ieee.org/document/682701
- Los Alamos High Precision Neutron Detector: Contributed all mechanical engineering support for the development, construction, assembly, and installation of this detector. https://www.sciencedirect.com/science/article/pii/S0168900201017879?via%3Dihub
- RHIC Polarized Atomic Hydrogen Jet: Lead mechanical engineer in the design, construction, installation and maintenance. This RHIC beam line diagnostic component has been operational since 2005. http://cerncourier.com/cws/article/cern/29436
- SNS Ring Magnets and Stands: Design, development, and assembly of mechanical components and magnetic elements. These warm bore magnets had been successfully delivered, installed and are in operation at the Oak Ridge National Laboratory Spallation Neutron Source.
- Proxiscan Compact Gamma Camera for Prostate Cancer Detection: Engineering support for this device from concept to completion. Device received FDA approval and was awarded the 2009 R&D 100 award. http://www.youtube.com/watch?v=B7P4eKE1c-Y
- Energy Recovery Linac magnets and transport line: Provided engineering support and design of magnets, stands, and transport lines for ERL. This facility is to be a coherent electron cooling proof of principle. http://www.c-ad.bnl.gov/ardd/ecooling/ERL_home.htm
- MicroBoone Time Projection Chamber: Mechanical engineer, draftsman, and construction technician of all mechanical components for detector installed at Fermi National Laboratory.https://www-microboone.fnal.gov/public/aboutdetector.html
- ANSTO Neutron Detector: Mechanical engineering and design of detector assembly to be installed at Australian Nuclear Science and Technology Organization. https://teamsites.bnl.gov/sites/ANSTO/SitePages/Home.aspx
- Coherent Electron Cooling magnets and beamline: Provided engineering support and design of magnets, stands, and transport lines for the Coherent Electron Cooling project installed at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory.
- Low Energy Electron Cooling magnets and beamline: Provided engineering support and design of magnets, stands, and transport lines for the Low Energy electron Cooling project installed at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory.
- Cbeta magnets: Provided engineering and construction support for the Halbach magnet assemblies used in a FFAG ring installed at Cornell University. https://www.classe.cornell.edu/Research/ERL/CBETA.html
- ATF magnets: Provided engineering and construction support for the Halbach magnet assemblies used in a FFAG transport line installed at Brookhaven National Laboratory.

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

François Méot, Physicist

Education and Training:

PhD in accelerator physics, CERN, 1979-1981
"Habilitation a diriger des recherches", Grenoble Polytechnic Institute, 1998
"Qualified Professorship of the French Universities", a National degree, 2003
Former accelerator physicist at CEA Saclay, 1982-2010, now on long-term leave
Former director of the European "Joint Universities Accelerator School", Geneva County, France, 2005-2010

Research and Professional Experience:

09/2010 – present	Accelerator Physicist, Brookhaven National Laboratory
	Adjunct Professor, Physics & Astronomy, Stony Brook, NYU
02/1982 – 08/2010	Accelerator Physicist, Commissariat à l'Énergie Atomique, Saclay

Publications:

Over 250 publications, as a main author for the essential, in peer-reviewed journals (40+), CERN yellow reports, conference proceedings, lab reports.

Lately (http://www.icfa-bd.org/Newsletter76.pdf): pp. 110-131, pp. 163-174, pp. 196-205.

Synergistic Activities:

RHIC, EIC (eRHIC and JLEIC), CBETA, iRCMS, diverse workshop and conference committees

Participate(d) in several international conference and workshop organizing committees

Scientific research responsibilities in several French and European program funded projects, 2000-2010, including the ANR RACCAM proton-therapy project (2005-2010), the ETOILE collaboration (2000-2010), the EU collaboration in the Neutrino Factory (2005-2009)

Referee for various journals and editions (Physical Review, PRAB, RAST, NIM A, Springer, etc.)

Fifteen years of teaching in French universities (math and physics), 1986-2005

Supervised about 30 students over 1982-present, from undergraduate to post-doctorate

Member of the APS

Identification of Potential Conflicts of Interest or Bias in Selection of Reviewers:

None

Collaborators and Co-editors:

Binping Xiao, S. Belomestnykh, J. M. Brennan, J. C. Brutus, G. McIntyre, K. Mernick, C. Pai, K. Smith, T. Xin, A. Zaltsman, and V. Veshcherevich

Graduate and Postdoctoral Advisors and Advisees:

Graduate: Prof. Germain Chartier

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

VITA
Mark Palmer, ATF Director, ASTI Director

Professional Preparation:

Princeton University	Physics	A.B. (*summa cum laude)*	1986
Princeton University	Physics	M.A.	1989
Princeton University	Physics	Ph.D. (Advisor: Val Fitch)	1993
University of Illinois (UIUC)	Particle Physics	Post-Doctoral Research Associate	1993-1996

Appointments:

Brookhaven National Laboratory	Senior Scientist	2016-
Fermi National Accelerator Laboratory	Scientist II	2012-2016
Cornell University – Lab. for Elementary Particle Physics	Senior Research Associate	2010-2012
	Research Associate	2000-2010
University of Illinois at Urbana-Champaign (CLEO Exp.)	Research Asst. Professor	1999-2000
	Visiting Research Asst. Prof.	1996-1999
	Research Associate	1993-1996
Cornell University	Wilson Fellow	1994-2000
Princeton University	NSF Fellow	1987-1989
Rijksuniversiteit Groningen, Netherlands	Fulbright Fellow	1986-1987

Professional Activities, Collaborations and Affiliations:

Assistant Deputy Director for Accelerator Science & Technology, BNL	2018-
Director, BNL Accelerator Test Facility	2016-
Director, U.S. Muon Accelerator Program	2012-2017
Fermilab Muon Accelerator R&D Department Head	2012-2016
CESR Test Accelerator (CESRTA) Project Director	2007-2012
Member and co-leader (TDR phase) of the ILC Damping Rings Area Group	2005-2012
Cornell Electron Storage Ring (CESR) Operations Group	2000-2012
CLEO Run Manager	1997-1998
CLEO Collaboration	1993-2000

European Accelerator R&D Roadmap – Deputy Head, Muon Beams Panel	2021
SC User Facilities Roundtable Panelist	2020
Member of LaserNetUS Scientific Advisory Board	2019-present
Member 2017 Cohort of the DOE Project Leadership Institute	2017
Member of the U.S. Magnet Development Program Technical Advisory Committee	2017-present
Member of the eRHIC Program Steering Group	2016-2019
Laboratory Operations Supervisor Academy, Battelle Memorial Institute	2016
Vice-Chair and Chair APS Robert R. Wilson Prize Committee	2015-2016
Strategic Business Leadership Program, University of Chicago Booth School of Business	2015
Strategic Laboratory Leadership Program, University of Chicago Booth School of Business	2014
Member NA-PAC`13 Scientific Program Committee, IPAC`14/`15/`18 Scientific Advisory Boards and NA-PAC`16 Program Coordinating Committee	2013-2018
Reviewer for DOE OPA and Programmatic Reviews	2013-present
Member of the ILC Project Advisory Committee	2013-15
Co-convener of the Capabilities Frontier: Lepton Collider Sub-Group for CSS2013	2012-2013
Member of the APS Division of Physics of Beams Nominating Committee	2010-2011
Member of the ICFA Beam Dynamics Panel	2009-present
Lecturer at the 3rd, 5th and 7th International Schools for Linear Colliders	2008,10,12
International Linear Collider Design Team (Management and Committee Duties)	2006-2012
CESR Operations Group Upgrade Activities (4 major projects)	2001-2008
Wilson Lab NSF REU Program Mentor and Outreach Contributor	1997-2012
Member of the CLEO II.V Silicon Vertex Detector and Tracking Groups	1993-2000

Member of the American Physical Society (DPB, DPF, DPP)
Member of IEEE (NPSS)

Recent Articles Relevant to this Proposal:

M. Boscolo, J-P. Delahaye, and M. Palmer, "The Future Prospects of Muon Colliders and Neutrino Factories," *Reviews of Accelerator Science and Technology*, Vol. 10 (2019) 189-214.
Long, K.R., Lucchesi, D., Palmer, M.A. *et al.* Muon colliders to expand frontiers of particle physics. *Nat. Phys.* (2021). https://doi.org/10.1038/s41567-020-01130-x.

June 4, 2021

CURRICULUM VITAE

Stephen Grenfell Peggs

Education	Oxford University	BA 1973	Physics
	Cornell University	PhD 1981	Accelerator Physics

Tenured accelerator physicist at Brookhaven National Laboratory.
Adjunct professor at Stony Brook University.
Fellow of the American Physical Society.

Current professional interests

Storage Rings for Quantum Computing (SRQC).
Electron-Ion Collider R&D (EIC).
BNL ion Rapid Cycling Medical Synchrotron (iRCMS).
Accelerator Driven Sub-critical Reactors (ADSR).
Accelerator design and dynamics.

Current committees and boards

Chair, BNL C-AD Scientific Appointments Committee, (2016 - present).
Lecturer, U.S. Particle Accelerator School (USPAS).

Students graduated

PhD: N. Cook (SBU), T. Satogata (Northwestern), C. Tang (SBU), J. Cardona (SBU), R. Calaga (SBU), R. Fliller (SBU), U. Iriso (U. Barcelona). **MS:** A. Warner (SBU).

Publications

Peggs & Satogata: "Introduction to Accelerator Dynamics", Oxford University Press, 2017.
List of publications available on request.

Career history

Oct 2019 - present	C-AD and EIC Accelerator Physicist, BNL
June 2016 - Sept 2019	CBETA Project Director, BNL
Jan 2015 - Sept 2016	Detailee in the DOE office of HEP, Germantown
May 2013 - Sept 2016	Hadron Therapy Group Leader, BNL
Sept 2009 - Apr 2013	Deputy Head of ESS Accelerator Division, Lund
Aug 2008 - Aug 2009	Sabbatical leave from BNL at CERN, Geneva
Sept 2004 - July 2008	LARP Program Leader, BNL/Fermilab
Oct 1999 - Aug 2004	Associate Head, Collider-Accelerator Department, BNL
Sept 1992 - Sept 1999	Head, RHIC Accelerator Physics Group, BNL
Oct 1989 - Aug 1992	Head, Accelerator Physics Department, Fermilab
Nov 1984 - Sept 1989	Accelerator Physicist, SSC CDG, Berkeley
Mar 1984 - Nov 1984	Research Associate, Cornell University
Dec 1981 - Jan 1984	CERN Fellow, Geneva
Jan 1981 - Nov 1981	Postdoctoral Physicist, Cornell University

Deepak Raparia
Brookhaven National Laboratory
Upton, NY 11986

Dr. Deepak Raparia is Head of BNL Preinjector which include 200 MeV H-linac, 2MeV/u ion injector based on EBIS and Tandem accelerators.

Dr. Raparia received a PhD in accelerator physics in1990.

Prior to the present position, Dr. Raparia served as group leader for BNL Linac and the SNS/BNL accelerator physics group and as the deputy group leader for the SNS/ORNL accelerator group.

Dr. Raparia has 40 years of experience in accelerator and his prior work include physics design of following: EBIS preinjector,superconducting linac injector for the VLBNO project at BNL, the POP H minus laser stripping experiment at 200 MeV BNL Linac, the SNS transfer lines, and injection system, the POP experiment for BNCT, The 600 MeV linac for the 5 MW Spallation Neutron source at BNL, The SSC 600 MeV linac as well as pioneering work on helical electrostatic quadrupoles for low energy beam transport, RFQ physics design for the ion implantation, and the charge exchange injections of 20, 000 turns into the TRIUMF Kaon factory.

Zhi Zhao

Education

- Ph. D, Chinese Academy of Sciences, Wuhan Institute of Phys. and Math., Physics, 2001
- MS, Central China Normal University, China, Physics, 1997
- BS, Central China Normal University, China, Physics, 1994

Research and professional experience

- Physicist (S1, S3, S4), 2015 - present
- Laser Scientist/Research Associate III and IV, Cornell University, 2009 - 2015
- Postdoctoral Research Associate, Oak Ridge National Laboratory, 2006 - 2009
- Marie Curie and Humboldt Fellow, University of Heidelberg, Germany, 2004 - 2006
- Adjunct Associate Professor, University of Sci. & Tech. of China, China, 2003 - 2006
- Postdoctoral Research Associate, Royal Institute of Technology, Sweden, 2003 - 2004
- Postdoctoral Research Associate, University of Sci. & Tech. of China, China, 2001 - 2003

Selected publications

1. Coauthor with A. V. Fedotov et al.
Experimental demonstration of hadron beam cooling using radio-frequency accelerated electron bunches
Phys. Rev. Lett. 124, 084801 (2020).
2. **Z. Zhao**, K. Mernick, M. Costanzo, and M. Minty
An ultrafast laser pulse picker technique for high-average-current high-brightness photoinjectors
Nucl. Instrum. Methods Phys. Res. Sect. A 959, 163586 (2020).
3. **Z. Zhao**, B. Sheehy, and M. Minty
Generation of 180 W average green power from a frequency doubled picosecond fiber amplifier
Optics Express 25, 8138 (2017).
4. **Z. Zhao**, A. Bartnik, F. W. Wise, I. Bazarov and B. M. Dunham
High-power fiber lasers for photocathode electron injector
Phys. Rev. ST – Accel. Beams 17, 053501(2014).
5. **Z. Zhao**, B. M. Dunham, I. V. Bazarov, and F. W. Wise
Generation of 110 W infrared and 65 W green power from a 1.3-GHz sub-picosecond fiber amplifier
Optics Express 20, 4850 (2012).
6. **Z. Zhao**, K. A. Meyer, W.B. Whitten, and R. W. Shaw
Optical absorption measurements with parametric down-converted photons
Anal. Chem. 80, 7635 (2008).
7. **Z. Zhao**, K. A. Meyer, W.B. Whitten, R. W. Shaw, R. S. Bennink, and W. P. Grice
Observation of spectral asymmetry in a cw pumped Type II spontaneous parametric down-conversion
Phys. Rev. A 77, 063828 (2008).
8. **Z. Zhao**, A.N. Zhang, X. Zhou, Y.A. Chen, A. Karlsson, and J.W. Pan
Experimental realization of optimal asymmetrical cloning and telecloning via partial teleportation
Phys. Rev. Lett. **95**, 030502 (2005).
9. **Z. Zhao**, A.N. Zhang, Y.A. Chen, H. Zhang, J. Du, T. Yang, and J.W. Pan
Experimental demonstration of nondestructive controlled-NOT gate for two independent photon qubits
Phys. Rev. Lett. 94, 030501 (2005).
10. **Z. Zhao**, Y.A. Chen, A.N. Zhang, T. Yang, H. J. Briegel, and J.W. Pan
Experimental demonstration of five-photon entanglement and open-destination teleportation
Nature 430, 54 (2004).

Synergistic Activities

Program committee for Quantum Communication and Quantum Imaging, SPIE Optics & Photonics Conference, 2006 – 2011

Referee for Physical Review Letters, Physical Review A, Optics Letters, Optics Express, Applied Optics, Applied Physics B: Lasers and Optics, and Optics & Laser Technology

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

Sandra Gail Biedron, Ph.D.
Departments of Electrical and Computer Engineering and Mechanical Engineering
University of New Mexico
708 638 6813 (m), biedron@unm.edu

(a) Professional Preparation

Trinity Christian College, Illinois Chemistry and Biology, Minor Math	B.A.	1994
Lund University, Sweden Accelerator Physics	Ph.D.	2001

(b) Professional Appointments

2017-Present Research Professor of ECE and Mechanical Engineering, University of New Mexico
IEEE Nuclear and Plasma Sciences Society (NPSS) Particle Accelerator Science and Technology Award, Citation: "For broad impact in accelerator science and technology." Awarded May 2018.

2017-Present Affiliate Professor of Electrical & Computer Engineering, Colorado State University

2017-Present Affiliate Professor, Department of Environmental and Radiological Health Sciences, College of Veterinary Medicine, Colorado State University

2002-Present Technology and Management Consultant - Clients include DOE labs, DOD, Sinctrotrone Trieste, and EEI Power Electronics

2011-2017 Associate Professor of Electrical & Computer Engineering, Colorado State University
2011-2014 Served as Deputy Integrated Project Team Lead for Integration and Test *for the Boeing management team (under contract) for a weapons demonstrator for the Office of Naval Research*
2013 - Fellow, American Physical Society (APS) *For her fundamental advancement of light sources, including the control of light and harmonic light generated from coherent electron beams and the development of high-power long wavelength sources.*
2013 - George T. Abell Outstanding Mid-Career Faculty Award, *College of Engineering, Colorado State University.*
2012 - Fellow, SPIE (The International Society for Optics and Photonics) *For achievements in detection systems and sensors, and nonlinear harmonic emission in high-gain harmonic generation free-electron lasers.*

2016-2017 Associate Professor, Department of Environmental and Radiological Health Sciences, College of Veterinary Medicine, Colorado State University

2005-2011 Director and Physicist, Department of Defense Project Office, Argonne National Laboratory (ANL) and Associate Director, Argonne Accelerator Institute
2010 – Letter of Commendation from the Chief of Naval Research

2007-2011 Technology and Management Consultant, FERMI@Elettra Project, Trieste, Italy

2007-2012 Honorary Senior Research Fellow, Faculty of Physics, Monash University

2006-2011 Visiting Researcher, Electrical & Computer Engineering, University of Maryland

2003-2005 Applied Physicist and Project Manager, Member of the Applied Science and Technology and National Security Associate Laboratory Directorship, ANL

1992-2003 Physicist, Member of the Administration of the XFD at the Advanced Photon Source, ANL;1998-2000 Chief of Operations of Accelerator Research and Development and Member of the Main Control Room Operations Group at the Advanced Photon Source, Accelerator Operations Division, ANL; 1997-2003 Member of the Accelerator Physics Group, MAX-Laboratory, Sweden; 1995-1998; Member of the Accelerator Physics Group, Advanced Photon Source, ANL; 1995-1996 Database assistance for experimental data (35,000 data tapes) and a run-time logbook using Oracle. Experiment 871, Fermi National Accelerator Laboratory; 1993-1995 Analytical Chemist Scientific Associate, Energy Systems, ANL

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

Salvador Sosa Guitron, Ph.D. – 510 604 0869 (m), salvadorsg@unm.edu
Postdoctoral Fellow at Electrical and Computer Engineering and Mechanical Engineering, UNM
(Elevation to Research Scholar planned July 2020)

Education and Training

Benemerita Universidad Autonoma de Puebla, Physics	B.S.	2012
Old Dominion University, Physics	M.S.	2014
Old Dominion University, Accelerator Physics	Ph.D.	2018
US Particle Accelerator School, University of New Mexico		2019
US Particle Accelerator School, Rutgers University		2015
US Particle Accelerator School, Old Dominion University		2015
US Particle Accelerator School, University of Texas, Austin		2012

Research and Professional Experience

2019-Present Postdoctoral Fellow at ECE, the University of New Mexico
2012-2018 Graduate Research Assistant, Old Dominion University

Related papers **1)** S. Smith, S. Biedron, T. Bolin, S. Sosa et al. "*3D Electromagnetic/PIC Simulations for a Novel RFQ/RFI Linac Design*", in Proceedings of the International Particle Accelerator Conference 2019: MOPTS118, Melbourne, Australia; **2)** S. Smith, S. Biedron, T. Bolin, S. Sosa et al. "*Exploration of high-gradient structures for 4th generation light sources*", in Proceedings of the International Particle Accelerator Conference 2019: MOPTS117, Melbourne, Australia; **3)** S. Sosa, R. Li, H. Park, S. De Silva, V. Morozov and J. Delayen, "*Coupled Bunch Instability from JLEIC Crab Cavity Higher Order Modes*", in Proceedings of the International Particle Accelerator Conference 2018: THPAK070, Vancouver, BC, Canada; **4)** S. Sosa, V. Morozov and J. Delayen, "*Modeling local crabbing dynamics in the JLEIC ion collider ring*", in Proceedings of the International Particle Accelerator Conference 2017: WEPIK043, Copenhagen, Denmark; **5)** S. Sosa, V. Morozov, S. De Silva and J. Delayen, "*Effects of crab cavity multipoles on JLEIC ion ring dynamic aperture*", in Proceedings of the International Particle Accelerator Conference 2017: WEPIK044, Copenhagen, Denmark; **6)** S. Sosa, G. Eremeev, J.Delayen et. al. "*Measurements of RF properties of thin film Nb_3Sn superconducting multilayers using a calorimetric technique*", in Proceedings of the International Conference on RF Superconductivity 2015: TUPB060, Whistler, BC, Canada.

Synergistic Activities – **1. Professional Societies** APS Member; IEEE Member; founding member of the Mexican Community for Particle Accelerators; **2. Contributor** AI for Science Report, 2019 https://www.anl.gov/ai-for-science-report . **3. Education.** Organizer of the 2nd Mexican Accelerator School (MePAS) in Guanajuato, Mexico 2015.

Potential Conflicts of Interest or Bias: Collaborators and Co-Editors –A. Aslam (University of New Mexico); S. G. Biedron (University of New Mexico); T. Bolin (University of New Mexico); J. Cary (Tech-X); M. Curtin (Ion Linac Systems); J. D. Cruz (University of New Mexico); S. U. De Silva (Old Dominion University); J. Delayen (Old Dominion University); H. Park (Old Dominion University); R. Pirayesh (University of New Mexico); R. Li (Jefferson Lab);F. Lin (Jefferson Lab); V. Morozov (Jefferson Lab); Edl Schamiloglu (University of New Mexico). **Graduate Advisors and Postdoctoral Sponsors -** Advisor – J. Delayen, Old Dominion University, USA; Post-doc PI – S. Biedron, University of New Mexico.

1. EQUIPMENT (Reference: DOE Order 413.2C for guidance on equipment restrictions)

Will LDRD funding be used to purchase equipment? Y/N N

If "Yes," provide cost and description of equipment

Year 1 -

Year 2 -

Year 3 -

Description:

Materials for building device (ceramics, rails, supports, electrodes, etc.), vacuum components, RF power supplies, laser systems and parts, diagnostics.

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. Y/N N

3. VERTEBRATE ANIMALS

Are live, vertebrate animals involved? Y/N N

If **yes**, attach copy of approval from BNL's Institutional Animal Care and Use Committee. Y/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/N 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? Y/N

(**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/N	Y
Is there an available waste disposal path for project wastes throughout the course of the experiment?	Y/N	Y
Is funding available to properly dispose of project wastes throughout the course of the experiment?	Y/N	Y
Are biohazards involved in the proposed work? If yes, attach a current copy of approval from the Institutional Biosafety Committee.	Y/N	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?	Y/N	Y

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.

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

7. ALIGNMENT WITH THE LABORATORY PRIORITIES

This proposal aligns with the Accelerator Science and Technology BNL priority, with initiatives that focus on Nuclear Physics and Quantum Information Science and Technology.

8. POTENTIAL FUTURE FUNDING

This proposal can have significant return on the investment by developing methods to cool low energy ion beams using lasers. The most direct benefit applies to the storage ring quantum computer concept, where 3D cooling is necessary to expose all quantum eigenstates in the system. Funding potentially could come from DOE Office of Science (NP and potential QIS FOA from other offices). As this is a new technology it offers SBIR/STTR opportunities since it could be commercialized for use at other laboratories.

DOE FOAs for innovative quantum information science (QIS) technologies have been increasing in recent years. For example, DOE FOA LAB 19-2110 anticipated $6.8M may be available for grants, with up to $1M per award. DOE FOA LAB 20-2225 anticipated $12M may be available for grants with up to $1.5M per year. Our applications to multiple FOAs have received high grades and favorable reviews but have yet to be funded. A significant factor is the lack of maturity in the concept. This LDRD, showing we can cool ions down to sufficiently low temperatures is a key hurdle in showing a more mature concept with supporting experimental data.

We have also spoken with two separate offices in the office of Naval Research (ONR). They both expressed interest but wanted to see a more well-developed concept. The Air Force Office of Scientific Research (AFOSR) also has funding announcements with significant funding levels.

Given success in reaching our goals, funding to develop systems for operational use would be pursued in the next few years. Techniques that stem from this research would apply to higher energy beams and a higher energy system could be developed in the AGS Booster and perhaps even in the AGS, to support the creation of brighter beams for EIC. Given the potential to create high quality beams for the EIC, funds could become available from DOE SC in support of creating operational systems. Such funding would likely be at the level of a few million dollars, but also could have impact by contributing to reaching EIC physics goals.

9. BUDGET JUSTIFICATION

Costs include engineering to work out design details, a laser engineer to design to the laser requirements for cooling, physicist time for simulations and calculations, post-doctoral researcher, and subcontract costs to support University of New Mexico early career scientist for RF simulations.
Materials costs include all parts and materials for building a prototype device (listed on p.5) and time for testing and proof of principle.
Budget is shown on p. 12.

10. NAME OF SUGGESTED BNL REVIEWERS

Okamura, Masahiro okamura@bnl.gov
Beebe, Edward N beebe@bnl.gov

APPROVALS (NPP)

Business Operations Manager _________Susan Pankowski_____

Department Chair/Division Manager _________Thomas Roser___________________________

Associate Laboratory Director for
Nuclear and Particle Physics ______________________________________

Haiyan Gao

APPROVALS (ATRO)

Business Operations Manager

Ken Koebel

Department Chair/Division Manager

Mark Palmer

Cognizant Associate Lab Director/
Computational Science Initiative Director/
Advanced Technology Research Office Director

David M Asner

FY21 Budget Proposal									
3D Laser Cooling for low energy ions for ultra-low emittance beams									
PI:	**Kevin Brown**								
($ in Whole Numbers)									
	Select project type from drop down menu>>>	**C-AD LDRD**							
R/C	**Description**		**FY22 Year 1**		**FY23 Year 2**		**FY24 Year 3**		**TOTAL**
100	Salaries		67,816		126,905		123,318		318,039
100	Salaries								-
100	Salaries								-
	Subtotal		67,816		126,905		123,318		318,039
	Total Labor		67,816		126,905		123,318		318,039
680	Misc Recharge Services (612,632,680)								-
	Total Dist. Tech. Services		-		-		-		-
280	**Foreign Travel**								-
290	**Domestic Travel**								-
300	**PO Purchases**		50,000		40,000		30,000		120,000
	Total MST		50,000		40,000		30,000		120,000
	Total High-Value Procurements		83,333		83,333		83,333		250,000
	Total Equipment (Low Value)								-
	Departmental Org. Burdens	7.62%	5,168	7.62%	9,670	7.62%	9,397		24,235
	Departmental Org. Burdens	0.95%	644	0.95%	1,206	0.95%	1,172		3,021
	Directorate Org Burdens	3.60%	2,441	3.60%	4,569	3.60%	4,439		11,449
	Distributed Org. Burdens		8,253		15,444		15,008		38,705.30
685	Distributed ODC	3.80%	2,577	3.80%	4,822	3.80%	4,686		12,085
	Total ODC		2,577		4,822		4,686		12,085
480	Space (direct) (480,482)								-
481	Space (distributed)	8.90%	6,036	8.90%	11,295	8.90%	10,975		28,305
482	Maint Space Charge - Direct								-
491	Tandem								-
493	BLIP								-
251	Building Power (distributed)	0.60%	407	0.60%	761	0.60%	740		1,908
250	Machine Power								-
	Total Power		407		761		740		1,908
507	Waste								-
653	Waste Mgmt Tech Recharge		-		-		-		-
699	Reserve - Fully Burdened								-
163	Pass Thru		-		-		-		-
696	Reserve - LDRD/FCR Burden Only								-
	Total Cost (Excluding Overhead)		218,422		282,561		268,061		769,043
745	Procurement	7.00%	9,333	7.00%	8,633	7.00%	7,933		25,900
746	Adj Proc Burden		-		-		-		-
735	VAB G&A	0.00%	-	0.00%	-	0.00%	-		-
711	Adj Traditional Burden		-		-		-		-
730	VAB Common Inst	43.30%	40,429	43.30%	71,832	43.30%	69,604		181,866
730	VAB Common Inst (JA Only)	11.30%	-	11.30%	-	11.30%	-		-
722	Safeguards & Securities	0.00%	-	0.00%	-	0.00%	-		-
738	FIE	0.00%	-	0.00%	-	0.00%	-		-
705	LDRD Burden	0.00%	-	0.00%	-	0.00%	-		-
	Total G&A	54.60%	40,429	54.60%	71,832	54.60%	69,604		181,866
	Project Total		268,184		363,026		345,598		976,809
	Full Cost Recovery	0.00%	-	0.00%	-	0.00%	-		-
	Sub Total		268,184		363,026		345,598		976,809
	Prior Year Carry Over		-		-		-		-
	Sub Total Project Funded Cost		268,184		363,026		345,598		976,809
	Expected Funding		-		-		-		-
	Total Authorized Funds (New Funds)		268,184		363,026		345,598		976,809
	Carry Forward		-		-		-		-
	Total Project Cost Plan		268,184		363,026		345,598		976,809

BNL's participation in this project will be subject to approval by DOE. BNL's participation also requires a formal agreement with the Sponsor that will contain terms and conditions which are approved by DOE. Kindly review the " DOE Guide to Partnering with DOE's National Laboratories " for information on the various partnering options and agreements. Feel free to contact Ivar Strand,