Center for Nuclear Femtography

Latifa Elouadrhiri
David Richards
Steering-Committee Co-Chairs

CNF2019
SURA, Washington DC
Aug 12/13, 2019

Virginia Center for Nuclear Femtography

- funded by Commonwealth to "*…..to facilitate the application of modern developments in **data science** to the problem of imaging and visualization of sub-femtometer scale structure of protons, neutrons, and atomic nuclei*"
- Multi-disciplinary, bringing together *nuclear theorists and experimentalists, mathematicians, computer scientists,… … and architects and artists!*
- Workshop at University of Virginia

CENTER *for* NUCLEAR FEMTOGRAPHY

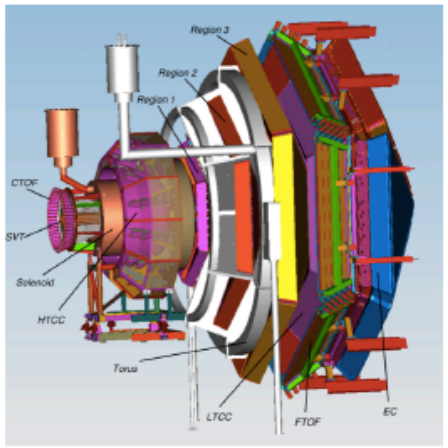
FEMTOGRAPHY 2018

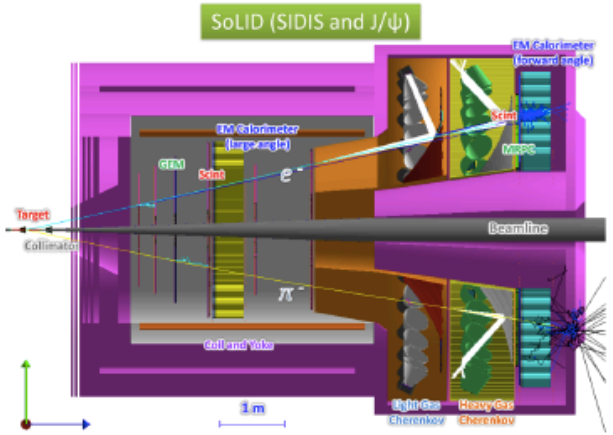
Symposium on Imaging and Visualization in Science

December 10-11, 2018, University of Virginia

The Symposium on Imaging and Visualization in Science will be held at the University of Virginia December 10-11, 2018. This symposium will bring together scholars and researchers from Virginia universities and research institutes to discuss recent developments and future opportunities in the imaging and visualization of scientific data.

Why Now?





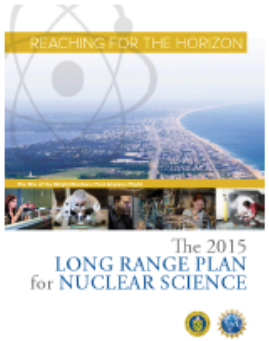
GPDs

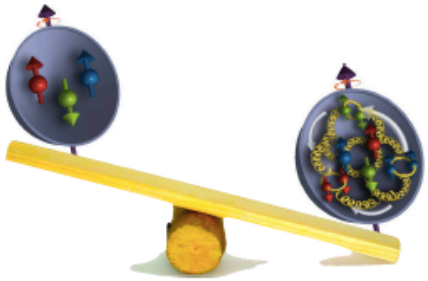
Lattice QCD

TMDs

Electron-Ion Collider

"Understanding the Glue That Binds Us All: The Next QCD Frontier in Nuclear Physics"





CNF Call for Proposals

- **Steering Committee established :** ***L.Elouadrhiri* (JLab), D.Richards* (JLab), A.Accardi (HU), D.Doughty (CNU), C.Hyde (ODU), S.Liuti (UVA), R.McKeown (JLab), N.Polys (VT), J.Qiu (JLab), A.Stathopoulos (WM), G.Triplett (VCU), R.Yoshida (JLab)***

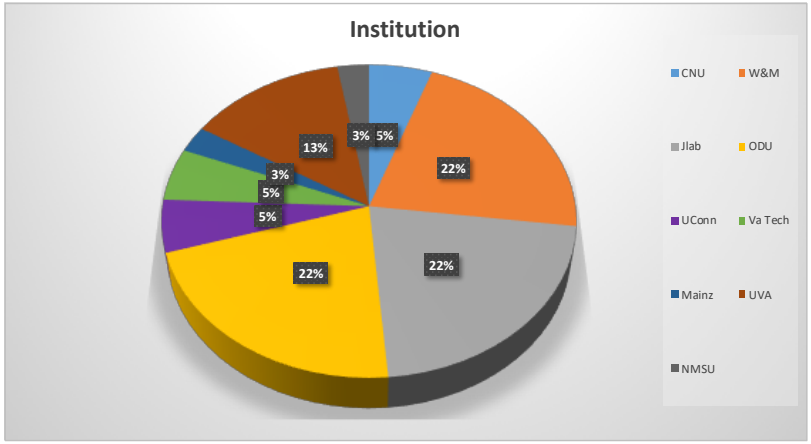
Request for Proposals

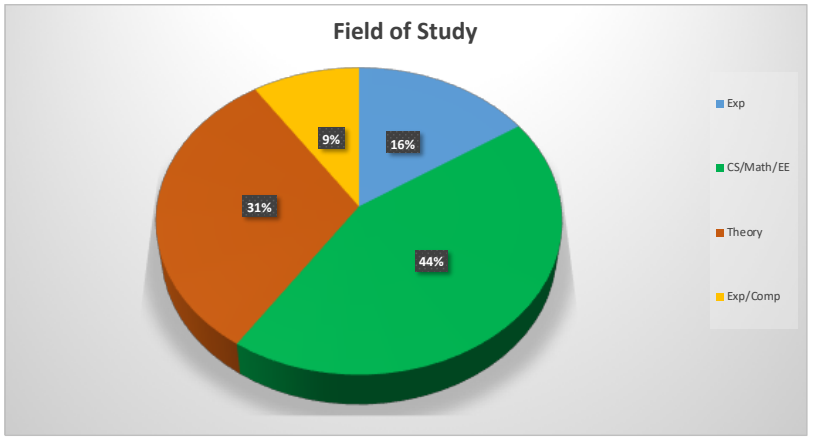
- **Circulated: 29th January, 2019**
- **Deadline: 15th February, 2019**
  - < 50K, with PI at Virginia Institution
  - **Topics**
    - *The construction of a QCD-inspired reference model for the nucleon, including that of the Wigner Distribution, that can serve as synthetic input for the activities below.*
    - *The development of images of the nucleon through fitting to experimental data with theoretical input, reflecting constraints arising from limitations both in experiment and theory.*
    - *The use of visualization, both as a means of imaging the nucleon and of refining our analysis methodology.*
    - *Applications of machine learning to data analysis, interpretation and classification.*
    - *The development and application of computational and mathematical methods and the associated computational infrastructure.*
  - **Aims**
    - **Near-term projects that can seed future activities of CNF**
    - **Contribute to a future Commonwealth of Virginia proposal for long-term world-leading center**

16 Proposals Received!

Diverse in Geography and Field

Distribution of PI's - *participation still wider*





Review Criteria

1) **Are the aims of the proposal in accord with the aim of the CNF "…..to facilitate the application of modern developments in data science to the problem of imaging and visualization of sub-femtometer scale structure of protons, neutrons, and atomic nuclei"?**

2) **Is the proposal multi-disciplinary, and/or innovative?**

3) **Are the goals clearly stated and achievable?**
   a. Does the proposal contain a timeline and milestones?
   b. Is there a mid-term milestone for 1st July, and a milestone for completion at 30th September?

4) **Will the success of the proposal lead to longer-term activities of the CNF and to the establishment of its long-term funding?**

5) **Are the resources adequate?**

All of high quality!

Funded Proposals

Next-generation imaging filters and mesh-based data representation for phase-space calculations in nuclear femtography

PI: Nikos Chrisochoides (ODU)

Co-PIs: Gagik Gavalian (JLAB) and Christian Weiss (JLAB)

Executive Summary:

We propose an interdisciplinary project to leverage advanced computational methods from medical imaging for processing phase space distributions in nuclear femtography experiments, with the aim to enable next-generation process simulations, data analyses, and physics model comparisons. The objectives are: **(O1)** Implement an n-dimensional Exact Signed Euclidean Distance Transform for image-to-mesh conversion of phase space data; **(O2)** Implement an n-dimensional mesh-based representation of phase space data using tessellation methods and test it in low-dimensional scenarios (n=3); **(O3)** Explore potential physics model comparisons enabled by the new technologies.

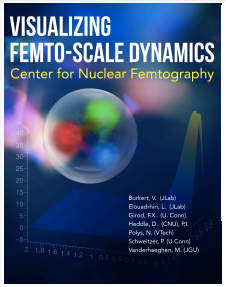
QCD theory and machine learning for global analysis

Nobuo Sato[1,2*], Ian Cloët[3], Michelle Kuchera[4], Yaohang Li[1], Wally Melnitchouk[2], Andreas Metz[5]

[1] *Old Dominion University,* [2] *Jefferson Lab,* [3] *Argonne National Laboratory,* [4] *Davidson College,* [5] *Temple University*

Executive Summary

The goal of this project is to build the next generation of global QCD analysis tools using machine learning techniques to study the quantum probability distributions characterizing the internal structure of the nucleon. In concert, QCD-inspired models will be developed and used to calculate Wigner distributions and their projections onto generalized parton distributions (GPDs) and transverse momentum dependent (TMD) distributions. The QCD theory will be used to help train and optimize machine learning algorithms by putting physical constraints on the mapping between observables and the quantum probability distributions. This project is multi-disciplinary in nature, requiring collaboration between *nuclear physicists*, *computer scientists* and *information technology specialists*. The resulting product will be a critical tool for the nuclear physics community, opening up new possibilities for collaboration with computer science in the exploration and visualization of the inner structure of hadrons and nuclei. This proposal directly addresses project areas 1, 2, and 4 as identified in the proposal call.



Visualizing Femto-Scale Dynamics

Center for Nuclear Femtography D. Heddle (CNU)

Executive Summary

Protons and neutrons constitute more than 99 percent of the mass in the visible universe. Through experiments using particle accelerators, we have learned much about these particles in the century since their discoveries. Yet very little is known about their internal mechanical and dynamical properties. With the advancement of accelerator, detector and associated electronics technologies, a new generation of experiments became possible at Jefferson Lab in Virginia. These experiments are generating the most comprehensive and the most precise data ever on their internal substructure, with data rates measured in Terabytes per hour. In the future, the proposed Electron Ion Collider (EIC) will allow scientists to explore these questions using precisely defined and controlled collisions of very-high energy ions and electrons at high luminosity.

Data Visualization and New Initiatives in Doubly Virtual Compton Scattering

Carl Carlson (WM), Marc Vanderhaeghen (Mainz)

Executive Summary

The flow of data from Jefferson Lab and other labs is already significant and the increase in the future will also be significant. Currently, much data that is presented as a many row by many column grid of small two-dimensional plots. Related problems are addressed, and to some extent solved, in the medical profession, where one often has a set of scans which can be presented as a set of fixed direction small two-dimensional images, looking rather like a grid of postage stamps. Computer processing turns these into interactive images that can be presented with arbitrary centers, with arbitrary scanning planes, and zoomable. We would aim, and be able to do, similar processing of nuclear science data.

A second and separate project concerns doubly virtual Compton scattering, $\gamma^* p \to \gamma^* p$, with the incoming γ spacelike and the outgoing γ timelike. This is an extension of approved experiments at JLab. Crucial applications of information obtained from such data are in evaluating two-photon exchange (TPE) corrections to radiative corrections in *ep* elastic scattering, TPE corrections to the Lamb shift in muonic hydrogen (critical for the proton radius measurements and puzzle), and for calculating the electromagnetic contribution to the neutron-proton mass difference (using the Cottingham formula). We would calculate the Bethe-Heitler amplitudes which interfere with the purely Compton amplitudes, and give expressions allowing extractions of information of the individual structures parameterizing the Compton amplitude.

Next-generation Visual Analysis Workspace for Multidimensional Nuclear Femtography Data

PI Nicholas Polys (VT, npolys@vt.edu)

CO-PIs Srijith Rajamohan (VT), Markus Diefenthaler (JLAB), Dmitry Romanov (JLAB)

Executive Summary

The experimental data in five or more kinematics dimensions that allows to constrain GPDs and TMDs is a multidimensional data science challenge. We propose to apply recent advances in scientific visualization to gain more insights into the multidimensional datasets at the forefront of Nuclear Femtography. In the initial phase of our project, we will explore Semantic Interactions as a visualization technique to analyze an ensemble of scientific data sets. This is motivated by our ongoing R&D and the direct connection between Semantic Interactions and machine learning.

Title: Parton Distribution Functions from Lattice QCD

PI: Konstantinos Orginos (W&M/JLab)
co-PI: Andreas Stathopoulos (W&M)
Grad Students: Joseph Karpie(W&M)
Post-doc: Eloy Romero(W&M)

Executive Summary:

In the last few years, a major achievement in hadron structure has been the development of new methods that allow for lattice QCD computations of parton distribution functions. This is a groundbreaking development as it allows for the first time to determine the full longitudinal momentum fraction dependence of the PDFs from lattice QCD, and thus opens up a new window for the theoretical study of the structure of fundamental building blocks of matter such as the pion and the nucleon. Experimentally hadron structure studies are a central part of DOE's nuclear physics programs both with current experimental facilities such as the 12 GeV upgrade of Jefferson Lab, as well as at the future electron-ion collider (EIC).

Principal Investigator: **Simonetta Liuti (UVA Physics)**

Wigner Imaging

Co-Principal Investigators: **Peter Alonzi (UVA School of Data Science)**
Matthias Burkardt (NMSU Physics)
Dustin Keller (UVA Physics)
Olivier Pfister (UVA Physics)
Petra Reinke (UVA School of Engineering and Applied Science)

The science of Nuclear Femtography probed by deeply virtual exclusive reactions has revolutionized our approach to exploring the internal structure of the nucleon. A new generation of current and planned experiments at the future EIC could in principle allow us to incorporate all the information from data and phenomenology into a tomographic image connecting the deepest part of the quantum world with what we see as everyday matter around us. However, to harness and organize information from experiment and increase the reach of this emergent field will require going beyond the standard computational toolbox. The proposed pilot project is an effort in this direction. It consists of two parts: computational and visualization on one side, and theoretical, on the other. In order to carry out our program we will: **(1)** examine and evaluate the use of new state of the art computational methods and techniques, including visualization to address the many layers of analysis which are necessary to extract the signal in its complex background after the large experimental data sets are acquired; **(2)** simultaneously develop a flexible model of the Wigner distribution which underlies the theoretical description of the data.

Aims of Symposium

- Bringing together of those interested in Nuclear Femtography
- Review, share, and capitalize on progress made so far.
- Explore new avenues and ideas - e.g *machine learning*
- Specific goals
  - *Development of next round of activities*
  - *Securing long-term future of effort*
    - *Proposal to Commonwealth of Virginia*
    - *Other Funding?*

DISCUSSION ON TUESDAY PM

Femtography 2019

Monday

08:45 - 10:10	Introduction and Femtography Science (Chair: Simonetta Liuti)
08:45	**Welcome** *10'* Speaker: Jerry Draayer (SURA)
08:55	**Introduction** *15'* Speaker: Robert McKeown (Jefferson Lab)
09:10	**Status of the Center** *30'* Speakers: Latifa Elouadrhiri (Jefferson Lab), David Richards (Jefferson Lab)
09:40	**Electron Ion Collider and Femtography Science** *30'* Speaker: Charles Hyde (Old Dominion University)
10:10 - 10:40	Coffee Break
10:40 - 12:10	Visualization and Simulation (Chair: Nicholas Polys)
10:40	**The Indispensable Role of Visualization in Obtaining Insight from Astrophysical Simulation** *45'* Speaker: Bronson Messer (Oak Ridge National Lab)
11:25	**First Images of a Black Hole** *45'* Speaker: Kazunori Akiyama (Massachusetts Institute of Technology)
12:10 - 13:30	Lunch
13:30 - 15:00	Machine Learning and Femtography - I (Chair: Gregory Triplett)
13:30	**Bayesian Optimization** *45'* Speaker: Barnabas Pozcos (Carnegie Mellon University)
14:15	**Scale and Style in Image Analysis via Deep Learning** *45'* Speaker: Chen Zeng (George Washington University)
15:00 - 15:30	Coffee Break
15:30 - 17:30	Machine Learning and Femtography - II (Chair: David Doughty)
15:30	**Machine Learning and Nuclear Femtography Experiments** *30'* Speaker: Gagik Gavalian (Jefferson Lab)
16:00	**Data Science and Femtography** *30'* Speaker: Peter Alonzi (University of Virginia)
16:30	**Panel Discussion on Machine Learning (Chair: Amber Boehnlein)** *1h0'* Speakers: Michelle Kuchera (Davidson College), Peter Alonzi (University of Virginia), Barnabas Pozcos (Carnegie Mellon University), Chen Zeng (George Washington University)
17:30 - 17:45	Summary *15'*
18:00 - 19:30	Networking Reception

Femtography 2019

Tuesday

08:30 - 10:30 Progress Reports on the Proposals - I (Chair: David Richards)

- 08:30 **Next-Generation Imaging Filters and Mesh-Based Data Representation for Phase-Space Calculations in Nuclear Femtography (CNF19-04)** *30'*
  Speakers: Nikos Chrisochoides (Old Dominion University), Gagik Gavalian (Jefferson Lab)
- 09:00 **QCD Theory and Machine Learning for Global Analysis (CNF19-06)** *30'*
  Speakers: Nobuo Sato (Old Dominion University), Michelle Kuchera (Davidson College)
- 09:30 **Visualization Femto-Scale Dynamics (CNF19-09)** *30'*
  Speaker: Volker Burkert (Jefferson Lab)
- 10:00 **Data Visualization and New Initiatives in Doubly Virtual Comption Scattering (CNF19-12)** *30'*
  Speaker: Carl Carlson (William & Mary)

10:30 - 11:00 Coffee Break

11:00 - 12:30 Progress Reports on the Proposals - II (Chair: Latifa Elouadrhiri)

- 11:00 **Parton Distribution Functions from Lattice QCD (CNF19-13)** *30'*
  Speaker: Kostas Orginos (William and Mary / JLab)
- 11:30 **Wigner Imaging and Femtography (CNF19-14)** *30'*
  Speaker: Simonetta Liuti (University of Virginia)
- 12:00 **Next-Generation Visual Analysis Workspace for Multidimensional Nuclear Femtography Data (CNF19-15)** *30'*
  Speaker: Nicholas Polys (Virginia Tech)

12:30 - 14:00 Lunch (Steering Committee Meeting)

14:00 - 15:30 General Discussion/Path Forward *1h30'*

15:30 - 16:00 Coffee Break

16:00 - 16:00 Adjourn