# Brief report on CFNS workshops on

## I. Short-range nuclear correlations at an EIC (Sept.5-7, 2018)
## II. Quantum entanglement at collider energies (Sept. 10-12, 2018)

Raju Venugopalan (BNL)

CFNS Inaugural meeting, Stony Brook, November 30, 2018

Both workshops supported by a BNL LDRD:
“Studying confinement and nuclear structure through correlations and quantum entanglement at an EIC”

PI: Thomas Ullrich; co-PI’s: Abhay Deshpande, Dima Kharzeev, RV
Post-doc on LDRD: Zhoumindang (Kong) Tu, hired as Goldhaber Fellow (June 2018)

# CFNS BNL Workshop:Short-range Nuclear Correlations at an Electron-Ion Collider (5-7 September)

Organizers: Deshpande, Kharzeev, Nazarewicz (MSU), Qiu, Ullrich, RV, Yoshida

37 participants, from RHIC, Jlab and FRIB user communities

Significant participation of nuclear structure colleagues (thanks to Witek!)

- Carlson, Dickhoff, Furnstahl, Lonardoni, Vary, Wiringa. A number of others were couldn't attend due to scheduling conflicts.

# CFNS BNL Workshop:Short-range Nuclear Correlations at an Electron-Ion Collider (5-7 September)

What can we learn about the quark-gluon structure of nuclear forces from EIC? Parton structure of a nucleus is different from that of the proton!

Lessons from successful Jlab program (striking result-strong dominance of n-n relative to n-p) – deep connections to EMC effect

Also of great interest for RHIC program – quantum fluctuations in wavefunctions imprinted on final states

EIC brings new tools – collider geometry, high energies, exclusive final states with quarkonium probes, … Diffraction allows one to separate “low energy” nuclear fragmentation region from high energy probe – challenges in measuring nuclear fragments

Theoretical approaches: Nuclear many-body methods, Nucleon-nucleon EFT, perturbative QCD, lattice QCD, CGC EFT

# CFNS Stony Brook workshop: Quantum entanglement at collider energies

Organizers: Keith Baker (Yale), Abhay Deshpande, Ian Cloet (Argonne),

Dima Kharzeev, Thomas Ullrich, RV, Yen-Jie Lee (MIT)

44 participants from a broad range of fields:

String theory, cold atomic gases and condensed matter physics, particle and nuclear physics – broad interest from theory and experimental colleagues in all these communities

# CFNS Stony Brook workshop: Quantum entanglement at collider energies

Protons and nuclei are entangled quantum states

Measurements look at some sub-set of all possible states. These are entangled in principle with the rest of the system. When can they be unentangled (factorized)and when not?

Are there universal features to entangled states – independent of microscopic dynamics? Example: non-thermal fixed points that are identical in Yang-Mills dynamics and cold atomic gases

Can we understand the big questions – confinement and topology of the QCD vacuum - common features of QCD and gravity - in the language of entanglement?

The unprecedented and clean access to multiparticle states (and corresponding n-particle correlations) at an EIC will allow us to frame questions about patterns in data in the language of entanglement entropy, mutual information, …

# CFNS Stony Brook workshop: Quantum entanglement at collider energies

Interesting synergies: as an example, Jorg Schmiedmayer (Vienna) told us about computations of 10 particle correlations measured in cold atom experiments that have interesting parallels to cumulant analyses in small systems at RHIC and LHC

Stefan Floerchinger (Heidelberg) outlined how themal looking spectra in e+e- may beunderstood as an example of entanglement. Some of these ideas may be implemented in event generators (PYTHIA,…) to analyze patterns in multi-particle production

Another interesting synergy is quantum computation to address questions about entangled states at high energy colliders. Discussed by several speakers