Review of 2024 and Plan for 2025

Chueng-Ryong Ji
North Carolina State University

Group Meeting on January 3, 2025

Outline

- Reminder of 2024 Spring & Summer
- Report of 2024 Fall & Winter
- Summary of 2024 Group Meetings
- Works to think and do
- Plans for the new year 2025
- Conclusion and Outlook

Reminder of 2024 Spring&Summer

Big Picture

11 Science Questions for the 21st Century

US Long Range Plan for Nuclear Science

5 Topical Collaboration Projects

Summer Activities May 15 - August 15

Eleven Science Questions for the 21st Century

- What is Dark Matter?
- What is the nature of Dark Energy?
- How did the Universe begin?
- Did Einstein have the last word on Gravity?
- What are the masses of the Neutrinos, and how have they shaped the evolution of the Universe?
- How do Cosmic Accelerators work and what are they accelerating?
- Are Protons unstable?
- What are the new states of matter at exceedingly High Density and Temperature?
- Are there Additional Space-Time Dimensions?
- How were the elements from Iron to Uranium made?
- Is a new theory of Matter and Light needed at the Highest Energies?

Nuclear Science

[Today and for the Next Decade]

General goal (from U.S. Long Range Plan):
Explain the origin, evolution, and structure of the visible matter of the universe—the matter that makes up stars, planets, and human life itself.

Frontiers:

- **Quantum Chromodynamics** (QCD) and **Hadrons**

  [LHC, RHIC, JLab, JPARC, $e^+ e^-$ (Beijing, DAPHNE, KEKB, Novosibirsk), . . ., FAIR]

- **Fundamental Symmetries** and **Neutrinos**

  [neutrinos, double-beta decay, low-energy Standard Model studies, edm's, . . .]

- **Physics of Nuclei** and **Nuclear Astrophysics**

2022 FOA physics topics in the context of NP program

Major Facilities and experiments:

Argonne Tandem Linac Accelerator System (**ATLAS**)

Facility for Rare Isotope Beams (**FRIB**)

Continuous Electron Beam Accelerator Facility (**CEBAF**)

Relativistic Heavy Ion Collider (**RHIC**)

Electron Ion Collider (**EIC**)

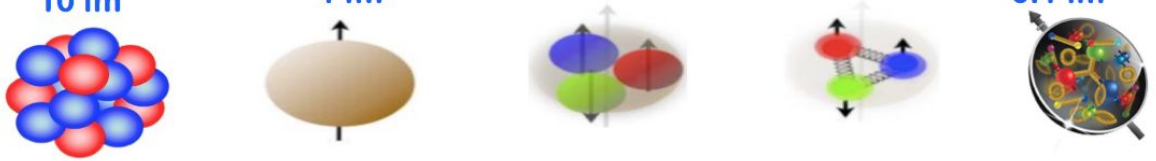
Energy Scale probed

~ 20 MeV — 200 MeV — > 2 GeV

Distance scale probed

Color Confinement — Asymptotic freedom — Q (GeV)

10 fm — 1 fm — 0.1 fm



Physics topics:

- Nuclear reactions
- Fission and nucleosynthesis
- Properties of nuclei
- Nuclear structure
- Microscopic models

- Hadron spectra
- Exotic states of QCD
- Neutrino and electron interactions in nuclei and dense matter

- Nuclear tomography at femtometer scale (New)
- Properties of quark-gluon plasma

QGT Collaboration:

3-dimensional imaging of the internal structure of nucleons and nuclei

Heavy-Flavor Theory (HEFTY) for QCD Matter :

Developing framework for Heavy quarks in QCD by employing Lattice QCD computation and rigorous statistical data analysis based on effective field theory

Saturated Glue Topical Collaboration (GURGE):

Establishing an end-to-end framework for small-x observables by employing Lattice QCD and light-cone method

Nuclear Theory for New Physics (NTNP):

Precision study of neutron and nuclear decays, neutrino interactions, and electric dipole moments to uncover fundamental laws of physics

Exotic Hadron Spectroscopy(ExoHad):

Explore all aspects of exotic hadron physics, through the numerical computations of Lattice QCD and extraction of experimental data for a robust determination of the presence and properties of exotic hadron states.

Summer Activities for May 15 - August 25

- May 15 - 21 KNU
- May 22 - 25 SNU KSHEP
- May 26 - June 1 APCTP
- June 2 - 23 KNU
- June 24 Mini Zoom in Seoul
- June 25 - 29 3D Workshop in Inchon
- June 30 - July 6 NCSU
- July 7 - 10 JLab
- July 11 - August 19 NCSU
- August 20 - 25 UKC in San Francisco

What did I learn from these activities?

- EIC physics intermediates between Hot and Cold QCD
- Degrees of freedom matter in physics description: nucleus, nucleon, meson, quarks and gluons…
  Lagrangian vs. Hamiltonian and IFD vs. LFD
  Energy scales for NJL, CQS, LFQM and PQCD
- Roper resonance and radial excitations may reveal QCD confining potential
- Timelike region of mass gap should be explored
- Hadron structure studies via SIDIS (TMDs,GPDs,TDAs)
- Theoretical Simulation vs. Experiments, Lattice, etc.
- Data analyses and Impact studies are called for more extensively

Report of 2024 Fall & Winter

- LC2024 at Huizhou, China, November 24- 29
- December 2 - 17 Visit

  to Hadron Theory Group at Inha University

  and Physics Dept. at Seoul National University
- Andrew Lundeen’s Final Defense on December 20.

Light-Cone 2024: Hadron Physics in the EIC Era (LC2024)

Nov. 24-30, Huizhou

Plenary:(30 mins) 5+6+6+6+6+5=34
(3 Gary McCartor award)

Parallel:(30 mins+20 mins) 63

posters 15

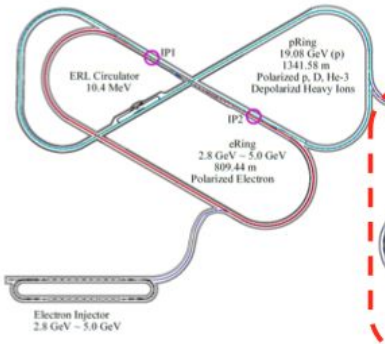
sum 112

Participants ~159

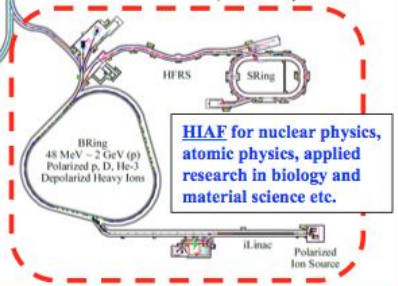
International ~45

https://indico.impcas.ac.cn/event/55/timetable/#20241129

Electron Ion Collider in China…Huizhou(惠州) in Guangdong province



High Intensity heavy-ion Accelerator Facility (HIAF)
2.5 billion RMB (Funded)



HIAF for nuclear physics, atomic physics, applied research in biology and material science etc.

HIAF under construction

EIC in China
~2035

Electron **I**on **C**ollider in **C**hina, EicC

https://english.imp.cas.cn/news/ln/202107/t20210712_281965.html

Thu 28/11

09:00

Three-dimensional structure of the proton and Sivers asymmetry within the BLFQ framework *Zhi HU*

Meeting Center, Institute of Modern Physics, Chinese Academy of Sciences, Huizhou, Guangdong, China 09:00 - 09:30

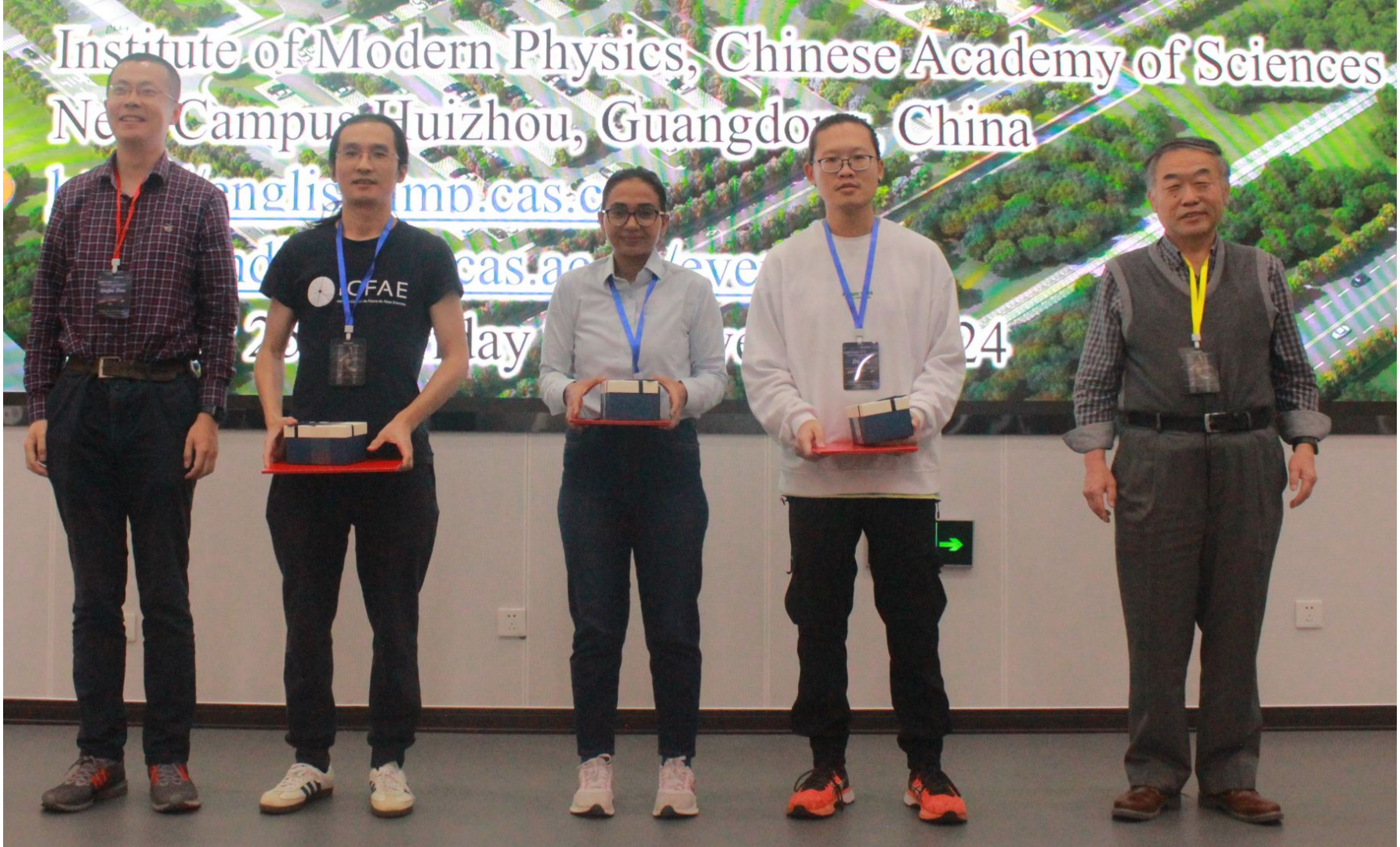
Gluon distributions in the proton in a light-front spectator model *Dr Poonam Choudhary*

Meeting Center, Institute of Modern Physics, Chinese Academy of Sciences, Huizhou, Guangdong, China 09:30 - 10:00

10:00

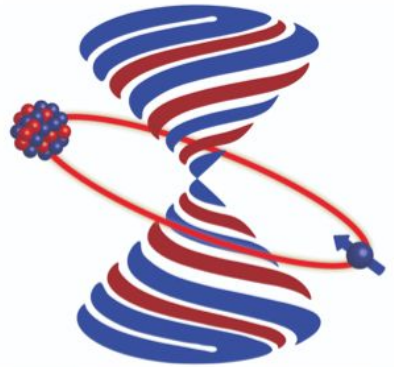
Quantum simulation of quark jet and gluon jet *Wenyang Qian*

Meeting Center, Institute of Modern Physics, Chinese Academy of Sciences, Huizhou, Guangdong, China 10:00 - 10:30


Institute of Modern Physics, Chinese Academy of Sciences
Campus, Huizhou, Guangdong, China

Bridge between QCD and Light-Front Quark Model

Chueng-Ryong Ji
North Carolina State University



Light Cone 2024

Nov. 28, Huizhou, China


TESTING & ASSEMBLY HALL 综合测试大厅


“十二五”国家重大科技基础设施建设项目—强流重离子加速器装置HIAF


“十二五”国家重大科技基础设施建设项目—强流重离子加速器装置HIAF
HIAF 简介
总体布局
科学目标
实验终端
HIAF核心关键技术
国际首台45GHZ超导ECR离子源
国际首台变前馈全储能二极磁铁电源
高梯度、宽频带、快响应通冷磁合金高频系统
骨架内衬超薄壁铝真空室
全专业BIM设计、数字孪生技术
里程碑


超导离子源可以产生自然界存在的最重的元素铀离子


HIAF
强流重离子加速器装置
16t


中央控制楼
HIAF CONTROL CENTER


1
2
3

Dirac Award:

1.Yi Chen

2. Ji-Xin Yu

3. Kamil Serafin

4. Satvir Kaur

5. Ho-Yeon Won

December 2-17 Visit to HTG and SNU

- Dec. 4: Effective theory for heavy-light quark systems from the instanton vacuum, Ki-Hoon Hong, Final PhD Defense
- Dec. 6: QCD and Light-Front Quark Model (HTG Seminar)
- Dec. 9: Link between QCD and LFQM (SNU Lecture 1)
- Dec. 11: Pion and Proton Phenomenology (SNU Lecture 2)

이학박사학위 논문

인스탄톤 진공에서 중경 (重輕) 쿼크계에 관한 유효이론

Effective theory for heavy-light quark systems from the instanton vacuum

2025년 2월

인하대학교 대학원

물리학과

홍 기 훈

이 논문을 홍 기 훈의 박사학위 논문으로 인정함.

2025년 2월

주 심 윤 진 희 인

부 심 김 현 철 인

위 원 Ulugbek Yakhshiev 인

위 원 지 청 룡 인

위 원 양 길 석 인

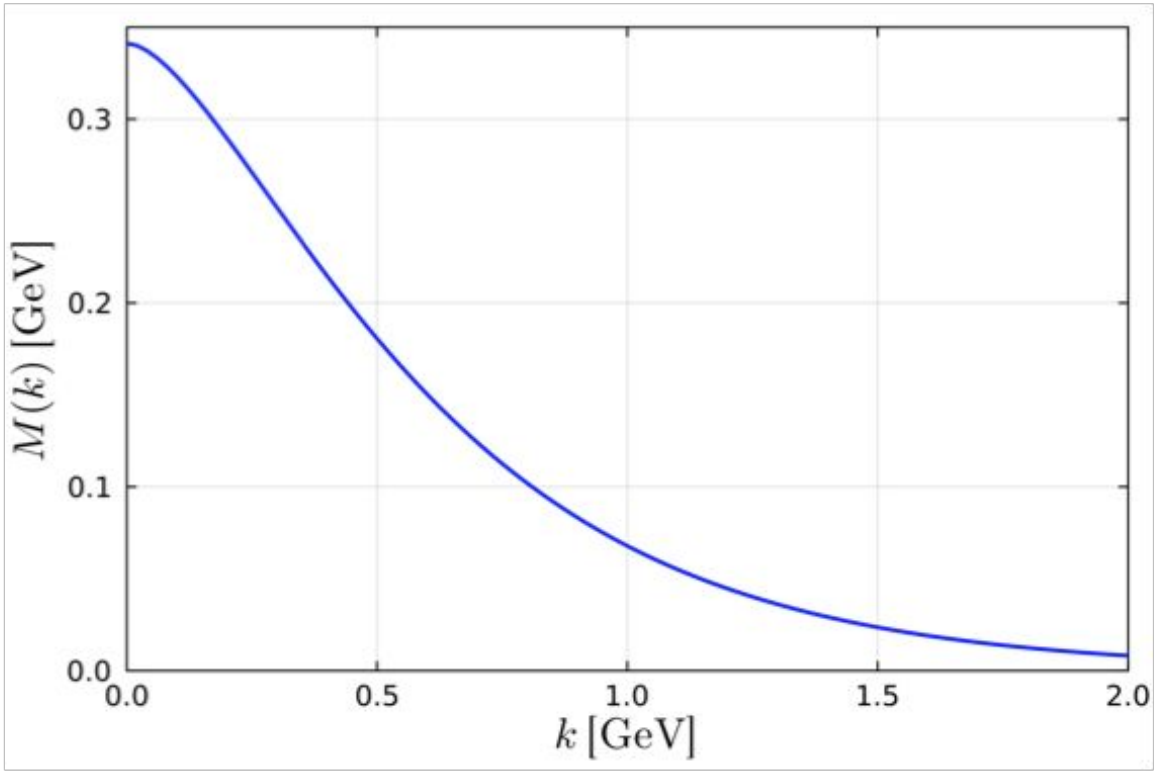


그림 III.3.1: The momentum-dependent dynamical quark mass. The y and $x-$axis are on the GeV scale. At zero momentum $k = 0$, $M(0) \approx 345\,\mathrm{MeV}$.


QCD and Light-Front Quark Model
North Carolina

SNU Lectures on QCD and Relativistic Quark Model

Chueng-Ryong Ji

North Carolina State University

December 9: Link between QCD and LFQM

December 11: Pion and Proton Phenomenology

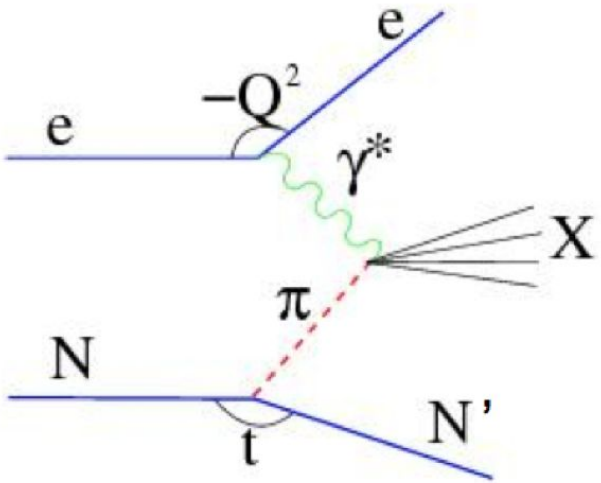
2024

Spontaneous Symmetry Breaking Phenomenology

- QCD Phases: Hot and Cold QCD, Dilute and Dense QCD
- Hidden Colors and Exotic Hadrons
- Supernova explosion and Neutron star formation
- Fermion Degeneracy and Quantum Correlation
- Nontrivial Vacuum Condensate and Phase Transition
- Meissner Effect of Superconductor and Higgs Mechanism
- QCD Chiral Dynamics and Nonanalytic Behavior
- Pion's Dichotomy and Proton Puzzle of Mass, Spin, etc.
- Flavor Asymmetry of Proton Sea and Pion Cloud
- Data Analyses of Pion and Proton PDFs
- LFQM Prospects

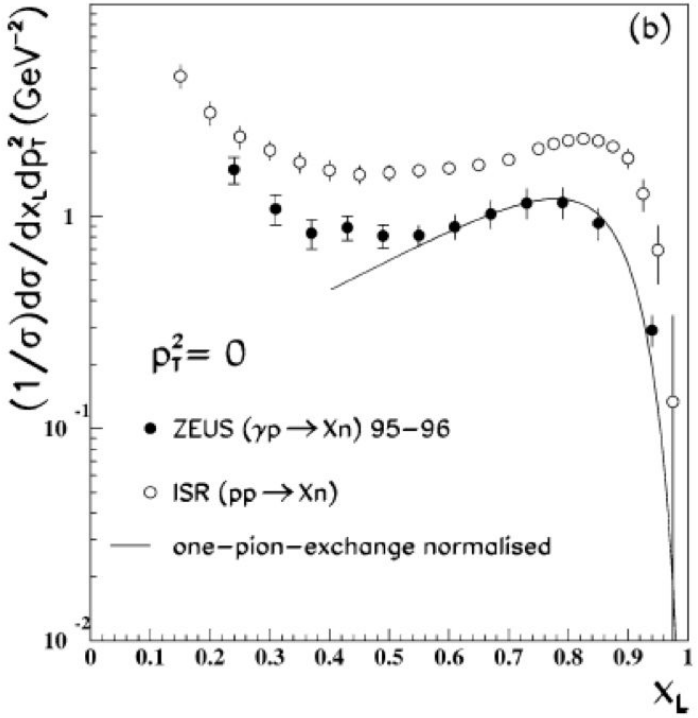
Measurement of Tagged Deep Inelastic Scattering (TDIS)

C.Keppel (Contact person)



$$e + p(or\ n) \rightarrow e' + p + X$$

$$e + D \rightarrow e' + p + p + X$$



Leading neutron production in e^+p collisions at HERA

ZEUS Collaboration, NPB 637 (2002) 3–56


OLIVE AVE
OLIVE AVE

NC STATE UNIVERSITY

Illuminating Hadronic Structures Through Exclusive Meson Electroproduction

Andrew Lundeen
Chair: Dr. Chueng-Ryong Ji
Final Exam
December 20th, 2024

Summary of Group Meetings in 2024

- Total 30 talks were presented in 2024
- Deepasika 4, Andy 3, Hari 3, Bailing 3, Marston 2,
- Patrick, Daniel, Arlee, Hunter, Paul&Connor,
- Hyun-Chul Kim, Hyeon-Dong Son, Jun-Young Kim (CQS)
- Jae-Weon Lee (ULDM)
- Hyeong-Chan Kim (Relativistic Thermodynamics)
- Ronaldo Thibes (BRST Symmetry)
- Ahmad Jafar Arifi (LFQM & Gaussian Expansion)
- Bheemsehan Gurjar (LF Spectator Model & Gluon Distribution)
- Ping Wang (Nonlocal QED & EFT)
- Stan Srednyak (First Principles for Bound States in QCD)

Works to think and do

- Impact study of global QCD analyses in EIC and JLab-TDIS
- VMP completion in 3+1 D for the feasibility study of GPDs
- Timelike mass gap & transition form factors in ‘tHooft model
- Quantum correlation and entanglement of LF zero-modes
- Coherent description of quantum states
- Utility of interpolation in solving relativistic dynamics
- Conformal symmetry of spacetime physics
- Correlation functions in classical and quantum physics

Plans for the new year 2025

- 3+1D electroproduction of mesons
- Theoretical simulations: CFFs, GPDs, gravitational FFs
- Wigner Function Formulation for correlation functions
- Impact studies for EIC, JLab 20+ GeV upgrade, etc.
- Timelike region of mass gap & transition form factor
- Confinement & linear potential phenomenology
- Quantum entanglement & Scaled interpolating variables
- Isometry of SO(4,2) and conformal symmetry
- Coherent description of quantum states
- Meson structure studies of LFQM to study the nucleon structures via the convolution with the splitting functions computed by the chiral effective theory.

Funding Support

-DOE: NCSU Nuclear Theory Group (Thomas Schaffer, Mithat Unsal, C.Ji)

NERSC is pleased to announce that you have received an Allocation Year 2025
DOE Mission Science award for your ERCAP request ERCAP0031668, titled:
"Quantum Chromodynamic Analysis of Hadron Structure and Application to Cosmology".

AY 2025 runs from January 15, 2025 through January 20, 2026.

Project name: m230
CPU Node Hours Award: 200,000
GPU Node Hours Award: 100
Archival Storage Award (TB): 1
Project Storage Award (TB): 20

Longer Term Collaborators

-Homyung Choi (KNU) : LFQM Phenomenology
-Bernard Bakker (VU) : DVCS & GPDs
-Wally Melnitchouk (JLab) : QCD Phenomenology
-Ping Wang (IHEP) : Nonlocal Chiral Effective Theory
-Patrick Barry (ANL Postdoc) : Data Aanalysis
-Bailing Ma (ANL Postdoc) : ‘tHooft Model Analysis

Current Ph.D. Students

-Andrew Lundeen (Defended in 2024 Winter, PhD May, 2025)
-Deepasika Dayananda (prelim in 2023 Summer)
-Daniel Piasecki (qual in 2024 Spring)
-Paul Ferrante (qual in 2025 Spring)
-Isaac Svedberg, Ben Cortes (rotation for 2025 Spring)
-Arlee Shelby (rotated in 2024 Spring)
-Hari Ravikumar (NMSC), Hunter Duggin (UNC-CH)

Undergraduate Students

-Connor Donovan (senior)

Visiting Researcher

-Ai-Lin Zhang (Shanghai U. Jan.15-Feb.15,2025)
-Josh McKinney (2023-2025)

- Patrick, Josh, Arlee : Global QCD Analysis of Pion/Kaon PDFs
- Bailing: Timelike Region Exploration in ‘tHooft Model
- Andy,Yongwoo: Virtual Meson Production in 3+1 Dimensions
- Deepasika: Quantum Correlation, Scaled Interpolation, 5D
- Hari: Conformal Poincare Symmetry 6D
- Daniel: Wigner Function Formulation and Application
- Isaac: Coherent States Investigation
- Ping: Nonlocal Chiral Effective Theory and Application
- Hunter: Interpolating ‘tHooft Model in Coulomb Gauge
- Paul, Connor: Path Integral Formulation of Linear Potential
- Marston: Phenomenology with Chiral Effective Theory
- Bhoomika: Heavy mesons with confining potential in LFQM
- Alex: AI

Conclusion and Outlook

- With the forthcoming EIC and topical collaborations in nuclear theory, the future of hadron physics looks bright.
- Maximal stability group of LFD saves a lot of dynamic efforts.
- Whole landscape between IFD and LFD has been revealed in QED(3+1) and QCD(1+1) with interpolating spinors, gauge bosons and their propagators.
- In particular, QCD(1+1) in large Nc ‘tHooft model provides initial bridge between QCD and LFQM.
- Interpolating QCD(3+1) in Nc=3 between IFD and LFD needs to be explored in particular in the timelike region to study the color confinement.
- Applying the alternative quasi-PDFs of the interpolating formulation is recommended in the lattice QCD.
- Relationship of mass gaps should be investigated between the Euclidean instanton vacuum solution and the Minkowski dynamic solution.